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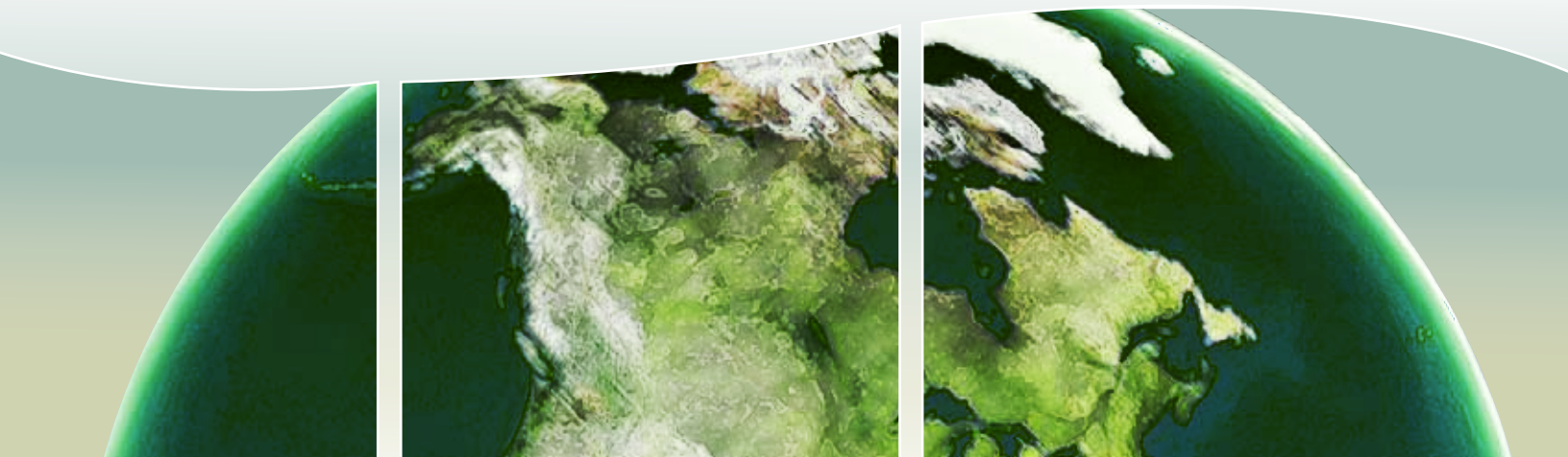
# National
# Inventory
# Report

## 1990-2009

### GREENHOUSE GAS SOURCES
### AND SINKS IN CANADA

The Canadian Government`s Submission
to the UN Framework Convention on Climate Change

## Part 2

Canada

# List of Acronyms, Abbreviations and Units

| | |
|---|---|
| AAC | Aluminum Association of Canada |
| AAFC | Agriculture and Agri-Food Canada |
| AC | air conditioning |
| AEUB | Alberta Energy and Utilities Board |
| AGEM | Aviation Greenhouse Gas Emission Model |
| Al | aluminium |
| $Al_2O_3$ | alumina |
| API | American Petroleum Institute |
| ASH | manure ash content |
| ATV | all-terrain vehicle |
| AWMS | animal waste management system |
| BADA | Base of Aircraft Data |
| $B_0$ | maximum methane production potential |
| $B_{100}$ | 100% biodiesel |
| BOD | biochemical oxygen demand |
| BOF | basic oxygen furnace |
| $BOD_5$ | five-day biochemical oxygen demand |
| C | carbon |
| CAC | Criteria Air Contaminant |
| $CaC_2$ | calcium carbide |
| $CaCO_3$ | calcium carbonate; limestone |
| $CaMg(CO_3)_2$ | dolomite (also $CaCO_3 \cdot MgCO_3$) |
| CanFI | Canada's National Forest Inventory |
| CANSIM | Statistics Canada's key socioeconomic database |
| CanSIS | Canadian Soil Information System |
| CanWEA | Canadian Wind Energy Association |
| CaO | lime; quicklime; calcined limestone |
| CAPP | Canadian Association of Petroleum Producers |
| CBM | Carbon Budget Model |
| CBM-CFS3 | Carbon Budget Model for the Canadian Forest Sector, version 3 |
| CCFM | Canadian Council of Forest Ministers |
| CEA | Canadian Electricity Association |
| CEPA 1999 | *Canadian Environmental Protection Act, 1999* |
| $CF_4$ | carbon tetrafluoride |
| $C_2F_6$ | carbon hexafluoride |
| CFC | chlorofluorocarbon |
| CFS | Canadian Forest Service |
| CGA | Canadian Gas Association |
| $CH_3OH$ | methanol |
| $CH_4$ | methane |
| $C_2H_6$ | ethane |
| $C_3H_8$ | propane |
| $C_4H_{10}$ | butane |
| $C_2H_4$ | Ethylene |
| $C_6H_6$ | Benzene |
| CIEEDAC | Canadian Industrial Energy End-Use Data Analysis Centre |
| CKD | cement kiln dust |
| CO | carbon monoxide |

| | |
|---|---|
| $CO_2$ | carbon dioxide |
| $CO_2$ eq | carbon dioxide equivalent |
| COD | chemical oxygen demand |
| CORINAIR | The Core Inventory of Air Emissions in Europe |
| CPPI | Canadian Petroleum Products Institute |
| CRF | Common Reporting Format |
| CSPA | Canadian Steel Producers Assocation |
| CT | conventional tillage |
| CTS | crop and tillage system |
| CVS | Canadian Vehicle Survey |
| DE | digestible energy |
| DM | dry matter |
| DMI | dry matter intake |
| DOC | degradable organic carbon |
| DOCF | degradable organic carbon dissimilated |
| DOM | dead organic matter |
| EAF | electric arc furnace |
| EC | Environment Canada |
| EDC | ethylene dichloride |
| EF | emission factor |
| $EF_{BASE}$ | basic emission factor |
| EMEP | European Monitoring and Evaluation Programme |
| EPA | Environmental Protection Agency (United States) |
| EPGTD | Electric Power Generation, Transmission and Distribution |
| eq | equivalent |
| ERCB | Energy Resources Conservation Board |
| ERT | Expert Review Team |
| EU | European Union |
| FAA | Federal Aviation Administration (United States) |
| FAACS | Feasibility Assessment of Afforestation for Carbon Sequestration |
| FCR | fuel consumption ratio |
| FGD | flue gas desulphurization |
| FLCL | forest land converted to cropland |
| FLSL | forest land converted to settlement |
| FLWL | forest land converted to wetland |
| FOI | Swedish Defence Research Agency |
| FTA | fraction of BOD in sludge that degrades anaerobically |
| FTILL | tillage ratio factor |
| g | gram |
| GCD | great-circle distance |
| GCV | gross calorific value |
| GDP | gross domestic product |
| GE | gross energy |
| Gg | gigagram |
| GHG | greenhouse gas |
| GHGRP | Greenhouse gas reporting program |
| GHV | gross heating value |
| GIS | geographic information system |
| GL | gigalitre |
| Gt | gigatonne |
| GTIS | Global Trade Information Services |

| | |
|---|---|
| GVWR | gross vehicle weight rating |
| GWP | global warming potential |
| $H_2$ | hydrogen |
| $H_2O$ | water |
| ha | hectare |
| HCFC | hydrochlorofluorocarbon |
| HCl | hydrochloric acid |
| HDD | heating degree-day |
| HDDT | heavy-duty diesel truck |
| HDDV | heavy-duty diesel vehicle |
| HDGV | heavy-duty gasoline vehicle |
| HE | harvest emissions |
| HFC | hydrofluorocarbon |
| HHV | higher heating value |
| HM | heavy metal |
| $HNO_3$ | nitric acid |
| HRAI | Heating, Refrigeration and Air Conditioning Institute of Canada |
| HSS | horizontal stud Søderberg |
| HWP | harvested wood product |
| HWP-C | carbon stored in harvested wood products |
| IAI | International Aluminium Institute |
| ICAO | International Civil Aviation Organization |
| IE | included elsewhere |
| IEA | International Energy Agency |
| I/M | inspection and maintenance |
| IPCC | Intergovernmental Panel on Climate Change |
| IT | intensive tillage |
| ITL | International Transaction Log |
| KAR | kilometre accumulation rate |
| k | methane generation rate constant |
| $K_2CO_3$ | potassium carbonate |
| kg | kilogram |
| kha | kilohectare |
| kPa | kilopascal |
| kt | kilotonne |
| kWh | kilowatt-hour |
| L | litre |
| $L_0$ | methane generation potential |
| lb. | pound |
| LDDT | light-duty diesel truck |
| LDDV | light-duty diesel vehicle |
| LDGT | light-duty gasoline truck |
| LDGV | light-duty gasoline vehicle |
| LFG | landfill gas |
| LHV | lower heating value |
| LMC | land management change |
| LPG | liquefied petroleum gas |
| LTO | landing and takeoff |
| LULUCF | Land Use, Land-use Change and Forestry |
| m | metre |
| $m^3$ | cubic metre |

| | |
|---|---|
| MAI | mean annual increment |
| MARS | Monitoring, Accounting and Reporting System |
| MC | motorcycle |
| MCED | Manufacturing, Construction and Energy Division of Statistics Canada |
| MCF | methane conversion factor (Agriculture) |
| MCF | methane correction factor (Waste) |
| Mg | magnesium; also megagram |
| $MgCO_3$ | magnesite; magnesium carbonate |
| MGEM | Mobile Greenhouse Gas Emission Model |
| MGEM07 | Mobile Greenhouse Gas Emission Model 2007 |
| MgO | magnesia; dolomitic lime |
| Mha | megahectare, equivalent to a million hectares |
| ML | megalitre |
| mol | mole |
| MMIC | Motorcycle & Moped Industry Council |
| MODTF | Modeling and Database Task Force |
| mol | mole |
| MS | manure system distribution factor |
| MSW | municipal solid waste |
| Mt | megatonne |
| MTOW | maximum takeoff weight |
| mV | millivolt |
| MW | megawatt |
| N | nitrogen |
| $N_2$ | nitrogen gas |
| $Na_2CO_3$ | sodium carbonate; soda ash |
| $Na_3AlF_6$ | cryolite |
| NA | not applicable |
| N/A | not available |
| NAICS | North American Industry Classification System |
| NCV | net calorific value |
| NE | not estimated |
| NEB | National Energy Board |
| NGL | natural gas liquid |
| $NH_3$ | ammonia |
| $NH_4+$ | ammonium |
| $NH_4NO_3$ | ammonium nitrate |
| NHTSA | National Highway Traffic Safety Administration (United States) |
| NIR | National Inventory Report |
| NMVOC | non-methane volatile organic compound |
| $N_2O$ | nitrous oxide |
| NO | nitric oxide; also used for not occurring |
| $NO_2$ | nitrogen dioxide |
| $NO_3$ | nitrate |
| $NO_x$ | nitrogen oxides |
| NOC | Nitrous Oxide of Canada |
| NPRI | National Pollutant Release Inventory |
| NRCan | Natural Resources Canada |
| NSCR | non-selective catalytic reduction |
| NT | no tillage |
| $O_2$ | oxygen |

| | |
|---|---|
| ODS | ozone-depleting substance |
| OECD | Organisation for Economic Co-operation and Development |
| OEM | original equipment manufacturer |
| OS/HOU | oil sands and heavy oil upgrading |
| PFC | perfluorocarbon |
| PJ | petajoule |
| PKT | passenger kilometres travelled |
| POP | persistent organic pollutant |
| ppb | part per billion |
| ppbv | part per billion by volume |
| P/PE | precipitation/potential evapotranspiration |
| ppm | part per million |
| QA | quality assurance |
| QC | quality control |
| RA | reference approach |
| RESD | Report on Energy Supply and Demand in Canada |
| RPP | refined petroleum product |
| RT | reduced tillage |
| SA | sectoral approach |
| SAGE | System for assessing Aviation's Global Emissions |
| SAN | styrene-acrylonitrile resin |
| SBR | styrene-butadiene |
| SCR | selective catalytic reduction |
| $SF_6$ | sulphur hexafluoride |
| SIC | Standard Industrial Classification |
| SiC | silicon carbide |
| SLC | Soil Landscapes of Canada |
| SMR | steam methane reforming |
| $SO_2$ | sulphur dioxide |
| $SO_x$ | sulphur oxides |
| SOC | soil organic carbon |
| STC | Statistics Canada |
| SUV | sport utility vehicle |
| t | tonne |
| TC | Transport Canada |
| t-km | tonne-kilometre |
| TKT | tonne-kilometres travelled |
| TJ | terajoule |
| TWh | terrawatt-hour |
| UN | United Nations |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UPCIS | Use Patterns and Controls Implementation Section |
| UOG | upstream oil and gas |
| VCM | vinyl chloride monomer |
| VKT | vehicle kilometres travelled |
| VSS | vertical stud Søderberg |
| VOC | volatile organic compound |
| VS | volatile solids |
| WMO | World Meteorological Organization |
| wt | weight |

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# Annex 1

## Key Categories

### A1.1.   Key Categories— Methodology

This annex presents the use of an IPCC Tier 1 key category analysis and results for Canada's inventory submission. Both the IPCC Good Practice Guidance (IPCC 2000) and the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (LULUCF) (IPCC 2003) recommend as good practice the identification of key categories of emissions and removals. The intent is to help inventory agencies prioritize their efforts to improve overall estimates. A key category is defined as "one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both" (IPCC 2000).

Good practice first requires that inventories be disaggregated into categories from which key sources and sinks may be identified. Source and sink categories are defined according to the following guidelines:

- IPCC categories should be used with emissions expressed in $CO_2$ equivalent units according to standard global warming potentials (GWPs).
- A category should be identified for each gas emitted or removed, since the methods, emission factors, and related uncertainties differ for each gas.
- Categories that use the same emission factors based on common assumptions should be aggregated before analysis.

The IPCC Tier 1 quantitative approach is used to identify key categories from two perspectives: their contribution to the overall emissions, and to the emission trend. The level assessment analyzes the emission contribution that each category makes to the national total (with and without LULUCF). The trend assessment uses each category's relative contribution to the overall emissions, but assigns greater weights to the categories whose relative trend

departs from the overall one (with and without LULUCF); in this assessment, trends are calculated as the absolute changes between the base and most recent inventory years. The percent contributions to both levels and trends in emissions are calculated and sorted from greatest to least. A cumulative total is calculated for both approaches. A cumulative contribution threshold of 95% for both level and trend assessments is a reasonable approximation of 90% uncertainty for the Tier 1 method of determining key categories (IPCC 2000). This threshold has therefore been used in this analysis to define an upper boundary for key category identification. Hence, when source and/or sink contributions are sorted in decreasing order of importance, those largest ones that together contribute to 95% of the cumulative total are considered quantitatively to be key.

Level contribution of each source is calculated according to Equation A1−1, which follows IPCC (2000), whereas Equation A1-2 is used to calculate the level contribution from both sources and sinks following IPCC (2003):

Equation A1−1:

$$L_{x,t} = \frac{E_{x,t}}{E_t}$$

where:

| | | |
|---|---|---|
| $L_{x,t}$ | = | the level assessment for source x in year t |
| $E_{x,t}$ | = | the emission estimate ($CO_2$ eq) of source category x in year t |
| $E_t$ | = | the total inventory estimate ($CO_2$ eq) in year t |

**A1**

Equation A1–2:

$$L^*_{x,t} = \frac{E^*_{x,t}}{E^*_t}$$

where:

$L^*_{x,t}$ = the level assessment for source or sink x in year t; the asterisk (*) indicates that contributions from all categories (including LULUCF) are entered as absolute values (i.e. negative values are always recorded as the equivalent positive values)

$E^*_{x,t}$ = $\left|E_{x,t}\right|$, the absolute value of the emission or removal estimate ($CO_2$ eq) of source or sink category x in year t

$E^*_t$ = $\sum_x \left|E_{x,t}\right|$, the sum of the absolute values of all emissions and removals ($CO_2$ eq) from all source or sink categories x in year t, kt $CO_2$ eq

Trend contribution of each source is calculated according to Equation Equation A1–3, which follows IPCC (2000), whereas

Equation A1–4 for source and sink category trend assessment:

is used to calculate the trend contribution from both sources and sinks following IPCC (2003):

Equation A1–3:     for source category trend assessment:

$$T_{x,t} = L_{x,t} \cdot \left| \left[ \frac{(E_{x,t} - E_{x,0})}{E_{x,t}} \right] - \left[ \frac{(E_t - E_0)}{E_t} \right] \right|$$

where:

$T_{x,t}$ = the contribution of the source category trend to the overall inventory trend (i.e. the trend assessment); the trend assessment is always recorded as an absolute value

$L_{x,t}$ = the level assessment for source x in year t (derived in Equation A1–1)

$E_{x,t}$ and $E_{x,0}$ = the emission estimates ($CO_2$ eq) of source category x in years t and 0, respectively

$E_t$ and $E_0$ = the total inventory estimates ($CO_2$ eq) in years t and 0, respectively

Equation A1–4:     for source and sink category trend assessment

$$T_{x,t} = \frac{E^*_{x,t}}{E^*_t} \cdot \left| \left[ \frac{(E_{x,t} - E_{x,0})}{E_{x,t}} \right] - \left[ \frac{(E_t - E_0)}{E_t} \right] \right|$$

where:

$T_{x,t}$ = the contribution of the source or sink category trend to the overall inventory trend (i.e. the trend assessment); the trend assessment is always recorded as an absolute value

$E^*_{x,t}$ = $\left|E_{x,t}\right|$, the absolute value of the emission or removal estimate ($CO_2$ eq) of source or sink category x in year t

$E^*_t$ = $\sum_x \left|E_{x,t}\right|$ the sum of the absolute values of the emission and removal estimates ($CO_2$ eq) in year t

$E_{x,t}$ and $E_{x,0}$ = the emission estimates ($CO_2$ eq) of source or sink category x in years t and 0, respectively

$E_t$ and $E_0$ = $\sum_x E_{x,t}$ and $\sum_x E_{x,0}$, the sum of all emissions and removals from source and sink categories x ($CO_2$ eq) in years t and 0, respectively; Et differs from Et* in Equation A1–2 in that the removals are not entered as absolute values

The overall purpose of identifying key categories is the institution of best practices in GHG inventory development. The appropriate aggregation of categories is crucial to reflect not only actual sources and sinks but also identical estimation procedures. Thus, while the UNFCCC common reporting format (CRF) categories provide a basis for identifying sources and sinks, some aggregation of these sources and sinks can occur when using the same emission factors based on common estimation assumptions. In this analysis, major categories such as Fuel Combustion, Fugitive Emissions, Industrial Processes, Agriculture and Waste are in keeping with the CRF. Within these major categories, the aggregation of subcategories occurs when estimates are made based on common assumptions with respect to emission factors and common activity data.

## A1.1.1. Summary Assessment

Key categories were assessed for the 2009 inventory year using level and trend criteria and for the base year on the level criterion only.

There were 30 level key categories in 1990, while in 2009 there were 36 with all combined criteria. In this year's key category analysis, all of the categories that were key in 1990 remained so in 2009. Results are shown in Table A1–1.

Table A1–1    Key Category Analysis Summary, 2009 Inventory

| Source Table | IPCC Category | Direct GHG | Key Category (1990/2009) | Criteria (1990/2009) L: Level T: Trend |
|---|---|---|---|---|
| 1-A* | Stationary Fuel Combustion - Solid Fuels | $CO_2$ | Yes/Yes | L/L,T |
| 1-A* | Stationary Fuel Combustion - Solid Fuels | $CH_4$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Solid Fuels | $N_2O$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Liquid Fuels | $CO_2$ | Yes/Yes | L/L,T |
| 1-A* | Stationary Fuel Combustion - Liquid Fuels | $CH_4$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Liquid Fuels | $N_2O$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Gaseous Fuels | $CO_2$ | Yes/Yes | L/L,T |
| 1-A* | Stationary Fuel Combustion - Gaseous Fuels | $CH_4$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Gaseous Fuels | $N_2O$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Other Fuels | $CO_2$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Other Fuels | $CH_4$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Other Fuels | $N_2O$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Biomass | $CO_2$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Biomass | $CH_4$ | No/No | |
| 1-A* | Stationary Fuel Combustion - Biomass | $N_2O$ | No/No | |
| 1-A-3-a | Fuel Combustion - Civil Aviation (Domestic Aviation) | $CO_2$ | Yes/Yes | L/L,T |
| 1-A-3-a | Fuel Combustion - Civil Aviation (Domestic Aviation) | $CH_4$ | No/No | |
| 1-A-3-a | Fuel Combustion - Civil Aviation (Domestic Aviation) | $N_2O$ | No/No | |
| 1-A-3-b | Fuel Combustion - Road Transportation | $CO_2$ | Yes/Yes | L/L,T |
| 1-A-3-b | Fuel Combustion - Road Transportation | $CH_4$ | No/No | |
| 1-A-3-b | Fuel Combustion - Road Transportation | $N_2O$ | Yes/No | L |
| 1-A-3-c | Fuel Combustion - Railways | $CO_2$ | Yes/Yes | L/L,T |
| 1-A-3-c | Fuel Combustion - Railways | $CH_4$ | No/No | |
| 1-A-3-c | Fuel Combustion - Railways | $N_2O$ | No/No | |
| 1-A-3-d | Fuel Combustion - Navigation (Domestic Marine) | $CO_2$ | Yes/Yes | L/L |
| 1-A-3-d | Fuel Combustion - Navigation (Domestic Marine) | $CH_4$ | No/No | |
| 1-A-3-d | Fuel Combustion - Navigation (Domestic Marine) | $N_2O$ | No/No | |
| 1-A-3-e | Fuel Combustion - Other Transport (Off Road) | $CO_2$ | Yes/Yes | L/L,T |

**A1**

Table A1-1: Key Category Analysis Summary, 2009 Inventory   (cont'd)

| Source Table | IPCC Category | Direct GHG | Key Category (1990/2009) | Criteria (1990/2009) L: Level T: Trend |
|---|---|---|---|---|
| 1-A-3-e | Fuel Combustion - Other Transport (Off Road) | $CH_4$ | No/No | |
| 1-A-3-e | Fuel Combustion - Other Transport (Off Road) | $N_2O$ | No/Yes | T |
| 1-A-3-e | Fuel Combustion - Pipeline Transport | $CO_2$ | Yes/Yes | L/L,T |
| 1-A-3-e | Fuel Combustion - Pipeline Transport | $CH_4$ | No/No | |
| 1-A-3-e | Fuel Combustion - Pipeline Transport | $N_2O$ | No/No | |
| 1-B-1-a | Fugitive Emissions - Coal Mining | $CH_4$ | No/Yes | T |
| 1-B-2-(a+c) | Fugitive Emissions - Oil | $CO_2$ | Yes/Yes | L/L,T |
| 1-B-2-(a+c) | Fugitive Emissions - Oil | $CH_4$ | Yes/Yes | L/L,T |
| 1-B-2-(a+c) | Fugitive Emissions - Oil | $N_2O$ | No/No | |
| 1-B-2-(b+c) | Fugitive Emissions - Natural Gas | $CO_2$ | Yes/Yes | L/L |
| 1-B-2-(b+c) | Fugitive Emissions - Natural Gas | $CH_4$ | Yes/Yes | L/L,T |
| 1-B-2-(b+c) | Fugitive Emissions - Natural Gas | $N_2O$ | No/No | |
| 2-A-1 | Industrial Processes - Cement Production | $CO_2$ | Yes/Yes | L/L,T |
| 2-A-2 | Industrial Processes - Lime Production | $CO_2$ | No/Yes | T |
| 2-A-3 | Industrial Processes - Limestone and Dolomite Use | $CO_2$ | No/No | |
| 2-A-4 | Industrial Processes - Soda Ash Production and Use | $CO_2$ | No/No | |
| 2-A-7-2 | Industrial Processes - Magnesite Use | $CO_2$ | No/No | |
| 2-B-1 | Industrial Processes - Ammonia Production | $CO_2$ | Yes/Yes | L/L |
| 2-B-2 | Industrial Processes - Nitric Acid Production | $N_2O$ | No/No | |
| 2-B-3 | Industrial Processes - Adipic Acid Production | $N_2O$ | Yes/Yes | L/T |
| | Industrial Processes - Petrochemical Production | $CH_4$ | No/No | |
| | Industrial Processes - Petrochemical Production | $N_2O$ | No/No | |
| 2-C-1 | Industrial Processes - Iron and Steel Production | $CO_2$ | Yes/Yes | L/L,T |
| 2-C-3 | Industrial Processes - Aluminium Production | $CO_2$ | No/Yes | T |
| 2-C-3 | Industrial Processes - Aluminium Production | PFCs | Yes/Yes | L/T |
| 2-C-4-1 | Industrial Processes - Aluminium Production | $SF_6$ | No/No | |
| 2-C-4-2 | Industrial Processes - Magnesium Production | $SF_6$ | No/No | |
| 2-C-5 | Industrial Processes - Magnesium Casting | $SF_6$ | No/No | |
| 2-E | Industrial Processes - Production of Halocarbons | HFCs | No/No | |
| 2-E | Industrial Processes - Production of Halocarbons | PFCs | No/No | |
| 2-E | Industrial Processes - Production of SF6 | $SF_6$ | No/No | |
| 2-F | Industrial Processes - Consumption of Halocarbons | HFCs | No/Yes | LT |
| 2-F | Industrial Processes - Consumption of Halocarbons | PFCs | No/No | |
| 2-F-6 | Industrial Processes - Consumption of SF6 for Semiconductor Manufacture | $SF_6$ | No/No | |
| 2-F-7 | Industrial Processes - Consumption of SF6 for Electrical Equipment | $SF_6$ | No/No | |
| 2-G | Industrial Processes - Other (Undifferentiated Processes) | $CO_2$ | Yes/Yes | L/L |
| 3-D | Solvent and Other Product Use | $N_2O$ | No/No | |
| 4-A | Agriculture - Enteric Fermentation | $CH_4$ | Yes/Yes | L/L,T |
| 4-B | Agriculture - Manure Management | $CH_4$ | No/No | |
| 4-B | Agriculture - Manure Management | $N_2O$ | Yes/Yes | L/L |

Table A1-1:   Key Category Analysis Summary, 2009 Inventory   (cont'd)

| Source Table | IPCC Category | Direct GHG | Key Category (1990/2009) | Criteria (1990/2009) L: Level  T: Trend |
|---|---|---|---|---|
| 4-D-1 | Agriculture - Direct Agricultural Soils | $N_2O$ | Yes/Yes | L/L,T |
| 4-D-2 | Agriculture - Animal Manure on Pasture, Range and Paddock | $N_2O$ | No/No | |
| 4-D-3 | Agriculture - Indirect Agricultural Soils | $N_2O$ | Yes/Yes | L/L,T |
| | Agriculture - Field Burning of Agricultural Soils | $CH_4$ | No/No | |
| | Agriculture - Field Burning of Agricultural Soils | $N_2O$ | No/No | |
| 5-A.1 | LULUCF - Forest Land remaining Forest Land | $CO_2$ | Yes/Yes | L/L,T |
| 5-A.1 | LULUCF - Forest Land remaining Forest Land | $CH_4$ | Yes/Yes | L/L,T |
| 5-A.1 | LULUCF - Forest Land remaining Forest Land | $N_2O$ | No/Yes | T |
| 5-A.2 | LULUCF - Land converted to Forest Land | $CO_2$ | No/No | |
| 5-B.1 | LULUCF - Cropland remaining Cropland | $CO_2$ | No/Yes | L,T |
| 5-B.2 | LULUCF - Land converted to Cropland | $CO_2$ | Yes/Yes | L/L,T |
| 5-B.2 | LULUCF - Land converted to Cropland | $CH_4$ | No/No | |
| 5-B.2 | LULUCF - Land converted to Cropland | $N_2O$ | No/No | |
| 5-D.1 | LULUCF - Wetlands remaining Wetlands | $CO_2$ | No/No | |
| 5-D.2 | LULUCF - Land converted to Wetlands | $CO_2$ | Yes/Yes | L/T |
| 5-D.2 | LULUCF - Land converted to Wetlands | $CH_4$ | No/No | |
| 5-D.2 | LULUCF - Land converted to Wetlands | $N_2O$ | No/No | |
| 5-E.2 | LULUCF - Settlements remaining Settlements | $CO_2$ | No/No | |
| 5-E.2 | LULUCF - Land converted to Settlements | $CO_2$ | Yes/Yes | L/L |
| 5-E.2 | LULUCF - Land converted to Settlements | $CH_4$ | No/No | |
| 5-E.2 | LULUCF - Land converted to Settlements | $N_2O$ | No/No | |
| 6-A | Waste - Solid Waste Disposal on Land | $CH_4$ | Yes/Yes | L/L,T |
| 6-B | Waste - Wastewater Handling | $CH_4$ | No/No | |
| 6-B | Waste - Wastewater Handling | $N_2O$ | No/No | |
| 6-C | Waste - Waste Incineration | $CO_2$ | No/No | |
| 6-C | Waste - Waste Incineration | $N_2O$ | No/No | |
| 6-C | Waste - Waste Incineration | $CH_4$ | No/No | |

## A1.2.    Key Category Tables

## A1.2.1.   Level Assessment With and Without LULUCF

Table A1–2 shows the 1990 key categories generated from level assessment with and without LULUCF, and Figure A1–1 shows the contribution of each 1990 key category to the level assessment.

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Table A1–2    1990 Key Categories by Level Assessment With and Without LULUCF

| Source Table | IPCC Source Category | Direct GHG | 1990 (kt CO₂ eq) | 2009 (kt CO₂ eq) | Level Assessment without LULUCF | Level Assessment with LULUCF | Cumulative Total without LULUCF | Cumulative Total with LULUCF |
|---|---|---|---|---|---|---|---|---|
| 1-A* | Stationary Fuel Combustion - Gaseous Fuels | $CO_2$ | 134 634 | 188 350 | 0.228 | 0.186 | 0.23 | 0.19 |
| 5-A.1 | LULUCF - Forest Land remaining Forest Land | $CO_2$ | -96 859 | -24 788 | NA | 0.134 | NA | 0.32 |
| 1-A-3-b | Fuel Combustion - Road Transportation | $CO_2$ | 93 216 | 127 541 | 0.158 | 0.129 | 0.39 | 0.45 |
| 1-A* | Stationary Fuel Combustion - Solid Fuels | $CO_2$ | 90 679 | 94 367 | 0.154 | 0.126 | 0.54 | 0.58 |
| 1-A* | Stationary Fuel Combustion - Liquid Fuels | CO2 | 47 759 | 25 223 | 0.081 | 0.066 | 0.62 | 0.64 |
| 1-A-3-e | Fuel Combustion - Other Transport (Off Road) | $CO_2$ | 21 464 | 30 048 | 0.036 | 0.030 | 0.66 | 0.67 |
| 6-A | Waste - Solid Waste Disposal on Land | $CH_4$ | 17 925 | 20 345 | 0.030 | 0.025 | 0.69 | 0.70 |
| 4-A | Agriculture - Enteric Fermentation | $CH_4$ | 16 294 | 19 325 | 0.028 | 0.023 | 0.71 | 0.72 |
| 1-B-2-(b+c) | Fugitive Emissions - Natural Gas | $CH_4$ | 14 619 | 23 553 | 0.025 | 0.020 | 0.74 | 0.74 |
| 1-B-2-(a+c) | Fugitive Emissions - Oil | $CH_4$ | 14 056 | 19 656 | 0.024 | 0.019 | 0.76 | 0.76 |
| 4-D-1 | Agriculture - Direct Agricultural Soils | $N_2O$ | 13 775 | 16 020 | 0.023 | 0.019 | 0.79 | 0.78 |
| 5-B.2 | LULUCF - Land converted to Cropland | $CO_2$ | 12 404 | 5 337 | NA | 0.017 | NA | 0.79 |
| 2-B-3 | Industrial Processes - Adipic Acid Production | $N_2O$ | 10 718 | 662 | 0.018 | 0.015 | 0.80 | 0.81 |
| 2-C-1 | Industrial Processes - Iron and Steel Production | $CO_2$ | 10 193 | 7 646 | 0.017 | 0.014 | 0.82 | 0.82 |
| 5-E.2 | LULUCF - Land converted to Settlements | $CO_2$ | 9 127 | 8 841 | NA | 0.013 | NA | 0.84 |
| 4-D-3 | Agriculture - Indirect Agricultural Soils | $N_2O$ | 8 736 | 10 898 | 0.015 | 0.012 | 0.84 | 0.85 |
| 2-G | Industrial Processes - Other (Undifferentiated Processes) | $CO_2$ | 8 030 | 9 435 | 0.014 | 0.011 | 0.85 | 0.86 |
| 1-A-3-a | Fuel Combustion - Civil Aviation (Domestic Aviation) | $CO_2$ | 7 152 | 7 081 | 0.012 | 0.010 | 0.86 | 0.87 |
| 1-A-3-e | Fuel Combustion - Pipeline Transport | $CO_2$ | 6 652 | 6 136 | 0.011 | 0.009 | 0.87 | 0.88 |
| 2-C-3 | Industrial Processes - Aluminium Production | PFCs | 6 539 | 2 163 | 0.011 | 0.009 | 0.88 | 0.89 |
| 1-A-3-c | Fuel Combustion - Railways | $CO_2$ | 6 159 | 6 114 | 0.010 | 0.009 | 0.90 | 0.90 |
| 1-B-2-(b+c) | Fugitive Emissions - Natural Gas | $CO_2$ | 6 002 | 6 978 | 0.010 | 0.008 | 0.91 | 0.90 |
| 1-B-2-(a+c) | Fugitive Emissions - Oil | $CO_2$ | 5 459 | 9 760 | 0.009 | 0.008 | 0.91 | 0.91 |
| 2-A-1 | Industrial Processes - Cement Production | $CO_2$ | 5 436 | 5 108 | 0.009 | 0.008 | 0.92 | 0.92 |
| 2-B-1 | Industrial Processes - Ammonia Production | $CO_2$ | 4 994 | 6 212 | 0.008 | 0.007 | 0.93 | 0.93 |
| 1-A-3-d | Fuel Combustion - Navigation (Domestic Marine) | $CO_2$ | 4 693 | 4 774 | 0.008 | 0.007 | 0.94 | 0.93 |
| 5-D.2 | LULUCF - Land converted to Wetlands | $CO_2$ | 3 976 | 584 | NA | 0.006 | NA | 0.94 |
| 1-A-3-b | Fuel Combustion - Road Transportation | $N_2O$ | 3 195 | 3 734 | 0.005 | 0.004 | 0.95 | 0.94 |
| 4-B | Agriculture - Manure Management | $N_2O$ | 3 121 | 3 878 | 0.005 | 0.004 | 0.95 | 0.95 |
| 5-A.1 | LULUCF - Forest Land remaining Forest Land | $CH_4$ | 2 954 | 5 580 | NA | 0.004 | NA | 0.95 |

Note: NA = Not applicable

Figure A1–1    Contributions of 1990 Key Categories to Level Assessment With and Without LULUCF
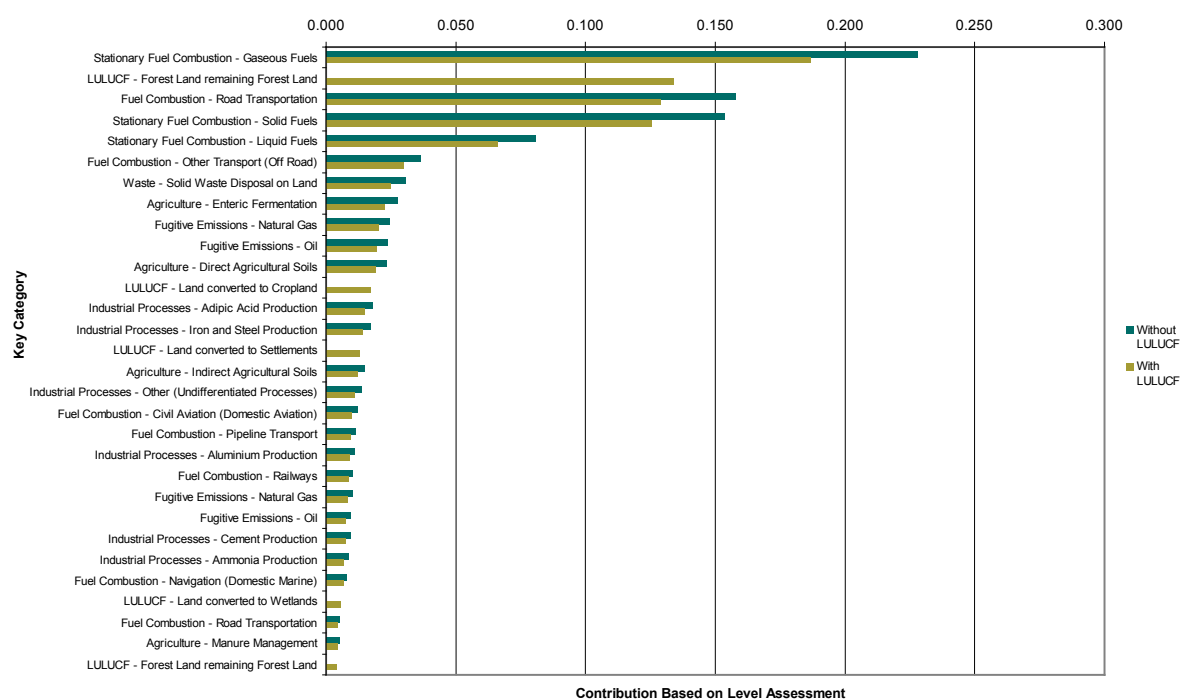


Table A1–3 shows the 2008 key categories generated from level assessment with and without LULUCF, and Figure A1–2 shows the contribution of each 2008 key category to the level assessment.

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Table A1–3    2009 Key Categories by Level Assessment With and Without LULUCF

| Source Table | IPCC Source Category | Direct GHG | 1990 (kt CO₂ eq) | 2009 (kt CO₂ eq) | Level Assessment without LULUCF | Level Assessment with LULUCF | Cumulative Total without LULUCF | Cumulative Total with LULUCF |
|---|---|---|---|---|---|---|---|---|
| 1-A* | Stationary Fuel Combustion - Gaseous Fuels | $CO_2$ | 134 634 | 188 350 | 0.273 | 0.250 | 0.27 | 0.25 |
| 1-A-3-b | Fuel Combustion - Road Transportation | $CO_2$ | 93 216 | 127 541 | 0.185 | 0.169 | 0.46 | 0.42 |
| 1-A* | Stationary Fuel Combustion - Solid Fuels | $CO_2$ | 90 679 | 94 367 | 0.137 | 0.125 | 0.59 | 0.54 |
| 1-A-3-e | Fuel Combustion - Other Transport (Off Road) | $CO_2$ | 21 464 | 30 048 | 0.044 | 0.040 | 0.64 | 0.58 |
| 1-A* | Stationary Fuel Combustion - Liquid Fuels | $CO_2$ | 47 759 | 25 223 | 0.037 | 0.033 | 0.67 | 0.62 |
| 5-A.1 | LULUCF - Forest Land remaining Forest Land | $CO_2$ | -96 859 | -24 788 | NA | 0.033 | NA | 0.65 |
| 1-B-2-(b+c) | Fugitive Emissions - Natural Gas | $CH_4$ | 14 619 | 23 553 | 0.034 | 0.031 | 0.71 | 0.68 |
| 6-A | Waste - Solid Waste Disposal on Land | $CH_4$ | 17 925 | 20 345 | 0.029 | 0.027 | 0.74 | 0.71 |
| 1-B-2-(a+c) | Fugitive Emissions - Oil | $CH_4$ | 14 056 | 19 656 | 0.028 | 0.026 | 0.77 | 0.73 |
| 4-A | Agriculture - Enteric Fermentation | $CH_4$ | 16 294 | 19 325 | 0.028 | 0.026 | 0.79 | 0.76 |
| 4-D-1 | Agriculture - Direct Agricultural Soils | $N_2O$ | 13 775 | 16 020 | 0.023 | 0.021 | 0.82 | 0.78 |
| 5-B.1 | LULUCF - Cropland remaining Cropland | $CO_2$ | -1 494 | -12 414 | NA | 0.016 | NA | 0.80 |
| 4-D-3 | Agriculture - Indirect Agricultural Soils | $N_2O$ | 8 736 | 10 898 | 0.016 | 0.014 | 0.83 | 0.81 |
| 1-B-2-(a+c) | Fugitive Emissions - Oil | $CO_2$ | 5 459 | 9 760 | 0.014 | 0.013 | 0.85 | 0.83 |
| 2-G | Industrial Processes - Other (Undifferentiated Processes) | $CO_2$ | 8 030 | 9 435 | 0.014 | 0.013 | 0.86 | 0.84 |
| 5-E.2 | LULUCF - Land converted to Settlements | $CO_2$ | 9 127 | 8 841 | NA | 0.012 | NA | 0.85 |
| 2-C-1 | Industrial Processes - Iron and Steel Production | $CO_2$ | 10 193 | 7 646 | 0.011 | 0.010 | 0.87 | 0.86 |
| 1-A-3-a | Fuel Combustion - Civil Aviation (Domestic Aviation) | $CO_2$ | 7 152 | 7 081 | 0.010 | 0.009 | 0.88 | 0.87 |
| 1-B-2-(b+c) | Fugitive Emissions - Natural Gas | $CO_2$ | 6 002 | 6 978 | 0.010 | 0.009 | 0.89 | 0.88 |
| 2-F | Industrial Processes - Consumption of Halocarbons | HFCs | NA | 6 786 | 0.010 | 0.009 | 0.90 | 0.89 |
| 2-B-1 | Industrial Processes - Ammonia Production | $CO_2$ | 4 994 | 6 212 | 0.009 | 0.008 | 0.91 | 0.90 |
| 1-A-3-e | Fuel Combustion - Pipeline Transport | $CO_2$ | 6 652 | 6 136 | 0.009 | 0.008 | 0.92 | 0.90 |
| 1-A-3-c | Fuel Combustion - Railways | $CO_2$ | 6 159 | 6 114 | 0.009 | 0.008 | 0.93 | 0.91 |
| 5-A.1 | LULUCF - Forest Land remaining Forest Land | $CH_4$ | 2 954 | 5 580 | NA | 0.007 | NA | 0.92 |
| 5-B.2 | LULUCF - Land converted to Cropland | $CO_2$ | 12 404 | 5 337 | NA | 0.007 | NA | 0.93 |
| 2-A-1 | Industrial Processes - Cement Production | $CO_2$ | 5 436 | 5 108 | 0.007 | 0.007 | 0.94 | 0.93 |
| 2-C-3 | Industrial Processes - Aluminium Production | $CO_2$ | 2 715 | 5 026 | 0.007 | 0.007 | 0.94 | 0.94 |
| 1-A-3-d | Fuel Combustion - Navigation (Domestic Marine) | $CO_2$ | 4 693 | 4 774 | 0.007 | 0.006 | 0.95 | 0.95 |
| 4-B | Agriculture - Manure Management | $N_2O$ | 3 121 | 3 878 | NA | 0.005 | NA | 0.95 |

Note: NA = Not applicable

Figure A1–2   Contributions of 2008 Key Categories to Level Assessment with and without LULUCF
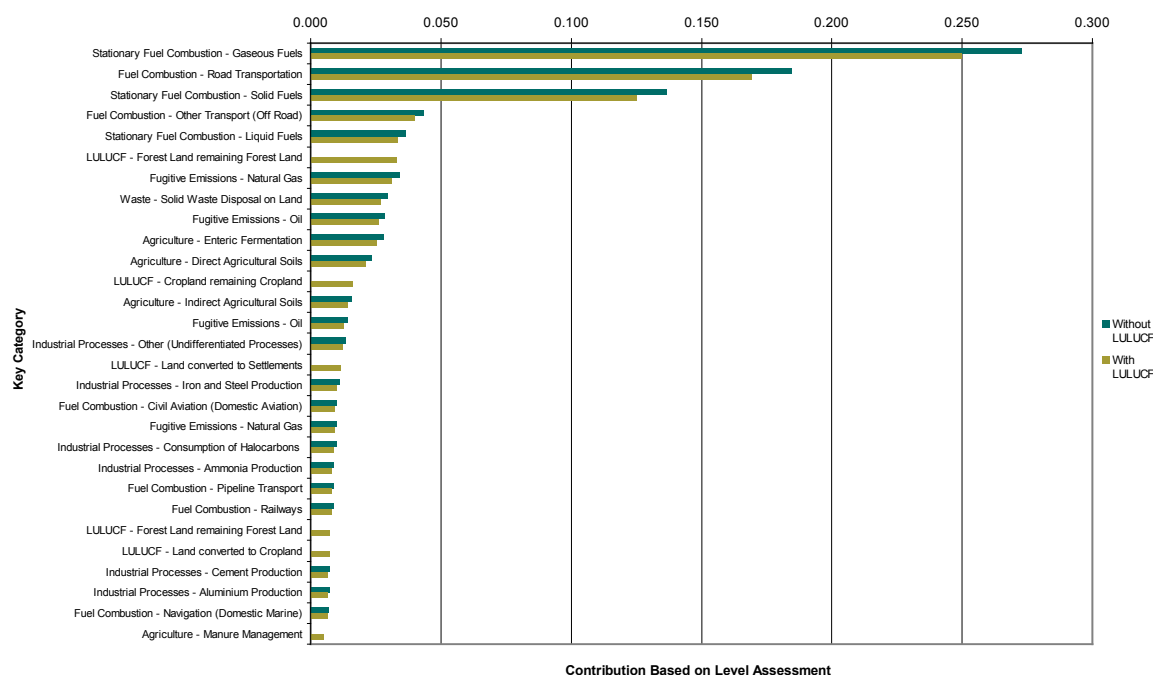


## A1.2.2.   Trend Assessment with and without LULUCF

Table A1–4 shows the key categories indicated from the trend assessment with and without LULUCF, and Figure A1–3 shows the contribution of key categories to the trend assessment.

In the level assessment presented in Section A1.2.1, above, the integration of the LULUCF sector introduces additional key categories without much alteration of the relative categories' contributions. However, the integration of LULUCF to the trend assessment considerably alters the overall trend, which causes a rearrangement in the ranking of key categories. A single LULUCF category, Forest Land Remaining Forest Land, contributes 27% to the overall trend. The trend assessment without LULUCF identifies 20 key categories, while the same analysis with LULUCF results in 23 key categories, including 6 categories from the LULUCF sector. The final list includes all the categories identified as key in either one of the analyses

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Table A1–4   Key Categories by Trend Assessment with and without LULUCF

| Source Table | IPCC Source Category | Direct GHG | 1990 (kt CO₂ eq) | 2009 (kt CO₂ eq) | Trend Assessment without LULUCF | Trend Assessment with LULUCF | Contribution to Trend without LULUCF | Contribution to Trend with LULUCF | Cumulative Total without LULUCF | Cumulative Total with LULUCF |
|---|---|---|---|---|---|---|---|---|---|---|
| 5-A.1 | LULUCF - Forest Land remaining Forest Land | CO₂ | -96 859 | -24 788 | NA | 0.097 | NA | 0.273 | 0.000 | 0.27 |
| 1-A* | Stationary Fuel Combustion - Gaseous Fuels | CO₂ | 134 634 | 188 350 | 0.038 | 0.061 | 0.199 | 0.171 | 0.20 | 0.44 |
| 1-A-3-b | Fuel Combustion - Road Transportation | CO₂ | 93 216 | 127 541 | 0.023 | 0.038 | 0.119 | 0.108 | 0.32 | 0.55 |
| 1-A* | Stationary Fuel Combustion - Liquid Fuels | CO₂ | 47 759 | 25 223 | 0.038 | 0.031 | 0.197 | 0.088 | 0.52 | 0.64 |
| 5-B.1 | LULUCF - Cropland remaining Cropland | CO₂ | -1 494 | -12 414 | NA | 0.014 | NA | 0.039 | 0.52 | 0.68 |
| 2-B-3 | Industrial Processes - Adipic Acid Production | N₂O | 10 718 | 662 | 0.015 | 0.013 | 0.076 | 0.038 | 0.59 | 0.72 |
| 1-B-2-(b+c) | Fugitive Emissions - Natural Gas | CH₄ | 14 619 | 23 553 | 0.008 | 0.011 | 0.042 | 0.030 | 0.63 | 0.75 |
| 5-B.2 | LULUCF - Land converted to Cropland | CO₂ | 12 404 | 5 337 | NA | 0.010 | NA | 0.027 | 0.63 | 0.77 |
| 1-A-3-e | Fuel Combustion - Other Transport (Off Road) | CO₂ | 21 464 | 30 048 | 0.006 | 0.010 | 0.032 | 0.027 | 0.66 | 0.80 |
| 2-F | Industrial Processes - Consumption of Halocarbons | HFCs | 0 | 6 786 | 0.008 | 0.009 | 0.044 | 0.024 | 0.71 | 0.82 |
| 1-B-2-(a+c) | Fugitive Emissions - Oil | CH₄ | 14 056 | 19 656 | 0.004 | 0.006 | 0.021 | 0.018 | 0.73 | 0.84 |
| 2-C-3 | Industrial Processes - Aluminium Production | PFCs | 6 539 | 2 163 | 0.007 | 0.006 | 0.035 | 0.017 | 0.76 | 0.86 |
| 1-B-2-(a+c) | Fugitive Emissions - Oil | CO₂ | 5 459 | 9 760 | 0.004 | 0.005 | 0.022 | 0.015 | 0.79 | 0.87 |
| 5-D.2 | LULUCF - Land converted to Wetlands | CO₂ | 3 976 | 584 | NA | 0.005 | NA | 0.013 | 0.79 | 0.89 |
| 2-C-1 | Industrial Processes - Iron and Steel Production | CO₂ | 10 193 | 7 646 | 0.005 | 0.004 | 0.027 | 0.011 | 0.81 | 0.90 |
| 5-A.1 | LULUCF - Forest Land remaining Forest Land | CH₄ | 2 954 | 5 580 | NA | 0.003 | NA | 0.009 | 0.81 | 0.91 |
| 4-A | Agriculture - Enteric Fermentation | CH₄ | 16 294 | 19 325 | NA | 0.003 | NA | 0.008 | 0.81 | 0.91 |
| 2-C-3 | Industrial Processes - Aluminium Production | CO₂ | 2 715 | 5 026 | 0.002 | 0.003 | 0.012 | 0.008 | 0.83 | 0.92 |
| 4-D-3 | Agriculture - Indirect Agricultural Soils | N₂O | 8 736 | 10 898 | NA | 0.002 | NA | 0.006 | 0.83 | 0.93 |
| 4-D-1 | Agriculture - Direct Agricultural Soils | N₂O | 13 775 | 16 020 | NA | 0.002 | NA | 0.006 | 0.83 | 0.93 |
| 6-A | Waste - Solid Waste Disposal on Land | CH₄ | 17 925 | 20 345 | NA | 0.002 | NA | 0.006 | 0.83 | 0.94 |
| 5-A.1 | LULUCF - Forest Land remaining Forest Land | N₂O | 1 825 | 3 462 | NA | 0.002 | NA | 0.006 | 0.83 | 0.95 |
| 1-B-1-a | Fugitive Emissions - Coal Mining | CH₄ | 1 914 | 709 | 0.002 | 0.002 | 0.010 | 0.005 | 0.84 | 0.95 |
| 1-A* | Stationary Fuel Combustion - Solid Fuels | CO₂ | 90 679 | 94 367 | 0.014 | NA | 0.075 | NA | 0.91 | NA |
| 1-A-3-a | Fuel Combustion - Civil Aviation (Domestic Aviation) | CO₂ | 7 152 | 7 081 | 0.002 | NA | 0.008 | NA | 0.92 | NA |
| 1-A-3-c | Fuel Combustion - Railways | CO₂ | 6 159 | 6 114 | 0.001 | NA | 0.007 | NA | 0.92 | NA |
| 1-A-3-e | Fuel Combustion - Other Transport (Off Road) | N₂O | 1 833 | 2 965 | 0.001 | NA | 0.005 | NA | 0.93 | NA |
| 1-A-3-e | Fuel Combustion - Pipeline Transport | CO₂ | 6 652 | 6 136 | 0.002 | NA | 0.011 | NA | 0.94 | NA |
| 2-A-1 | Industrial Processes - Cement Production | CO₂ | 5 436 | 5 108 | 0.002 | NA | 0.008 | NA | 0.95 | NA |
| 2-A-2 | Industrial Processes - Lime Production | CO₂ | 1 759 | 1 214 | 0.001 | NA | 0.005 | NA | 0.95 | NA |

Note: NA = Not applicable

Figure A1–3   Contributions of Key Categories to Trend Assessment With and Without LULUCF
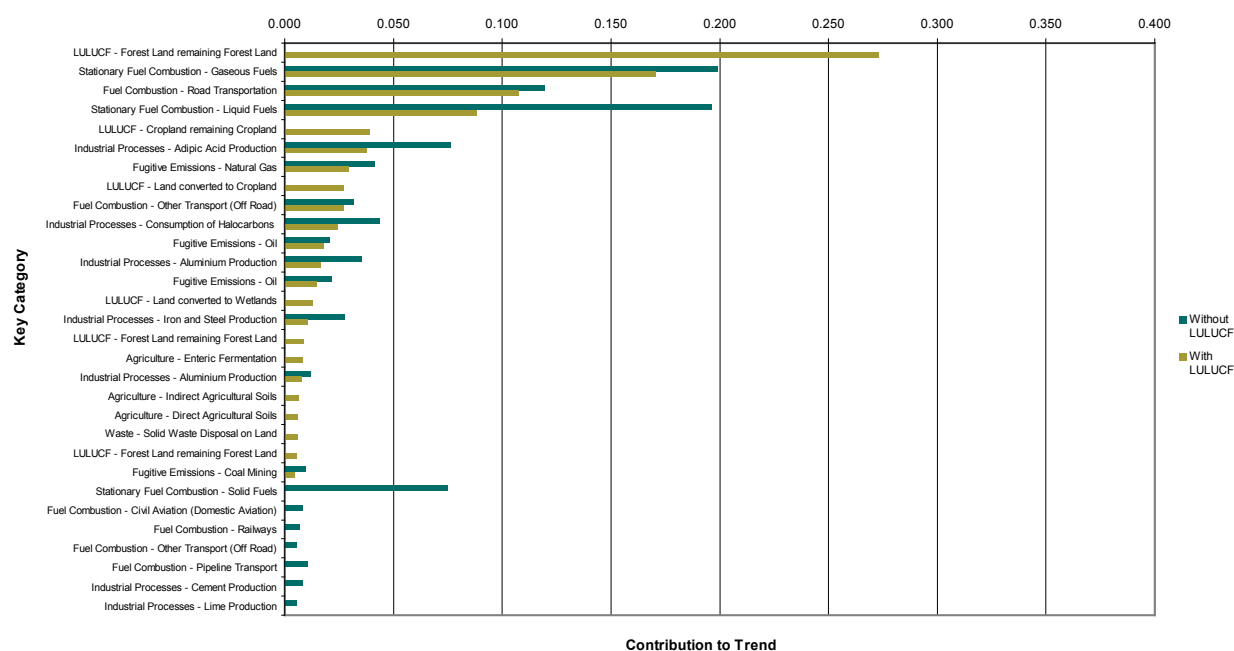
# Annex 2

## Methodology and Data for Estimating Emissions from Fossil Fuel Combustion

The following presents an overview of the methodology, activity data and emission factors used to estimate $CO_2$, $CH_4$ and $N_2O$ emissions from fuel combustion sources for the Energy Sector. Additional methodological details and refinements to the general approach are presented in Section A2.4.1 for stationary and A2.4.2 for transport sources.

## A2.1.    Methodology

In general, a top-down method following the Tier 3 and Tier 2 sectoral approach from the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) is used to estimate greenhouse gas (GHG) emissions from fuel combustion based on country-specific emission factors and on the quantity of fuel consumed at the source category level. As illustrated by Equation A2–1, for each source category, the quantity of fuel at the national and/or provincial level of detail is multiplied by a specific emission factor. Further refinements and deviations from the general approach to estimating combustion emissions are discussed in the stationary combustion and transport sections of this annex (sections A2.4.1 and A2.4.2, respectively). The purpose of these refinements is to increase the accuracy and allocation of the emissions associated with each source category when additional details or parameters are available. Specific methodological issues are presented in the Energy chapter (Chapter 3) of this report.

Equation A2–1:    for general fuel combustion:

$$E_{Category,\,G} = FC_{F,\,R} * EF_{G,\,F,\,R,\,t}$$

where:

$E_{Category,G}$ = GHG emissions by source category and by gas.

$FC_{F,R}$ = Quantity of fuel consumed (in physical units, such as kg, L, or $m^3$) by type of fuel (i.e. natural gas, sub-bituminous coal, kerosene, etc.) and by region.

$EF_{G,F,R,T}$ = Country-specific emission factor (in physical units) by GHG, by fuel type, by region (where available) and by technology (for non-$CO_2$ factors).

Relational databases are primarily used in stationary and transport models to process activity data and emission factors at national and provincial levels of detail in estimating GHG emissions (Figure A2–1). The national energy balance is prepared by Statistics Canada. The fuel consumption and disposition data on which the national energy balance is based are reported to Statistics Canada by the producing and consuming sectors in physical units rather than energy units, as physical units are considered more accurate. Country-specific emission factors, as applied, are in physical units to minimize the number of additional conversion factors and thus to limit the uncertainty associated with estimates. When higher-resolution emission factors at the regional level are available, then regional information is applied rather than national values to further reduce the uncertainty of these estimates (e.g. coal and natural gas emission factors account for the variation in the carbon content across various regions). Combustion technology differences are addressed by non-$CO_2$ emission factors.

## A2.2.    Activity Data from Statistics Canada

The principal source of fossil fuel and energy data used to estimate combustion emissions is the annual *Report on Energy Supply-Demand in Canada* (RESD) (Statistics Canada #57-003). The RESD uses a top-down approach to estimate the supply of, and demand for 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, residential and industry. Industrial energy-

Figure A2–1   GHG Estimation Process Flow
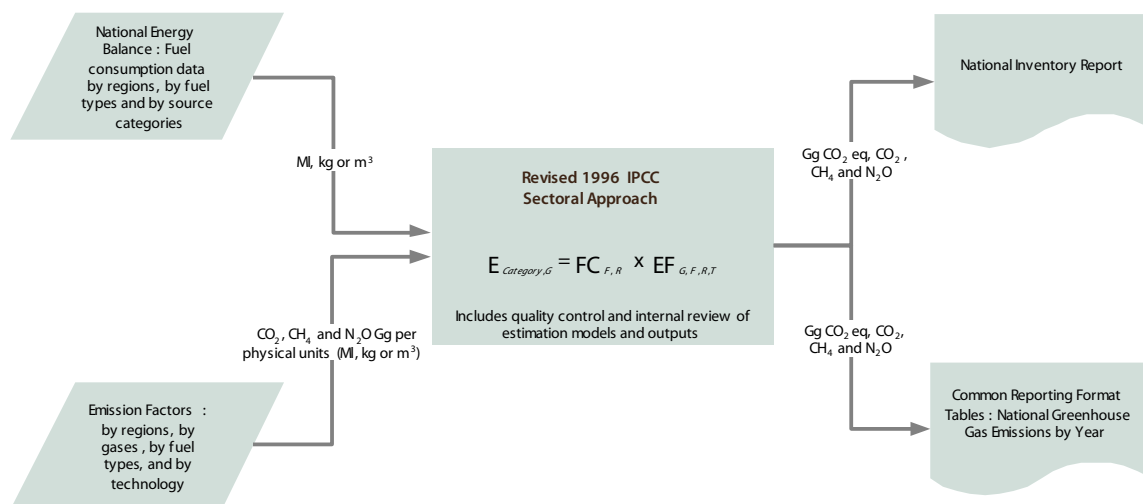


use data are divided into broad sectors based on the Standard Industrial Classification (SIC). Currently, these sectoral industrial energy-use data do not include energy used to generate electricity or steam by industry (autoproducers). This energy is captured in the RESD in two separate lines (one for electricity and one for steam); however, they are summary lines and not divided by sector. In order to allocate this energy, these summary lines are fractionally allocated based on the quantities reported by sector in the *Industrial Consumption of Energy Survey* (ICE).

While the RESD provides fuel-use estimates at a provincial level, in general, the accuracy of these data is not as high as that of the national data. Statistics Canada generally collects the fuel data for the RESD through a number of specific surveys directed at suppliers of energy, provincial energy ministries and some users of energy. The accuracy of the sectoral end-use data is less than that of the total energy supply data. As a result, the total emission estimates for Canada are known with more certainty than the emissions from specific categories. Since 1995, Statistics Canada has been collecting energy-use statistics from end users through the annual *Industrial Consumption of Energy Survey* (ICE). This bottom-up approach to estimating fuel use by industry (as opposed to the top-down approach used in the RESD) may provide more accurate information at the sectoral level for future inventories. Refer to Annex 4, Section A4.3 – National Energy Balance for additional discussion on the development of the RESD and the ICE data set, including a discussion on Statistics Canada's quality assurance/quality control activities. Sector-specific surveys, like the *Electric Power Thermal Generating Station Fuel*

*Consumption Annual Survey* (TGS) are also used to verify sector trends and emission allocation.

The combustion and transport models apply the quantity of fossil fuel consumed in physical units rather than in energy units, since this is how the information is reported to Statistics Canada by reporting facilities under the *Statistics Act*. The quantities of fossil fuel consumed are also available in gross calorific units; however, this is assumed to be less accurate, since Statistics Canada applies, in most cases, constant energy conversion factors (from 1990 to 1997 and from 1998 onward) to each fuel type. One exception to this approach involves the quantity of still gas reported in the RESD. The physical units are back-calculated from the reported energy values, since the physical volume of still gas consumed by refineries and oil sands upgraders as reported in the RESD is on a liquid basis, while the still gas emission factor is on a gaseous basis. The only other exception involves waste fuels, the data for which are only available in energy units from the Cement Association of Canada.

Additional non-Statistics Canada activity data sources used by the combustion and transport models, such as landfill gas quantities, waste fuel consumption and vehicle fleet information, are included in the specific methodological discussions (sections A2.4.1 and A2.4.2).

## A2.3.    Fuel Combustion Emission Factors

A description of emission factors employed in estimating the emissions for the current fossil fuel combustion models can be found in Annex 8. The following is generally true:

*Natural Gas:* The emission factors for $CO_2$ vary depending on the source of natural gas and whether or not the product is marketable or non-marketable (raw natural gas for on-site consumption by natural gas producers). Therefore, emission factors are assigned for different provinces based upon the origin and quality of the natural gas. The emission factors for $CH_4$ and $N_2O$ vary with the combustion technology.

*Refined Petroleum Products (RPP):* The emission factors vary by fuel type and/or combustion technology.

*Coal:* The emission factors for $CO_2$ vary with the properties of the coal. Therefore, emission factors are assigned for different provinces based upon the origin of the coal (domestic or foreign). The emission factors for $CH_4$ and $N_2O$ vary with the combustion technology.

### A2.3.1.    $CO_2$ Emission Factors

$CO_2$ emissions from fuel combustion activities depend upon the amount of fuel consumed, the carbon content of the fuel and the IPCC default oxidation value. The basis of the $CO_2$ emission factor derivations are discussed in Annex 8, in the *Fossil Fuel and Derivative Factors* (McCann 2000) study and in previous inventory publications (e.g. Jaques 1992). The methods used to determine fuel properties such as carbon content, density and heating value are based on accepted industrial testing standards, such as the American Society for Testing and Materials (ASTM) and the Canadian General Standards Board (CGSB). Both the hydrocarbons and particulates formed during combustion are accounted for to some extent, but emissions of CO are included in the estimates of $CO_2$ emissions. It is assumed that CO in the atmosphere undergoes complete oxidation to $CO_2$ shortly after combustion (within 5 to 20 weeks of its release).

As stated above, the emission factors used in Canada's GHG inventory are based upon the physical quantity of fuel combusted rather than on the energy content of the fuel, with the exception of the emission factor for waste fuels. The waste fuel factor is based on energy content, as the data reported by the Cement Association of Canada (CAC) are in energy units. The emission factors employed to estimate emissions are subdivided by the type of fuel used and, in the case of $N_2O$ and $CH_4$ emissions, the combustion technology employed.

### A2.3.2.    Non-$CO_2$ Emission Factors

Emission factors for all non-$CO_2$ GHGs from combustion activities vary to a lesser or greater degree with:

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

During the combustion of carbon-based fuels, a small portion of the fuel remains unoxidized as $CH_4$. Additional research is necessary to better establish $CH_4$ emission factors for many combustion processes. Overall factors are developed for sectors based on typical technology splits and available emission factors for the sector. In several sectors, $CH_4$ emission factors are not known.

During combustion, some of the nitrogen in the fuel and air is converted to $N_2O$. The production of $N_2O$ is dependent upon the combustion temperature and the control technology employed. Additional research is necessary to better establish $N_2O$ emission factors for many combustion processes. Overall factors are developed for sectors based on typical technologies and available emission factors for the sector. In several sectors, $N_2O$ emission factors are not known. Non-$CO_2$ emission factors in this inventory are listed in Annex 8.

### A2.3.3.    Biomass

For reporting under the United Nations Framework Convention on Climate Change (UNFCCC), $CO_2$ emissions from biomass fuels (including landfill gas) are not to be included in the Energy Sector total. $CO_2$ emissions from biomass fuel combustion are accounted for in the Land Use, Land-Use Change and Forestry (LULUCF) Sector as a loss of biomass (forest) stocks. $CO_2$ from biomass combustion for energy purposes is reported as a memo item of the UNFCCC's Common Reporting Format (CRF) table for information only. $CH_4$ and $N_2O$ emissions from biomass fuel combustion are reported in the Energy Sector in the appropriate subsectors and included in inventory totals.

## A2.4. Methodology for Stationary Combustion and Transport

### A2.4.1. Stationary Combustion

The methodology used to estimate GHG emissions from stationary fuel combustion is consistent with the IPCC Tier 2 sectoral approach, along with country-specific emission factors as outlined in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). The methodology and emissions of $SF_6$ from the transmission of electricity generation (CRF Category 1.A.1.a) are included in the Industrial Processes Sector.

The emissions are calculated based on nationally reported activity data, except when emission factors are available at the provincial/territorial level. In these instances, the provincial/territorial emissions are aggregated to a national total.

Table A2–1 presents a breakdown by source category of the application of activity data and emission factors. Discussions on assumptions of the estimation methodology for the following subsectors are also provided:

- Public Electricity and Heat Production;
- Fossil Fuel Industries;
- Manufacturing Industries and Construction;
- Other Sectors; and
- Pipelines.

Details on specific source categories are included in the notes section of Table A2–1 The complexity of the stationary combustion model lies in the allocation and distribution of the data presented in the RESD in order to comply with the UNFCCC CRF table. Emission estimates are calculated using Equation A2–1 exclusively and are consistent with the IPCC Tier 2 approach.

Table A2–1 presents the methodology and emission factors according to fuel types as presented in Table A2–2. Fossil fuels have been grouped based on their physical state at the point of consumption (solid, liquid and gaseous fuel, with the exception of biomass). For example, natural gas liquids (NGLs) such as propane, ethane and butane are classified as gaseous fuels, whereas petroleum coke is included under solid fuels. Fuels organized by IPCC groupings are presented in Annex 4, where a comparison is made to the grouping based on physical state at the point of consumption.

Table A2–1    Estimation Methodology for GHG Emissions from Stationary Combustion

| CRF Source Category[1] | Fuels List | Activity Data Source[2] | Notes |
|---|---|---|---|
| 1.A.1.a.i Electricity Generation – Utilities | Solid Fuels Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details Line 10 – Transformed to Other fuels: Electricity – By utilities | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | "iquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil, motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel | Table D – Refined Petroleum Products Line 10 – Transformed to Other fuels: Electricity – By utilities | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids Line 10 – Transformed to Other fuels: Electricity – By utilities | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for the remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | Biomass | NA | NA |
| 1.A.1.a.ii Electricity Generation – Industry | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry | Line 11 is allocated to 1.A.1.b, 1.A.1.c and 1.A.2 based on fractions developed from sector data reported in ICE, prior to calculating emissions. |

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| CRF Source Category[1] | Fuels List | Activity Data Source[2] | Notes |
|---|---|---|---|
| 1.A.1.a.i Electricity Generation – Utilities (cont'd) | "iquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil, motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel | Table D – Refined Petroleum Products<br><br>Line 10 – Transformed to Other fuels: Electricity – By utilities | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids Line 10 – Transformed to Other fuels: Electricity – By utilities | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for the remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD.<br><br>Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | Biomass | NA | NA |
| 1.A.1.a.ii Electricity Generation – Industry | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry | Line 11 is allocated to 1.A.1.b, 1.A.1.c and 1.A.2 based on fractions developed from sector data reported in ICE, prior to calculating emissions. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil, motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel | Table D – Refined Petroleum Products<br><br>Line 11 – Transformed to Other Fuels: Electricity – By industry | Line 11 is allocated to 1.A.1.b, 1.A.1.c and 1.A.2 based on fractions developed from sector data reported in ICE, prior to calculating emissions. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids<br><br>Line 11 – Transformed to Other Fuels: Electricity – By industry | Line 11 is allocated to 1.A.1.b, 1.A.1.c and 1.A.2 based on fractions developed from sector data reported in ICE, prior to calculating emissions. |
| | Biomass | NA | NA |
| 1.A.1.a.iii Heat & Steam Generation | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details<br><br>Line 14 – Transformed to Other Fuels: Steam Generation | Canada total for CO2 is the sum of all provinces'/territories' emissions due to regional emission factors being used.<br><br>Canada totals for CH4 and N2O are based on the national total reported in the RESD.<br><br>The portion of Line 14 not reallocated to an industrial sector is left in this CRF source category. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products<br><br>Line 14 – Transformed to Other Fuels: Steam Generation | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. Motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel are not included in this subsector because there are no data reported in the table.<br><br>The portion of Line 14 not reallocated to an industrial sector is left in this CRF source category. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Line 14 – Transformed to Other Fuels: Steam Generation | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD.<br><br>Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.<br><br>The portion of Line 14 not reallocated to an industrial sector is left in this CRF source category. |

Table A2-1    Estimation Methodology for GHG Emissions from Stationary Combustion  (cont'd)

| CRF Source Category[1] | Fuels List | Activity Data Source[2] | Notes |
|---|---|---|---|
| 1.A.1.a.iii Heat & Steam Generation (cont'd) | *Biomass* Landfill gas | Landfill gas utilization provided by the Waste Sector | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total provided by the Waste Sector. $CO_2$ emissions are not included in national totals, but are reported as a memo item in the CRF table. |
| 1.A.1.b. Petroleum Refining (Upstream & Downstream Oil and Gas Industries) | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 25 – Petroleum refining  Table 21 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total MINUS that used by crude bitumen upgraders reported in the RESD.  Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
|  | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil, motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel | Table D – Refined Petroleum Products  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 25 – Petroleum refining | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD MINUS emissions related to flaring. The activity data reported in the RESD include the amount of fuel used to flare. $CO_2$, $CH_4$ and $N_2O$ emissions from flaring activity are considered a fugitive source following the IPCC Guidelines; therefore, the fugitive emission and fuel value is subtracted from the estimated emissions and the RESD value. Only flaring emissions from the petroleum refining fugitive model are subtracted.  All other flaring emissions are subtracted from Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c).  A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
|  | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 25 – Petroleum Refining  Table 21 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD.  Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
|  | *Biomass* | NA | NA |
| 1.A.2.a. Iron and Steel | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 22 – Iron and steel | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.  Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  $CO_2$ emissions from coke are not included here, but are included in Industrial Processes. However, $CH_4$ and $N_2O$ emissions are counted here. The $CO_2$ is considered to be a product of the process (the reduction of iron), while the $CH_4$ and $N_2O$ are by-products of combustion. |

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Table A2-1    Estimation Methodology for GHG Emissions from Stationary Combustion  (cont'd)

| CRF Source Category[1] | Fuels List | Activity Data Source[2] | Notes |
|---|---|---|---|
| 1.A.2.a. Iron and Steel (cont'd) | | | A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 22 – Iron and steel | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. $CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 22 – Iron and steel | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | Biomass | NA | NA |
| 1.A.2.b. Non-ferrous Metals | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 23 – Smelting and refining, non-ferrous | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 23 – Smelting and refining, non-ferrous | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. $CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is are allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane" | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 23 – Smelting and refining, non-ferrous | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Biomass* | NA | NA |

Table A2-1    Estimation Methodology for GHG Emissions from Stationary Combustion  (cont'd)

| CRF Source Category[1] | Fuels List | Activity Data Source[2] | Notes |
|---|---|---|---|
| 1.A.2.c. Chemicals | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table F – Coal Details<br><br>Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 26 – Chemicals | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.<br><br>Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.<br><br>A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products<br><br>Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 26 – Chemicals | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD.<br><br>$CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector.<br><br>A portion of the Electricity by Industry and Steam Generation lines from the RESD is allocated to this source category prior to calculating emissions. |
| | Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids<br><br>Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 26 – Chemicals | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD.<br><br>Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.<br><br>A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | Biomass | NA | NA |
| 1.A.2.d. Pulp, Paper and Print | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details<br><br>Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 21 – Pulp and paper | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.<br><br>Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.<br><br>A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products<br><br>Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 21 – Pulp and paper | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD.<br><br>$CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e., gasoline and diesel) are included in the Transport subsector.<br><br>A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |

Table A2-1    Estimation Methodology for GHG Emissions from Stationary Combustion  (cont'd)

| CRF Source Category[1] | Fuels List | Activity Data Source[2] | Notes |
|---|---|---|---|
| 1.A.2.d. Pulp, Paper and Print (cont'd) | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 21 – Pulp and paper | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD.  Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
|  | *Biomass* Spent pulping liquor, solid wood waste | Table 20 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption | Total biomass is the amount of solid wood waste and spent pulping liquors combusted.  Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. Biomass $CO_2$ emissions are not included in the national totals, although $CH_4$ and $N_2O$ emissions are. |
| 1.A.2.e. Food Processing, Beverages and Tobacco | *Solid Fuels* | Included elsewhere | Emissions for this subsector are included in 1.A.2.f.iv. – Other Manufacturing. |
|  | *Liquid Fuels* | Included elsewhere | Emissions for this subsector are included in 1.A.2.f.iv. – Other Manufacturing. |
|  | *Gaseous Fuels* | Included elsewhere | Emissions for this subsector are included in 1.A.2.f.iv. – Other Manufacturing. |
|  | *Biomass* | Included elsewhere | Emissions for this subsector are included in 1.A.2.f.iv. – Other Manufacturing. |
| 1.A.2.f.i. Cement | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous Waste Fuel | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 24 – Cement  Waste fuel data reported by the Cement Association of Canada (CAC) and published by the Canadian Industrial Energy End-use Data Analysis Centre (CIEEDAC) | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke and waste fuel emissions, which are based on the national total.  Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
|  | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 24 – Cement | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  $CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector.  A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
|  | Gaseous Fuels Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 24 – Cement | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD.  Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |

Table A2-1    Estimation Methodology for GHG Emissions from Stationary Combustion  (cont'd)

| CRF Source Category[1] | Fuels List | Activity Data Source[2] | Notes |
|---|---|---|---|
| 1.A.2.f.i. Cement (cont'd) | Biomass | NA | NA |
| 1.A.2.f.ii. Mining | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 20 – Total mining & oil & gas extraction | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD. Mining, according to the RESD, includes fuel consumed for mining and extraction of oil and gas.  Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 20 – Total mining & oil & gas extraction | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  $CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector.  A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 20 – Total mining & oil & gas extraction | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD.  Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Biomass* | NA | NA |
| 1.A.2.f.iii. Construction | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details  Line 30 – Construction | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for petroleum coke emissions, which are based on the national total reported in the RESD.  Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products  Line 30 – Construction | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD.  $CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids  Line 30 – Construction | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD.  Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Biomass* | NA | NA |

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Table A2-1    Estimation Methodology for GHG Emissions from Stationary Combustion  (cont'd)

| CRF Source Category[1] | Fuels List | Activity Data Source[2] | Notes |
|---|---|---|---|
| | *Biomass* | NA | NA |
| 1.A.2.f.iv. Other Manufacturing | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details<br><br>Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 27 – Other manufacturing | A weighted emission factor is calculated for $CH_4$ and $N_2O$ based on fuel consumption and applied on an annual basis.<br><br>A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products<br><br>Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 27 – Other manufacturing | A weighted emission factor is calculated for $CH_4$ and $N_2O$ based on fuel consumption and applied on an annual basis.<br><br>$CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector.<br><br>A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids<br><br>Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 27 – Other manufacturing | A weighted emission factor is calculated for $CH_4$ and $N_2O$ based on fuel consumption and applied on an annual basis.<br><br>A weighted emission factor is calculated for $CH_4$ and $N_2O$ and applied on an annual basis.<br><br>A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | Biomass | NA | NA |
| 1.A.3.e. Pipelines (Transport) | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details<br><br>Line 39 – Pipelines | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil Motor gasoline, diesel fuel oil, aviation gasoline, aviation turbo fuel | Table D – Refined Petroleum Products<br><br>Line 39 – Pipelines | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids<br><br>Line 39 – Pipelines | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD.<br><br>Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Biomass* | NA | NA |
| 1.A.4.a.i. Commercial and Other Institutional | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details Line 46 – Commercial and institutional | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used.<br><br>Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |

Table A2-1    Estimation Methodology for GHG Emissions from Stationary Combustion  (cont'd)

| CRF Source Category[1] | Fuels List | Activity Data Source[2] | Notes |
|---|---|---|---|
| 1.A.4.a.i. Commercial and Other Institutional (cont'd) | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products Line 46 – Commercial and institutional | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. $CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still Gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids Line 46 – Commercial and institutional | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Biomass* | NA | NA |
| 1.A.4.a.ii. Public Administration | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details Line 45 – Public administration | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products Line 45 – Public administration | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. $CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids Line 45 – Public administration | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Biomass* | NA | NA |
| 1.A.4.b. Residential | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details Line 44 – Residential | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products Line 44 – Residential | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids Line 44 – Residential | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Biomass* Residential firewood | Firewood consumption estimated using the residential firewood model. | Total biomass is the amount of residential firewood combusted and is based on Environment Canada's survey data. $CO_2$ emissions are not included in the national totals, but $CH_4$ and $N_2O$ emissions are. |

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Table A2-1    Estimation Methodology for GHG Emissions from Stationary Combustion  (cont'd)

| CRF Source Category[1] | Fuels List | Activity Data Source[2] | Notes |
|---|---|---|---|
| 1.A.4.c.i. Forestry | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 29 – Forestry | Canada total for $CO_2$ is the sum of all provinces'/territories emissions due to regional emission factors being used. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | Liquid Fuels Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 29 – Forestry | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. $CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 29 – Forestry | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions, based on fractions developed from sector data reported in ICE. |
| | *Biomass* | NA | NA |
| 1.A.4.c.ii. Agriculture | *Solid Fuels* Coke Petroleum Coke – Refineries & Others Coal: Canadian bituminous, sub-bituminous, lignite, anthracite, foreign bituminous | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table F – Coal Details Line 43 – Agriculture | Canada total for $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Liquid Fuels* Kerosene and stove oil, light fuel oil, heavy fuel oil | Table D – Refined Petroleum Products Line 43 – Agriculture | Canada totals for $CO_2$, $CH_4$ and $N_2O$ are based on the national total reported in the RESD. $CO_2$, $CH_4$ and $N_2O$ associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. |
| | *Gaseous Fuels* Natural gas, coke oven gas Still Gas – Refineries & Others Propane, Butane, Ethane | Table B – Primary and Secondary Energy Table D – Refined Petroleum Products Table 17 – Details of Natural Gas Liquids Line 43 – Agriculture | Canada total for natural gas $CO_2$ is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel $CO_2$ are based on the national total reported in the RESD. Canada totals for $CH_4$ and $N_2O$ are based on the national total reported in the RESD. |
| | *Biomass* | NA | NA |
| 1.A.5. Other Information (not included elsewhere) | Included elsewhere | Included elsewhere | Emissions for this subsector are included in 1.A.2.f.iv. – Other Manufacturing. |

Notes:
1.    The CRF categories listed are the lowest-level subsectors for which emissions are estimated.
2.    Activity data refer to the specific location of the data in the annual Report on Energy Supply–Demand in Canada (RESD) (Statistics Canada #57-003). Also refer to Table A2–3 for more RESD data source references.
NA = Not Applicable

Table A2–2    General Fuel Type Categories for Stationary Combustion Methodology

| Fuel Types | Fuels |
|---|---|
| Liquid Fuels | Motor gasoline |
| | Kerosene and stove oil |
| | Diesel fuel oil |
| | Light fuel oil |
| | Heavy fuel oil |
| | Aviation gasoline |
| | Aviation turbo fuel |
| Solid Fuels | Coke (coal) |
| | Canadian bituminous |
| | Sub-bituminous (foreign & domestic) |
| | Lignite |
| | Anthracite |
| | Foreign bituminous |
| | Petroleum Coke–Refineries & Others |
| | Petroleum Coke–Upgraders |
| | Waste fuel |
| Gaseous Fuels | Natural gas |
| | Coke oven gas |
| | Propane |
| | Butane |
| | Ethane |
| | Still Gas–Refineries & Others |
| | Still Gas–Upgraders |
| Biomass | Solid wood waste |
| | Spent pulping liquor |
| | Residential firewood |
| | Landfill gas |

Table A2–3    Activity Data Model References

| Title |
|---|
| – Statistics Canada – Manufacturing, Construction and Energy Division; annual *Report on Energy Supply–Demand in Canada* (RESD), #57-003-XPB. |
| Table B – Primary and Secondary Energy |
| Table D – Refined Petroleum Products |
| Table E – Non-energy Refined Petroleum Products |
| Table F – Coal Details |
| Table 17 – Details of Natural Gas Liquids |
| Table 20 – Solid Wood Waste and Spent Pulping Liquor |
| Table 21 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil |
| – Waste fuel data – CIEEDAC. (2009). A *Review of Energy Consumption and Related Data: Canadian Cement Manufacturing Industry 1990 to 2007*. Prepared by Nyboer and Jaccard for the Cement Association of Canada. Canadian Industrial Energy End-use Data Analysis Centre. |
| – Residential fuelwood consumption – Based on Environment Canada. (1999). *1995 Criteria Contaminants Emissions Inventory Guidebook*, Version 1, Section 2.4. National Emissions Inventory and Projections Task Group, Criteria Air Contaminants Division, Environment Canada, March 1999. |
| – Landfill Gas Utilization – See Annex 3, Additional Methodologies. |

Activity data sources are presented in Table A2–3 for reference in the stationary combustion model methodology. The data are made available to Environment Canada in electronic format and may differ slightly when compared with Statistics Canada's rounded, published values.

### A2.4.1.1.    Public Electricity and Heat Production (CRF Category 1.A.1.a)

The Public Electricity and Heat Production subsector includes the 1.A.1.a.i – Electricity Generation; 1.A.1.a.ii – Combined Heat and Power Generation; and 1.A.1.a.iii – Heat Plants categories. This subsector should include all

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emissions from main activity producers (previously known as public utilities) of electricity generation, combined heat and power generation and heat plants. Emissions from autoproducers are allocated to the industrial subsector where they were generated. Currently, emissions associated with the combustion of landfill gas are included under 1.A.1.a.iii – Heat Plants.

$CO_2$, $CH_4$ and $N_2O$ emissions are estimated by applying Equation A2–1 to activity data and emission factors for specific fuels on a national basis. Coal and natural gas emission factors for these subsectors have been developed on a regional basis. As previously discussed, nationally reported activity data are of a higher quality than provincial/territorial data. In order to obtain higher accuracy in GHG emissions, regional emission factors are applied to provincial/territorial data in this circumstance. For the remaining fuels, the emission factors are applied to the nationally reported data.

### A2.4.1.2.  Fossil Fuel Industries
#### (CRF Categories 1.A.1.b and 1.A.1.c)

The Fossil Fuel Industries include 1.A.1.b – Petroleum Refining and 1.A.1.c – Manufacture of Solid Fuels and Other Energy Industries. The emissions total for the Fossil Fuel Industries has a higher level of accuracy owing to the resolution of the activity data. To meet CRF reporting category requirements, activity data from the whole industry were reallocated into two separate categories. These categories include combustion emissions that support 1) the refining of crude oil and some upgrading of oil sands bitumen; and 2) the production of coal, natural gas and crude oil.

The methodology for estimating emissions from these sectors involves applying Equation A2–1 on a national basis and subtracting emissions associated with flaring from the total GHG emissions for each category. The fuel-use data reported in the RESD include volumes of flared fuels; however, flaring emissions are calculated and reported separately in the fugitive category. The fuel use, energy content and emission data associated with flaring are subtracted to avoid double counting.

To determine the activity data associated with the Petroleum Refining Sector, some data reported in the RESD must be reallocated. All refined petroleum products (RPPs) that are reported as Producer-consumed are allocated to the Petroleum Refining Sector based on the assumption that they are consumed by the producers. Calculating the

emissions associated with the fuels listed below involves summing the activity data reported under Petroleum Refining and Producer-consumed and applying Equation A2–1 to:

- petroleum coke;
- still gas;
- kerosene;
- light fuel oil; and,
- heavy fuel oil.

In addition, activity data, in the form of fuel used by industry (including Petroleum Refining) to generate electricity or steam, are currently reported in summary lines in the RESD (Lines 11 and 14). A portion of each of these lines needs to be reallocated to the Petroleum Refining subsector. This is completed using fractions developed based on the quantities reported by the Petroleum Refining subsector in the ICE survey. For each fuel and each province, the fuel use data reported by industry in ICE for electricity generation are used to develop each industry's fraction of the total fuel use. The fractions are then used with the Electricity - By Industry line from the RESD to determine what portion of that line should be reallocated to a particular industry. This portion is added to the activity data already reported for that industry. The same procedure is completed with the steam generation line in the RESD and the corresponding ICE data for steam generation. Since ICE data are not available prior to 1995, for years between 1990 and 1995, the 1995 fractions were used.

To estimate emissions for the Petroleum Refining subsector from the consumption of the transportation fuels listed below, the activity data reported under Producer-consumed are used in Equation A2–1 and the emissions are included under Petroleum Refining. Due to a lack of resolution in the RESD, the Manufacture of Solid Fuels and Other Energy Industries subsector does not include emissions associated with the list of fuel (as presented below); instead their emissions are accounted for in the Petroleum Refining subsector:

- gasoline;
- diesel fuel oil;
- aviation gasoline; and
- aviation turbo fuel.

The IPCC default emission factors for $N_2O$ are used to estimate emissions for petroleum coke and motor gasoline, and are based on the calorific value of the fuel. The gross

calorific value (GCV) for petroleum coke is reported in the RESD and can change annually. As such, the emission factor for petroleum coke for both oil sands/crude bitumen production and refineries changes on an annual basis. The conversion between the GCV and the net calorific value (NCV) is based on data reported to and published by the Canadian Industrial Energy End-use Data Analysis Centre (CIEEDAC 2009).

To calculate GHG emissions from the Manufacture of Solid Fuels and Other Energy Industries subsector, activity data for the following fuels reported as Producer-consumed in the RESD are used in Equation A2–1:

- natural gas;
- coal;
- propane;
- butane; and
- ethane.

The following fuels are reported as Producer-consumed in the oil sands/crude bitumen production industry in the RESD. These amounts are subtracted from the Petroleum Refining subsector and included in the Manufacture of Solid Fuels and Other Energy Industries subsector. Consumption of both fuels is reported in a separate table in the RESD and allocated to upgrading facilities:

- petroleum coke; and
- still gas.

As previously mentioned in Section A2.4.1.1, coal emissions are estimated at a provincial/territorial level and aggregated to a national level.

To avoid double counting, the emissions associated with flaring are subtracted from the total for this Sector and reported in the relevant fugitive tables (1.B.2). Flaring emissions from the fugitive Petroleum Refining model are subtracted from Petroleum Refining (1.A.1.b) while all other flaring emissions from the fugitive model are subtracted from Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c).

## A2.4.1.3. Manufacturing Industries and Construction (CRF Category 1.A.2)

The Manufacturing Industries and Construction subsector include a number of industrial categories. Activity data in the RESD are reported for the main economic and fuel-consuming industrial categories; however, this does not include fuel used to generate electricity or steam by industry. This energy is captured in the RESD in two separate lines (one for electricity and one for steam); however, they are summary lines and not divided by industrial categories. Future improvement to the RESD will allow for further disaggregation of these industrial categories to be consistent with the North American Industrial Classification System (NAICS).

Emissions are calculated for the following categories:

- Mining;
- Iron and Steel;
- Non-ferrous Metals;
- Chemicals;
- Pulp, Paper and Print;
- Cement;
- Construction; and
- Other Manufacturing (includes Food Processing, Beverages and Tobacco).

In order to reallocate the fuel reported in the summary lines for electricity and steam in the RESD (Lines 11 and 14) a fractional allocation method was developed based on the quantities reported by category in the ICE survey. For each fuel and each province, the fuel use data reported by industry in ICE for electricity generation are used to develop each industry's fraction of the total fuel use. The fractions are then used with the Electricty – By Industry line from the RESD to determine what portion of that line should be reallocated to a particular industry. This portion is added to the activity data already reported for that industry. The same procedure is completed with the steam generation line in the RESD and the corresponding ICE data for steam generation. Since ICE data are not available prior to 1995, for years between 1990 and 1995, the 1995 fractions were used.

GHG emissions associated with the Manufacturing Industries and Construction subsector are calculated by applying Equation A2–1 to activity data reported in the RESD and emission factors for specific fuels on a national basis. Coal emissions are handled as described in Section A2.4.1.1 Emissions resulting from fuels used as feedstocks are reported under the Industrial Processes Sector, whereas emissions generated from the use of transportation fuels (e.g. diesel and gasoline) are reported under the Transport subsector.

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$CO_2$ emissions associated with the use of metallurgical coke in the iron and steel industry for the reduction of iron ore in blast furnaces have been allocated to the Industrial Processes Sector. $CH_4$ and $N_2O$ emissions, however, are included, as they are by-products of the combustion process.

$CO_2$ emissions associated with biomass combustion in the Pulp, Paper and Print subsector are not included in the national totals; however, $CH_4$ and $N_2O$ emissions are included in the totals. Industrial consumption of biomass and spent pulping liquors is reported in the RESD; however, some of the data are limited. The RESD 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 RESD data. For 1992, the data for Newfoundland and Nova Scotia were also combined, and there were no comparable data to allow separation of these provinces. Emissions are listed under Nova Scotia. In 2010, Environment Canada conducted a review of available wood waste moisture content data and concluded that for the purposes of the NIR, solid wood waste activity data are reported on a wet weight basis and that the average moisture content is 50%.

$CO_2$ emissions from the combustion of waste fuels in the cement industry are calculated based on data provided by the Cement Association of Canada and reported by CIEEDAC (2009) on an energy basis. Based on a review of the industry, it is assumed that all the waste fuel consumed comes from tires. Although other waste fuels (waste oil, solvents) are consumed, their contribution to the total is small, and the level of detail required to distinguish the different sources is currently not available.

### A2.4.1.4.   Other Sectors (CRF Category 1.A.4)

The Other Sectors subsector consists of three categories: Commercial/Institutional, Residential and Agriculture/Forestry/Fisheries. GHG emissions associated with the Other Sectors subsector (with the exception of emissions from the combustion of residential firewood) are calculated by applying Equation A2–1 to activity data reported in the RESD and emission factors for specific fuels on a national basis.

The activity data used in the calculation of GHG emissions from the combustion of residential firewood are based on estimated fuel use. Fuel-use data are based on the criteria air contaminant inventory (Environment Canada 1999). Residential fuel-use data from Statistics Canada and

Natural Resources Canada were not used since they appear to greatly underestimate firewood consumption (as a significant portion of firewood consumed in Canada is not from commercial sources).

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

1.   Conventional stoves
     • non-airtight
     • airtight, non-advanced technology
     • masonry heaters

2.   Stove/fireplace inserts with advanced technology or catalyst control
     • advanced-technology fireplaces
     • advanced-technology stoves
     • catalytic fireplaces
     • catalytic stoves

3.   Conventional fireplaces
     • without glass doors
     • with non-airtight glass doors
     • with airtight glass doors

4.   Furnaces
     • wood-burning furnaces

5.   Other equipment
     • other wood-burning equipment

The firewood consumption data for the other years were extrapolated based on the number of houses in each province using wood as a principal or supplementary heat source (from Statistics Canada 1995) in relation to 1995. GHG emissions were calculated by multiplying the amount of wood burned in each appliance by the emission factors.

$CO_2$ emissions associated with biomass combustion in the Residential category are not included in the national total; however, $CH_4$ and $N_2O$ emissions are included.

The Agriculture/Forestry/Fisheries category (CRF Category 1.A.4.c) includes emissions from stationary fuel combustion only from the agricultural and forestry industries. Emissions are from on-site machinery operation and from space heating and are estimated based on fuel use data for agriculture and forestry as reported in the RESD. Fishery emissions are reported under either the Transportation or Other Manufacturing (i.e. food processing) category. Mobile emissions associated with this category are not disaggregated and are included as off-road or marine emissions reported under Transport.

## A2.4.2. Transport
### (CRF Category 1.A.3)

GHG emissions from the Transport subsector are divided into five categories:

- Civil Aviation (Domestic Aviation);
- Road Transportation;
- Railways;
- Navigation (Domestic Marine); and
- Other Transportation (Off-road and Pipelines).

Emission estimates are developed at the provincial/territorial level and aggregated to the national level.

Fuel combustion emissions associated with the Transport subsector are calculated using various adaptations of Equation A2–1.

$CO_2$ emissions are predominantly dependent on the type and characteristics of fuel being combusted, whereas $N_2O$ and $CH_4$ emissions are dependent on both the fuel combusted and emission control technologies present. Annex 8 provides a complete listing of transportation-related emission factors and their specific references.

Owing to the complexity of the Transport subsector, Canada's Mobile Greenhouse Gas Emission Model (MGEM) and the Aviation Greenhouse Gas Emission Model (AGEM) are used to calculate the emissions from Road Transportation, Railways, Navigation, Off-road and Aviation. The combustion emissions associated with pipeline transport are estimated separately.

## A2.4.2.1. Road Transportation
### (CRF Category 1.A.3.b)

The methodology used to estimate Road Transportation GHG emissions follows a detailed IPCC Tier 3 approach.

**Step 1:**

**Activity Data – Vehicle Populations, Technology Penetration, Catalyst Survival Rate, Fuel Consumption Ratios and Kilometre Accumulation Rates**

*Vehicle Populations*

Vehicles are separated into different classes depending on their fuel type, body configuration (car versus truck) and gross vehicle weight rating (GVWR). GVWR is the maximum allowable weight of a fully loaded road vehicle, including the weight of the vehicle, fuel, passengers, cargo and other miscellaneous items, including optional accessories.

Two distinct data sets are used to develop a complete vehicle population profile. Light-duty vehicle and truck populations for 1990–2002 were obtained from the *Canadian Vehicles in Operation Census,* which is maintained by DesRosiers Automotive Consultants Inc. Light-duty vehicle and truck populations for 2003–2009 were derived from Statistics Canada's *Canadian Vehicle Survey* (CVS). Heavy-duty vehicle populations were obtained from R.L. Polk & Co. for 1994–2002. Heavy-duty vehicle populations for 2003–2009 were derived from Statistics Canada's *Canadian Vehicle Survey*, while populations for 1990–1993 were estimated based on historical population trends. Light-duty vehicles (cars) and light-duty trucks (pickups, minivans, SUVs, etc.) are those with a GVWR of less than or equal to 3900 kg, whereas heavy-duty classes have a GVWR above 3900 kg.

Motorcycle populations for 1990–2009 were obtained from the Motorcycle & Moped Industry Council (MMIC 2009).

*Technology Penetration*

To account for the effects that emission control technologies have on emissions of $CH_4$ and $N_2O$, estimates of the number of vehicles on the road equipped with catalytic converters and other control technologies were developed. Figure A2–2 illustrates the varying penetration percentages of evolving technologies into new light-duty gasoline vehicles (LDGVs) and light-duty gasoline trucks (LDGTs) in successive model years. Technology penetration for heavy-duty gasoline vehicles (HDGVs), heavy-duty diesel vehicles (HDDVs), light-duty diesel vehicles (LDDVs), light-duty diesel trucks (LDDTs) and motorcycles (MCs) are detailed in Table A2–4 (U.S. EPA 2010).

*Catalyst Survival Rate*

With use, catalytic converters deteriorate, affecting tail-pipe emission rates. Based on information from industry experts, a technology-specific deterioration rate is applied to LDGVs and LDGTs with catalytic controlled technologies. To model the deterioration effect, the vehicles with deteriorated catalysts are assigned to the non-catalytic controlled technology. For provinces with inspection and maintenance (I/M) programs (Ontario and British Columbia), the catalyst survival rate is not applied to Tier 0, Tier 1,

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or Tier 2 technologies, as these emission control technologies are inspected and replaced or repaired as necessary.

*Fuel Consumption Ratios*

Average provincial fuel consumption ratios (FCRs) by vehicle class and model year (based on provincial vehicle sales) are available for LDGVs, LDGTs, LDDVs and LDDTs (NRCan 2010). FCRs for HDGVs are based on a vehicle class and model year average (IPCC/OECD/IEA 1997). HDDV and motorcycle FCRs are based on a yearly fleet average (NRCan 2010).

Laboratory FCRs are determined by standardized vehicle emission tests. However, research has shown that real-world fuel consumption is consistently higher than laboratory-generated data. Based on studies performed in the United States, on-road vehicle fuel consumption figures in MGEM have been adjusted to 25% above the laboratory FCR ratings (Maples 1993).

*Kilometre Accumulation Rates*

Kilometre accumulation rates (KARs) are a measure of the average annual kilometres travelled by vehicle class and vehicle age. Light-duty car and truck KARs are estimated from the results of a report examining the differences in vehicle odometer readings recorded during successive inspection and maintenance (I/M) tests from Ontario and British Columbia (Stewart Brown Associates 2010). Due to the absence of I/M programs in other jurisdictions, the Ontario KAR estimates are adopted in all other provinces and territories excluding British Columbia, where the B.C. KAR estimates are directly applied.

**Step 2:**

**On-road Fuel Calculation**

On-road gasoline and diesel fuel consumption is estimated using Equation A2–2:

Equation A2–2:

$$FuelConsumption = Population * KAR * FCR$$

For the most part, these parameters are different for each province, vehicle class, model year and inventory year. On-road vehicles are grouped into seven major vehicle classes, identical to those used by the U.S. Environmental Protection Agency (U.S. EPA) in its MOBILE emissions factor model. The U.S. EPA designations are as follows:

- LDGVs;
- LDGTs;
- HDGVs;
- MCs;
- LDDVs;
- LDDTs; and
- HDDVs.

It is assumed that all natural gas and propane fuel is consumed by light-duty vehicles. No breakdown by vehicle classification is utilized for natural gas and propane vehicles. The methodologies for propane and natural gas vehicles follow an IPCC Tier 1 method.

**Step 3:**

**Normalization**

In an effort to improve the allocation of diesel and gasoline between on- and off-road applications, a balancing algorithm has been incorporated into MGEM. This algorithm attempts to reconcile the fuel reportedly consumed by fuel surveys and the fuel consumption calculated by MGEM.

*Gasoline*

The first on-road gasoline estimate is calculated in step 2 and represents a bottom-up estimate based upon vehicle population FCRs and KARs.

The second estimate is based on the top-down gross and taxed gasoline sales reported by Statistics Canada (CAN-SIM, Table 405-0002). This survey polls individual provinces for their retail and non-retail fuel sales. The value reported as gross gasoline sales (taxed plus non-taxed) is adjusted to equal the total gasoline available for transport as reported in the RESD (Statistics Canada #57-003). That same adjustment is then applied to the taxed gasoline sales and becomes the second, or top-down, on-road gasoline estimate.

At a provincial level, top-down and bottom-up gasoline consumption estimates differ slightly; however, at a national level, there is a high degree of correlation between the two estimates. If the bottom-up estimate is larger than the top-down one, the adjusted taxed sales are taken as the final on-road gasoline estimate. If the top-down estimate exceeds the bottom-up estimate, the average of

the two estimates is taken as the final on-road gasoline estimate.

### Diesel Oil

The first on-road diesel estimate is calculated in step 2 (bottom-up).

The second estimate (top-down) is based on taxed diesel sales reported by Statistics Canada (CANSIM, Table 405-0002).

At a provincial level, the two estimates of on-road diesel consumption differ slightly; however, at a national level, there is a high degree of correlation between the two estimates. If the first on-road diesel estimate is larger than the second estimate, the taxed sales are taken as the final on-road diesel estimate. If the second estimate is larger than the first estimate, the average of the two estimates is taken as the final on-road diesel estimate.

### Step 4: On-road Emission Calculation

Emission estimates are based on fuel type, the total fuel consumed and the appropriate emission factor.

Emissions are calculated using Equation A2–1.

## A2.4.2.2.  Off-road (CRF Category 1.A.3.e)

The methodology used to estimate GHG emissions from off-road transportation follows an IPCC Tier 1 approach.

### Step 1: Off-road Fuel Calculation

Off-road fuel is calculated using Equation A2-3:

Equation A2–3:

$$\text{Off-road Fuel Consumption} = \\ \text{Fuel Available for Transportation} - \text{On Road Fuel Consumption}$$

### Step 2: Off-road Emission Calculation

Emission estimates are based on fuel type, the total fuel consumed and an emission factor.

Emissions are calculated using Equation A2–1.

## A2.4.2.3.  Civil Aviation (Domestic Aviation) (CRF Category 1.A.3.a)

The methodology used to estimate GHG emissions from Civil Aviation employs a modified IPCC Tier 1 approach

Figure A2–2    Technology Penetration for Light-duty Gasoline Vehicles and Trucks

**A2**
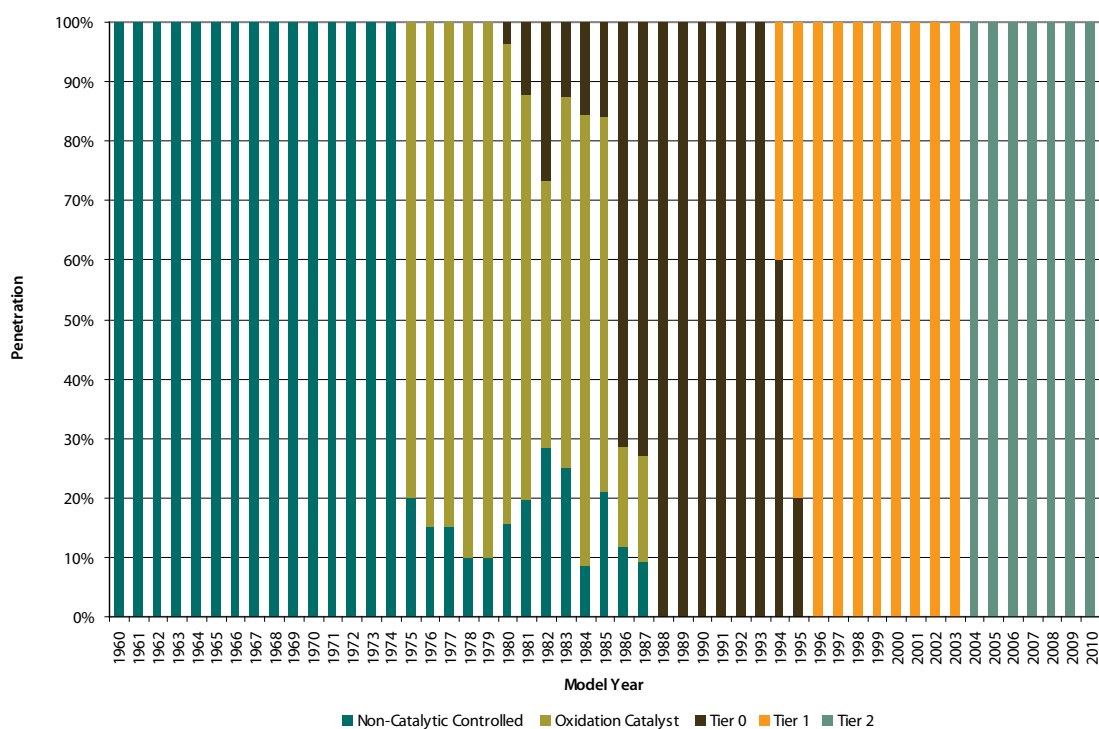
| Control Technology | Model Years |
| --- | --- |
| **Heavy-duty Gasoline Vehicles (HDGVs)** | |
| Uncontrolled | 1960–1984 |
| Non-catalytic Controlled | 1985–1995 |
| Three-way Catalyst | 1996–2010 |
| **Heavy-duty Diesel Vehicles (HDDVs)** | |
| Uncontrolled | 1960–1982 |
| Moderate Controls | 1983–1995 |
| Advanced Controls | 1996–2010 |
| **Light-duty Diesel Vehicles and Trucks (LDDVs and LDDTs)** | |
| Uncontrolled | 1960–1982 |
| Moderate Controls | 1983–1995 |
| Advanced Controls | 1996–2003 |
| Tier 2 | 2004–2010 |
| **Motorcycles (MCs)** | |
| Uncontrolled | 1960–1995 |
| Non-catalytic Controlled | 1996–2010 |

for aviation gasoline and a modified IPCC Tier 3 approach for aviation turbo fuel. This is the first year that the Tier 3 method results are being used in the Canadian inventory, thereby allowing a much higher (finer) resolution on aircraft activity and fuel consumption patterns. The Aviation model has been named AGEM as an acronym for Aviation Greenhouse Gas Emission Model.

This subsector includes all emissions from domestic air transport (commercial, private, agricultural, etc.). In accordance with the Revised 1996 IPCC Guidelines, and because of the new Tier 3 approach, military air transportation emissions attributed to the consumption of aviation turbo fuel are reported in the Other subsector (CRF Category 1.A.5). However, military emissions generated by the consumption of aviation gasoline remain in this category (1.A.3.a) since the current data source for this type of fuel consolidates military and civil fuel use to facilitate confidentiality. Excluded are emissions from fuel used at airports for ground transport (reported under Other Transportation – Off-road) and fuel used in stationary combustion applications at airports. Emissions from international flights are designated as "bunker" emissions and are not included in national totals but are estimated and reported separately under international bunkers.

Emission estimates for aviation gasoline are calculated using the quantity of aircraft fuel apparently consumed (IPCC/OECD/IEA 1997) and the fuel-specific emission

factor. Aviation fuel sales are reported in the RESD (Statistics Canada #57-003) representing that sold to Canadian airlines, foreign airlines, public administration and commercial/institutional sectors. All aviation gasoline use is designated domestic, other than that reported under foreign airlines.

**Tier 3 Methodology**

**Step 1:**

**Activity Data: Aircraft Movements, Flight Path Length, Airport Coordinates, Aircraft Fuel Use Characteristics, Representative Aircraft Mappings, Aircraft Emission Performance**

*Aircraft Movements*

The aircraft movement data (AMS 2009) used in AGEM are flight-by-flight tower data collected by NAV Canada starting in November 1996 and Transport Canada before November 1996. Both data streams are processed by Statistics Canada and redistributed to NAV Canada and Transport Canada. Environment Canada receives the information directly from Statistics Canada, including small airport movements that Statistics Canada collects directly and appends to the tower data from NAV Canada.

The data identifies, among other things, the origin, destination and plane type for any given movement occurring in Canada. Statistics Canada's processing of the data

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includes adding information based on other raw data fields provided to them as well as validation of airports, plane types, and various data fields that are not crucial to modelling fuel use.

Military emissions are estimated based on the movement data, as they are labelled as military by Statistics Canada.

## Flight Path Length

The flight path length is the true distance travelled between two airports. The movement data used for modelling are not radar data and thus do not track the exact path travelled by each individual movement. AGEM estimates the flight path length based on additional information obtained from the Federal Aviation Administration (FAA). The FAA operates an aviation model titled SAGE that is based on true radar data. The FAA provided Environment Canada with an extract from their model for calendar year 2005 involving Canadian airports and included the statistical measures (maximum, minimum, average, standard deviation) for the radar distance travelled between any Canadian origin and final destination for a given plane type (Fleming 2008a). The average distance from these combinations was then used as the distance flown when the same combination appeared in AGEM's movement data (regardless of the calendar year of the movement). There are cases, however, when a combination in AGEM exists without a corresponding average distance. In these cases another method needed to be developed.

An adjusted great circle distance (GCD[1]) is used when the average radar distance is unknown. A factor applied to the GCD was developed by comparing GCD to radar distance for a given origin/destination/plane type. Graphing the known radar lengths against their corresponding GCDs leads to an equation that can be used for adjusting all raw GCD distances. Therefore, all GCDs are adjusted by a factor to approximate the flight path length with the factors decreasing in magnitude as the GCD increases.

## Airport Coordinates

All possible airport entries within the AGEM movement data were extracted and defined. Information on the airports such as latitude, longitude, name, elevation, etc. were compiled from various sources including Transport Canada (Cadieux 2006), the Canada Flight Supplement (NAV Canada 2009), SAGE (Fleming 2008b), the Modeling

and Database Task Force (MODTF) (Fleming 2008c), the FAA (FAA 2009) and previous departmental work (Manning 2007). The main information required is the geographical coordinates so that a GCD can be calculated and used to determine the flight path length.

## Aircraft Fuel Use Characteristics

Once the flight path length is determined, the fuel consumed by the airplane for that movement can be calculated knowing the fuel characteristics of that plane. The fuel characteristics of various representative aircraft are drawn from the Base of Aircraft Data (BADA) (BADA 2009), the International Civil Aviation Organization (ICAO) via their engine emissions databank (ICAO 2009) and the Swedish Defence Research Agency (FOI) via their turbo prop engine emissions databank (Hagstrom 2010). The information in BADA is used for estimating fuel use from just after takeoff to landing. The ICAO information is used for defining the remaining portions of the landing and takeoff cycle (LTO) which are taxi and takeoff (explained in more detail in Step 2). Finally, FOI serves the same purpose as ICAO but covers the smaller turbo prop type aircraft not available in the ICAO data.

## Representative Aircraft Mappings

All possible aircraft type entries within the AGEM movement data were extracted and defined. Once defined, each aircraft was mapped to a representative aircraft with known fuel use characteristics so that fuel consumption could be calculated for all aircraft in AGEM. The mapping was done using published mapping guides whenever possible (BADA 2009; IPCC 2006; ICAO 2008; EMEP/CORINAIR 2006) and matching plane characteristics (MTOW,[2] number of engines, engine type, etc.) when there was no published mapping for a given aircraft.

## Aircraft Emission Performance

In an attempt to better estimate $CH_4$ emissions, aircraft-specific emission factors are used within AGEM for the LTO cycle. The factors are taken from Table 3.6.9 in the 2006 IPCC Guidelines (IPCC 2006), in the form of total emissions per LTO cycle. These factors are then adjusted by a ratio based on the total LTO fuel difference between that published in the table and that calculated in AGEM. It is recognized that a one-to-one adjustment of $CH_4$ emissions based on fuel ratio differences may not be entirely correct; however, lacking any additional information, this

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1    Great circle distance (GCD) is the shortest distance between two points on a sphere; in the case of aviation it is the shortest possible flight path length between the origin and destination of a flight movement.

2    Maximum takeoff weight.

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modification was made recognizing that the default values from Table 3.6.9 do not truthfully reflect AGEM's methodology. For the cruise portion, $CH_4$ emissions are assumed to be zero (Wiesen et al. 1994). For ease of use by the general public, the published $CH_4$ emission factor will be a fleet average across the entire time series and based on total fuel consumed (LTO and cruise).

Table 3.6.9 also has $N_2O$ plane-specific emission factors on a total LTO cycle basis; however, they are calculated using a Tier 1 fuel-based emission factor and therefore the Tier 1 factor is used directly since the amount of fuel consumed during the LTO cycle is calculated by AGEM.

## Step 2 Aviation Fuel Calculation

Fuel consumed by each individual movement is estimated using: Equation A2–4.

Equation A2–4:

$$FuelConsumption_{FlightTotal} = FuelConsumption_{LTO} + FuelConsumption_{Cruise}$$

The LTO phase of flight (3000 ft and below) consists of takeoff (accelerating down the runway until liftoff), climb out (from liftoff to 3000 ft), approach (3000 ft to landing) and taxi in/out (manoeuvring from the airport runway to/from the gate). The takeoff and taxi portions of the LTO cycle are calculated based on standard ICAO time-in-modes (0.7 min for takeoff and 26 min total taxi time) (EMEP/CORINAIR 2006) multiplied by the fuel consumption rate for that mode, which is either drawn from the ICAO or FOI emissions databank. The climb out and approach portions are calculated based on the BADA fuel use characteristics of the plane.

The cruise phase of flight (above 3000 ft) is calculated based on the BADA fuel use characteristics of the plane and the flight path length of the movement. The cruise phase is broken up into three parts consisting of climb (3000 ft to cruise altitude), steady-state cruise (constant cruise altitude reached after completion of climb) and descent (from cruise altitude to 3000 ft). The distance it takes to reach and descend from the steady-state cruise altitude (including the LTO portions of climb out and approach) is subtracted from the flight path length when determining the distance travelled at the steady-state cruise altitude.

The LTO and cruise phases of flight for any given move-

ment are estimated by first using the representative aircraft mapping information, which relates the aircraft identified in the movement data to a representative aircraft with known performance characteristics. For the fuel rates of the representative aircraft that are distance based, the flight path length for the movement is drawn from either the list of radar movement data provided by the FAA or calculated by quantifying the GCD and multiplying by an adjustment factor as explained above. The fuel rates that are time based in the LTO cycle already have the time-in-mode defined. With the known fuel characteristics of the plane, the time-in-mode and flight path length, the LTO and cruise fuel estimates can be computed.

## Step 3: Normalization

All aviation turbo fuel apparently consumed in Canada is reported in the RESD (Statistics Canada #57-003). The fuel consumed, as estimated by the bottom-up approach of AGEM, is adjusted to match that of the RESD at a national level. The adjustment to LTO and cruise fuel estimates takes place at the individual movement level, across all movements.

## Step 4: Emission Calculation

Emission estimates are generated at the individual movement level based on the normalized total fuel consumed and the appropriate emission factor as outlined in Equation A2–1 (as mentioned previously, the $CH_4$ LTO emission estimate at the movement level is not fuel dependent). The individual emission estimates are then summed to generate the national emission estimate.

### A2.4.2.4.   Navigation (Domestic Marine)
#### (CRF Category 1.A.3.d)

The emission calculation methodology is considered to be an IPCC Tier 1 method. Domestic marine fuel consumption reported in the RESD (Statistics Canada #57-003) is multiplied by fuel-specific emission factors (see Annex 8). Emissions resulting from fuel sold to foreign marine vessels are assumed to be used only for international travel and are reported separately under international bunkers.

Some Canadian vessels are engaged in international marine travel. Comprehensive data that would allow an accurate disaggregation of domestic and international shipping activities by Canadian vessels are currently unavailable.

### A2.4.2.5. Railways (CRF Category 1.A.3.c)

The methodology is considered to be an IPCC Tier 1 method. Railway fuel consumption reported in the RESD (Statistics Canada #57-003) is multiplied by fuel-specific emission factors (see Annex 8).

In Canada, locomotives are powered primarily by diesel fuel. Emissions associated with steam trains are assumed to be negligible, whereas electrically driven locomotives are accounted for under electricity production.

### A2.4.2.6. Biomass (CRF Category 1.A.3.e)

The methodology used to estimate emissions from the consumption of biogenic Transport fuels (ethanol and biodiesel) follows a modified IPCC Tier 1 method for gasoline and diesel on-road transportation and an IPCC Tier 1 method for off-road transportation, railways and domestic marine. The volume of biofuels apparently consumed for Transportation is proportionally reallocated back into the respective diesel and gasoline emission technology classes based on those classes' initial consumption volumes.

The volumes of biogenic-based fuels used for Transportation purposes for the calendar years 1990–2007 were obtained from a 2008 report examining biofuel production and consumption in Canada (TFIS Inc. 2008). Biofuel consumption was held constant at 2007 levels for the 2008 and 2009 calendar years due to the absence of more current information during the development of this submission. An updated biofuel study should be completed in 2011.

In lieu of reviewed $CH_4$ and $N_2O$ emission factors for biofuels, the gasoline and diesel emission factors from the equivalent emission technology classes are applied. $CO_2$ emission factors are developed according to the chemical properties of the fuel.

### A2.4.2.7. Pipelines (CRF Category 1.A.3.e)

Pipelines represent fossil fuel combustion engines used to power motive compressors to transport oil and natural gas products. The fuel used is primarily natural gas, but some refined petroleum such as diesel fuel is also used. Oil pipelines tend to use electric motors to operate pumping equipment.

Combustion-related GHG emissions associated with this equipment are calculated by applying Equation A2–1 to activity data and emission factors for specific fuels on a

provincial (for natural gas) and national basis.

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# Annex 3

## Additional Methodologies

### A3.1. Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission, and Distribution

A detailed methodology of fugitive emission sources from solid fuel production and the oil and gas industry is covered in this annex.

As the primary source of fugitive emissions, Canada's large oil and gas industry consists of a mix of production types, including natural gas production and processing; light, medium and heavy crude oil production; oil sands mining and extraction; and synthetic oil production. Refer to Chapter 3 of this report for a detailed description of sources of fugitive emissions.

All GHG emissions from fuel combustion activities associated with fossil fuel exploration, production, processing, transmission and distribution are reported under the Energy Industries (Section 3.2.1) and Transport (Section 3.2.3) sections of Chapter 3, and their respective methodologies can be found in Annex 2 (sections A2.4.1 and A2.4.2).

### A3.1.1. Solid Fuels

### A3.1.1.1. Coal—Production

Fugitive emission estimates are based on the study *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options,* prepared by B. King in 1994 for Neill and

Gunter Ltd (King 1994). In the study, emission factors were calculated for all types of coal and coal mines. There are two types of coal mines in Canada: underground mines and surface mines. The method used by King (1994) to estimate emission rates from coal was based on a modified procedure from the Coal Industry Advisory Board. It consists of a hybrid of IPCC Tier 3- and Tier 2-type methodologies, depending on the availability of mine-specific data. Underground mining activity emissions and surface mining activity emissions are separated, with both including post-mining activity emissions. The methodologies used to estimate the emissions from both types are explained below. For further details, please consult the King (1994) study.

#### Underground Mines

King (1994) estimated emissions for underground mines on a mine-specific basis by summing emissions from the ventilation system, degasification systems and post-mining activities. Emissions from the mine shaft ventilation system were estimated (if measured data were not available) using Equation A3–1:

Equation A3–1:

$$Y = 4.1 + (0.023 \times X)$$

where:

| | | |
|---|---|---|
| Y | = | emissions of $CH_4$ per tonne of coal mined, $m^3$ $CH_4$/t coal |
| X | = | depth of mine, m |

Emissions from post-mining activities were estimated by assuming that 60% of the remaining coal $CH_4$ (after removal from the mine) is emitted to the atmosphere before combustion. If the gas content of the mined coal was not known, then it was assumed that the $CH_4$ content was 1.5 $m^3$/t (the global average for coals). Emissions from post-mining activities are included in the coal production emission factors.

#### Surface Mines

For surface mines, it was assumed that the average $CH_4$ content of surface-mined bituminous or sub-bituminous coals was 0.4 $m^3$/t (based on U.S. measured data). Of this, it was assumed that 60% is released to the atmosphere before combustion (King 1994). For lignite, gas content values determined previously for Canada were used (Hollingshead 1990).

A significant source of emissions from surface mines is the surrounding unmined strata. An attempt was made to account for this by applying a high-wall adjustment to account for the outgassing of the surrounding unmined strata to a depth of 50 m below the mining surface. It was estimated that base emission factors for surface mining should be increased by 50% (King 1994) to account for this. The emission factors shown in Table A3–1 have been adjusted accordingly.

The emission factors for $CH_4$ from coal mining determined in the King (1994) study are used to estimate the $CH_4$ fugitive emissions from coal mines in Canada. The emission factors vary for each region and the type of mine, above or below ground.

To obtain the emissions from coal mining, Equation A3–2 is used:

Equation A3–2:

$$ProvincialEmissions = \sum \left( EF_{i,j,k} \times Coal_{i,j,k} \right)$$

where:

$EF_{i,j,k}$ = the emission factor from the King (1994) study for province i, coal type j and mine type k

$Coal_{i,j,k}$ = the gross production data of coal mined for province i, coal type j and mine type k

Emissions are calculated for each province and then summed to determine the emission estimate for Canada.

### A3.1.1.2. Activity Data

The activity data required are the gross mine output data for each type of coal mined in each province from Statistics Canada's *Coal and Coke Statistics* publication (#45-002, Table 2). However, the *Coal and Coke Statistics* publication was cancelled in 2002 by Statistics Canada and this information is now provided directly to Environment Canada through a memorandum of understanding. A consistent data set was used to estimate emissions from 1990 to 2001 and from 2004 to 2007. For 2002–2003, an interpolation model was developed to estimate provincial emissions based on publicly available national quantities of coal produced by mines (regions) and by coal types.

### A3.1.1.3. Emission Factors

The specific emission factors by mine and coal type that were determined in the King (1994) study are listed in Table A3–1.

## A3.1.2. Oil and Natural Gas

### A3.1.2.1. Upstream Oil and Natural Gas Production

Fugitive emissions from the upstream oil and gas (UOG) industry are based on the study *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide ($H_2S$) Emissions by the Upstream Oil and Gas Industry* (CAPP 2005a), as prepared for the Canadian Association of Petroleum Producers (CAPP) by Clearstone Engineering Ltd. A Tier 3 analysis was performed to estimate all GHG emissions from the UOG sector for the year 2000, with the exclusion of oil sands mining, extraction and upgrading. The emissions were then backcast to the years 1990 through to 1999 to develop emission estimates

Table A3–1   Fugitive Emission Factors for Coal Mining

| Area | Coal Type | Mine Type | Emission Factor | Units |
|---|---|---|---|---|
| Nova Scotia | Bituminous | Surface | 0.13 | t $CH_4$/kt coal mined |
| Nova Scotia | Bituminous | Underground | 13.79 | t $CH_4$/kt coal mined |
| New Brunswick | Bituminous | Surface | 0.13 | t $CH_4$/kt coal mined |
| Saskatchewan | Lignite | Surface | 0.06 | t $CH_4$/kt coal mined |
| Alberta | Bituminous | Surface | 0.45 | t $CH_4$/kt coal mined |
| Alberta | Bituminous | Underground | 1.76 | t $CH_4$/kt coal mined |
| Alberta | Sub-bituminous | Surface | 0.19 | t $CH_4$/kt coal mined |
| British Columbia | Bituminous | Surface | 0.58 | t $CH_4$/kt coal mined |
| British Columbia | Bituminous | Underground | 4.1 | t $CH_4$/kt coal mined |

Source: King (1994).

for the industry. The UOG fugitive emissions for 1990–2000 were taken directly from the UOG study (CAPP 2005a).

UOG fugitive emissions for 2001 and onwards are projected using the UOG estimation model (CAPP 2005b) (hereafter referred to as the UOG model). The UOG model was also prepared for CAPP by Clearstone Engineering Ltd. (CAPP 2005b) and is based on information from CAPP (2005a). The UOG model is divided into the same sectors and sources as the 1990–2000 UOG inventory.

Table A3–2 lists the sectors and sources that were estimated in the UOG study (CAPP 2005a) and the allocation of these emissions according to the Common Reporting Format (CRF) category.

The methodology, emission factors and activity data used to estimate the 1990–1999 and 2001 to 2009 emissions were developed by Clearstone Engineering Ltd. and are presented in the following subsections. For further details, please consult the UOG study (CAPP 2005a) and the UOG model (CAPP 2005b).

## Methodology for the 2000 Estimates

The 2000 UOG emissions estimates were developed using a bottom-up approach, beginning with individual facilities and their equipment. To fulfil this, the study drew on official data from the producing provinces, supplemented by survey information on 1500 facilities provided by oil and

Table A3–2    Allocation of UOG Inventory Emissions to CRF Fugitive Categories

| Sector | Source | CRF Fugitive Category |
|---|---|---|
| Accidents and Equipment Failures | Surface Casing Vent Flow / Gas Migration | 2.B.iii Natural Gas—Other Leakage at Industrial Plants and Power Stations |
| Accidents and Equipment Failures | Spills / Pipeline Ruptures | 2.B.iii Natural Gas—Other Leakage at Industrial Plants and Power Stations |
| Conventional Oil Production | Glycol Dehydrator Off-gas | 2.C.i Venting—Oil |
| Conventional Oil Production | Flaring | 2.C.i Flaring—Oil |
| Conventional Oil Production | Fugitive Equipment Leaks | 2.A.ii Oil—Production |
| Conventional Oil Production | Loading/Unloading | 2.A.ii Oil—Production |
| Conventional Oil Production | Reported Venting | 2.C.i Venting—Oil |
| Conventional Oil Production | Storage Losses | 2.A.ii Oil—Production |
| Conventional Oil Production | Unreported Venting | 2.C.i Venting—Oil |
| Oil and Gas Well Drilling | Reported Venting | 2.C.ii Venting—Combined |
| Natural Gas Production | Glycol Dehydrator Off-gas | 2.C.ii Venting—Natural Gas |
| Natural Gas Production | Flaring | 2.C.ii Flaring—Natural Gas |
| Natural Gas Production | Fugitive Equipment Leaks | 2.B.i Natural Gas—Production/Processing |
| Natural Gas Production | Reported Venting | 2.C.ii Venting—Natural Gas |
| Natural Gas Production | Storage Losses | 2.B.i Natural Gas—Production/Processing |
| Natural Gas Production | Unreported Venting | 2.C.ii Venting—Natural Gas |
| Natural Gas Processing | Glycol Dehydrator Off-gas | 2.C.ii Venting—Natural Gas |
| Natural Gas Processing | Flaring | 2.C.ii Flaring—Natural Gas |
| Natural Gas Processing | Fugitive Equipment Leaks | 2.B.i Natural Gas—Production/Processing |
| Natural Gas Processing | Loading/Unloading | 2.B.i Natural Gas—Production/Processing |
| Natural Gas Processing | Formation CO2 | 2.C.ii Venting—Natural Gas |
| Natural Gas Processing | Storage Losses | 2.B.i Natural Gas—Production/Processing |
| Natural Gas Processing | Unreported Venting | 2.C.ii Venting—Natural Gas |
| Heavy Oil / Cold Bitumen Production | Glycol Dehydrator Off-gas | 2.C.i Venting—Oil |
| Heavy Oil / Cold Bitumen Production | Flaring | 2.C.i Flaring—Oil |
| Heavy Oil / Cold Bitumen Production | Fugitive Equipment Leaks | 2.A.ii Oil—Production |
| Heavy Oil / Cold Bitumen Production | Loading/Unloading | 2.A.ii Oil—Production |
| Heavy Oil / Cold Bitumen Production | Reported Venting | 2.C.i Venting—Oil |
| Heavy Oil / Cold Bitumen Production | Storage Losses | 2.A.ii Oil—Production |
| Heavy Oil / Cold Bitumen Production | Unreported Venting | 2.C.i Venting—Oil |
| Thermal Operations | Flaring | 2.C.i Flaring—Oil |
| Thermal Operations | Fugitive Equipment Leaks | 2.A.ii Oil—Production |
| Thermal Operations | Loading/Unloading | 2.A.ii Oil—Production |
| Thermal Operations | Reported Venting | 2.C.i Venting—Oil |
| Thermal Operations | Storage Losses | 2.A.ii Oil—Production |
| Thermal Operations | Unreported Venting | 2.C.i Venting—Oil |

Table A3–2  Allocation of UOG Inventory Emissions (cont'd)

| Sector | Source | CRF Fugitive Category |
|---|---|---|
| Liquid Product Transportation | Flaring | 2.C.i Flaring—Oil |
| Liquid Product Transportation | Fugitive Equipment Leaks | 2.A.iii Oil—Transport |
| Liquid Product Transportation | Storage Losses | 2.A.iii Oil—Transport |
| Liquid Product Transportation | Reported Venting | 2.C.i Venting—Oil |
| Well Testing | Flaring | 2.C.iii Flaring—Combined |
| Well Testing | Reported Venting | 2.C.iii Venting—Combined |

gas producers. The following fugitive emissions sources were estimated:

- flaring;
- formation $CO_2$, releases;
- venting; and
- fugitive and other unintentional releases (equipment leaks, storage and handling losses, and accidental releases).

The resulting emissions were then aggregated to determine overall emissions by facility type, activity type and geographic area. The basic methods used to estimate GHG emissions are the following:

- emission monitoring results;
- emission source simulation results;
- emission factors; and
- destruction and removal efficiencies.

The following data were collected from the facilities and used to develop the 2000 inventory:

- measured volumes of natural gas taken from the process;
- vented and flared waste gas volumes;
- fuel purchases (propane, diesel fuel, etc.);
- fuel analyses;
- emission monitoring results;
- process operating conditions that may be used to infer the work being done by combustion devices (gas compositions, temperatures, pressures and flows, etc.); and
- spill and inspection reports.

Other required data included the following:

- types of processes being used;
- equipment inventories;
- emission source control features;
- sulphur content of the fuels consumed and waste gas flared; and
- composition of the inlet and outlet streams.

The data were compiled and used to estimate the 2000 UOG fugitive emissions. Refer to the UOG study (CAPP 2005a) for further details.

## Methodology for the 1990–1999 estimates

The emissions for 1990–1999 were backcast for the UOG industry at a provincial level based on the 2000 UOG data (CAPP 2005a) and annual production data, with the exception of Nova Scotia. Nova Scotia switched production in 2000 from an oil-only producing province (from 1992 to 1999) to a gas-only from 2000 onwards. Nova Scotia's fugitive emissions were extrapolated based on CAPP's 1995 UOG study data (CAPP 1999).

Refer to the UOG study (CAPP 2005a) for further details.

## Methodology for the 2001–2009 estimates

Emissions for 2001 to 2009 were estimated by extrapolating the 2000 UOG emission data using activity data for each emission source in each subsector. There are 12 activity parameters for each province/territory and year; these were used to pro-rate the 2000 estimates from the UOG study for the years 2001–2009:

- gas production;
- conventional oil (CO);
- heavy oil (HO);
- crude bitumen (CB);
- fuel gas;
- flared gas;
- wells drilled;
- spills;
- total wells;
- CO + HO + CB;
- HO + CB; and
- shrinkage.

Equation A3-3 was used for pro-rating:

Equation A3–3:

$$ER^k_{i,j} = ER^{2000}_{i,j} \times \left( \frac{AF^k_j}{AF^{2000}_j} \right)$$

where:

| | | |
|---|---|---|
| $ER^k_{i,j}$ | = | emission rate of compound i, source j, and year k, t/year |
| $ER^{2000}_{i,j}$ | = | base year (2000) emission rate for compound i and source j, t/year |
| $AF^k_j$ | = | activity factor for source j and year k |
| $AF^{2000}_j$ | = | base year activity factor for source j |

The activity data listed in Table A3–3 are used to calculate the 12 activity parameters given above, which are used in the estimation of the emissions for 2001 to 2009. These

data are input into the model, and the outputs are the UOG fugitive emission estimates for the specified year.

Table A3–4 contains a list of the activity factors used to estimate emissions and the dependent source category.

### A3.1.2.2.  Natural Gas Transmission

**Methodology**

Virtually all of the natural gas produced in Canada is transported from the processing plants to the gate of the local distribution systems by high-pressure pipelines. The majority of emissions are from equipment leaks and process vents along these pipelines.

Fugitive emissions for natural gas transmission are based on two documents. The first, *CH₄ and VOC Emissions from the Canadian Upstream Oil and Gas Industry* (CAPP 1999), was prepared by Clearstone Engineering Ltd. for CAPP in July 1999. The second source is ancillary tables provided by

Table A3–3    **Source of Activity Data Required by UOG Model**

| Publisher | Publication | Activity Data |
|---|---|---|
| Statistics Canada | CANSIM Table 131-0001 Supply and disposition of natural gas, monthly (Statistics Canada 2010a) | Less field flared and waste<br>Field disposition and usage<br>Gathering system disposal and use<br>Plant uses<br>Shrinkage |
| | Energy Statistics Handbook (Statistics Canada 2009b) | Gross new production<br>Heavy crude oil<br>Light and medium crude oil<br>Synthetic crude oil<br>Crude bitumen |
| Saskatchewan Ministry of Energy and Resources | 2009 Monthly Production and Disposition of Crude Oil at the Producer Level (Saskatchewan Energy and Resources 2010a)<br>2009–2010 Annual Report (Saskatchewan Energy and Resources 2010b) | Light and medium crude oil production<br>Heavy crude oil production<br><br>Total capable wells (Saskatchewan) |
| Canadian Association of Petroleum Producers (CAPP) | Statistical Handbook for Canada's Upstream Petroleum Industry (CAPP 2010) | Total wells drilled (including dry and service) |
| Energy Resources Conservation Board (ERCB) | ST-57 Public Safety / Field Surveillance Provincial Summary 2008 (ERCB 2010a) | Sum of blowouts (drilling, servicing and other), kicks and pipeline ruptures |
| | ST-59 Alberta Drilling Activity, Monthly Statistics, December 2008 (ERCB 2010b) | December capable oil and gas wells (Alberta) |
| British Columbia Ministry of Energy, Mines and Petroleum Resources | Oil and Gas Production and Activity in British Columbia 2010 [1] | Sum of producing oil wells and producing gas wells (British Columbia) |
| Manitoba Innovation, Energy and Mines | Manitoba Petroleum Statistics [2] | Wells capable of producing (December) (Manitoba) |
| Canada–Newfoundland and Labrador Offshore Petroleum Board (CNLOPB) | Development Wells – Hibernia (CNLOPB 2010a)<br>Development Wells – Terra Nova (CNLOPB 2010b)<br>Development Wells – White Rose (CNLOPB 2010c) | Sum of all oil producers and gas injectors<br>Sum of all oil producers and gas injectors<br>Sum of all oil producers and gas injectors |

1.  Mou C. 2010. Personal Communication (email from Mou C to Smyth S, Project Engineer, Pollutant Inventories and Reporting Division, dated 13 Oct 2010). British Columbia Ministry of Energy, Mines and Petroleum Resources.

2.  Legare P. 2010. Personal Communication (email from Legare P to Smyth S, Project Engineer, Pollutant Inventories and Reporting Division, dated 28 Oct 2010). Manitoba Innovation, Energy and Mines.

Table A3–4   Activity Data Used to Pro-rate Emission Sectors and Sources

| Emission Sector Category | Emission Source Category | Activity Factors |
| --- | --- | --- |
| Accidents / Equipment Failures | Spills, Ruptures, Blowouts | Total number of spills, ruptures and blowouts |
| Accidents / Equipment Failures | Surface Casing Vent Flows, | Total number of capable wells |
| Accidents / Equipment Failures | Gas Migration | Total number of capable wells |
| Light/Medium Oil Production | Flaring | Flared gas volume |
| Light/Medium Oil Production | Fugitive Equipment Leaks | Light/medium oil production |
| Light/Medium Oil Production | Glycol Dehydrator Off-gas | Light/medium oil production |
| Light/Medium Oil Production | Loading/Unloading Losses | Light/medium oil production |
| Light/Medium Oil Production | Reported Venting | Light/medium oil production |
| Light/Medium Oil Production | Storage Losses | Light/medium oil production |
| Light/Medium Oil Production | Unreported Venting | Light/medium oil production |
| Well Drilling | Venting | Wells drilled |
| Gas Production | Flaring | Flared gas volume |
| Gas Production | Fugitive Equipment Leaks | Raw gas production |
| Gas Production | Glycol Dehydrator Off-gas | Raw gas production |
| Gas Production | Loading/Unloading Losses | Raw gas production |
| Gas Production | Reported Venting | Raw gas production |
| Gas Production | Storage Losses | Raw gas production |
| Gas Production | Unreported Venting | Raw gas production |
| Gas Processing | Flaring | Flared gas volume |
| Gas Processing | Fugitive Equipment Leaks | Raw gas production |
| Gas Processing | Glycol Dehydrator Off-gas | Raw gas production |
| Gas Processing | Loading/Unloading Losses | Raw gas production |
| Gas Processing | Formation $CO_2$ | Shrinkage |
| Gas Processing | Reported Venting | Raw gas production |
| Gas Processing | Storage Losses | Raw gas production |
| Gas Processing | Unreported Venting | Raw gas production |
| Heavy Oil Cold Production | Flaring | Flared gas volume |
| Heavy Oil Cold Production | Fugitive Equipment Leaks | Heavy oil production |
| Heavy Oil Cold Production | Glycol Dehydrator Off-gas | Heavy oil production |
| Heavy Oil Cold Production | Loading/Unloading Losses | Heavy oil production |
| Heavy Oil Cold Production | Reported Venting | Heavy oil production |
| Heavy Oil Cold Production | Storage Losses | Heavy oil production |
| Heavy Oil Cold Production | Unreported Venting | Heavy oil production |
| Well Service | Venting | Wells drilled |
| Well Service | Flaring | Wells drilled |
| Heavy Oil / Bitumen Thermal Production | Flaring | Flared gas volume |
| Heavy Oil / Bitumen Thermal Production | Fugitive Equipment Leaks | Heavy oil and crude bitumen production |
| Heavy Oil / Bitumen Thermal Production | Loading/Unloading Losses | Heavy oil and crude bitumen production |
| Heavy Oil / Bitumen Thermal Production | Reported Venting | Heavy oil and crude bitumen production |
| Heavy Oil / Bitumen Thermal Production | Storage Losses | Heavy oil and crude bitumen production |
| Heavy Oil / Bitumen Thermal Production | Unreported Venting | Heavy oil and crude bitumen production |
| Product Transportation | Flaring | Fuel gas volume |
| Product Transportation | Fugitive Equipment Leaks | Light/medium oil, heavy oil, and crude bitumen production |
| Product Transportation | Venting | Light/medium oil, heavy oil, and crude bitumen production |
| Product Transportation | Storage Losses | Light/medium oil, heavy oil, and crude bitumen production |
| Well Testing | Flaring | Wells drilled |
| Well Testing | Venting | Wells drilled |

Source: Extrapolation of the 2000 UOG Emission Inventory to 2001, 2002 and 2003. CAPP (2005b).

Brian Ross from Clearstone Engineering Ltd. that describe the $CO_2$ emissions. There are no $N_2O$ fugitive emissions from natural gas transmission. The $CO_2$ and $CH_4$ emissions for 1990–1996 are taken directly from the two sources. The $CO_2$ and CH4 emissions for 1997 to 2009 are estimated using specific provincial emission factors.

Equation A3–4: is used to estimate the emissions:

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Equation A3–4:

$$Emissions\,(kt) = Transmission\,Pipeline\,Length\,(km) \times \\ Emission\,Factor\,(leakage\,Rate,\,kt/km)$$

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The emissions are calculated per province, as the provinces have unique emission factors, and then summed to get the total $CO_2$ and $CH_4$ emissions for Canada. Newfoundland and Labrador, Prince Edward Island, Yukon, and Nunavut do not have natural gas transmission pipelines. However, there are natural gas gathering lines in Yukon, and those fugitive emissions are accounted for in the 1.B.2.b.ii Natural Gas Production/Processing category of the CRF table.

## Emission Factors

Provincial emission factors from 1997 onward (Table A3–5) were developed based on the 1996 emissions and lengths of pipeline from CAPP (1999). No fugitive emissions were present up to and including 1998 in Nova Scotia, New Brunswick or the Northwest Territories, since natural gas transmission pipelines were not operating in these regions until 1999.

Table A3–5    Natural Gas Transmission Emission Factors for 1997–2009

| Province | Emission Factors (kt/km) | |
|---|---|---|
| | $CO_2$ | $CH_4$ |
| Nova Scotia | $2.40 \times 10^{-5}$ | 0.0032 |
| New Brunswick | $2.40 \times 10^{-5}$ | 0.0032 |
| Quebec | $7.20 \times 10^{-5}$ | 0.0096 |
| Ontario | $1.60 \times 10^{-5}$ | 0.0022 |
| Manitoba | $2.90 \times 10^{-5}$ | 0.0039 |
| Saskatchewan | $1.50 \times 10^{-5}$ | 0.0021 |
| Alberta | $2.80 \times 10^{-5}$ | 0.0038 |
| British Columbia | $2.90 \times 10^{-5}$ | 0.0039 |
| Northwest Territories | $2.40 \times 10^{-5}$ | 0.0032 |

## Activity Data

The activity data required to estimate the fugitive emissions for 1997 to 2009 are the length of the natural gas pipeline used for natural gas transmission for each year. These data were published annually in Natural Gas Transportation and Distribution (Statistics Canada #57-205). Statistics Canada has discontinued this publication. Pipeline lengths for 2007 and 2008 were provided by Statistics Canada[1], while pipeline lengths for 2009 were estimated. For the provinces of Quebec, Ontario, Manitoba, Saskatchewan, Alberta and British Columbia, as well as for the Northwest Territories, the 2009 pipeline length was estimated based on the average annual change in length between 1999 and 2008. The 2009 value was assumed to be the same as 2008 for New Brunswick and Nova Scotia since the natural gas transmission pipeline lengths have not changed since 2003 and 2002, respectively. Improvements to the model are being investigated. Refer to Chapter 3 for more details.

### A3.1.2.3.    Petroleum Refining

The refinery model is based on the study *Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production* (CPPI 2004), prepared for the Canadian Petroleum Products Institute (CPPI), Natural Resources Canada (NRCan), Environment Canada and Industry Canada in 2004 by Levelton Consultants Ltd. The study surveyed the refining industry and used these data, along with data collected by the Canadian Industrial Energy End-Use Data and Analysis Centre, to develop GHG emission estimates for 1990 and 1994–2002.

There are three sections in the refinery methodology: fugitive, flare and process venting. The combustion methodology for petroleum refining is discussed in Annex 2 of the National Inventory Report.

## Methodology

*Fugitive Emissions*

The fugitive emissions for 1991–2009 are generated using Equation A3–5:

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1    Statistics Canada. 2010. Personal communication (email from Bristow C, Manufacturing and Energy Division, Statistics Canada to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated 7 Dec 2010).

Equation A3–5:

$$FugitiveGHGEmissions(t) = EmissionFactor(t/GJ) \times$$
$$RefineryAnnualEnergyConsumption(GJ)$$

The refinery annual energy consumption (in GJ) is the sum of the energy of all fuels consumed by refineries in the Report on Energy Supply–Demand in Canada (Statistics Canada #57-003-XIB), including fuels listed under producer consumption from the refined petroleum product table. The energy consumption value is the same as that in the stationary combustion model for 1.A.1.b Petroleum Refining of the CRF table.

The $CO_2$ and $CH_4$ emission factors were developed by Levelton Consultants Ltd. and presented in the refinery study (CPPI 2004). These emission factors are used to estimate the fugitive emissions for the years not included in the study: 1991–1993 and 2003 to 2009.

The emission factors are:

- $CO_2$: 2.78 t $CO_2$/GJ
- $CH_4$: 11.89 t $CH_4$/GJ

The refinery study has listed fugitive $N_2O$ emissions for 1990 and 1994–2002 as a constant 0.1 kt $N_2O$/year; however, there were not enough data to develop an emission factor for them. The $N_2O$ emissions were kept constant at 0.1 kt $N_2O$/year for the years 1991–1993 and 2003 to 2009. It is assumed that the reported $N_2O$ emissions from the refinery study are a residual from combustion sources and that the majority of $N_2O$ emissions associated with petroleum refining are correctly reported in the stationary combustion section of the inventory.

## Process Emissions (Venting)

Process emissions are mainly associated with the venting of $CO_2$ from the production of hydrogen using natural gas. This hydrogen is used as an input in the production of refined petroleum products (RPPs). Using data provided from the refinery study for the years 1990, 1994–1998 and 2000–2002, $CO_2$ emissions from the production of hydrogen were correlated to refinery annual RPP production. These results were used to estimate $CO_2$ emissions for the years 1991–1993, 1999 and 2003 to 2009.

## Flaring Emissions

Flaring emissions have been determined for $CO_2$, $CH_4$ and $N_2O$ using the estimates from the refinery study and RPP production by Canadian refineries. The study provided emissions for the years 1990, 1994–1998 and 2000–2002, and these emissions were correlated to refinery annual RPP production. Flaring emissions for the years 1991–1993, 1999 and 2003 to 2009 were estimated based on this correlation and known RPP production data.

## Activity Data

The activity data required to estimate the fugitive emissions from refineries are listed in Table A3–6:

## A3.1.2.4.  Natural Gas Distribution

## Methodology

Fugitive emissions from natural gas distribution are based on the Canadian Gas Association (CGA) report, *1995 Air Inventory of the Canadian Natural Gas Industry* (CGA 1997) and V*ented Emissions from Maintenance at Natural Gas Distribution Stations in Canada* (GRI 2000). The GRI (2000) report is an update to the CGA (1997) study with more

Table A3–6    Required Refinery Activity Data and Their Source

| Publisher | Publication | Activity Data |
|---|---|---|
| Statistics Canada | Report on Energy Supply–Demand in Canada (RESD) (Statistics Canada #57-003-XIB) | Refinery and producer consumption (by refineries) annual energy consumption |
| Canadian Petroleum Products Institute (CPPI) | Economic and Environmental Impacts of Removing Sulphur from Canadian Gasoline and Distillate Production by Levelton Consultants Ltd. (CPPI 2004) | - Fugitive Emissions Table 3-2 CPPI Regional GHG Inventory—Detailed (kilotonnes) -Process Emissions Table 3-2 CPPI Regional GHG Inventory—Detailed (kilotonnes) -Flaring Emissions Appendix E— Flare Gas |

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accurate and better substantiated data for station vents. The emissions are estimated using activity data from Statistics Canada and the leakage rate developed from CGA (1997) and GRI (2000). This is the case for all years from 1990 to 2009. Only fugitive emissions of $CH_4$ occur in the distribution of natural gas. The relationship between the data and emission factors is as follows:

Equation A3–6:

$$Emissions\,(kt) = DistributionPipelineLength(km) \times EmissionFactor(leakageRate, kt/km)$$

The fugitive emissions for natural gas distribution are estimated for each province and then summed to get the overall emissions for Canada. For the years 1990 to 2009, there were no natural gas distribution pipelines in the following provinces and territories: Newfoundland and Labrador, Prince Edward Island, Nunavut, Yukon, and Nunavut.

### Emission Factors

General emission factors were developed for the distribution system based on the study data (CGA 1997; GRI 2000) and gas distribution pipeline distances from Statistics Canada. The average $CH_4$ leakage rate for all regions is 0.00036 kt/km.

### Activity Data

The activity data required are the length of natural gas distribution pipeline per province. These data were published annually in *Natural Gas Transportation and Distribution* (Statistics Canada #57-205) but have since been discontinued. Pipeline lengths for 2007 and 2008 were provided by Statistics Canada.[2] Lengths for 2009 for all provinces were estimated based on the change in length between 2007 and 2008.

For New Brunswick and Nova Scotia, distribution lengths for 2000–2006 were provided by Enbridge Gas New

Brunswick[3] and Heritage Gas,[4] respectively. In the Northwest Territories, the Ikhil Pipeline began providing Inuvik with natural gas in 1999 (Quenneville 2009). Distribution lengths for 1999–2006 were backcasted based on the change in distribution length between 2007 and 2008.

Finally, the 2007 length for British Columbia provided by Statistics Canada was twice as large as the 2006 value. Statistics Canada confirmed that the data for 2006 and previous years were incorrect but were unable to provide corrected distribution lengths in time for publication. It was assumed that the 1999 value was correct and a linear trend was used to fill in 2000 to 2006 data. Improvements to the model are being investigated. Refer to Chapter 3 for more details.

### A3.1.2.5. Oil Sands and Heavy Oil Upgrading Industry

The oil sands and heavy oil upgrading (OS/HOU) industry produces synthetic crude oil and other products from bitumen. Bitumen is a naturally occurring viscous mixture consisting of hydrocarbons heavier than pentane and other contaminants (e.g. sulphur compounds), which in its natural state will not flow under reservoir conditions or on the surface. Bitumen occupies the lower end of the range of heavy crude oils and is sometimes referred to as ultra-heavy crude oil. "Oil sands" is a term applied by the Government of Alberta to a particular geographical area of the province of Alberta that contains concentrations of bituminous sands as well as deposits of other heavy crude oil. Bituminous sands are an unconsolidated mixture of sand, clay, water and bitumen.

In this area, bitumen is extracted from open-pit mined oil sands or from *in situ* bitumen operations using thermal extraction techniques. The emissions from *in-situ* bitumen extraction are included in the UOG study (CAPP 2005a). Emissions from the mining, processing and upgrading of bitumen and heavy oil are taken from the report *An Inventory of GHGs, CACs, and $H_2S$ Emissions by the Canadian Bitumen Industry: 1990 to 2003* (CAPP 2006), prepared by Clearstone Engineering Ltd. for CAPP.

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2   Statistics Canada. 2010. Personal communication (email from Bristow C, Manufacturing and Energy Division, Statistics Canada to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated 7 Dec 2010).

3   Enbridge Gas New Brunswick. 2010. Personal communication (email from Nicholson L, Communications Coordinator, Enbridge Gas New Brunswick to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated 7 Dec 2010).

4   Heritage Gas. 2010. Personal communication (email from Bracken J, President, Heritage Gas to Smyth S, Pollutant Inventories and Reporting Division, Environment Canada, dated 7 Dec 2010).

The bitumen report (CAPP 2006) is the basis for the 1990–2003 fugitive emissions from oil sands mining and upgrading activities.

From 2004 onwards, the emissions are estimated using the Bitumen-Oil Sands Extrapolation Model – Rev 3, created by Clearstone Engineering Ltd. for Environment Canada in 2007 (Environment Canada 2007) (hereafter referred to as the bitumen model). The bitumen model uses results from the bitumen report (CAPP 2006) as its basis, along with annual production data as reported by the Energy Resources Conservation Board (ERCB) and the National Energy Board (NEB). The methodology, model and data used are briefly discussed below. For more details, please refer to the bitumen report (CAPP 2006).

The major emission sources in the OS/HOU industry are the following:

- process emissions from the steam reforming of natural gas to produce hydrogen for upgraders;
- $CH_4$ present in the oil sands deposits that is released during mining, mine dewatering and ore handling activities;
- volatilization of hydrocarbons from the exposed oil sands and during transport and handling of the oil sands;
- biogenic gas formation (primarily $CH_4$) in some tailings ponds;
- volatilization and decomposition of residual bitumen and diluent, which carry through to the tailings ponds;
- fugitive equipment leaks, venting, flaring and storage losses at ore preparation, extraction and upgrader plants and their associated utility and cogeneration plants;

- spills and accidental releases; and
- secondary sources, such as sewage treatment facilities, landfills, onsite construction and fabrication activities, motor vehicle fleets, corporate aircraft, and boats and dredges used on the tailings ponds.

These emissions have been grouped in the source categories and process areas listed in Table A3–7.

## Bitumen Report: 1990–2003 Emission Estimates

The bitumen report (CAPP 2006) is a compilation of the individual Tier 3 inventories of the facilities involved in the OS/HOU industry: Syncrude Canada Ltd. (Mildred Lake mining, extraction and upgrading facility and Aurora North mining and extraction facility); Suncor Energy (mining, extraction and upgrading facility); Husky Energy (Lloydminster upgrader); Consumers' Co-operative Refineries Limited (Regina upgrader); Albian Sands Energy (Muskeg River mining and extraction facility); and Shell Canada Limited (Scotford upgrader). The facility boundaries were determined to ensure that all target emissions, including those from cogeneration facilities, were included.

Where available, the bitumen report (CAPP 2006) used the emissions from the individual facility reports. These emissions were verified against inventories and data reported to Alberta Environment. When this was not possible, emissions were estimated based on available activity data and emission factor data. There were two methods for estimating emissions. The first method––the emission factor method––uses specific activity data and standard emission factors. If there were no activity data available, the emission factor ratio technique was applied. Refer directly to

Table A3–7    Emission Source Categories and Process Areas in the Bitumen Report (CAPP 2006)

| Source Category | Process Area |
| --- | --- |
| Flaring | All |
| Fugitives | American Petroleum Institute (API) Separator |
| | Equipment Leaks |
| | Exposed Oil Sands |
| | Ponds |
| | Other |
| | Storage Tanks |
| Process Venting | Flue Gas Desulphurization (FGD) |
| | Formation $CO_2$ from Acid Gas |
| | Hydrogen Plant |
| | Non-Combustion Point Sources |

the bitumen report (CAPP 2006) for specific methodological discussions.

The following sources were used to estimate emissions:

- facility operator information;
- energy statistics published by the Energy Resources Conservation Board (ERCB);
- source emission monitoring results reported to Alberta Environment;
- data from company submissions to the Voluntary Challenge Registry;
- Environment Canada's National Pollutant Release Inventory (NPRI);
- environmental impact assessment files as part of recent energy development applications in the OS/HOU industry; and
- open literature.

Consult the bitumen report (CAPP 2006) for more details.

## Bitumen Model: 2004 to 2009

The bitumen model estimates GHG emissions from thermal heavy oil production and oil sands mining, extraction and upgrading in Canada. The model was developed based on the results from the bitumen report (CAPP 2006) along with publicly available activity data and facility-specific emission data to extrapolate emissions for the years 2004 to 2009. It provides the same level of disaggregation of the emissions by source category as is reported in the base inventories.

In year 2006, the Petro-Canada Fort Hills oil sands operations started reporting to the ERCB. It has yet to produce any product. In 2008 the CNRL Horizon mining, extraction and upgrading operation and OPTI-Nexen upgrader came online. Emissions from the CNRL Horizon mining, extraction and upgrading operations were estimated using various emission factors from Suncor, Syncrude and Albian's Muskeg River operations, while emissions from the OPTI-Nexen upgrader were estimated using emission factors from the Shell Scotford upgrader. These approximations are problematic in that each facility has different processes with different emissions, especially when comparing the Nexen and Scotford upgraders. The Nexen upgrader is the only facility to employ gasification technology that transforms waste product (asphaltenes) into syngas used to create steam for *in-situ* extraction and hydrogen for upgrading (ERCB 2010c). These approximations will be addressed when a new bitumen study is conducted in the future. Refer directly to the report on the bitumen model

(Environment Canada 2007) for specific methodological discussions.

### Estimation Methodology

The bitumen model provides emission estimates for the OS/HOU industry for the years 2004 to 2009 by applying facility-specific emission factors and pro-rating factors derived from the facility base inventories (1990–2003) to appropriate publicly available activity data for the specific year. It uses Equation A3–7 to extrapolate

---

Equation A3–7:

$$ER_i = EF_i \times (A_1 + A_2)$$

where:

| | | |
|---|---|---|
| $ER_i$ | = | emissions of substance i, t/year |
| $EF_i$ | = | emission factor for substance i |
| $A_1, A_2$ | = | activity values applicable to the emission factor |

---

### Emission Factors

For the OS/HOU sector in Alberta and Saskatchewan, source-specific factors were developed for each facility by correlating the most recent three or four years of emission data for the facility, from the bitumen report (CAPP 2006), with available site-specific production accounting data. These emission factors can be found in the bitumen model (Environment Canada 2007)

### Activity Data

Two activity data sources are used to extrapolate emissions. Alberta facilities data are extracted from ST-43: *Mineable Alberta Oil Sands, Annual Statistics for 2009* (ERCB 2010d), which is published annually. Data for Saskatchewan are taken from the National Energy Board's (NEB) *2009 Estimated Production of Canadian Crude Oil and Equivalent* (NEB 2010) table. The required data are listed in Table A3–8.

Table A3–8   Activity Data Required for the Bitumen Model

**Required data from the ERCB ST-43 Report for Alberta emission estimates**

| Operator | Site | Required Parameters |
|---|---|---|
| | Muskeg River | Bitumen Production |
| | | Oil Sands Mined |
| Petro-Canada UTS | Fort Hills | Bitumen Production |
| | | Oil Sands Mined |
| Shell | Scotford Upgrader | Process Gas Flared/Wasted |
| | | Synthetic Crude Production |
| | | Synthetic Crude Deliveries |
| Suncor | Tar Island | Diluent Naphtha Flared/Wasted |
| | | Diluent Naphtha Further Processed |
| | | Diluent Naphtha Production |
| | | Sulphur Flared/Wasted |
| | | Synthetic Crude Fuel/Used |
| | | Synthetic Crude Production |
| | | Oil Sands Mined |
| Syncrude | Mildred Lake | Bitumen Production |
| | | Intermediate Hydrocarbon Production |
| | | Oil Sands Mined |
| | | Synthetic Crude Fuel/Used |
| | | Synthetic Crude Production |
| | Aurora | Bitumen Production |
| | | Oil Sands Mined |
| | | Synthetic Crude Fuel/Used |
| CNRL | Horizon | Bitumen Production |
| | | Oil Sands Mined |
| | | Synthetic Crude Production |
| | | Diluent Naphtha Further Processed |
| | | Diluent Naphtha Production |
| | | Sulphur Flared/Wasted |
| OPTI Canada Inc. | OPTI-Nexen Upgrader | Synthetic Crude Production |
| | | Synthetic Crude Deliveries |
| | | Process Gas Flared/Wasted |
| Williams Energy, Inc. | Tar Island - Williams Energy | Process Gas Flared/Wasted |
| | | Diluent Naphtha Production |

**Required data from the NEB for Saskatchewan emission estimates**

| Crude Type | Crude Subcategory | Province |
|---|---|---|
| Heavy Crude | SK CONV | Saskatchewan |

## A3.2. Methodology for Industrial Processes

The Industrial Processes Sector covers greenhouse gas (GHG) emissions arising from non-energy-related industrial activities. Categories of activities included in this sector are Mineral Products, Chemical Industry, Metal Production, Production and Consumption of Halocarbons, $SF_6$ Use in Electric Utilities and Semiconductors, and Other and Undifferentiated Production. Each of these can be further divided into various subcategories, such as $CO_2$ emissions from iron and steel production and $SF_6$ emissions from magnesium casting, which have been discussed in Chapter 4. This section of Annex 3 is to describe in detail the methodologies (i.e. specific equations, activity data and emission factors) used to estimate:

- $CO_2$ from ammonia production;
- $CO_2$ from other and undifferentiated production; and
- $SF_6$ from electrical equipment.

### A3.2.1. $CO_2$ Emissions from Ammonia Production

#### A3.2.1.1. Methodology

To estimate emissions from ammonia production, an emission factor of 1.56 t $CO_2$/t NH3 produced was used. The emission factor was developed in *Canada's Greenhouse Gas Emissions: Estimates for 1990* (Jaques 1992), based on the natural gas requirement for producing one tonne of

liquefied ammonia. Information on the feedstock requirement for the steam methane reforming (SMR) process was originally obtained from Industrial Chemicals (Lowenheim and Moran 1980). Table A3–9 details the derivation of the ammonia production-based emission factor (1.56 t $CO_2$/t $NH_3$).

Since the hydrogen needed for the Haber-Bosch process can be acquired from processes other than SMR, not all ammonia production involves emissions of $CO_2$. Therefore, it is necessary to multiply only the net $CO_2$-related ammonia production by the emission factor. Data on $CO_2$-related production used in the calculation can be either directly collected from ammonia plants or estimated nationally.

Not all of the ammonia manufacturing plants provided their 1990–2009 operational data. In order to estimate the unreported part of the $CO_2$-emitting ammonia production, the amount of ammonia produced using by-product hydrogen and that using hydrogen from SMR, as reported by plants, are subtracted from the national total ammonia production found in *Industrial Chemicals and Synthetic Resins* (Statistics Canada #46-002) for 1990-2007 and in Statistics Canada (2010) for 2008–2009. The total unreported production is then multiplied by the capacity share of each of the non-reporting plants to give the estimated unreported production by plant. (It should be noted here that plants using by-product hydrogen had all reported their productions and emissions; hence, the unreported part of the emissions related to the $CO_2$-emitting ammonia plants only.) Multiplying both reported and unreported

Table A3–9    Derivation of Ammonia Production-based Emission Factor

**Basis of derivation: 1 t $NH_3$**
**Volume of natural gas required to make 1 t $NH_3$: 812 m³ (A)**
**Molar volume of natural gas at 15°C: 0.02365 m³/mol (B)**

| Natural Gas Component | No. of Carbons | Potential $CO_2$ Emissions per Mole of Component (g/mol) | Natural Gas Composition (% by volume) | Volume of Each Component in 812 m³ of Natural Gas (m³) | No. of Moles of Each Component in 812 m³ of Natural Gas (mol) | $CO_2$ Emissions from Each Component (t) |
|---|---|---|---|---|---|---|
| | **C** | **D** = C × 44 g $CO_2$/mol | **E** | **F** = E × A | **G** = F / B | **H** = G × D / 1 000 000 |
| Methane (CH₄) | 1 | 44 | 92 | 747 | 31 554 | 1.39 |
| Ethane (C₂H₆) | 2 | 88 | 3.6 | 29 | 1 235 | 0.11 |
| Propane (C₃H₈) | 3 | 132 | 1.0 | 8 | 343 | 0.05 |
| Butane (C₄H₁₀) | 4 | 176 | 0.3 | 2 | 103 | 0.02 |
| Nitrogen | 0 | 0 | 3.1 | 25 | 1 063 | 0.00 |
| **Resulting Emission Factor (t $CO_2$/t $NH_3$)** | | | | | | **1.56** |

$CO_2$-related ammonia production by the emission factor of 1.56 t CO2/t NH3 gives the total amount of $CO_2$ generated. To estimate by province the amount of $CO_2$ generated from the SMR process, the plant-specific estimated production and reported production are aggregated by province, based on location. Once the provincial total production is calculated, it is then multiplied by the output-based emission factor. However, for inventory purposes, the provincial $CO_2$ generation estimates for ammonia production are included in the Other and Undifferentiated Production category.

It should be noted that the quantity of natural gas used to produce the hydrogen that feeds the ammonia production process was also recorded by Statistics Canada with all other non-energy uses of natural gas. Therefore, to avoid double counting at the national level, the $CO_2$ emissions from ammonia production were subtracted from the total non-energy fossil fuel use $CO_2$ emissions (as reported under the Other and Undifferentiated Production category).

The estimation technique (emissions = production of ammonia × emission factor) described in this section is one of the default methods suggested in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). However, it should be noted that the emission factor of 1.56 t CO2/t NH3 produced is a national average value. Methodological issues for calculating $CO_2$ emissions from ammonia production are not addressed specifically in the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000).

### A3.2.1.2.   Data Sources

Ammonia production data are collected from facilities, whenever possible. Production data for 1990–2004 were collected through or estimated in the 2006 Cheminfo study (Cheminfo Services 2006). For 2005–2009, data are reported by companies to the Greenhouse Gas Division on a voluntary basis. *Industrial Chemicals and Synthetic Resins* (Statistics Canada #46-002) and Statistics Canada (2010) provide data on national total ammonia production.

## A3.2.2.   $CO_2$ Emissions from Other and Undifferentiated Production

### A3.2.2.1.   Methodology

$CO_2$ emissions from the non-energy use of hydrocarbons that are not reported elsewhere in the inventory are reported under the category of Other and Undifferentiated Production. These emissions primarily relate to petrochemical production activities, although there are a number of other non-energy uses of fuel in the non-ferrous mining and processing, iron and steel, and other chemical industries such as the production of carbon black. Within the petrochemical and carbon black industries, primary and secondary fossil fuels (e.g. natural gas, petroleum products, coal) are used for non-fuel purposes in the production of products. The use of these fossil fuels may involve the combustion of part of the hydrocarbon content of the fuel to produce heat for the process (i.e. via the combustion of by-products fuel gases). Examples of non-energy use of fuels included elsewhere in the inventory are coke used in iron and steel production, and carbon-based anodes used to electrically reduce alumina to aluminium in the aluminium production process. The fossil fuels can be grouped into three types: gaseous, solid and liquid. Estimations of emissions coming from each type of fuel are discussed separately in the following subsections.

**Gaseous Fuels**

The only gaseous fuel considered in this category is natural gas used for non-energy purposes. Although it can be used in methanol and thermal carbon black production, a big portion of it actually goes to SMR for producing the hydrogen needed in ammonia plants. To estimate $CO_2$ emissions, non-energy use of natural gas in each province/ territory is multiplied by an emission factor of 1522 g $CO_2$ emitted/$m^3$ (Cheminfo Services 2005). Summing all the provincial/territorial emissions together gives the national estimate. At the national level, the $CO_2$ emissions from non-energy use of natural gas are adjusted for the $CO_2$ emissions associated with ammonia production. (More specifically, $CO_2$ from ammonia production, at the national level, is subtracted from total $CO_2$ from non-energy use of natural gas to avoid double counting.) It should also be noted that emissions arising from the non-energy use of natural gas to produce hydrogen in the oil refining and bitumen industries are allocated to the Energy Sector of the inventory.

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## Solid Fuels

Solid fuels considered in the Other and Undifferentiated Production category are

- Canadian bituminous coal;
- sub-bituminous coal;
- foreign bituminous coal;
- lignite;
- anthracite; and
- metallurgical coke.

To determine, by province, the $CO_2$ emissions coming from these solid fuels, fuel-, province- and year-specific emission factors (Jaques 1992; McCann 2000), shown in Table A8-7 of Annex 8, are applied to the consumption quantities reported as non-energy use. The national emission estimate for non-energy use of solid fuels is the total of all provincial/territorial emissions.

The emission factors used for estimating releases of $CO_2$ from the non-energy use of coal and coal products are the same as those for combustion; it is assumed that 99% of the carbon in these products will eventually be oxidized and emitted as CO2.

## Liquid Fuels

In addition to the emissions coming from the gaseous and solid fuels mentioned above, $CO_2$ emissions from the non-energy use of liquid fuels, primary natural gas liquids (NGLs), oil refinery petrochemical feedstocks, petroleum coke and lubricants are also included in the category of Other and Undifferentiated Production.

To estimate these emissions at provincial/territorial levels, the quantity of non-energy use of fuel is multiplied by the corresponding emission factor, as shown in Table A8-5 of Annex 8 for petroleum coke, and in Table A3–10 and Table A3–11 for other liquid fuels. The summation of the provincial/territorial estimates gives the national emission estimate.

It should also be noted that, owing to the way in which energy statistics are currently collected in Canada, a portion of non-energy use of liquid fuels has been reported under energy use, which is accounted for in the Energy Sector.

In the case of non-energy use of NGLs, the potential emission factors that occur when all the carbon is oxidized are provided in the McCann (2000) study. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) show a default value for the fraction of carbon stored in products when propane, butane or ethane are used as feedstock. The McCann (2000) potential emission factors are then multiplied by (1 - IPCC default fraction of carbon stored of 0.8) to give the non-energy use emission factors of the three NGLs as shown in Table A3–10

The non-energy use of petroleum products coming out of the oil refineries (i.e. petrochemical feedstocks, naphthas, lubricants, greases and other petroleum products) also results in $CO_2$ emissions, and is accounted for in the Other and Undifferentiated Production category. Their carbon factors (mass of carbon emitted per unit of fuel used) come from Jaques (1992). These factors are then multiplied by the molecular weight ratio of $CO_2$ to carbon, which is 44/12, and by (1 - fraction of carbon stored) to give the $CO_2$ emission factors used to estimate emissions. The default values of the fraction of carbon stored are also provided in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). Derivations of the non-energy use emission factors are shown in Table A3–11. To estimate emissions at national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

The gross emission total for the category of Other and Undifferentiated Production is the sum of emission estimates for the non-energy use of gaseous, liquid and solid fuels. To calculate the net emission totals (i.e. the reported emission estimates) at the national level, all emissions from the non-energy use of fuel accounted for in other categories are subtracted from the gross emission totals. For instance,

Table A3–10    $CO_2$ Emission Factors for Natural Gas Liquids

|  | Fraction of Carbon Stored in Products | Emission Factors (g $CO_2$/L) | Sources |
|---|---|---|---|
| Propane | 0.8 | 303 | IPCC/OECD/IEA (1997); McCann (2000) |
| Butane | 0.8 | 349 | IPCC/OECD/IEA (1997); McCann (2000) |
| Ethane | 0.8 | 197 | IPCC/OECD/IEA (1997); McCann (2000) |

Table A3–11   $CO_2$ Emission Factors for Non-Energy Petroleum Products

| Non-Energy Products | Carbon Factor (g C/L) | Molecular Weight Ratio between $CO_2$ and Carbon | Fraction of Carbon Stored (IPCC Default) | Resulting $CO_2$ Emission Factor (g $CO_2$/L) |
|---|---|---|---|---|
| | A | B | C | D = A × B × (1 − C) |
| Petrochemical Feedstocks | 680 | 44/12 | 0.8 | 500 |
| Naphthas | 680 | 44/12 | 0.75 | 625 |
| Lubricating Oils and Greases | 770 | 44/12 | 0.5 | 1410 |
| Petroleum Used for Other Products | 790 | 44/12 | 0.5 | 1450 |

$CO_2$ emissions from the electrode consumption in aluminium production, from the use of natural gas for ammonia production, and from the consumption of EAF electrodes in iron and steel making are reported in other categories; hence, they are subtracted from the gross national emission of Other and Undifferentiated Production to avoid double counting. However, it should be noted that, to derive a provincial level emission, only $CO_2$ emissions from aluminium production and iron and steel making are subtracted.

### A3.2.2.2.    Data Sources

The *Report on Energy Supply–Demand in Canada* (RESD; Statistics Canada #57-003) is the activity data source for the Other and Undifferentiated Production category. This report presents data by fuel type and area of application (i.e. energy-use versus non-energy-use applications).

## A3.2.3.    $SF_6$ Emissions from Electrical Equipment

### A3.2.3.1.    Methodology – Derivation of the Country-Specific Quantification Method

To quantify SF6 emissions (for 2006–2009), the Canadian electricity industry uses a method derived from the basic tier 3 IPCC life cycle equation below.

Equation A3–8:

$$\text{Total Emissions} = \sum \text{Equipment Manufacturing Emissions}$$
$$+ \sum \text{Equipment Installation Emissions}$$
$$+ \sum \text{Equipment Use Emissions}$$
$$+ \sum \text{Equipment Decommisioning and Failure Emissions}$$
$$+ \sum \text{Emissions from } SF_6 \text{ Recycling and Destruction}$$

The sections below explain in detail how the country-specific quantification method is derived from Equation A3–8.

### A3.2.3.1.1.    Equipment Manufacturing Emissions

Since Canadian electric utilities do not manufacture their transmission and distribution equipment, they are not responsible for the $SF_6$ released during the manufacturing stage. In fact, according to some utilities, electrical equipment purchased by the Canadian electricity industry is manufactured in the United States, Europe or Asia, and hence, emissions associated with manufacturing would have occurred mainly outside of Canada. As such, emissions from equipment manufacturing (i.e. the first term of Equation A3–8) are assumed to be not applicable to the electricity industry.

### A3.2.3.1.2.    Equipment Installation Emissions

$SF_6$ equipment is delivered to utilities pre-charged with some $SF_6$, and it is charged to full capacity at installation. In the Canadian electricity industry, the potential for $SF_6$ emissions during equipment installation is considered to be extremely rare. A vacuum hold check is typically performed prior to the installation of new equipment to ensure that the equipment is gas tight.

### A3.2.3.1.3.    Equipment Use Emissions

The primary source of $SF_6$ releases is associated with the cumulative minute releases that occur during normal equipment operation. Gas releases could potentially occur during gas handling and transfer operations, although such releases would be significantly smaller in magnitude than emissions that occur during normal operations.

Due to the $SF_6$ leakage that occurs during the above circumstances, utilities are required to "top up" their equipment to keep their equipment properly charged and op-

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erational. By topping up equipment with $SF_6$ gas, utilities are able to replace the amount of gas that has escaped.

### A3.2.3.1.4. Equipment Decommissioning and Failure Emissions

During the decommissioning of retired equipment, $SF_6$ gas must be recovered from the retired equipment prior to disposal. As $SF_6$ gas releases may occur from the way in which the gas is transferred out of the equipment during gas recovery, decommissioning of retired equipment becomes a potential source of $SF_6$ releases.

When catastrophic failures of equipment occur, a significant amount of $SF_6$ is leaked out of the equipment. Hence, equipment damages are a potential source of emissions.

Retired equipment and damaged equipment that cannot be repaired are sent off-site for disposal.

### A3.2.3.1.5. Emissions from $SF_6$ Recycling

When $SF_6$ gas is recovered from equipment, it is filtered through a gas cart or other filtering equipment to remove moisture and impurities before it is reused. When $SF_6$ gas has been contaminated with air and impurities, and has a purity of less than a certain level (the acceptable level can vary between 95 and 99%, depending on utility practices), it cannot be reused and is sent for off-site purification in the U.S. There are no facilities in Canada that perform $SF_6$ gas purification. One of the methods utilized to purify $SF_6$ gas is the use of a cryogenic process to separate and remove the air/nitrogen from the $SF_6$ gas. The purification of $SF_6$ gas does not produce $SF_6$ emissions. Hence, emissions from $SF_6$ recycling are eliminated from the calculation of total emissions.

Given the reasoning above, the Canadian electricity industry will use a modified Tier 3 IPCC approach (which is country-specific) to estimate $SF_6$ releases. Equation A3–8 is simplified to include only emissions from equipment use and decommissioning, as shown in Equation A3–9.

Equation A3–9:

$$\text{Total Utility } SF_6 \text{ Emissions} = \sum \text{EquipmentUse Emissions} + \sum \text{Equipment Decommissioning and Failure Emissions}$$

### A3.2.3.2. Methodology – Quantifying Equipment Use Emissions

Emissions that occur during equipment use are a result of leakages during gas transfer and handling operations and during normal operation of the equipment. In order to keep equipment properly charged and operational, utilities must fill their equipment to replace the amount that has escaped. This amount is referred to as a "top-up."

Leakages of $SF_6$ are also seen during maintenance/repair activities. When equipment needs to be repaired or sent for maintenance, $SF_6$ gas is recovered from equipment and once equipment is repaired, it is refilled with the $SF_6$ gas that was recovered. There will be an additional amount needed to refill the equipment, since some gas may have escaped due to normal operations and during the transfer of the recovered gas from the equipment to gas carts (or storage cylinders) and back to the equipment again. It is this additional/incremental amount of $SF_6$ gas that is referred to as the "top-up."

Hence, an accurate estimate of the amount of $SF_6$ released is the amount used by utilities to top up their equipment during the equipment use stage, as shown in Equation A3–10.

Equation A3–10:

$$\text{Equipment Use Emissions} = \sum SF_6 \text{ used to top up equipment}$$

### A3.2.3.2.1. Options for Tracking $SF_6$ Consumed for Top-Ups

Based on Equation A3–10, utilities are able to estimate $SF_6$ releases from equipment use by tracking the amount of $SF_6$ used to top up their equipment. The following is a list of options for Canadian electric utilities to track the amount of $SF_6$ that is used for top-up purposes in order to quantify emissions of $SF_6$ from the equipment use phase. These options are listed in order of most accurate to least accurate. The most accurate method involves directly measuring the amount of gas transferred during top-ups, and the less accurate methods involve utilities relying on inventory records or purchase receipts to obtain an estimate. Each utility will have discretion over which method to use.

For all of the tracking options discussed below, it is assumed that the quantities of the $SF_6$ gas tracked do not

include the gas used to pressurize the new switchgear to its full capacity at time of installation. Quantities of gas used for this pressurization are typically provided by the switchgear vendor at time of installation and hence do not come out of the utility inventory (please see also A3.2.3.1.2– Equipment Installation Emissions).

## Option 1: Mass Flow Meters

Mass flow meters provide the most accurate method for measuring the quantity of $SF_6$ consumed during each equipment top-up operation. The sum of all measured quantities during top-up operations will be used to determine the equipment use emissions.

## Option 2: Weigh Scales

Utilities may choose to weigh their $SF_6$ cylinders to determine the quantity of $SF_6$ consumed for top-up operations. Weighing of cylinders can be performed every time there is an equipment top-up operation, or it can be performed on an inventory basis. When using this method, utilities should ensure that the accuracy of the weigh scale is compatible with the weight of the cylinders to be weighed. For example, utilities should use a scale accurate to ±1 kg, instead of ± 5 kg, to weigh a 50-kg cylinder.

## Option 2a: Weighing Individual Cylinders Before and After Top-Ups

Under this approach, a utility weighs each individual cylinder before and after it is used to top up or refill equipment. The difference in weight then represents the amount that was used to top up the equipment. This procedure can be represented by Equation A3–11 below.

Equation A3–11:

$$SF_6 \text{ Used to top up equiment} = \sum \left( \begin{array}{l} \text{Weight of Individual } SF_6 \text{ Cylinders before Top-Up} \\ - \text{ Weight of Individual } SF_6 \text{ Cylinders after Top-Up} \end{array} \right)$$

## Option 2b: Weighing $SF_6$ Cylinders on an Inventory Basis

With this approach, utilities weigh all $SF_6$ cylinders that are placed in their maintenance inventory at the beginning of the year and the end of the year. They must also account for any purchases or additions to the inventory, weight of $SF_6$ cylinders returned to suppliers and the quantity of $SF_6$ sent off-site for recycling or destruction during the year. This method can be represented by Equation A3–12 below.

Equation A3–12:

$$\begin{aligned} SF_6 \text{ Used to top up equipment} = & \text{ Weight of } SF_6 \text{ Cylinders in Maintenance Inventory}_{Beginning of Year} \\ & - \text{ Weight of } SF_6 \text{ Cylinder in Maintenance Inventory}_{End of Year} \\ & + \text{ Weight of } SF_6 \text{ Cylinders Purchased/Acquired} \\ & - \text{ Weight of } SF_6 \text{ Cylinders Returned to Suppliers} \\ & - \text{ Weight of } SF_6 \text{ sent off-site for recycling or destruction} \end{aligned}$$

## Option 3: Cylinder Count

In the absence of mass flow meters or weigh scales, utilities may choose to rely on information from supplier or inventory records and from purchase receipts to obtain the number and weight of $SF_6$ cylinders purchased for top-up purposes. The mass of $SF_6$ consumed can generally be calculated in two ways:

- By obtaining the number of cylinders purchased in a year from purchase records and multiplying this number by the $SF_6$ weight in a cylinder; or

- By tracking the number of cylinders entering and leaving the maintenance inventory during the reporting year and multiplying this number by the $SF_6$ weight in a cylinder.

The weight of $SF_6$ found in different types of cylinders should be known. Therefore, utilities can simply obtain the weight of $SF_6$ consumed for top-up purposes by performing a cylinder count. If more than one type of cylinder is used, utilities must ensure that the number of cylinders of each type is multiplied by the cylinder weight for that type. The products obtained for all cylinder types are then summed together to give the total $SF_6$ use. More details on these two options are provided in the following subsections.

## Option 3a: Counting Number of Cylinders Purchased in One Year

The amount of $SF_6$ consumed for top-up purposes under this approach is based on purchase or inventory records of each utility or facility. From purchase records, utilities can extract the number of cylinders purchased. The assumption made is that the amount of $SF_6$ purchased and placed in inventory will eventually be used to replace releases from existing equipment.

When relying on inventory or purchase records, it is important to take into consideration the amount of residual gas left in the cylinders after it is used for top-ups. According to information supplied by two major $SF_6$ gas distribu-

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tors, approximately 12% of gas is left in cylinders after they are used. This amount should be subtracted from the total amount of $SF_6$ found in inventory records. Equation A3–13 represents the $SF_6$ tracking method based on the central purchasing or inventory records.

Equation A3–13:

$$SF_6 \text{ Used to top up equiment} = \sum \left( \begin{array}{l} \text{Weight of Individual } SF_6 \text{ Cylinders before Top-Up} \\ - \text{ Weight of Individual } SF_6 \text{ Cylinders after Top-Up} \end{array} \right)$$

where:

| | | |
|---|---|---|
| $i$ | $=$ | different types of cylinders |
| $y$ | $=$ | % of gas left in cylinders when returned to suppliers |

*(Note: utilities may choose to directly weigh the residual gas in cylinders and calculate the residual gas in % as y, or may use a default value of 12% for y.)*

### Option 3b: Tracking Cylinder Inventory Count Throughout the Year

This approach is similar to the method in Option 2b," Weighing $SF_6$ Cylinders on an Inventory Basis," except that utilities need only count the number of cylinders purchased and placed in inventory at the beginning of the year and at the end of the year instead of having to directly weigh these cylinders throughout the year. The count of cylinders is then multiplied by the known weight of the $SF_6$ cylinders.

Since utilities are not weighing their cylinders, an estimate of the amount of residual gas left in the cylinders when returned to suppliers must be estimated. Utilities may choose to weigh this amount or use the suggested 12% explained above. This methodology is represented by Equation A3–14.

Equation A3–14:

$$SF_6 \text{ Used for Top-Up} = \sum_{i=1}^{n} \left( \begin{array}{l} [C_i \text{ at beginning of year} + C_i \text{ purchased} - C_i \text{ at end of year}] \\ * SF_6 \text{ weight in cylinder } i * (1-y) \end{array} \right) - \text{outflows}$$

where:

| | | |
|---|---|---|
| $i$ | $=$ | different types of cylinders |
| $Ci$ | $=$ | number of cylinders of type i |
| $y$ | $=$ | % of gas left in cylinders when returned to suppliers |
| outflows | $=$ | (Note: utilities may choose to directly weigh the residual gas in cylinders and calculate the residual gas in % as y, or may use a default value of 12% for y.) |
| | | amount (in weight units) of $SF_6$ sent off-site for recycling or destruction |

## A3.2.3.3. Methodology – Quantifying Equipment Disposal and Failure Emissions

Equipment disposal and failure emissions include emissions from decommissioning of retired equipment and emissions that result from the rare event of catastrophic equipment failures.

In the decommissioning of retired equipment, $SF_6$ losses occur as gas is being recovered from the retired equipment. Emissions can be estimated by taking the difference between the nameplate capacity of the equipment and the recovered amount of $SF_6$ .

Equation A3–15:

$$\text{Equipment decommisioning emissions} = \text{Nameplate capacity of retired equipment} - SF_6 \text{ amount recovered from retired equipment}$$

The value of nameplate capacity (in mass units) can be obtained from equipment specifications provided by the equipment manufacturer or from sound engineering estimates. The amount of recovered $SF_6$ gas is weighed.

When equipment failures or damages occur to the point where they cannot be repaired, the nameplate capacity of the equipment can provide a reasonable estimate of emissions that have taken place as a result of equipment failures (see Equation A3–16).

Equation A3–16:

$$\text{Emissions from damaged equipment} = \text{Nameplate capacity of damaged equipment}$$

The information provided in this section (A3.2.3) is extracted from the *SF$_6$ Emission Estimation and Reporting Protocol for Electric Utilities* (Environment Canada and Canadian Electricity Association 2008), available upon request at http://www.ec.gc.ca/Publications/default. asp?lang=En&xml=5926D759-36A6-467C-AE05-077C5E-6C12A2. For further details on data uncertainty, data quality control, data verification by third party, transfer of information and data to the GHG Division, documentation and archiving, new information or data updates, and protocol reviews and amendments, please refer to the Protocol.

### A3.2.3.4. Data Sources

The SF$_6$ emission estimates by province for 2006–2009 were provided by the Canadian Electricity Association (CEA)—which represents electricity companies across Canada, except for the province of Quebec—and Hydro Quebec (HQ).

## A3.3. Methodology for the Agriculture Sector

This section of Annex 3 describes the estimation methodologies, equations, activity data, emission factors and parameters that are used to derive the GHG estimates in the Agriculture Sector, namely:

- $CH_4$ emissions from enteric fermentation;
- $CH_4$ and $N_2O$ emissions from manure management and field burning of agricultural residues; and
- $N_2O$ emissions from agricultural soils (direct emissions, indirect emissions and animal manure emissions on pasture, range and paddock).

The sources of animal population data required to calculate agricultural emissions of $CH_4$ and $N_2O$ are presented first in Section A3.3.1. Cattle populations are then characterized in Section A3.3.2. The methods used to calculate agricultural GHG emissions are described in sectionsA3.3.3 to A3.3.6. Note that agricultural soils also emit and sequester $CO_2$, but these sources/sinks are reported in the Land Use, Land-use Change and Forestry (LULUCF) Sector (see Annex 3.4).

## A3.3.1. Animal Population Data Sources

Annual livestock population data at a provincial level were used to develop emission estimates. Livestock and poultry populations, by animal subcategory, and by province, were obtained from Statistics Canada Table A3–12 Annual populations are derived from the *Census of Agriculture*, which is conducted every five years, combined with semi-annual or quarterly surveys for important animal categories.

Annual animal populations of cattle, sheep, lamb and swine that are reported in both the *Census of Agriculture* and in semi-annual or quarterly surveys are presented as the simple mean of the different surveys. The populations of horses, goats, buffalo,[5] llamas, alpacas and poultry are monitored every five years by the *Census of Agriculture* exclusively. Annual populations are developed by linear interpolation in order to avoid large changes in census years. Populations since the last census (2006) have been maintained constant and will be recalculated by linear interpolation after the next census. Buffalo populations were

5  The IPCC animal category buffalo is used; however, in Canada, it  refers to North American bison (Bison bison) that are raised for meat.

Table A3–12  Animal Categories and Sources of Population Data

| Category | Sources/Notes |
|---|---|
| Cattle | Statistics Canada. 2010a. "Cattle Statistics, 2010." Vol. 9, no. 2. Statistics Canada Catalogue no. 23-012-XWE. http://www.statcan.gc.ca/cgi-bin/af-fdr.cgi?l=eng&loc=http://www.statcan.gc.ca/pub/23-012-x/23-012-x2010001-eng.pdf&t=Cattle%20Statistics (accessed Sept. 30, 2010). |
| —Dairy Cattle | All cattle used in the production of milk and milk products |
| —Non-dairy Cattle | All other cattle |
| Buffalo, Goats, Horses, Llamas and Alpacas | Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue # 23-502-X)  —linear interpolation between census years, constant since 2006. |
| Mules and Asses | —Not raised for commercial purposes in Canada |
| Sheep and Lambs | Statistics Canada. 2010b. "Sheep Statistics, 2010." Vol. 9, no. 2. Statistics Canada Catalogue no. 23-011-XWE. http://www.statcan.gc.ca/cgi-bin/af-fdr.cgi?l=eng&loc=http://www.statcan.gc.ca/pub/23-011-x/23-011-x2010001-eng.pdf&t=Sheep%20Statistics (accessed Sept. 30, 2010). |
| Swine | Subcategories: Boars, Sows, Growers under 20 kg, 20 to 60 kg, and over 60 kg. |
|  | Statistics Canada. 2010c. "Hog Statistics, 2010." Vol. 9, no. 4. Statistics Canada Catalogue no. 23-010-XWE. http://www.statcan.gc.ca/cgi-bin/af-fdr.cgi?l=eng&loc=http://www.statcan.gc.ca/pub/23-010-x/23-010-x2010004-eng.pdf&t=Hog%20Statistics (accessed Sept. 30, 2010). |
| Poultry | Farm data and farm operator data tables (section 6.5 of publication #95-629) (Statistics Canada [2007a]) |
|  | Selected historical data from the Census of Agriculture, Canada and provinces: census years 1976 to 2006 (Table 2.16 and section 4.6 of Statistics Canada catalogue #95-632). (Statistics Canada [2007b]).  —linear interpolation between census years, constant since 2006. |

not collected in 1986; thus, the buffalo population was set constant for 1990 at the 1991 level.

## A3.3.2.    Cattle Characterization

For beef and dairy cattle, the IPCC Tier 2 approach (IPCC 2000) was adopted to estimate $CH_4$ emission factors from enteric fermentation and manure management. The subcategories of provincial cattle populations collected by Statistics Canada were further dissaggregated into sub-annual production stages to isolate and quantify the effect of specific production practices on gross energy intake and as a consequence, GHG emission. Data to describe the production environment and associated performance of classes of animals were collected from a combination of production and management practices published in scientific journals, a survey of dairy and beef production practices conducted and administered to regional and pro-vincial beef and dairy cattle specialists across the country, and consultation with scientists at universities and federal research institutions, as well as from provincial/national as-sociations and provincial/regional performance-recording organizations (Boadi et al. 2004b).

These data were used to create an annual cattle produc-tion model that takes into account regional and seasonal variations in production practices. The eight cattle subcat-egories were broken down into 38 distinct cattle produc-tion stages, 29 for non-dairy cattle and 9 for dairy cattle, observed throughout the different provinces of Canada (Table A3–13). The model characterizes cattle by physio-logical status, diet, age, sex, weight, growth rate, activity level and production environment.

The feeding practices for beef and dairy cattle are detailed in the next section.

### A3.3.2.1.    Dairy Cattle

**Production and Performance**

Production practices vary across the country because of differences in land values, climate, forage availability and market access. The predominant management practices for each province are reflected by the province-specific parameters entered into the IPCC Tier 2 equations.

Table A3–14 provides an example of production perform-ance data collected for Canadian dairy cattle and incorpor-ated in the Tier 2 model.

Currently, it is assumed that all production characteristics of the Canadian dairy herd have remained constant over the 1990–2009 time period, including the live weight of dairy cows, as data from Holstein Ontario do not indicate increases in weight over this period. As a result, dairy cows' and dairy heifers' live weights are set constant to the 2001 weight, estimated in Boadi et al. (2004b).

### *Milk Yield and Fat Data*

Milk productivity has increased in all Canadian provinces (Table A3–15), as documented by the CanWest Dairy Herd Improvement (DHI) Services, representing more than two thirds of the Canadian dairy cow population. The trend in increased milk production is reflected in the emission fac-tor for dairy cows.

### *Duration of Time in a Production Environment*

It was assumed that animals that were dry during the sum-mer months were on pasture; animals that were dry during the remainder of the year were in confinement. Replace-ment heifers were assumed to calve at 24 months.

### *Percentage of Cows Pregnant*

An estimate of the percentage of cows pregnant in the herd at any given time was calculated according to Boadi et al. (2004b) using the following formula:

$$\text{Percentage of cows pregnant} = \left( \frac{\text{gestation length}}{\text{calving interval}} \times 100 \right)$$
$$- \text{percentage of cows culled due to reproductive failure}$$

### *Ration Digestible Energy*

Digestible energy (DE) values determined by Christensen et al. (1977) for forages grown on the Prairies were used to estimate DE for Alberta, Saskatchewan and Manitoba. National Research Council values (NRC 2001) were used to estimate the DE for British Columbia and the eastern provinces. Due to limited information regarding other feed ingredients, total mixed rations for cattle were assumed to be mainly forage and grain. Overall, DE ranged from 60 to 70% depending on rations and feeding regimes. It was also assumed that lactating cows on pasture were supple-mented with grain; therefore, DE values were assumed to be similar to those of rations fed in confinement (Boadi et al. 2004b).

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Table A3–13    Cattle Stage Production Model

| Category | Sources/Notes | Period of Year[1] | Province |
|---|---|---|---|
| Beef cows | Pregnant, confined | Jan-Apr/Oct-Dec | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Beef cows | Lactating, pasture | May-Oct | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Beef cows | Pregnant, confined | Feb-Mar | Man. |
| Beef cows | Lactating, pasture | Jan/Mar-Dec | Man. |
| Breeding bulls | Mature, confined | Jan-Apr/Nov-Dec | P.E.I./N.S./Que./Ont./Man./Sask./Alta./B.C. |
| Breeding bulls | Mature pasture | May-Oct | P.E.I./N.S./Que./Ont./Man./Sask./Alta./B.C. |
| Breeding bulls | Young confined | Mar-Apr | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Breeding bulls | Young pasture | May-Oct | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Breeding bulls | Young confined | Nov-Dec/Jan-Feb | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Beef calves | Birth to pasture | Mar | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Beef calves | Pasture | Apr-Sep | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Beef calves | Heifer replacement | Oct-Dec/Jan-Mar | P.E.I./N.S./N.B./Ont./Man./Sask./Alta./B.C. |
| Beef calves | Background heifers | Oct-Dec/Jan-Mar | P.E.I./N.S./N.B./Ont./Man./Sask./Alta./B.C. |
| Beef calves | Background steers | Oct-Dec/Jan-Mar | N.L./P.E.I./N.S./N.B./Ont./Man./Sask./Alta./B.C. |
| Beef calves | Finisher heifers | Oct-Dec/Jan-Mar | P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Beef calves | Finisher steers | Oct-Dec/Jan-Mar | P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Heifer replacement | Young, not pregant | Apr-May | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Heifer replacement | Early gestation | Jun-Sep | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Heifer replacement | Late gestation | Oct-Dec/Jan-Mar | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Finisher heifers | Feedlot, short-keeps | Apr-Jun | P.E.I./N.S./N.B./Ont./Man./Sask./Alta./B.C. |
| Finisher steers | Feedlot, short-keeps | Apr-Jun | P.E.I./N.S./N.B./Ont./Man./Sask./Alta./B.C. |
| Finisher heifers | Feedlot short keep-long finish | April-Jul | N.S./Ont./Man. |
| Finisher steers | Feedlot short keep-long finish | April-Jul | N.S./Ont./Man. |
| Background heifers | Confined | Mar-May | N.L./N.S./Ont./Man./Sask./Alta./B.C. |
| Background steers | Confined | Mar-May | N.L./N.S./Ont./Man./Sask./Alta./B.C. |
| Background heifers | Pasture | Jun-Sep | N.L./N.S./Ont./Man./Alta./B.C. |
| Background steers | Pasture | Jun-Sep | N.L./N.S./Ont./Man./Alta./B.C. |
| Finisher heifers | Feedlot, long-keeps | Oct-Dec | P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Finisher steers | Feedlot, long-keeps | Oct-Dec | P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Dairy cow | Lactating, confined | var[2] | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Dairy cow | Lactating, pasture | var | N.L./P.E.I./N.B. |
| Dairy cow | Lactating, confined (after pasture) | var | P.E.I. |
| Dairy cow | Dry, low-quality feed | var | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./B.C. |
| Dairy cow | Dry, high-quality feed | var | Man./Sask./Alta./B.C. |
| Dairy cow | Dry, pasture | var | N/L./Ont. |
| Dairy heifer | Confined (243 days year) | Jan-Apr/Oct-Dec | N.L./P.E.I./N.S./N.B./Que./Ont./Man./Sask./Alta./B.C. |
| Dairy heifer | Pasture | May-Oct | N.L./P.E.I./N.B./Ont./Sask. |
| Dairy heifer | Confined (365 days year) | Jan-Dec | N.B./Ont./Sask. |

Notes:
1. Actual period of the year could vary slightly from province to province.
2. Variable dependant on farm, province and animal cycles.

Table A3–14   Typical Characteristics of Dairy Production in 2001 in Canada[1]

| Animal Category/Parameters | Production Characteristics[2] | Data Sources[3] |
|---|---|---|
| Dairy Cows | | |
| Average weight, kg | 634 (51) | Okine and Mathison (1991); Kononoff et al. (2000); Petit et al. (2001) |
| Mature weight, kg | 646 (55) | |
| Conception rate, % | 59.2 (7.3) | |
| Calves | | |
| Birth weight, kg | 41 (3.3) | |
| Average weight, kg | 186 (18.5) | |
| Mature weight, kg | 330.5 (37.6) | |
| Daily weight gain, kg/day | 0.7 (0.3) | |
| Calf crop[4], % | 93 (6) | |
| Replacement heifers | | |
| Average weight, kg | 461.6 (24.7) | |
| Beginning weight (1 year), kg | 327.8 (31.0) | |
| Mature weight at calving, kg | 602.1 (45.9) | |
| Mature weight, kg | 646.1 (54.9) | |
| Daily weight gain, kg/day | 0.77 (0.14) | |
| Replacement rate, % | 32.3 (3.2) | Western Canadian Dairy Herd Improvement Services (2002) |

Notes:
1. Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian dairy production, as reported in the CRF.
2. The numbers in parentheses are the standard deviation.
3. Values with no reference were obtained from expert consultations (see Boadi et al. 2004b).
4. "Calf crop" is the percentage of the overwintering cows that produced a live calf.

Table A3–15   Average Milk Production from 1990 to 2009 at a Provincial Level

| | Average Milk Production (kg/head/day)[1] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | N.L. | P.E.I. | N.S. | N.B. | Que. | Ont. | Man. | Sask. | Alta. | B.C. |
| 1990 | 23.6 | 24.3 | 24 | 23.9 | 23 | 24.5 | 25.2 | 25.5 | 26.9 | 26.8 |
| 1991 | 23.9 | 24.6 | 24.4 | 24.2 | 23.3 | 24.6 | 25.6 | 25.9 | 27.3 | 27.2 |
| 1992 | 24.8 | 25.6 | 25.3 | 25.2 | 24 | 26 | 26.6 | 26.9 | 28.3 | 28.2 |
| 1993 | 25.4 | 26.2 | 25.9 | 25.7 | 23.9 | 26.2 | 27.2 | 27.5 | 28.9 | 28.8 |
| 1994 | 26.4 | 27.2 | 26.9 | 26.7 | 23.7 | 26.7 | 28.2 | 28.5 | 30.1 | 30 |
| 1995 | 26 | 26.8 | 26.5 | 26.4 | 24.2 | 27 | 27.6 | 27.9 | 29.4 | 29.5 |
| 1996 | 26.6 | 27.4 | 27.2 | 27 | 24.6 | 27.3 | 28.7 | 29.2 | 30.6 | 30.3 |
| 1997 | 27 | 27.8 | 27.5 | 27.4 | 25 | 28.9 | 29 | 29.7 | 30.9 | 29.9 |
| 1998 | 27.4 | 28.3 | 28 | 27.8 | 26.2 | 28.5 | 29.3 | 30.6 | 31.5 | 30.7 |
| 1999 | 25.5 | 25.2 | 26.5 | 26.4 | 25.3 | 26.1 | 25 | 25.5 | 26.8 | 29.6 |
| 2000 | 28.6 | 25.9 | 27.2 | 27 | 25.9 | 27 | 27.4 | 27.3 | 30 | 32.1 |
| 2001 | 27.4 | 25.3 | 26.4 | 26.5 | 25.5 | 26.1 | 26.6 | 27.8 | 29.7 | 31.1 |
| 2002 | 26.1 | 25.4 | 26.5 | 27 | 26 | 26.5 | 26.3 | 28.9 | 30.1 | 32.1 |
| 2003 | 27.3 | 25.4 | 26.5 | 26.2 | 25.6 | 26.4 | 27.1 | 28.1 | 29.8 | 31.4 |
| 2004 | 25.6 | 25.6 | 26.4 | 26.3 | 25.6 | 26.7 | 26.9 | 27.9 | 29.1 | 31.1 |
| 2005 | 27.2 | 27.2 | 27.1 | 27.1 | 26.2 | 27.4 | 26.2 | 28.3 | 29.6 | 30.8 |
| 2006 | 27.1 | 27.1 | 26.4 | 26.4 | 26.7 | 27.8 | 26.5 | 29.5 | 31.3 | 31.8 |
| 2007 | 25.9 | 25.9 | 26 | 25.9 | 26.7 | 27.4 | 27 | 29.1 | 30.9 | 31.4 |
| 2008 | 26.5 | 26.5 | 26.3 | 25.4 | 26.6 | 27.3 | 26.4 | 28.8 | 30.2 | 30.3 |
| 2009 | 26.5 | 25.3 | 26.5 | 25.7 | 25.9 | 26.8 | 27.7 | 30.4 | 31.4 | 30.5 |

1. Data source: CanWest DHI.

### A3.3.2.2.    Non-Dairy Cattle

**Production Practices and Performance**

Production practices for non-dairy cattle also vary across the country due to climate, land prices and differences in traditional farming practices. The study conducted by Boadi et al. (2004b) characterized the predominant practices in the year 2001, for each province according to animal type, physiological status, age, gender, growth rate, activity level and production environment. The values presented in Table A3–16 represent typical values observed in the provinces.

Table A3–16    Typical Characteristics of Beef Production in Canada in 2001[1]

| Animal Category | Production Characteristics[2] | Data Sources[3] |
|---|---|---|
| **Beef Cows** | | |
| Average weight, kg | 603 (36) | Kopp et al. (2004) |
| Mature weight, kg | 619 (52) | AAFRD (2001) |
| Milk, kg/day | 7.3 (1.2) | Kopp et al. (2004) |
| Milk fat, % | 3.6 (0.6) | Kopp et al. (2004) |
| Conception rate, % | 93.7 (1.3) | Manitoba Agriculture and Food (2000); AAFRD (2001) |
| **Replacement Heifers** | | |
| Average weight, kg | 478 (34) | |
| Mature weight, kg | | |
| Daily weight gain, kg/day | 0.64 (0.14) | |
| Replacement rate, % | 14.4 (3.1) | Manitoba Agriculture and Food (2000) |
| **Bulls** | | |
| Yearling weight, kg | 541 (18) | |
| Average weight, kg | 940 (98) | |
| Mature weight, kg | 951 (112) | |
| Daily weight gain, kg/day | 1.0 (0.17) | |
| **Calves (including Dairy Calves)** | | |
| Birth weight, kg | 40 (3) | AAFRD (2001) |
| Wean weight, kg | 258.4 (19.1) | Small and McCaughey (1999) |
| Age at weaning, days | 215 (15) | |
| **Daily Weight Gain, kg/day** | | |
| - Replacement heifers | 0.67 (0.13) | Kopp et al. (2004) |
| - Backgrounder | 0.98 (0.17) | |
| - Finisher | 1.37 (0.12) | |
| Calf crop, % | 95 (2.3) | |
| **Heifer and Steer Stockers** | | |
| Average weight, kg | 411 (47) | Kopp et al. (2004) |
| Mature weight, kg | 620 (51) | |
| Daily weight gain, kg/day | 0.98 (0.16) | |
| Proportion to feedlot, % | 65 (30) | |
| **Feedlot Animals** | | |
| Average weight, kg | | |
| - Direct finish | 540 (25) | |
| - Background finish | 562 (64) | |
| Mature weight, kg | 630 (46) | |
| Finish weight, kg | 609 (28) | |
| Daily weight gain, kg/day | 1.37 (0.12) | |

Note:
1.    Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian beef production, as reported in the CRF.
2.    The numbers in parentheses are the standard deviations.
3.    Values with no reference were obtained from expert consultations compiled in Boadi et al. (2004b).

Trends in carcass weights are used as an indicator of changes in mature weight from the 2001 benchmark values established by Boadi et al. (2004b) for the specific animal subcategories presented in Table A3–17. Carcass weight data are collected by the Canadian Beef Grading Agency (CBGA) and published by Agriculture and Agri-Food Canada (AAFC 1990–2008). Carcass weights increased from 1990 to 2003 for beef cows, heifers for slaughter, steers and bulls (Figure A3–1). Since 2003 carcass weights have remained more or less stable.

In 2003, the Canadian cattle meat industry was affected by bovine spongiform encephalopathy (BSE) disease, which shut down beef exports to the United States. After 2003 the slaughtered carcass weight of bulls had evidently increased due to the culling of older bulls. To provide an estimate more representative of the on-farm herd, the average live weights of bulls was retained at their 2002

value; however, in 2009, the slaughter weight of bulls was, once again, used in the time series.

## Duration of Time in a Production Environment

Replacement heifers over 15 months of age are assumed to be bred or pregnant. All replacement stock (breeding bulls, young and replacement heifers over 12 months of age) are assumed to enter the breeding herd (mature breeding bulls, and beef cows) at 24 months of age. Slaughter heifers and steers at 12 months of age either enter into feedlots or are backgrounded. Animals scheduled for slaughter may be either identified as short- or long-keeps; short-keeps go directly to the feedlot to be slaughtered after 3 to 4 months, as opposed to long-keeps that are typically backgrounded for 6 months before being sent to feedlots where they are finished after 2 to 4 months.

Figure A3–1    Non-dairy Cattle Carcass Weight, Based on Data Collected by CBGA and Published by AAFC
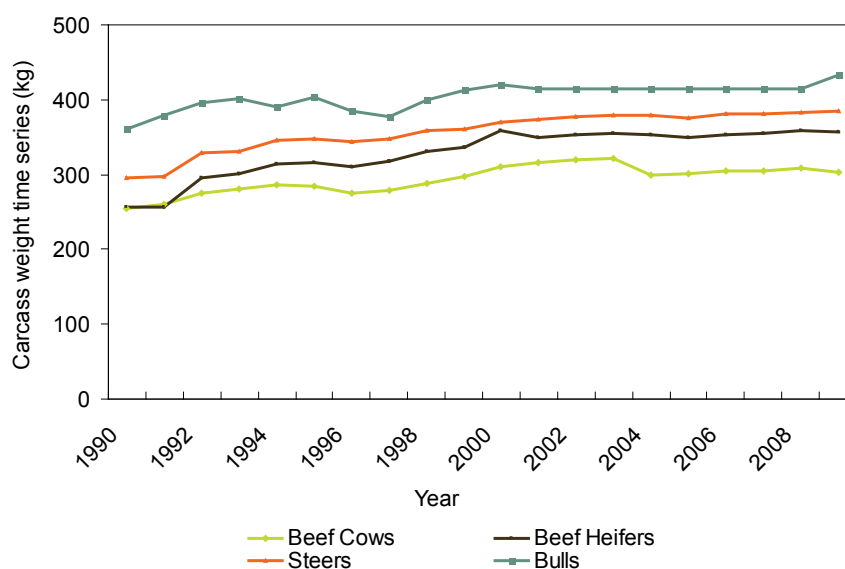


Table A3–17    Carcass Weights Used as an Indicator of Live Body Weight Change Over Time for Non-dairy Cattle

| Cattle Subcategory | Trend in Live Weight Applied |
| --- | --- |
| Beef cows | Trends in beef cow carcass weight used as an indicator of live weight from 1990 to 2009 |
| Heifers for slaughter | Trends in heifer carcass weight used as an indicator of live weight from 1990 to 2009 |
| Beef heifers | Trends in beef cow carcass weight used as an indicator of live weight from 1990 to 2009 |
| Steers | Trends in steer carcass weight used as an indicator of live weight from 1990 to 2009 |
| Bulls | Trends in bull carcass weight used as an indicator of live weight from 1990 to 2002; 2003 to 2008 live weight are set constant to the 2002 live weight; 2009 uses carcass weight again |
| Calves | No change |
| Dairy heifers[1] | No change |

Note:

1. As dairy cows' live weight did not increase over time, it was assumed that dairy heifers did not increase either.

**Ration Digestible Energy**

Forage DE values determined by Christensen et al. (1977) for forages grown on the Prairies were used to estimate DE for Saskatchewan and Manitoba. Values from Alberta Agriculture and Rural Development and the University of Alberta (2003) were used for Alberta, whereas NRC (2001) values were used to estimate the DE of rations for British Columbia and the eastern provinces. Overall, DE ranged from 60 to 84%, depending on rations and feeding regimes.

Calves were assumed to have a non-functional rumen or to consume very small amounts of dry feed from birth until two or three months of age. Therefore, enteric $CH_4$ emissions in these first few months are assumed to be zero.

## A3.3.3.  $CH_4$ Emissions from Enteric Fermentation

The release of $CH_4$ from enteric fermentation from all categories of livestock in Canada is calculated using Equation A3–17. $CH_4$ emissions from enteric fermentation for cattle are estimated using the country-specific emission factors derived from IPCC (2000) Tier 2 equations (Table A3–18). For the other animal categories, the IPCC Tier 1 methodology and default emission factors are applied (see Annex 8).

Equation A3–17:

$$CH_{4EF} = \sum_T \left( N_T \times EF_{(EF)T} \right)$$

where:

| | | |
|---|---|---|
| $CH_{4E}F$ | = | $CH_4$ emissions from enteric fermentation for all animal categories |
| $N_T$ | = | animal population for the Tth animal category or subcategory in each province |
| $EF_{(EF)T}$ | = | emission factor for the Tth animal category or subcategory (Table A3–18 for cattle; for other animal categories, see Annex 8). |

## A3.3.3.1.  Enteric $CH_4$ Emission Factors for Cattle

Emission factors were derived at the provincial level using IPCC (2000) Tier 2 equations for different subcategories of cattle (dairy cows, dairy heifers, beef cows, beef heifers, bulls, calves, heifer replacement, heifers > 1 year and

steers > 1 year) based on stages of production. Tier 2 enteric fermentation estimates require an approximation of gross energy consumed (GE) calculated according to Equation A3–18.

Equation A3–18:

$$GE = \left[ \left[ \frac{(NEm + NEa + NEl + NEmob + NEp)}{(NEm/DE)} \right] + \left[ \frac{NEg}{(NEg/DE)} \right] \right] \Big/ \left[ \frac{DE}{100} \right]$$

where:

| | | |
|---|---|---|
| GE | = | gross energy, MJ/day |
| NEm | = | net energy required for maintenance, MJ/day |
| $NE_a$ | = | net energy required for activity, MJ/day |
| $NE_l$ | = | net energy required for lactation, MJ/day |
| $NE_{mob}$ | = | net energy mobilized by weight loss during lactation, MJ/day |
| $NE_p$ | = | net energy required for pregnancy, MJ/day |
| $NE_m/DE$ | = | ratio of net energy available in a diet for maintenance to digestible energy |
| NEg | = | net energy required for growth, MJ/day |
| NEg/DE | = | ratio of net energy available in a diet for growth to digestible energy |
| DE | = | digestible energy of the ration, % |

Different stages of production require different consumption patterns to supply the necessary energy for specific animal products and environmental conditions, and therefore have different GE values. For example, dairy cattle emissions were estimated for two production categories: dry cows and lactating cows. Lactating cattle require high consumption rates (GE) for milk production. Dry cattle may also be confined or on pasture, which also modifies their required energy intake.

The total duration of time an animal spends in a production stage can also be variable; a weighted average emission factor was calculated. Criteria used in the weighting included duration of time spent in the production category and relative percentage of the population in each stage of production. Furthermore, some net energy calculations may be modified based on a factor that takes into account the time that the energy is supplied within a production stage. For example, weight loss during lactation in dairy cattle only occurs within the first 70 days of lactation; therefore $NE_{mob}$ is modified by a ratio of the days of weight loss over the total lactation period. For each province an emission factor ($EF_{(EF)}$) is calculated according to Equation A3–19. Provincial emission factors were weighted on the basis of the proportion of the provincial animal

population relative to the national population to calculate a national emission factor for each subcategory, for each year in the time series (Table A3–18).

Equation A3–19:

$$EF_{(EF)T} = \sum_{T} GE_T \times TP_T \times Y_{mT}$$

where:

EF$_{(EF)}$T = annual emission factor for defined animal population T, kg/head/year

GE$_T$ = gross energy, MJ/day within the defined population T, kg/day

Y$_{mT}$ = methane conversion rate at which the fraction of gross energy is converted to methane by an animal within defined population T, m³/kg

TP$_T$ = time (days/year) of a stage of production with defined population T

## A3.3.3.2. Verification of Parameter Selection Against Canadian Research

The Enteric Fermentation source category has undergone a Tier 2 quality assurance / quality control (QA/QC) (MacDonald et al. 2011). In this analysis, a review and complilation of Canadian literature related to methane production from enteric fermentation was carried out.

Research measuring enteric fermentation in Canada indicates that the average measured methane conversion rates (Ym), are 6.6% (±1.2) of GE for non-dairy cattle outside of feedlots, 3.2% (±0.85) GE on feedlots and 6.6% (±2.1) for dairy cattle (McCaughey et al. 1997, 1999; Boadi and Wittenberg 2002; Boadi et al. 2002, 2004a; McGinn et al. 2004, 2008, 2009; Beauchemin and McGinn 2005, 2006; Chaves et al. 2006; Kebreab et al. 2006; Ominski et al. 2006; Odongo et al. 2007; Eugène et al. 2008; Van Haarlem et al. 2008; Beauchemin et al. 2009). These values tend to agree with the values published in the *2006 IPCC Guidelines for*

Table A3–18    CH$_4$ Emission Factors for Enteric Fermentation for Cattle from 1990 to 2009

| | EF$_{(EF)T}$ - (kg CH$_4$/head/year)[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Dairy Cows | Dairy Heifers[2] | Bulls | Beef Cows | Beef Heifers | Heifers for Slaughter | Steers | Calves |
| 1990 | 115.7 | 72.2 | 79.7 | 81.6 | 69.2 | 52.7 | 48.6 | 39.8 |
| 1991 | 116.3 | 72.2 | 82.5 | 82.4 | 69.8 | 52.9 | 48.9 | 39.8 |
| 1992 | 119.2 | 72.3 | 84.8 | 84.6 | 70.7 | 55.5 | 50.9 | 39.7 |
| 1993 | 120.3 | 72.2 | 85.4 | 85.6 | 71.1 | 56.6 | 50.5 | 39.7 |
| 1994 | 120.4 | 72.2 | 83.9 | 86.5 | 71.6 | 57.2 | 51.7 | 39.7 |
| 1995 | 121.0 | 72.1 | 86.1 | 86.1 | 71.5 | 57.1 | 51.2 | 39.7 |
| 1996 | 123.5 | 72.1 | 83.3 | 84.5 | 70.5 | 57.4 | 51.4 | 39.6 |
| 1997 | 124.1 | 72.1 | 82.2 | 85.0 | 71.3 | 58.3 | 52.2 | 39.7 |
| 1998 | 125.6 | 72.2 | 85.7 | 86.6 | 72.3 | 59.4 | 53.4 | 39.7 |
| 1999 | 120.4 | 72.2 | 87.6 | 87.8 | 73.1 | 60.3 | 54.2 | 39.6 |
| 2000 | 123.3 | 72.3 | 88.4 | 89.8 | 74.1 | 61.7 | 54.8 | 39.7 |
| 2001 | 121.9 | 72.3 | 87.8 | 90.4 | 74.6 | 61.2 | 54.7 | 39.8 |
| 2002 | 123.2 | 72.4 | 87.7 | 90.9 | 75.2 | 61.3 | 54.7 | 39.7 |
| 2003 | 122.6 | 72.4 | 87.6 | 91.0 | 75.0 | 60.8 | 54.2 | 39.5 |
| 2004 | 122.6 | 72.4 | 87.6 | 87.4 | 72.4 | 60.7 | 53.5 | 39.5 |
| 2005 | 124.2 | 72.4 | 87.6 | 87.5 | 72.1 | 60.8 | 53.5 | 39.5 |
| 2006 | 125.7 | 72.3 | 87.5 | 88.0 | 72.4 | 61.0 | 54.2 | 39.5 |
| 2007 | 125.2 | 72.4 | 87.6 | 88.1 | 72.5 | 61.2 | 54.4 | 39.5 |
| 2008 | 124.9 | 72.4 | 87.5 | 88.5 | 73.0 | 61.4 | 54.0 | 39.5 |
| 2009 | 124.6 | 72.4 | 90.0 | 87.8 | 72.6 | 61.2 | 54.1 | 39.6 |

Note:
1. Enteric mission factors are derived from Boadi et al. (2004b), modified to take into account trends in milk production in dairy cattle and carcass weights for several beef cattle categories.
2. Reported as kg/hd/yr; however, emissions are calculated based on time to slaughter.

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*National Greenhouse Gas Inventories* (IPCC 2006). From the same compilation of research, the emission factor for non-dairy cattle is observed to be 57 (±11) kg/head/year outside of feedlots and 56 kg/head/year in feedlots, and the average measured dairy cattle emission factors are 124 kg/head/year (±29).

Caution must be used in interpreting these values, as the large majority of studies focus on yearling heifers and steers, and the average value does not take into account the relative importance of different cattle subcategories on the average emission factor. Nonetheless, the emission factor values do agree, in general, with the emission factors used by Canada: non-dairy emission factors from 60 to 65 kg/head/year and dairy emission factors from 116 to 125 kg/head/year. In the Canadian cattle model, a $Y_m$ of 6% GE for non-dairy cattle outside of feedlots and dairy cattle and 4% GE for non-dairy cattle in feedlots is used, taken from the IPCC Good Practice Guidance (IPCC 2000).

As it currently stands, no evident bias could be identified from the review of Canadian literature results. It appears that any bias that is introduced through the use of the $Y_m$ values from the 2000 Good Practice Guidance is compensated for by the estimate of GE for specific animal subcategories. Though no specific bias can be clearly identified in the enteric emission estimate, improvements could be made in the cattle model by developing consistency between the measured $Y_m$ values, the estimated GE and measured emission factors.

Researchers from Canada have participated in some extensive reviews and validations of the IPCC Tier 2 enteric fermentation model comparing measured and observed emissions using Canadian data. In general, model analysis indicates that the IPCC Tier 2 model tends to underestimate high-emitting animals and overestimate low-emitting animals (Ellis et al. 2007, 2009, 2010).

This literature analysis indicates that no improvements could be made to Canadian estimates by updates of single parameters. Improving on the current model would require the development and introduction of country-specific Tier 3 calculation methodology.

### A3.3.3.3. Enteric $CH_4$ Emission Factors for Non-cattle

For non-cattle animal categories, IPCC Tier 1 emission factors are used to calculate emissions (see Annex 8).

### A3.3.4. $CH_4$ Emissions from Manure Management

The IPCC Tier 2 methodology is used to estimate $CH_4$ emission factors from manure management systems (IPCC 2000). Equation A3–20 is used to calculate $CH_4$ emissions from manure management for all categories of livestock in Canada. Sources of animal population data are the same as those used in the enteric fermentation estimates and are listed in Table A3–12.

Equation A3–20:

$$CH_{4MM} = \sum_T \left( N_T \times EF_{(MM)T} \right)$$

where:

| | | |
|---|---|---|
| $CH_{4MM}$ | = | emissions for all animal categories |
| $N_T$ | = | animal population for the Tth animal category or subcategory in each province |
| $EF_{(MM)}T$ | = | emission factor for the Tth animal category or subcategory calculated according to Equation A3–21 |

To develop Tier 2 $CH_4$ emission factors from manure management, country-specific inputs were required that take into account climate, livestock rations and the type of manure storage system. The following equation represents an IPCC Tier 2 estimate of $CH_4$ emission factors from manure management systems:

Equation A3–21:

$$EF_{(MM)T} = VS_T \times 365 \times Bo_T \times 0.67 kg \cdot m^{-3} \times \sum_{ij} MCF_{ij} \times MS_{Tij}$$

where:

| | | |
|---|---|---|
| $EF_{(MM)T}$ | = | annual emission factor for defined animal population T, kg/head-year |
| $VS_T$ | = | Daily volatile solids excreted for an animal within the defined population T, kg/day |
| $Bo_T$ | = | maximum $CH_4$ producing potential for manure produced by an animal within defined population T, $m^3$/kg VS |
| $MCF_{ij}$ | | $CH_4$ conversion factor for each manure management system i in climate region j |
| $MS_{Tij}$ | | system distribution factor, defined as the fraction of animal category T's manure that is handled using manure system i in climate region j (IPCC 2000, Equation 4.17, p. 4.34), equivalant to AWMS |

The following sections outline the sources of input values for Equation A3–21: VS, DE, ASH, $B_0$, MCF and MS.

### A3.3.4.1. Volatile Solids (VS)

**Cattle (VS)**

Volatile solids (VS) are the organic fraction of total solids in manure. The VS of manure was estimated using the IPCC methodology based on the digestible energy (DE) of dietary intake, manure ash content and gross energy (GE) consumed by a given animal category, according to Equation A3–22 (IPCC 2006).

For cattle subcategories, the GE depends on the cattle production model defined for enteric fermentation (Boadi et al. 2004b), as shown in Equation A3–18. Estimates of VS were derived for each cattle subcategory at the provincial level based on regional and seasonal stages of production. Increases in milk production in dairy cattle and carcass weight in beef cattle have increased VS and, as a result, $CH_4$ emission factors over the time series.

Equation A3–22:

$$VS = GE \times \left( \frac{1\,kg\,dm}{18.45\,MJ} \right) \times \left( 1 - \frac{DE}{100} \right) \times \left( 1 - \frac{ASH}{100} \right)$$

where:

| | | |
|---|---|---|
| VS | = | volatile solids excretion, kg/head/day |
| GE | = | gross energy consumed by a given animal, MJ/head/day |
| DE | = | digestible energy of the ration, % |
| dm | = | dry matter, part of conversion factor from energy to weight where 1 kg of dry matter represents 18.45 MJ of energy. |
| ASH | = | ash content of the manure, % |

**Non-Cattle (VS)**

Volatile solids for animal categories other than cattle were calculated by Marinier et al. (2004) using a stochastic approach, taking into account the variability in the values of DMI, DE and ASH derived from expert opinion surveys. The values for DMI, DE and ASH taken from that survey were used to calculate VS for non-cattle livestock categories for each individual province. A Monte Carlo simulation of Equation A3–23 was performed using Crystal Ball® (Decisioneering 2000), resulting in a mean value of VS and a probability distribution based on the variance in expert opinion and scientific literature (Table A3–19).

Equation A3–23:

$$VS = DMI \times \left( 1 - \frac{DE}{100} \right) \times \left( 1 - \frac{ASH}{100} \right)$$

where:

| | | |
|---|---|---|
| VS | = | volatile solids excretion, kg/head/day |
| DMI | = | dry matter intake kg/head/day |
| DE | = | digestible energy of the ration, % |
| ASH | | ash content of the manure, % |

Table A3–19  Mean Volatile Solids in Manure of Non-cattle Animal Categories and Associated 95% Confidence Interval, Expressed as a Percentage of the Mean

| Animal Category | Mean Volatile Solids (kg/head/day) | 95% Confidence Interval (%) |
|---|---|---|
| Sheep and Lambs[1] | 0.55 | 31 |
| Mature Horses | 3.2 | 16 |
| Swine | 0.23 | 50 |
| Goats | 0.64 | 41 |
| Poultry | 0.022 | 20 |

Note:
1. Llamas and alpacas are given the same values as sheep and lambs, whereas buffalo are treated as non-dairy cattle.

The following sections outline the data sources for estimating VS developed by Marinier et al. (2004).

**Digestible Energy (DE) and Dry Matter Intake (DMI)**

The sources of information used for DE for both dairy and non-dairy cattle are detailed in sections A3.3.2.1 and A3.3.2.2 respectively.

Broad regional differences in ration composition were identified for sheep, horses and swine. Regional differences were not considered for goats or poultry, since these data were not available.

Generally, rations for grazing livestock consist of roughage and grains. Diet digestibility will vary, with grains having a higher digestibility than roughage. The distribution of grain-based and roughage-based diets was estimated for sheep and horses in each province. A weighted estimate of DE was calculated using the known approximate DE for grains and roughage for each animal type and the distribution of grain and roughage usage by province (Table A3–20). This method does not, however, account for

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Table A3–20    Approximate Digestible Energy (DE) for Selected Livestock Subcategories and Data Sources[1]

| Animal Category | DE (%) | Data Sources[1] |
|---|---|---|
| Goat | 65 | W. Whitmore, Manitoba Agriculture and Food |
| Laying Hen | 80 | S. Leeson, University of Guelph; D. Korver, University of Alberta |
| Chicken | 80 | S. Leeson, University of Guelph; D. Korver, University of Alberta |
| Turkey | 78 | S. Leeson, University of Guelph |
| Swine | 87 | C.F. deLange, University of Guelph |
| **Feeding on Grain Diet** | | |
| Sheep | 74 | Weston (2002) |
| Horse | 70 | L. Warren, Colorado State University |
| **Feeding on Roughage Diet** | | |
| Sheep | 65 | W. Whitmore, Manitoba Agriculture and Food |
| Horse | 60 | L. Warren, Colorado State University |

Note:
1.    Data sources: Expert consultations (Marinier et al. 2004).

Table A3–21    Dry Matter Intake for Selected Livestock

| Animal Category | DMI (kg/head/day) | Data Sources[2] |
|---|---|---|
| Sheep and Lamb | | |
| Ewes | 1.2–2.8 | NRC (1985) |
| Rams | 2.1–3.0 | W. Whitmore, Manitoba Agriculture and Food |
| Replacement Lambs | 1.2–1.5 | NRC (1985) |
| Market Lambs | 1.3–1.6 | NRC (1985) |
| **Horses** | | |
| Mature Idle Horses | 7.4–11 | NRC (1989); L. Warren, Colorado State University |
| Mature Working Horses | 7.4–13.7 | NRC (1989); L. Warren, Colorado State University |
| **Weanlings** | 3.6–6.3 | NRC (1989) |
| Swine | | |
| Starters (5–20 kg) | 0.55–0.72 | C. Wagner-Riddle, University of Guelph |
| Growers (20–60 kg) | 1.4–2.1 | J. Patience, Prairie Swine Centre |
| Finishers (60–110 kg) | 2.1–3.3 [1] | M. Nyachoti, University of Manitoba; C. Pomar, Agriculture and Agri-Food Canada |
| Sows | 2.28 | C. Wagner-Riddle, University of Guelph |
| Boars | 2.0–2.5 | M. Nyachoti, University of Manitoba; NRC (1998) |
| Goats | | |
| Does | 1.2–2.8 | NRC (1981) |
| Bucks | 1.4–2.3 | CRAAQ (1999) |
| Kids | 1.4 | CRAAQ (1999) |
| Poultry | | |
| Laying Hens | 0.072–0.11 | S. Leeson, University of Guelph; D. Korver, University of Alberta |
| Broilers | 0.085–0.088 | S. Leeson, University of Guelph; D. Korver, University of Alberta |
| Turkeys | 0.023–0.53 | Hybrid (2001) |

Note:
1.    Calculated as 3.5% of body weight.

2.    Data sources: Expert consultations (Marinier et al. 2004).

Table A3–22 Manure Ash Content for Selected Livestock and Data Sources

| Animal Category | ASH (%) | Data Sources |
|---|---|---|
| Cattle | 8 | IPCC (2000) |
| Sheep | 8 | IPCC (2000) |
| Goat | 8 | IPCC (2000) |
| Horse | 4 | IPCC (2000) |
| Laying Hen | 10 | Marinier et al. (2004) |
| **Chicken** | 7 | Marinier et al. (2004) |
| Turkey | 5 | Marinier et al. (2004) |
| Swine | 5 | Marinier et al. (2004) |

additives that may increase or decrease digestibility. The DMI for non-cattle was determined through consultation with experts and published values (Table A3–21).

### Manure Ash Content (ASH)

The ash content in the manure is the inorganic portion of the manure. Table A3–22 contains the values used in this inventory for ash content in volatile solid calculations and their sources.

### A3.3.4.2. Maximum $CH_4$ Producing Potential ($B_0$)

The $B_0$ is defined as the maximum volume of $CH_4$ that can be produced from 1 kg of VS loaded into a manure management system and is expressed in $m^3$/kg VS loaded. Because it is a measure of the maximum $CH_4$ production, $B_0$ is not affected by the temperature at which manure is stored (Hashimoto et al. 1981). Factors that affect $B_0$ include diet, age of manure, amount of foreign material and species. The B0 was determined from several studies examining anaerobic digestion (Hashimoto et al. 1981; Safely et al. 1992). Swine manure has the highest $CH_4$ producing potential, followed by poultry, beef cattle and dairy cattle. The values published in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) were used for all animals. For buffalo, non-dairy cattle values were used.

### A3.3.4.3. Methane Conversion Factor (MCF)

The MCF describes the proportion of $B_0$ that is attained, depending on the storage system and climate region. The values published in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* were used for all animals.

### A3.3.4.4. Manure System Distribution Factor (MS)

The MS factor is the proportional distribution of AWMS of a livestock category within a given area. There is little reliable information published on the distribution of manure management systems in Canada. A survey of experts in manure management and animal production was conducted in 2003–2004 as part of the Tier 2 study by Marinier et al. (2004); national averages of results are summarized in Table A3–23. Briefly, among the dominant animal production categories across the country, swine manure is mainly handled as liquid manure, while poultry manure is stored as solid manure. On average, dairy cattle manure storage is evenly distributed among solid and liquid forms, with roughly 20% being deposited on pastures; however in certain provinces, the proportion of dairy manure handled as liquid can be as high as 89% (British Columbia), and as low as 20% (Manitoba and Prince Edward Island). Beef cattle manure is equally distributed between solid storage and deposition on pastures, with the exception of British Columbia and Manitoba, where the majority of manure is deposited in pastures.

No specific data were available for covered lagoons and biodigesters; they are assumed to be part of other systems.

### A3.3.4.5. Cattle Manure Management $CH_4$ Emission Factors

Cattle emission factors developed to calculate $CH_4$ emissions from manure management vary by animal subcategory and over time (Table A3–24). As VS was calculated based on the GE derived from the enteric fermentation cattle production model, an emission factor time series was derived for cattle to reflect i) the increase in milk productivity of dairy cows, and ii) the increase in live weight

of non-dairy cattle as explained in sections A3.3.2.1 and A3.3.2.2, respectively. Emission factors are highest from dairy cattle, reflecting their high rates of confinement, high proportions of liquid manure management systems and high dietary intake for sustained milk production. Beef cattle emission factors are lower, reflecting their lower rates of confinement, lower GE and the fact that the majority of manure is managed in a solid form with a low MCF.

### A3.3.4.6. Non-Cattle Manure Management $CH_4$ Emission Factors

Manure management emission factors for non-cattle animals vary by animal subcategory but are constant over time Table A3–25). For the largest non-cattle animal categories—swine, sheep and poultry—growth stages for animals are taken into account. The emission factor calculations use VS derived from Marinier et al. (2004). However, emission factors were recalculated to incorporate the latest scientific information available on $B_o$ and MCF taken

Table A3–23   Percentage of Manure Handled by Animal Waste Management Systems (AWMS) for Canada (Marinier et al. 2004), Presented as National Averages

| Animal Category | Liquid Systems (NL) | Solid Storage and Drylot (NSSD) | Pasture, Range and Paddock (NPRP) | Other Systems (NO) |
|---|---|---|---|---|
| Non-dairy Cattle | 1 | 48 | 47 | 4 |
| Dairy Cattle | 39 | 43 | 18 | 0 |
| Poultry | 10 | 89 | 1 | 0 |
| Sheep and Lamb | 0 | 32 | 68 | 0 |
| Llamas and Alpacas1 | 0 | 32 | 68 | 0 |
| **Swine** | 96 | 3 | 0 | 1 |
| Goat | 0 | 42 | 58 | 0 |
| Horse | 0 | 26 | 74 | 0 |
| Buffalo | 1 | 48 | 47 | 4 |

Table A3–24   Emission Factors to Estimate $CH_4$ Emissions from Manure Management for Cattle Subcategories from 1990 to 2009[1]

| Year | Dairy Cows | Dairy Heifers[1] | Bulls | Beef | Beef Heifers | Heifers for Slaughter | Steers | Calves |
|---|---|---|---|---|---|---|---|---|
| 1990 | 24.4 | 18.2 | 3.2 | 3.1 | 2.6 | 1.6 | 1.5 | 1.5 |
| 1991 | 24.6 | 18.3 | 3.3 | 3.2 | 2.6 | 1.6 | 1.5 | 1.5 |
| 1992 | 25.3 | 18.4 | 3.4 | 3.2 | 2.6 | 1.7 | 1.5 | 1.5 |
| 1993 | 25.7 | 18.4 | 3.4 | 3.3 | 2.7 | 1.7 | 1.5 | 1.5 |
| 1994 | 25.8 | 18.4 | 3.3 | 3.3 | 2.6 | 1.7 | 1.6 | 1.5 |
| 1995 | 26.0 | 18.3 | 3.4 | 3.3 | 2.6 | 1.7 | 1.5 | 1.5 |
| 1996 | 26.5 | 18.3 | 3.3 | 3.2 | 2.6 | 1.7 | 1.5 | 1.5 |
| 1997 | 26.7 | 18.2 | 3.2 | 3.2 | 2.6 | 1.7 | 1.6 | 1.5 |
| 1998 | 26.8 | 18.3 | 3.3 | 3.3 | 2.6 | 1.7 | 1.6 | 1.5 |
| 1999 | 25.6 | 18.6 | 3.4 | 3.3 | 2.6 | 1.7 | 1.6 | 1.5 |
| 2000 | 26.4 | 18.8 | 3.4 | 3.4 | 2.7 | 1.8 | 1.6 | 1.5 |
| 2001 | 26.2 | 18.8 | 3.3 | 3.4 | 2.7 | 1.8 | 1.6 | 1.5 |
| 2002 | 26.6 | 18.8 | 3.3 | 3.4 | 2.7 | 1.8 | 1.6 | 1.5 |
| 2003 | 26.6 | 18.9 | 3.3 | 3.4 | 2.7 | 1.8 | 1.6 | 1.5 |
| 2004 | 26.6 | 18.8 | 3.3 | 3.3 | 2.6 | 1.8 | 1.6 | 1.5 |
| 2005 | 26.9 | 18.7 | 3.3 | 3.3 | 2.5 | 1.8 | 1.6 | 1.5 |
| 2006 | 27.2 | 18.6 | 3.3 | 3.3 | 2.5 | 1.8 | 1.6 | 1.5 |
| 2007 | 27.0 | 18.8 | 3.3 | 3.3 | 2.5 | 1.8 | 1.6 | 1.5 |
| 2008 | 27.0 | 19.0 | 3.3 | 3.3 | 2.6 | 1.8 | 1.6 | 1.5 |
| 2009 | 27.1 | 19.1 | 3.4 | 3.3 | 2.6 | 1.8 | 1.6 | 1.5 |

Note:

1. For dairy heifers, emission factors were estimated using $B_o$, MCF and manure management systems for dairy cows.

from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). The largest emission factors are from swine, varying between 1.8 and 7.9 kg/head/year depending on growth stage, due to the high percentage of manure that is stored in liquid form. Emission factors for other minor categories tend to be low due to the large portion of manure that is either deposited on pasture, range or paddock or in solid form in pens and holding yards. Buffalo manure management emission factors are equal to the non-dairy emission factors for each individual province.

## A3.3.4.7.  Verification of Parameter Selection Against Canadian Research

The Manure Management source category is also a part of a Tier 2 QA/QC for the Agriculture Sector (MacDonald et al. 2011) including a review and compilation of Canadian literature related to methane production from enteric fermentation.

Table A3–25   $CH_4$ Emission Factors for Manure Management for Non-Cattle

| Non-cattle Animal Categories | Manure Management Emission Factors EF(MM) (kg CH4/head/year) |
|---|---|
| **Pigs** | |
| Boars | 6.4 |
| Sows | 6.3 |
| Pigs < 20 kg | 1.8 |
| Pigs 20–60 kg | 5.1 |
| Pigs > 60 kg | 7.9 |
| **Other Livestock** | |
| Sheep | 0.3 |
| Lambs | 0.2 |
| Goats | 0.3 |
| Horses | 2.3 |
| Buffalo | 2.3-3.2 |
| **Poultry** | |
| Chickens | 0.03 |
| Hens | 0.03 |
| Turkeys | 0.08 |

There not many studies that have measured emissions from manure storage and quantified the emission characteristics of manure in Canada. Observed values are highly variable, as are measurement techniques. This makes

comparison of specific Tier 2 parameters extremely difficult. When the liquid storage MCF is estimated from *in situ* measurements it varies from greater than 100% to as low as 14% in the case of swine and from 4% to 62% for dairy with no mitigation measures in place (Kaharabata et al. 1998; Massé et al. 2003, 2008; Wagner-Riddle et al., 2006; Laguë et al. 2005; Park et al. 2006, 2010; VanderZaag et al. 2009, 2010). Some studies exist in Canada on emissions from solid manures and other storage methods (composting) (Pattey et al. 2003; Xu et al. 2007; Hao et al. 2001b, 2007, 2008, 2009, 2010a, 2010b). As was the case with liquid manure systems, variability in emissions and methodology make comparisons to IPCC parameters difficult.

A recent article with a small sample from eastern Canadian farms suggested that the B0 values for swine, beef and dairy cattle were consistent with IPCC (2006) values, at 0.47–0.42, 0.21–0.19 and 0.35–0.30, respectively (Godbout et al. 2010). Quantities of volatile solids stored in the manure management systems for different animal categories tend to be consistent with quantities estimated in inventory calculations; therefore the variability observed in studies is likely linked to a combination of differences in measurement methodology, variability in manure characteristics ($B_0$) and in a number of physical and biochemical factors for each experimental situation that are not taken into account in the IPCC Tier 2 model. These factors include temperature, manure composition, storage dimension, storage duration and storage cleaning procedures—all of which may influence emissions from manure storage (Pattey et al. 2003; Laguë et al. 2005; Park et al. 2006, 2010; Wagner-Riddle et al. 2006; Massé et al. 2008; VanderZaag et al. 2009, 2010). Furthermore, these factors are not controlled in research, making comparisons even more difficult. More standardized factorial research focused on understanding of the relative weight of factors that influence emissions from manure storage is required in order to refine emission estimate methodology.

Based on current research results, no specific bias can be determined in manure management results, as there is no clear standard to evaluate whether IPCC parameters are appropriate for estimating emissions from manure management systems.

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## A3.3.5.  N₂O Emissions from Manure Management

During the storage and handling of animal manure, $N_2O$ emissions can occur. Emissions of $N_2O$ from manure management systems result from mineralization of organic materials, nitrification and denitrification of mineral nitrogen. Three factors are required to estimate $N_2O$ emissions from manure management systems using the IPCC Tier 1 methodology: 1) N excretion rates for various animal types and categories; 2) types of AWMS; and 3) emission factors associated with each manure management system (Equation A3–24).

Equation A3–24:

$$N_2O_{AWMS} = \sum_i \sum_{AWMS,\, T} \left( N_T \times N_{i,\, AWMS} \times N_{EX,\, T} \times EF_{AWMS} \right) \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_{AWMS}$ | = | $N_2O$ emissions for all AWMS and provinces, excluding manure N on pasture, range and paddock, kg $N_2O$/yr |
| NT | = | population for the Tth animal category or subcategory in province i (see Section A3.3) |
| $N_{AWMS}$ | = | percentage of N handled by each AWMS in province i, fraction (see Table A3–23) |
| NEX,T | | N excretion rate for the Tth animal category or subcategory (see Table A3–27 for non cattle and Table A3–26 for cattle), kg N/head/year |
| EFAWMS | | $N_2O$ emission factors from manure management for each specific AWMS (see Annex 8), kg $N_2O$-N/kg N |
| 44/28 | | coefficient converting $N_2O$-N to $N_2O$, kg $N_2O$ /kg $N_2O$-N |

Table A3–23 summarizes the distribution of manure management systems in Canada by animal category. Emissions of $N_2O$ from manure on pasture, range and paddock systems are not included under Manure Management, as they are reported under the category of Agricultural Soils, Section A3.3.6.2. Animal population data are detailed in Section A3.3.1.

### A3.3.5.1.  Nitrogen Excretion Rates for Various Domestic Animals

Manure N excretion from cattle varies by animal subcategory, and also over the time series, due to the increase in animal weight. Annual live weights (see Section A3.3.2) were multiplied by the IPCC default N excretion rate (IPCC

2006) to produce a time series of manure N excretion rates (Table A3–26). Annual manure N excretion rates from non-cattle domestic animals, according to IPCC Tier 1 default values, vary by livestock category. Poultry have high excretion rates (Table A3–27), while horses and buffalo have the lowest excretion rates; however, on a per-head basis, buffalo are the largest N excretors in the non-cattle category. In the case of cattle, dairy cows have very high excretion factors due to the protein requirements of sustained milk production.

### A3.3.5.2.  Emission Factors Associated with AWMS

The type of AWMS has a significant impact on $N_2O$ emissions. Less-aerated systems such as liquid systems generate little $N_2O$, whereas drylots or manure on pasture and paddock produce more. However, there is little scientific information in Canada specifying amounts of $N_2O$ emissions associated with manure management systems. Therefore, IPCC default emission factors, as listed in Annex 8, were used to estimate emissions.

## A3.3.6.  N₂O Emissions from Agricultural Soils

Emissions of $N_2O$ from agricultural soils consist of direct and indirect emissions as well as emissions from animal manure on pasture, range and paddock. The emissions of $N_2O$ that result from anthropogenic N inputs occur through direct pathways, i.e., from the soils to which the N is added, and indirect pathways through i) volatilization of synthetic N fertilizers and manure N as $NH_3$ and $NO_x$ and subsequent deposition; and ii) leaching and runoff of N.

### A3.3.6.1.  Direct N₂O Emissions from Soils

Direct sources of emissions from agricultural soils include synthetic fertilizers, animal manure applied as fertilizers, crop residue decomposition and soil organic matter decay as affected by tillage practices, summerfallow, irrigation, and cultivation of histosols. The $N_2O$ emission factors for most of the direct emission sources are country-specific, and incorporate the influence of moisture regimes, landscape position and soil texture on rates of $N_2O$ production and emissions (Rochette et al. 2008).

Table A3–26    Time Series of Manure N Excretion Rates for Cattle (kg N/head/year)[1]

| Year | Dairy Cows | Beef Cows | Bulls | Heifers | Steers | Calves |
|------|-----------|-----------|-------|---------|--------|--------|
| 1990 | 102.6 | 57.2 | 88.0 | 47.8 | 48.4 | 26.6 |
| 1991 | 102.6 | 58.3 | 92.6 | 48.0 | 48.7 | 26.5 |
| 1992 | 102.6 | 61.6 | 96.8 | 50.7 | 53.9 | 26.5 |
| 1993 | 102.6 | 62.9 | 98.0 | 51.3 | 54.1 | 26.5 |
| 1994 | 102.6 | 64.1 | 95.2 | 52.1 | 56.5 | 26.5 |
| 1995 | 102.6 | 63.7 | 98.8 | 52.1 | 56.9 | 26.5 |
| 1996 | 102.6 | 61.7 | 94.2 | 51.3 | 56.2 | 26.5 |
| 1997 | 102.6 | 62.3 | 92.2 | 52.2 | 56.8 | 26.5 |
| 1998 | 102.6 | 64.7 | 98.1 | 54.0 | 58.7 | 26.5 |
| 1999 | 102.6 | 66.4 | 101.3 | 54.9 | 59.1 | 26.5 |
| 2000 | 102.6 | 69.4 | 102.9 | 57.3 | 60.4 | 26.5 |
| 2001 | 102.6 | 70.5 | 101.7 | 57.0 | 61.0 | 26.5 |
| 2002 | 102.6 | 71.4 | 101.6 | 57.6 | 61.6 | 26.5 |
| 2003 | 102.6 | 71.7 | 101.9 | 57.6 | 61.9 | 26.5 |
| 2004 | 102.6 | 66.9 | 101.9 | 56.5 | 61.7 | 26.5 |
| 2005 | 102.6 | 67.2 | 101.9 | 56.4 | 61.2 | 26.5 |
| 2006 | 102.6 | 68.0 | 102.0 | 57.0 | 62.2 | 26.5 |
| 2007 | 102.6 | 68.2 | 101.9 | 57.4 | 62.3 | 26.5 |
| 2008 | 102.6 | 68.8 | 101.9 | 57.6 | 62.4 | 26.5 |
| 2009 | 102.6 | 67.8 | 106.6 | 57.3 | 62.5 | 26.5 |

Note:

1. N excretion rate for dairy cattle is 0.44 kg N/1000 kg/day (IPCC 2006 Table 10.10); N excretion rate for other cattle is 0.31 kg N/1000 kg/day (IPCC 2006 Table 10.10). Data source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land

Table A3–27    Manure N Excretion Rates for Non-cattle

| Animal Categories | N Excretion Rate[1] (kg N/1000 kg/day) | Average Body Weight[2] (kg) | Annual Manure N (kg N/head/year) |
|-------------------|----------------------------------------|------------------------------|-----------------------------------|
| Swine | 0.5 | 61 | 11.1 |
| Sheep | 0.42 | 27 | 4.1 |
| Lambs | 0.42 | 27 | 4.1 |
| Goats | 0.45 | 64 | 10.5 |
| Horses | 0.3 | 450 | 49.3 |
| Llamas and Alpacas | 0.42 | 112 | 17.2 |
| Buffalo | 0.32 | 510 | 59.5 |
| Hens | 0.83 | 1.8 | 0.5 |
| Broilers | 1.1 | 0.9 | 0.4 |
| Turkeys | 0.74 | 6.8 | 1.8 |

Notes:
1. Data source: IPCC (2006).
2. For Buffalo, average live weight was assumed to be the same as Steers and varied from year to year.

The approach involves determining base emission factors "$EF_{BASE}$" for each of 449 ecodistricts,[6] using long-term precipitation and potential evapotranspiration. The $EF_{BASE}$ is subsequently modified to reflect site-specific practices and conditions. Data on long-term climate normals and topographic characteristics are used to develop an $EF_{BASE}$ (Equation A3–25).

6    "Ecodistrict" represents one level within Canada's National Ecological Framework. The country includes 1027 ecodistricts, characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies and fauna.

Equation A3–25:

$$EF_{BASE} = EF_{CT, P/PE = 1} \times F_{TOPO} + EF_{CT} \times (1 - F_{TOPO})$$

where:

| | | |
|---|---|---|
| $EF_{CT}$ | = | emission factor, estimated at actual P/PE accounting for moisture regime and topography in an ecodistrict, kg $N_2$O-N/kg N (see Figure A3–2) |
| $EF_{CT, P/PE}$ | = | emission factor of 0.017 estimated at P/PE = 1, kg $N_2$O-N/kg N applied |
| $F_{TOPO}$ | = | fraction of the ecodistrict area in the lower section of the toposequence See Rochette et al. (2008) |
| P | = | long-term mean growing season precipitation from May to October in an ecodistrict, mm |
| PE | | long-term mean potential evapotranspiration from May to October, mm |

## Base $N_2$O Emission Factor ($EF_{BASE}$)

Nitrous oxide is mostly produced during denitrification and, therefore, is greatly influenced by soil oxygen status. Accordingly, in moisture-limited conditions, $N_2$O emission factors have been shown to increase with increased rainfall (Dobbie et al. 1999), and climate-variable emission factors have been used in estimating soil $N_2$O inventory (Flynn et al. 2005). Similarly, this methodology estimates emission factors including winter and spring thaw emissions at the ecodistrict level as a function of the ratio of the long-term normals of precipitation over potential evapotranspiration (P/PE) from May to October (Figure A3–2). The $EF_{BASE}$ factors were determined using the same approach as for the determination of the IPCC Tier 1 emission factor by Bouwman (1996), i.e., $EF_{BASE}$ = slope of the "$N_2$O emissions versus N fertilizer rate" relationship. The $EF_{BASE}$ was estimated for the three regions where field $N_2$O measurements are available: Quebec–Ontario; the Brown and Dark Brown soil zones of the Prairies; and the Grey and Black soil zones of the Prairies. The soil $N_2$O emissions versus fertilizer N relationship determined for the Quebec–Ontario region has a similar slope (0.012 kg $N_2$O-N/kg N) (Gregorich et al. 2005) and fit ($r^2 = 0.43$) as the IPCC Tier 1 default emission factor derived by Bouwman (1996) using global data. In the Prairie region, low and variable $N_2$O emissions were measured across the range of N fertilizer rates (Brown and Dark Brown soils = 0.0016 kg $N_2$O-N/kg N; Grey and Black soils = 0.008 kg $N_2$O-N/kg N). These observations suggest that soil $N_2$O production in the Prairie region is not limited by mineral N availability but rather by the low denitrifica-

tion activity under well-aerated soil conditions. Despite the uncertainty in the determination of emission factors in the Prairie region, this approach is deemed a valid option to account for the influence of moisture limitations on $N_2$O emissions in that region.

To account for a topographical effect, an $EF_{BASE}$ of 0.017 kg $N_2$O-N/kg N applied ($EF_{BASE}$ at P/PE = 1) was used for the lower sections of the landscapes. The fraction of the landscape to which this condition was applied differs among landscape types. Landscape segmentation data were incorporated into the calculation of the national $N_2$O emission estimates, based upon the observations that $N_2$O emissions are greater in lower sections of the landscape, where intermittently saturated soil conditions are favourable to denitrification (Corre et al. 1996, 1999; Pennock and Corre 2001; Izaurralde et al. 2004). The fraction of the landscape occupied by such lower sections ($F_{TOPO}$) was applied to concave portions of the landscape (i.e. lower and depressional landscape positions) where soils are likely to be saturated for significant periods of time on a regular basis and soils are imperfectly and poorly drained with mottles[7] within 50 cm of the land surface. MacMillan and Pettapiece (2000) used digital elevation models to characterize the areal extent of upper, mid, lower and depressional portions of the landscape and their associated characteristics (slope and length). Their results were used to determine the proportional distribution of different landforms (such as lower sections) in the Soil Landscapes of Canada (SLC), which was the basis for determining the proportion of the landscape to which $F_{TOPO}$ would be applied to derive $N_2$O emission estimates (Rochette et al. 2008).

### $N_2$O Emissions during Winter and Spring Thaw

Field measurements of $N_2$O flux using chambers in Eastern Canada are usually made during the snow-free period (Gregorich et al. 2005). Average annual snowfall in eastern Canada varies between 1.0 and 4.5 m (Environment Canada 2002). Snowmelt water in the spring creates wet soil conditions that often stimulate $N_2$O production (Grant and Pattey 1999; Wagner-Riddle and Thurtel 1998). The intensity of soil freezing was also found to influence spring thaw emissions (Wagner-Riddle et al. 2007). Limiting emission estimates to the snow-free period therefore underestimates total annual N2O emissions in that region. Rochette et al. (2008) reported mean $N_2$O emissions during

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7    Mottles are the product of intermittent oxidation/reduction cycles of (generally) iron present in the soil profile. Prevalence, size and colour of mottles are indicative of the soil materials being intermittently saturated for significant periods of time.

Figure A3–2   $EF_{CT}$ as a Function of Long-term Ratio of Precipitation over Potential Evapotranspiration (P/PE) from 1971 to 2000
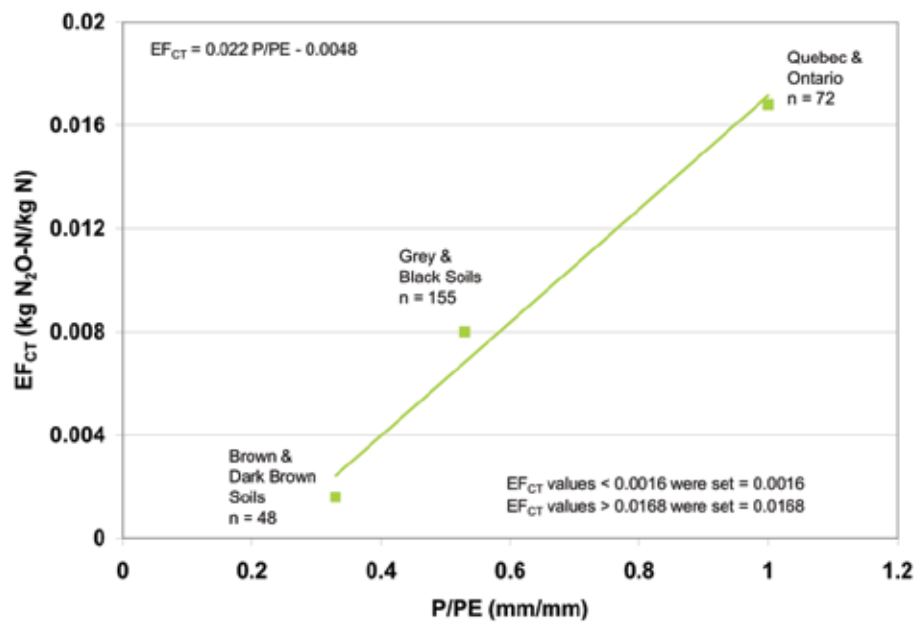


the winter and spring thaws in southern Ontario to be 1.2 kg $N_2O$-N/ha (Wagner-Riddle et al. 2007; Wagner-Riddle and Thurtell 1998); these emissions were included in the relationship between $EF_{CT}$ and P/PE shown in Figure A3–2.

Emissions of $N_2O$ during spring thaw also occur on the Prairies but are usually lower than in eastern Canada (Lemke et al. 1999). Chamber flux measurements used to estimate $EF_{CT}$ on the Prairies include spring thaw emissions, because low snow accumulation in that region allows chamber deployments during that period. Therefore, no adjustment to the $EF_{CT}$ for the spring thaw emissions is required on the Prairies.

There are 958 weather stations in the AAFC-archived weather database.[8] These stations (80°00'N–41°55'N, 139°08W–52°40W) across Canada (758 stations) and the United States (200 stations) were used to interpolate monthly precipitation and potential evapotranspiration from May to October from 1971 to 2000 to the ecodistrict centroids. AAFC-archived weather data were provided by the Meteorological Service of Canada, Environment Canada.

## Soil Texture and $N_2O$ Emissions

Soil texture does not directly influence $N_2O$ production in soils. However, it correlates with several physical and chemical parameters that control $N_2O$ production and transport in the soil profile (Arrouays et al. 2006; da Sylva and Kay 1997; Minasny et al. 1999). Consequently, soil texture-related variables often correlate with $N_2O$ emissions from agricultural soils (Hénault et al. 1998; Corre et al. 1999; Chadwick et al. 1999; Bouwman et al. 2002; Freibauer 2003).

The impact of soil texture on $N_2O$ emissions from agricultural soils was incorporated in the emission factor using a ratio factor ($RF_{TEXTURE}$) defined as the ratio of $N_2O$ emissions on soils of a given textural class to the mean emissions from soils of all textures (Equation A3–26). A value of 0.8 was assigned to the $RF_{TEXTURE-COARSE}$ and $RF_{TEXTURE-MEDIUM}$ and 1.2 for $RF_{TEXTURE-FINE}$ (Rochette et al. 2008). $RF_{TEXTURE}$ could not be estimated in regions other than Quebec, Ontario and the Atlantic provinces. Assuming a low influence of soil texture on $N_2O$ emissions ($RF_{TEXTURE}$ =1) is likely justified under dry climates such as in the Prairie region, where low soil water content results in low $N_2O$ emissions, regardless of the soil texture.

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8   Gameda, S. Personal communication, Agriculture and Agri-Food Canada (2006).

**Equation A3–26:**

$$RF_{TEXTURE,i} = (RF_{TEXTURE-FINE, i} \times FRAC_{TEXTURE-FINE, i})$$
$$+ (RF_{TEXTURE-COARSE, i} \times FRAC_{TEXTURE-COARSE, i})$$
$$+ (RF_{TEXTURE-MEDIUM,i} \times FRAC_{TEXTURE-MEDIUM, i})$$

where:

| | | |
|---|---|---|
| $RF_{TEXTURE,i}$ | = | a weighted soil texture ratio factor of $N_2O$ for an ecodistrict i for Ontario, Quebec and the Atlantic provinces |
| $RF_{TEXTURE-FINE, i}$ | = | a ratio factor of $N_2O$ for fine-textured soils for an ecodistrict i |
| $FRAC_{TEXTURE-FINE, i}$ | = | fraction of fine-textured soils in an ecodistrict i |
| $RF_{TEXTURE-COARSE, i}$ | | a ratio factor of $N_2O$ for coarse-textured soils for an ecodistrict i |
| $FRAC_{TEXTURE-COARSE, i}$ | | fraction of coarse-textured soils in an ecodistrict i |
| $RF_{TEXTURE-MEDIUM, i}$ | | a ratio factor of $N_2O$ for medium-textured soils for an ecodistrict i |
| $FRAC_{TEXTURE-MEDIUM, i}$ | | fraction of medium-textured soils in an ecodistrict i |

## Manure Applied as Fertilizer

Emissions of $N_2O$ from manure N applied as fertilizers include $N_2O$ produced from the application of manure from drylot and solid storage, liquid and other waste management systems on agricultural soils. A country-specific Tier 2 methodology is used for estimating $N_2O$ emissions from manure N applied as fertilizers. The methodology is based on the quantity of manure N produced by domestic animals (see Section A3.3.5) and country-specific $EF_{BASE}$ taking into account moisture regime and topographic conditions at the ecodistrict level. Estimates of $N_2O$ emissions from this source are calculated using Equation A3–27.

**Equation A3–27:**

$$N_2O_{MAN} = \sum_i (N_{MAN, CROPS, i} \times EF_{BASE, i} \times RF_{TEXTURE, i}) \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_{MAN}$ | = | emissions from manure N applied to cropland as fertilizers, kg $N_2O$/year |
| $N_{MAN,CROPS,i}$ | = | total amount of manure N applied as fertilizers to cropland in ecodistrict i, kg N/year (see Equation A3–28) |
| $EF_{BASE,i}$ | = | a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg $N_2O$-N/kg N-year |
| $RF_{TEXTURE,i}$ | | soil texture $N_2O$ ratio factor for ecodistrict i |
| 44/28 | | coefficient converting $N_2O$-N to $N_2O$, kg $N_2O$ /kg $N_2O$ -N |

**Equation A3–28:**

$$N_{MAN, CROPS, i} = \sum_i (N_T \times N_{EX, T}) \times (1 - N_{PRP, T}) \times (1 - FRAC_{LossMS,T})$$

where:

| | | |
|---|---|---|
| $N_{MAN,CROPS,i}$ | = | animal manure applied as N fertilizers on cropland in ecodistrict i, kg N/year |
| $N_T$ | = | population for animal category or subcategory T, heads |
| $N_{EX,T}$ | = | N excretion rate for animal category or subcategory T, kg N/head/year |
| $N_{PRP,T}$ | | fraction of manure N on pasture, range and paddock for each animal category or subcategory T in ecodistrict i (see Table A3–23) |
| $FRAC_{(LossMS,T)}$ | | fraction of total losses of manure N for each animal category or subcategory T excluding pasture, range and paddock in ecodistrict i (Table A3–17) |

Animal population data sources and population accounts are detailed in Section A3.3.1 Annual livestock population data from each animal category or subcategory at the provincial level are disaggregated into ecodistricts based on the *Census of Agriculture*. Between two consective census years, livestock population at the ecodistict level is interpolated.

## Synthetic Nitrogen Fertilizers

The method for estimating $N_2O$ emissions from synthetic N fertilizer application on agricultural soils takes into account moisture regimes and topographic conditions. Equation A3–29 is used to estimate $N_2O$ emissions by ecodistrict. Emission estimates at the provincial and national scales are obtained by aggregating estimates at the ecodistrict level.

**Equation A3–29:**

$$N_2O_{SFN} = \sum_i (N_{FERT, i} \times EF_{BASE, i} \times RF_{TEXTURE, i}) \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_{SFN}$ | = | emissions from synthetic N fertilizers, kg $N_2O$/year |
| $N_{FERT,i}$ | = | total synthetic fertilizer consumption in ecodistrict i, kg N/year; $N_{FERT}$ at an ecodistrict level is estimated using Equation A3–33 |
| $EF_{BASE,i}$ | = | a weighted average of emission factors at ecodistrict i, taking into account moisture regimes and topographic conditions, kg $N_2O$-N/kg N-year |
| $RF_{TEXTURE,i}$ | = | soil texture $N_2O$ ratio factor for ecodistrict i |
| 44/28 | = | coefficient converting $N_2O$-N to $N_2O$, kg $N_2O$ /kg N2O -N |

Table A3–28   Total N, NH$_3$-N and NO$_x$-N Losses Associated with Various Livestock and Manure Management Systems[1]

| Animal Categories | Manure Management Systems | FRAC$_{(LossMS)}$ (%)[1] | NH$_3$-N and NO$_x$-N Loss (%)[1,2] (FRAC$_{GASM}$) |
|---|---|---|---|
| Dairy Cow | Liquid | 40 (15–45) | 40 (15–45) |
| | Solid Storage | 35 (10–55) | 25 (10–40) |
| | Pasture and Range | | 20 (5–50) |
| Non-dairy Cattle | Liquid | 40 (15–45) | 40 (15–45) |
| | Solid Storage | 40 (20–50) | 30 (20–50) |
| | Pasture and Range | | 20 (5–50) |
| Swine | Liquid | 48 (15–60) | 48 (15–60) |
| | Solid Storage | 50 (20–70) | 45 (10–65) |
| Sheep, Lamb, Llamas and Alpacas | Solid Storage | 15 (5–20) | 12 (5–20) |
| | Pasture and Range | | |
| Goat and Horse | Solid Storage | 15 (5–20) | 12 (5–20) |
| | Pasture and Range | | 20 (5–50) |
| Poultry | Liquid | 50 | 50 |
| | Solid Storage | 53 (20–80) | 48 (10–60) |
| | Pasture and Range | | 20 (5–50) |

Notes:
1.  Numbers in parentheses indicate a range.
2.  Data sources: Hutchings et al. (2001); U.S. EPA (2004); Rotz (2004).

Data for synthetic N fertilizer sales are available by province only and were disaggregated to the ecodistrict level. The approach was based on the assumption that the amount of synthetic N fertilizers applied (N$_{APPLD}$) is equal to the difference between recommended N rates (N$_{RCMD}$) and manure N available for application on cropland (N$_{MAN-AV,CROPS}$).

Equation A3–30:

$$N_{APPLDP, i} = N_{RCMD, i} - N_{MAN-AV, CROPS,i}$$

where:

N$_{APPLDP,i}$ = total N fertilizer potentially applied in ecodistrict i, kg N/year

N$_{RCMD,i}$ = recommended fertilizer application in ecodistrict i, kg N/year

N$_{MAN-AV,CROPS,i}$ = available N from manure applied to crops in ecodistrict i, kg N/year

Based on the work of Yang et al. (2007), NRCMD was estimated as the sum of the products of each crop type and the recommended fertilizer application rate for that crop in that ecodistrict:

Equation A3–31:

$$N_{RCMD, i} = \sum_{ij} (CROPA_{ij} \times N_{RECRT, i}) \times \frac{44}{28}$$

where:

CROPA$_{ij}$ = area of crop type j in ecodistrict i, ha

N$_{RECRTij}$ = recommended annual N application rate for crop type j in ecodistrict i, kg N/ha/year

N$_{MAN-AV,CROPS}$ was calculated as the sum of all manure N from all farm animals in the ecodistrict as follows:

Equation A3–32:

$$N_{MAN-AV, CROPS, i} = N_{MAN, CROPS, i} - UNAV$$

where:

N$_{MAN,CROPS,i}$ = total amount of manure N applied as fertilizers to cropland in ecodistrict i, kg N/year

UNAV = fraction of manure N that is either in organic form or unavailable for crops: 0.35 (Yang et al. 2007)

Because the potential amount of fertilizer needs to be reconciled with the total amount sold in the province (N$_{SALES}$) to estimate the actual amount applied (N$_{FERT}$), N$_{APPLD}$ is adjusted in each ecodistrict as follows:

Equation A3–33:

$$N_{FERT, i} = N_{APPLD, i} \times \left[ \frac{\sum_{i}^{p} N_{APPLD, i}}{N_{SALES, p}} \right]$$

where:

$N_{FERTi}$ = total fertilizer N actually applied to all crops in ecodistrict i, kg

$N_{APPLDi}$ = total fertilizer N potentially applied to all crops in ecodistrict i, kg

$N_{SALESp}$ = total amount of fertilizer N sold in province p, kg

For years between census years (census years are 1991, 1996, 2001 and 2006), $N_{RCMD}$ was linearly interpolated to successively estimate annual values of $N_{APPLDi}$ and $N_{FERT}$ at the ecodistrict level. The consumption of synthetic N fertilizers in Canada has significantly increased, from 1.2 Mt to 1.9 Mt N, since 1990 mainly because of the intensification of cropping systems (Figure A3–3).

From 1990 to 2002, Agriculture and Agri-Food Canada collected annual fertilizer N consumption data at the provincial level and published *Canadian Fertilizer Consumption, Shipments and Trade*. From 2003 to 2006, fertilizer N data were collected and published by the Canadian Fertilizer Institute.[9] Since 2007, Statistics Canada has collected and published fertilizer sales data annually.

9   Available online at http://www.cfi.ca/Publications/Statistical_Documents.asp

## Biological Nitrogen Fixation

Biological N fixation by the legume–rhizobium association, a major source of $N_2O$ in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997), is not included in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). This decision is supported by the findings of Rochette and Janzen (2005) that there is no evidence that measurable amounts of $N_2O$ are produced in Canadian agricultural soils during the N fixation process itself. Therefore, Canada decided to report this source as "not occurring." However, the contribution of legume N to $N_2O$ emissions is included as a source of $N_2O$ emissions from crop residue decomposition on agricultural soils ($N_{RES}$).

## Crop Residue Decomposition

The transformations (nitrification and denitrification) of the N released during the decomposition of crop residues result in $N_2O$ emissions into the atmosphere. A country-specific Tier 2 methodology similar to that for synthetic N fertilizers and manure applied as fertilizers is used to estimate $N_2O$ emissions from crop residues, based on Equation A3–34, Equation A3–35 and Equation A3–36. The amount of N contained in the above-ground crop residues subjected to field burning is removed from the emission estimate to avoid double counting.

Figure A3–3   Synthetic Nitrogen Fertilizer Sales in Canada from 1990 to 2009
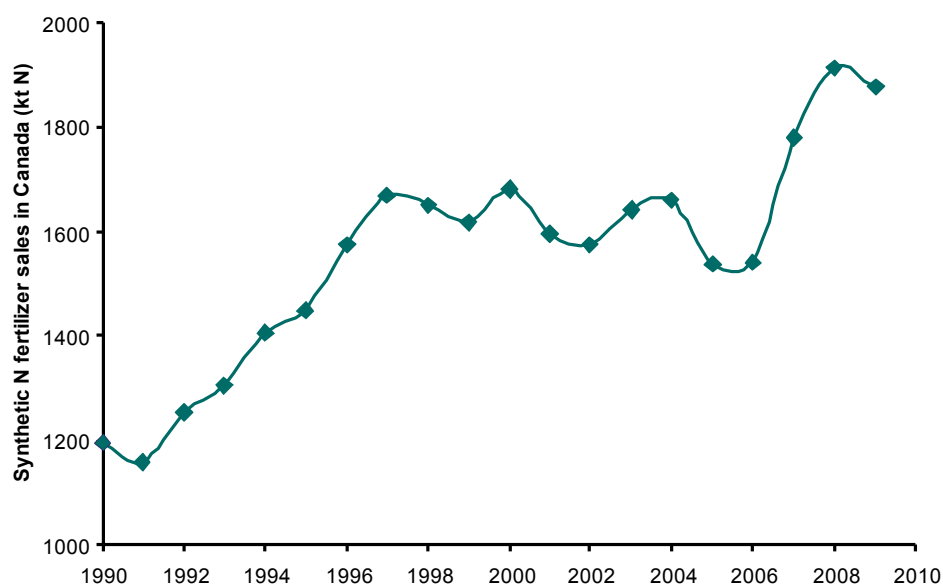
**Equation A3–34:**

$$N_2O_{RES} = \sum_i (N_{RES,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}) \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_{RES}$ | = | emissions from crop residue decomposition, kg $N_2O$/year |
| $EF_{BASE,i}$ | = | a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg $N_2O$-N/kg N/year |
| 44/28 | = | coefficient converting $N_2O$-N to $N_2O$, kg $N_2O$ /kg $N_2O$ -N |
| $N_{RES,i}$ | = | total amount of crop residue N that is returned to the cropland for ecodistrict i, exluding N losses due to residue burning, kg N/year (see Equation A3–35) |
| $RF_{TEXTURE,i}$ | = | soil texture $N_2O$ ratio factor for ecodistrict, i |

**Equation A3–35:**

$$N_{RES,i} = \sum_{T,i} \left[ P_{T,i} \times FRAC_{RENEW,T,i} \times \left( R_{AG,T} \times N_{AG,T} + R_{BG,T} \times N_{BG,T} \right) \right]$$

where:

| | | |
|---|---|---|
| $FRAC_{RENEW,T,i}$ | = | fraction of total area under crop T that is renewed annually in ecodistrict i |
| $R_{AG,T}$ | = | ratio of above-ground residues to harvested yield for crop T, kg dry matter (DM)/kg |
| $N_{AG,T}$ | = | N content of above-ground residues for crop T, kg N/kg DM |
| $R_{BG,T}$ | = | ratio of below-ground residues to harvested yield for crop T, kg DM/kg |
| $N_{BG,T}$ | = | N content of below-ground residues for crop T, kg N/kg DM |
| $P_{T,i}$ | = | total production of the $T^{th}$ crop type that is renewed annually in ecodistrict i, kg DM/year (Equation A3–36). |

**Equation A3–36:**

$$P_{T,i} = \frac{A_{T,i} \times Y_{T,i}}{\sum_{i=1}^{N} \left( A_{T,i} \times Y_{T,i} \right)} \times P_{T,p} \times (1 - H_2O_T)$$

where:

| | | |
|---|---|---|
| $A_{T,i}$ | = | area under crop type T in ecodistrict i, ha |
| $Y_{T,i}$ | = | average crop yield for crop type T in ecodistrict i, kg/ha-year |
| $H_2O_T$ | = | water content of crop T, kg/kg |
| $P_{T,p}$ | = | total crop production for crop type T in province p, kg DM/year |

Statistics Canada (2009) (Statistics Canada #22-002) collects and publishes annual field crop production data by province. Crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard

seed, sunflower seed, canary seeds, fodder corn, sugar beets, tame hay, dry peas, soybean, dry white beans, coloured beans, chick peas and lentils. The area seeded and the yield of each crop are reported at the census agricultural region and provincial levels, and yields have been allocated to Soil Landscapes of Canada (SLC) polygons through area overlays by Agriculture and Agri-Food Canada. Specific parameters for each crop type are listed in Janzen et al. (2003).

## Cultivation of Organic Soils (Histosols)

Cultivation of organic soil (histosols) for annual crop production produces $N_2O$. The IPCC Tier 1 methodology is used to estimate $N_2O$ emissions from cultivated organic soils (Equation A3–37).

**Equation A3–37:**

$$N_2O_H = \sum_i (A_{OS,i} \times EF_{HIST}) \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_H$ | = | $N_2O$ emissions from cultivated histosols, kg $N_2O$-N/year |
| $A_{OS,i}$ | = | total area of cultivated organic soils in province i, ha |
| $EF_{HIST}$ | = | IPCC default emission factor for mid-latitude organic soils, 8.0 kg $N_2O$-N/ha/year (IPCC 2000) |
| 44/28 | = | coefficient converting $N_2O$-N to $N_2O$, kg $N_2O$ /kg $N_2O$ -N |

Areas of cultivated histosols at a provincial level are not collected as part of the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada indicate that the total area of cultivated organic soils from 1990 to 2009 in Canada was 16 kha (Liang et al. 2004).

## Change in $N_2O$ Emissions from Adoption of No-Till and Reduced Tillage

This category is specific to Canada and does not derive from additional N inputs such as fertilizer, manure and crop residue, but rather is implemented as modifications to $EF_{BASE}$ due to the switch from conventional to conservation tillage practices – namely no-tillage (NT) and reduced tillage (RT).

Field studies in Quebec and Ontario showed that NT practices increased $N_2O$ emissions, whereas on the Prairies the opposite was observed (Gregorich et al. 2005). To quantify the impact of tillage practices on $N_2O$, a tillage ratio factor ($F_{TILL}$) defined as the ratio of mean $N_2O$ fluxes on NT or RT

to mean $N_2O$ fluxes on IT ($N_2O_{NT}/N_2O_{IT}$), is used as follows (Rochette et al. 2008):

Equation A3–38:

$$N_2O_{TILL} = \sum_i \left[ (N_{FERT, \, i} + N_{MAN, \, CROPS, \, i} + N_{RES, \, i}) \times (EF_{BASE, \, i} \times FRAC_{NT - RT, \, i} \times (F_{TILL} - 1)) \right] \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_{TILL}$ | = | Change in $N_2O$ emissions resulting from the adoption of NT and RT, kg $N_2O$/year |
| $N_{FERT,i}$ | = | total synthetic fertilizer N consumption in ecodistrict i, kg N/year |
| $N_{MAN,CROPS,i}$ | = | total amount of manure N applied as fertilizers to cropland in ecodistrict i, kg N/year |
| $N_{RES,i}$ | = | total amount of crop residue N that is returned to the cropland for ecodistrict i, kg N/year |
| $EF_{BASE,i}$ | = | a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg $N_2O$-N/kg N-year |
| $FRAC_{NT-RT,i}$ | = | fraction of cropland on NT and RT in ecodistrict i |
| $F_{TILL}$ | = | a ratio factor adjusting $EF_{BASE}$ due to the adoption of NT and RT: $F_{TILL} = 1.1$ in eastern Canada; $F_{TILL} = 0.8$ on the Prairies (Rochette et al. 2008) |
| 44/28 | | coefficient converting $N_2O$-N to $N_2O$, kg $N_2O$ /kg $N_2O$ -N |

The fraction of cropland under NT and RT ($FRAC_{NT-RT}$) for each ecodistrict was derived from the *Census of Agriculture* and is identical to that used in the LULUCF Cropland Remaining Cropland category for NT and RT practices (see Section 3 – Cropland in Annex A3.4). These data are published at the census agricultural region, census division and provincial and national levels. Annual $FRAC_{NT-RT}$ between two consecutive census years is adjusted through interpolation.

## $N_2O$ Emissions Resulting from Summerfallow

Summerfallowing is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, no fertilizer or manure is applied. Several factors may stimulate $N_2O$ emissions relative to a cropped situation, such as higher soil water content, temperature and available carbon and N. Field studies have shown that $N_2O$ emissions in fallow fields are similar to emissions from continuously cropped fields

(Rochette et al. 2008). In order to account for these emissions not captured by the default IPCC input-driven approach, the following country-specific method is used to estimate the effect of summerfallow on $N_2O$ emissions. During a crop year, direct $N_2O$ emissions from a given field are summarized as follows:

Equation A3–39:

$$N_2O_{CROP} = N_2O_{BACK} + N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES}$$

where:

| | | |
|---|---|---|
| $N_2O_{CROP}$ | = | emissions from a cropped rotation, kg $N_2O$/year |
| $N_2O_{SFN}$ | = | emissions from synthetic N fertilizers, kg $N_2O$/year |
| $N_2O_{MAN}$ | = | emissions from animal manure applied as fertilizers, kg $N_2O$/year |
| $N_2O_{RES}$ | = | emissions from crop residue decomposition, kg $N_2O$/year |
| $N_2O_{BACK}$ | = | the background soil N2O emissions that are not due to crop residue-N, fertilizer-N or manure-N additions |

In the absence of external N inputs, $N_2O$ emissions during the fallow year ($N_2O_{FALLOW}$) can be seen as consisting of 1) background emissions that would have occurred regardless of fallow ($N_2O_{BACK}$); and 2) emissions due to the modifications to the soil environment by the practice of summerfallow ($N_2O_{FALLOW-EFFECT}$):

Equation A3–40:

$$N_2O_{FALLOW} = N_2O_{BACK} + N_2O_{FALLOW-EFFECT}$$

Since $N_2O$ emissions are estimated to be equal during fallow and cropped years ($N_2O_{CROP} = N_2O_{FALLOW}$) and assuming that $N_2O_{BACK}$ is the same in cropped and fallow situations, $N_2O_{FALLOW-EFFECT}$ can be empirically estimated as follows:

Equation A3–41:

$$N_2O_{SFN} + N_2O_{MAN} + N_2O_{RES} = N_2O_{FALLOW-EFFECT}$$

The $N_2O$ emissions due to the practice of summerfallow are therefore calculated for each ecodistrict by applying emissions from N inputs to annual crops (crop residues, fertilizers and manure) to the area of that ecodistrict under summerfallow:

Equation A3–42:

$$N_2O_{FALLOW} = \sum_i \left[ (N_2O_{SFN,i} + N_2O_{RES,i} + N_2O_{MAN,i}) \times FRAC_{FALLOW,i} \right]$$

where:

| | | |
|---|---|---|
| $N_2O_{FALLOW}$ | = | emissions due to the effect of summer-fallow, kg $N_2O$-N/year |
| $N_2O_{SFN,i}$ | = | emissions from synthetic N fertilization in ecodistrict i, kg $N_2O$-N/year |
| $N_2O_{RES,i}$ | = | emissions from crop residue decomposition in ecodistrict i, kg $N_2O$-N/year |
| $N_2O_{MAN,i}$ | = | emissions from animal manure applied as fertilizers to cropland in ecodistrict i, kg $N_2O$-N/year |
| $FRAC_{FALLOW,i}$ | = | fraction of cropland in ecodistrict i that is under summerfallow |

Estimates of $N_2O_{SFN}$, $N_2O_{RES}$ and $N_2O_{MAN}$ at an ecodistrict level are those derived from synthetic N fertilizers, manure N applied as fertilizers and crop residue N. The fraction, $FRAC_{FALLOW}$, is derived from the *Census of Agriculture* for each ecodistrict and is identical to that used in the LULUCF Cropland Remaining Cropland category for the summer-fallow practice (see Section 3 – Cropland in Annex A3.4). Annual $FRAC_{FALLOW}$ between two consecutive census years is adjusted through interpolation.

## N₂O Emissions from Irrigation

Higher soil water content under irrigation increases $N_2O$ emissions by increasing biological activity and reducing soil aeration (Jambert et al. 1997). Accordingly, the highest $N_2O$ emissions from agricultural soils in the northwestern United States (Liebig et al. 2005) and western Canada (Hao et al. 2001a) were observed on irrigated cropland, followed by non-irrigated cropland and rangeland. Field studies directly comparing $N_2O$ emissions under irrigated and non-irrigated conditions are lacking in Canada. Therefore, an approach was used based on the assumptions that 1) irrigation water stimulates $N_2O$ production in a way similar to rainfall; 2) irrigation is applied to eliminate any moisture deficit such that "precipitation + irrigation water = potential evapotranspiration;" and 3) the effect of irrigation on $N_2O$ emissions is in addition to those of the non-irrigated area within an ecodistrict. Consequently, the effect of irrigation on $N_2O$ emissions from agricultural soils was accounted for using an $EF_{BASE}$ estimated at a P/PE = 1 ($EF_{BASE}$ = 0.017 $N_2O$-N/kg N) for the irrigated areas of an ecodistrict:

Equation A3–43:

$$N_2O_{IRRI} = \sum_i \left[ (N_{FERT,i} + N_{MAN,CROPS,i} + N_{RES,i}) \times (0.017 - EF_{BASE,i}) \times FRAC_{IRRI,i} \right] \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_{IRRI}$ | = | emissions from irrigation, kg $N_2O$/year |
| $N_{FERT,i}$ | = | total synthetic fertilizer N consumption in ecodistrict i, kg N/year |
| $N_{MAN,CROPS,i}$ | = | total amount of manure N applied as fertilizers to cropland in ecodistrict i, kg N/year |
| $N_{RES,i}$ | = | total amount of crop residue N that is returned to the cropland for ecodistrict i, kg N/year |
| $EF_{BASE,i}$ | = | a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg $N_2O$-N/kg N/year for ecodistrict i |
| $FRAC_{IRRI,i}$ | = | fraction of irrigated cropland in ecodistrict i |
| 44/28 | = | coefficient converting $N_2O$-N to $N_2O$, kg $N_2O$ /kg $N_2O$ -N |

The fraction, $FRAC_{IRRI}$, is derived from the *Census of Agriculture* for each ecodistrict (see Section 3 – Cropland in Annex A3.4). Annual $FRAC_{IRRI}$ between two consecutive census years is adjusted through interpolation.

## A3.3.6.2. Manure on Pasture, Range and Paddock from Grazing Animals

The IPCC Tier 1 methodology is used to estimate $N_2O$ emissions from manure on pasture, range and paddock. The IPCC methodology is based on the quantity of manure N produced by domestic animals on pasture, range and paddock. $N_2O$ emissions are calculated using Equation A3–44

**A3**

Equation A3–44:

$$N_2O_{PRP} = \sum_T \left[ (N_T \times N_{EX,T} \times N_{PRP,T}) \right] \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_{PRP}$ | = | emissions from manure on pasture, range and paddock from grazing animals, kg $N_2O$/year |
| $N_T$ | = | animal population of category or subcategory T in a province, heads |
| $N_{EX,T}$ | = | annual N excretion rate for animal category or subcategory T, kg N/head-year (Table A3–26: Time Series of Manure N Excretion Rates for Cattle (kg N/head/year)1 and Table A3–27: Manure N Excretion Rates for Non-cattle) |
| $N_{PRP,T}$ | = | fraction of manure N excreted on pasture, range and paddock by animal category or subcategory T (Table A3–23 Percentage of Manure Handled by Animal Waste Management Systems (AWMS) for Canada (Marinier et al. 2004), Presented as National Averages). |
| $EF_{PRP,T}$ | = | emission factor for manure N deposited by animals on pasture, range and paddock (IPCC 2006) (Annex 8) |
| 44/28 | = | coefficient converting $N_2O$-N to $N_2O$, kg $N_2O$ /kg $N_2O$ -N |

Animal population data and data sources are detailed in Section A3.3.1.

### A3.3.6.3.  Indirect $N_2O$ Emissions from Soils

**Volatilization and Redeposition of Nitrogen**

The IPCC Tier 1 methodology is used to estimate indirect $N_2O$ emissions from volatilization and redeposition of fertilizer and manure N applied to agricultural soils. The emission calculation is shown in Equation A3–45:

Equation A3–45:

$$N_2O_{VD} = \sum_i \left[ (N_{FERT,i} \times FRAC_{GASF}) + (N_{MAN,CROPS,i} + FRAC_{GASM}) + N_{MAN-VOLAT,i} \right] \times EF_{VD} \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_{VD}$ | = | emissions from volatilization and redeposition of N, kg $N_2O$/year |
| $N_{FERT,i}$ | = | synthetic N fertilizer consumption in ecodistrict i, kg N/year |
| $FRAC_{GASF}$ | = | fraction of synthetic fertilizer N applied to soils that volatilizes as $NH_3$- and $NO_x$-N: 0.1 kg ($NH_3$-N + $NO_x$-N)/kg N (IPCC 2006) |
| $N_{MAN,CROPS,i}$ | = | total amount of animal manure N applied as fertilizers to cropland in ecodistrict i, kg N/year |
| $FRAC_{GASM}$ | = | fraction of volatilized manure N applied as fertilizers to cropland: 0.2 kg ($NH_3$-N + $NO_x$-N)/kg N (IPCC 2006) |
| $EF_{VD}$ | = | emission factor due to volatilization and redeposition: 0.01 kg $N_2O$-N/kg N (IPCC/OECD/IEA 1997) |
| 44/28 | = | coefficient converting $N_2O$-N to $N_2O$, kg $N_2O$ /kg $N_2O$ -N |
| $N_{MAN-VOLAT,i}$ | = | total manure N lost as $NH_3$-N and $NO_x$-N from livestock excretion in ecodistrict i, kg N (Equation A3–46) |

Equation A3–46:

$$N_{MAN-VOLAT,i} = \sum_{mT} \left[ (N_T \times N_{EX,T} \times AWMS_{m,T} \times FRAC_{GASMm,T}) \right]$$

where:

| | | |
|---|---|---|
| $N_T$ | = | animal population for animal category or subcategory T, head, kg N |
| $N_{EX,T}$ | = | N excretion from animal category or subcategory T, kg N/year (Table A3–26: Time Series of Manure N Excretion Rates for Cattle (kg N/head/year)1 and Table A3–27: Manure N Excretion Rates for Non-cattle) |
| $AWMS_{m,T}$ | = | fraction of manure N from animal category or subcategory T under manure management system m (Table A3–23: Percentage of Manure Handled by Animal Waste Management Systems (AWMS) for Canada (Marinier et al. 2004), Presented as National Averages) |
| $FRAC_{GASMm,T}$ | = | fraction of manure N excreted by animal category or subcategory under manure management system m that volatilizes as $NH_3$-N and $NO_x$-N (Table A3–28: Total N, $NH_3$- and $NO_x$-N Losses Associated with Various Livestock and Manure Management Systems[1]) |

Data sources for estimating $N_{FERT}$ and $N_{MAN-VOLAT}$ at an ecodistrict level are provided in the previous sections (Section A3.3.6.1 and Equation A3–22).

## Leaching and Runoff

A modified IPCC Tier 1 methodology is used to estimate $N_2O$ emissions from leaching and runoff of fertilizer, manure and crop residue N from agricultural soils:

Equation A3–47:

$$N_2O_L = \sum_i \left[ (N_{FERT,i} + N_{MAN,CROPS,i} + N_{PRP,i} + N_{RES,i}) \times FRAC_{LEACH,i} \times EF_{LEACH} \right] \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_L$ | = | emissions from leaching and runoff of N, kg $N_2O$/year |
| $N_{FERT,i}$ | = | synthetic N fertilizers applied for ecodistrict i, kg N |
| $N_{MAN,CROPS,i}$ | = | manure N applied as fertilizers for ecodistrict i, kg N |
| $N_{PRP,i}$ | = | manure N deposited on pasture, range and paddock for ecodistrict i, kg N |
| $N_{RES,i}$ | = | crop residue N for ecodistrict i, kg N |
| $FRAC_{LEACH,i}$ | = | fraction of N that is lost through leaching and runoff for ecodistrict i, as defined below |
| $EF_{LEACH}$ | = | leaching/runoff emission factor: 0.025 kg $N_2O$-N/kg N (IPCC 2000) |
| 44/28 | = | coefficient converting $N_2O$-N to $N_2O$, kg $N_2O$ /kg $N_2O$ -N |

### Determining the Fraction of Nitrogen That is Leached ($FRAC_{LEACH}$) at the Ecodistrict Level in Canada

In Canada, leaching losses of N vary widely among regions. High N inputs in humid conditions may lead to losses greater than 100 kg N/ha-year in some farming systems of southern British Columbia (Paul and Zebarth 1997; Zebarth et al. 1998). Those farming systems, however, represent only a small fraction of Canadian agroecosystems. In Ontario, Goss and Goorahoo (1995) predicted leaching losses of 0-37 kg N ha$^{-1}$, representing between 0 and 20% of N inputs. Leaching losses in most of the Prairie region may be smaller due to lower precipitation and lower N inputs on an areal basis. Based on a long-term experiment in central Alberta, Nyborg et al. (1995) suggested that leaching losses were minimal, and Chang and Janzen (1996) found no evidence of N leaching in non-irrigated, heavily manured plots, despite large accumulations of soil nitrate in the soil profile.

The default value for $FRAC_{LEACH}$ in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) was 0.3. The values for $FRAC_{LEACH}$ can be as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC 2006), such as in the Prairie region of Canada. Accordingly, it was assumed that $FRAC_{LEACH}$, depending on the ecodistrict, would vary from 0.05 to 0.3.

Figure A3–4    Determination of the Ecodistrict FRACLEACH Values
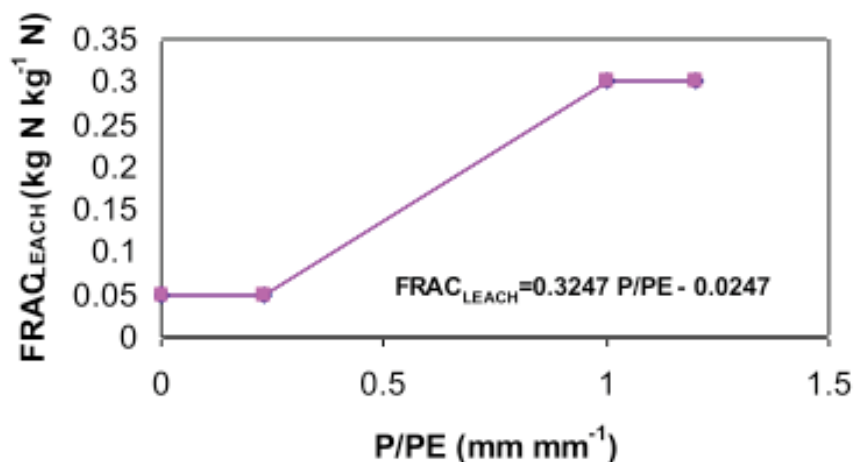
For ecodistricts with a P/PE value for the growing season (May through October) greater than or equal to 1, the maximum $FRAC_{LEACH}$ value recommended by the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) of 0.3 was assigned. For ecodistricts with the lowest P/PE value (0.23), a minimum $FRAC_{LEACH}$ value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged between 0.23 and 1, $FRAC_{LEACH}$ was estimated by the linear function that joins the two-end points (P/PE, $FRAC_{LEACH}$) = (1,0.3; 0.23,0.05) (Figure A3–4).

Data sources for $N_{FERT}$ (Section A3.3.6.1), $N_{MAN,CROPS}$ (Section A3.3.6.1), $N_{PRP}$ (SectionA3.3.6.2) and $N_{RES}$ (Section A3.3.6.1) at an ecodistrict level are provided in the previous sections.

Long-term normals of monthly precipitation and potential evapotranspiration from May to October, 1971–2000 (AAFC-archived database) were used to calculate $FRAC_{LEACH}$ at an ecodistrict level.

## A3.3.7. CH₄ and N₂O Emissions from Field Burning of Agricultural Residues

Crop residues are sometimes burned in Canada, as a matter of convenience and disease control through residue removals, even though this practice has declined in recent years because of soil quality and environmental issues.

Field burning of agricultural residues emits $CH_4$ and $N_2O$. The quantity of crop residue burning in Canada can be estimated as follows:

Equation A3–48:

$$Q_{BURN} = \sum_{T} \left( Production \times (1 - Moisture_T) \times RatioAR/P_T \times PCB_T \times Ratio_{SCALE} \right)$$

where:

| | | |
|---|---|---|
| $Q_{BURN}$ | = | quantity of crop residue burned from crop T for each province, Mg dry matter/year |
| $Production_T$ | = | total production of crop T, Mg dry matter/year |
| $Moisture_T$ | = | moisture content of the product from crop T, fraction |
| $RatioAR/P_T$ | = | Ratio of above-ground crop residue to the crop product for crop T , unitless |
| $PCB_T$ | = | perent of crop residue that is subject to field burning for crop T, fraction |
| $Ratio_{SCALE}$ | = | a scaling factor or an intensity factor adjusted for burning in 2006, unitless |

Data in 2001 and 2006 by Statistics Canada collected through its Farm Environmental Management Survey (FEMS)[10] related to the methods of crop residue management, include crop residue burning. To establish a complete time series of activity data (Table A3–29), additional information on crop residue burning for 1991 and 1996 has been gathered through expert consultations (Coote et al. 2008). The type of crop and the extent of crop residue burning for each province were only available for 2006; these data were collected in FEMS, and summarized in Table A3–30. Thus, it is assumed that the same crop and its extent of burning for each province were the same for the entire time series as in 2006.

The intensity of the crop residue burning in each province for 1991, 1996 and 2001 was adjusted as a ratio based on the average burning for 2006. Basic characteristics of crops, such as moisture content of crop product and ratio of above-ground crop residue to crop product, are reported by Janzen et al. (2003). Annual production of each crop subject to residue burning is available (Statistics Canada 2009, catalogue no. 22-002). Other parameters such as fraction of residue burned and emission factors required for emission estimates were obtained from the Good Practice Guidance (IPCC 2000).

Emissions of $N_2O$ and $CH_4$ from crop residue burning are estimated using the following equation:

Equation A3–49:

$$EMISSION_{BURN} = \sum_{Province, i} \left( Q_{BURNi} \times C_F \times G_{EF} \right) / 1000$$

where:

| | | |
|---|---|---|
| $EMISSION_{BURN}$ | = | emissions of $N_2O$ or $CH_4$ from the burning of crop residues for Canada (kt $N_2O$ or $CH_4$) |
| $Q_{BURNi}$ | = | quantity of crop residue burnt from province i, Mg, dry matter/year |
| $C_F$ | = | fuel efficiency (the default value for agricultural crop residues from the Good Practice Guidance [IPCC 2000] is 0.9), unitless |
| $G_{EF}$ | = | emission factor (the default values of $N_2O$ and $CH_4$ in the Good Practice Guidance [IPCC 2000] are 0.07 g $N_2O$/kg dry matter burned and 2.7 g $CH_4$/kg dry matter burned) |
| 1000 | = | converting Mg to kt |

10   Available at http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5044&lang=en&db=imdb&adm=8&dis=2#a4

Table A3–29    Crop residue burning by province in Canada
                for 1991, 1996, 2001 and 2006

|  | 1991 | 1996 | 2001 | 2006 |
|---|---|---|---|---|
|  | *% of crop residue burned* | | | |
| Newfoundland and Labrador | 0 | 0 | 0 | 0 |
| Prince Edward Island | 0.4 | 0.4 | 0.4 | 0.4 |
| Nova Scotia | 0.5 | 0.5 | 0.5 | 0.5 |
| New Brunswick | 0.5 | 0.5 | 0.5 | 0.5 |
| Quebec | 0.4 | 0.4 | 0.4 | 0.3 |
| Ontario | 0.7 | 0.7 | 0.7 | 0.3 |
| Manitoba | 12.6 | 10.1 | 8.9 | 2.3 |
| Saskatchewan | 8.1 | 5.8 | 3.9 | 1.5 |
| Alberta | 0.8 | 0.7 | 0.2 | 0.2 |
| British Columbia | 0 | 0 | 0 | 0 |

Data sources: data for 2001 and 2006 were extracted from FEMS 2001
and 2006 collected by Statistics Canada, and for 1991 and 1996 were
gathered through consultations by Coote et al. (2008).

Table A3–30    Burning of crop residues by crop types in 2006

|  | Spring wheat | Winter wheat | Oats | Barley | Mixed grains | Flaxseed | Canola |
|---|---|---|---|---|---|---|---|
|  | *% of crop residue burned* | | | | | | |
| Newfoundland and Labrador | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Prince Edward Island | 3 | 0 | 0 | 1 | 0 | 0 | 0 |
| Nova Scotia | 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| New Brunswick | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Quebec | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Ontario | 0 | 0 | 0 | 1 | 2 | 0 | 0 |
| Manitoba | 2 | 3 | 3 | 1 | 0 | 17 | 1 |
| Saskatchewan | 0 | 0 | 0 | 0 | 0 | 15 | 1 |
| Alberta | 0 | 0 | 0 | 0 | 0 | 8 | 0 |
| British Columbia | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## A3.4. Methodology for Land Use, Land-use Change and Forestry

The Land Use, Land-use Change and Forestry (LULUCF) Sector of the inventory includes the greenhouse gas (GHG) emissions/removals associated with managed lands and with the conversion of land from one category to another.

As in Chapter 7, the structure of this annex attempts to maintain the land-based reporting categories, while grouping related data collection and estimate development methodologies. Section A3.4.1 summarizes the spatial framework for estimate development and area reconciliation. The general approach for estimating carbon stock changes, emissions and removals in all forest-related categories, including managed forests, forest conversion to other lands and lands converted to forests, is briefly described in Section A3.4.2; this description is not repeated under the Forest Land converted to the Cropland, Grassland, Wetlands and Settlements categories. The Cropland section specifically describes methods to quantify the effect of management practices on agricultural land. Likewise, the sections on wetlands and settlements focus on category-specific estimation methodologies.

Selected approaches to the estimation of delayed carbon emissions due to long-term carbon storage in harvested wood products are briefly described in Section A3.4.7, along with implications for Canada.

### A3.4.1. Spatial Framework for LULUCF Estimate Development and Area Reconciliation

Canada's monitoring system for LULUCF draws on the close collaboration among several scientists and experts in different disciplines. Early on, it was recognized that the approaches, methods, tools and data that are available and most suitable for monitoring human activities in one land category are not always appropriate for another. Important differences exist in the spatial framework specific to each land category, with the risk that activity data and estimates become spatially inconsistent. A hierarchical spatial framework was agreed upon by all partners of the national LULUCF Monitoring, Accounting and Reporting System (MARS), to ensure the highest possible consistency and spatial integrity of the GHG inventory.

At the finest level of spatial resolution are analysis units, which are specific to each estimation system. In managed forests, the analysis units are the management units found in provincial and territorial forest inventories. For the purpose of this assessment, managed forests were classified into some 523 analysis units across 12 provinces and territories (Table A3–31). Analysis units typically result from the intersection of administrative areas used for timber management and ecological boundaries. Changes in the number of spatial analysis units from the previous submission (542 to 523) reflect some refinements in the integration of multiple spatial layers. For example, the modifications of administrative boundaries, timber areas and parks can result in units that do not meet the criteria for separate analysis; these units are therefore regrouped.

Table A3–31    Spatial Analysis Units of Managed Forests

| Province/Territory | Number of Analysis Units |
| --- | --- |
| Newfoundland and Labrador | 24 |
| Nova Scotia | 1 |
| Prince Edward Island | 1 |
| New Brunswick | 1 |
| Quebec | 129 |
| Ontario | 52 |
| Manitoba | 70 |
| Saskatchewan | 40 |
| Alberta | 70 |
| British Columbia | 92 |
| Yukon | 13 |
| Northwest Territories | 30 |
| Canada | 523 |

The most suitable spatial framework for GHG monitoring of agricultural lands (Cropland category) is the National Soil Database of the Canadian Soil Information System[11] and its underlying soil landscapes. The full array of attributes that describe a distinct type of soil and its associated landscapes, such as surface form, slope, typical soil carbon content under native and dominant agricultural land use, and water table depth, is called a soil landscape. Soil landscapes are spatially associated with Soil Landscapes of Canada (SLC) polygons (the analysis units), that may contain one or more distinct soil landscape components. The SLC polygons are in the order of 1000 to 1 000 000

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11    Available online at http://sis2.agr.gc.ca/cansis/

Table A3–32   Estimates of Land, Water, Managed Forest and Cropland Areas in 2009

| Reporting Zone Number and Name | | Total Area (kha) | Total Land Area (kha) | Total Fresh Water Area (kha) | Managed Forest Area (kha) | Cropland Area (kha) |
|---|---|---|---|---|---|---|
| 1 | Arctic Cordillera | 24 278 | 23 992 | 286 | | |
| 2 | Northern Arctic | 151 023 | 142 416 | 8 606 | | |
| 3 | Southern Arctic | 84 636 | 74 609 | 10 027 | | |
| 4 | Taiga Shield East | 74 834 | 65 669 | 9 166 | 1 103 | |
| 5 | Boreal Shield East | 111 057 | 99 129 | 11 928 | 55 652 | 639 |
| 6 | Atlantic Maritime | 20 939 | 19 737 | 1 202 | 15 455 | 1 036 |
| 7 | Mixedwood Plains | 16 781 | 11 015 | 5 766 | 2 688 | 5 246 |
| 8 | Hudson Plains | 37 371 | 36 394 | 977 | 302 | |
| 9 | Boreal Shield West | 83 951 | 71 112 | 12 839 | 28 780 | 180 |
| 10 | Boreal Plains | 73 612 | 67 186 | 6 426 | 36 087 | 10 299 |
| 11 | Subhumid Prairies | 22 341 | 21 599 | 742 | 1 844 | 16 109 |
| 12 | Semiarid Prairies | 23 966 | 23 494 | 473 | 18 | 12 664 |
| 13 | Taiga Plains | 65 804 | 58 219 | 7 585 | 20 038 | 2 |
| 14 | Montane Cordillera | 48 471 | 47 226 | 1 244 | 35 420 | 1 230 |
| 15 | Pacific Maritime | 20 810 | 20 488 | 322 | 13 206 | 111 |
| 16 | Boreal Cordillera | 46 785 | 45 842 | 944 | 16 618 | 1 |
| 17 | Taiga Cordillera | 26 530 | 26 374 | 157 | 412 | |
| 18 | Taiga Shield West | 63 168 | 52 178 | 10 990 | 1 829 | |

hectares (ha) in area and are appropriate for mapping at the scale of 1:1 million.

SLC polygons are also the basic units of Canada's National Ecological Framework, a hierarchical, spatially consistent national context within which ecosystems at various levels of generalization can be described, monitored and reported on (Marshall and Schut 1999). The 12 353 SLC polygons are nested in the next level of generalization (1027 ecodistricts), which are further grouped into 194 ecoregions and 15 ecozones.

Analysis units for estimating the areas of forest converted to other uses are the result of the spatial intersection of forest conversion strata (see Figure A3–8) with ecological and administrative boundaries. Forest conversion strata were developed on the basis of expected conversion rates and characteristics. The sampling approach used to monitor forest conversion requires that analysis units be (i) as consistent as possible with respect to the patterns of forest conversion and (ii) large enough to provide an acceptable sample size given the predetermined sampling rate.

The LULUCF Sector of the GHG inventory reports information in 18 reporting zones (Chapter 7, Figure 7-1). These reporting zones are essentially the same as the ecozones

of the National Ecological Framework, with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairies ecozone is divided into a semi-arid and a subhumid component. These subdivisions do not alter the hierarchical nature of the spatial framework. Table A3–32 provides the land and water areas of each reporting zone, as well as the estimated area of managed forest and cropland for the 2009 inventory year. Methods and data sources used for developing this information are described in McGovern (2008).

The analysis units of different land-use categories often overlap. Furthermore, the exact location of events, stands or activities within a unit is not known. Therefore, the activity data pertaining to different land-use categories cannot be harmonized at the level of analysis units. The spatial harmonization is conducted within 60 reconciliation units, which are derived from the spatial intersection of reporting zones with provincial and territorial boundaries. Quality control and quality assurance procedures are conducted at the levels of analysis units during estimate development and of reconciliation units during estimate compilation.

## A3.4.2. Forest Land and Forest-related Land-use Change

### A3.4.2.1. Carbon Modelling

The estimation of carbon stock changes, emissions from and removals by managed forests, forest conversion to other land uses, and land converted to forests was conducted with version 3 of the Carbon Budget Model of the Canadian Forest Sector [CBM-CFS3] (Kurz et al. 2009), the most recent of a family of models whose development goes back to the late 1980s (Kurz et al. 1992). The model integrates forest inventory information (forest age, area and species composition), libraries of merchantable volume over age curves, equations to convert stand merchantable volume into total biomass, data on natural and anthropogenic disturbances, and simulations of carbon transfers between pools and with the atmosphere that are associated with ecosystem processes and various events.

The ecosystem processes (or "annual processes") modelled by the CBM-CFS3 to generate the estimates submitted in this report are growth, litter fall, non-disturbance tree mortality and decomposition. The CBM-CFS3 also models events, such as management activities, forest conversion and natural disturbances. Management activities represented are commercial thinning, clear-cutting, partial cutting, salvage cutting[12] and the burning of harvest residues during site preparation or for fire risk management. Different practices of forest conversion are also simulated, including controlled burning.

The forest carbon pools represented in the CBM-CFS3 can be matched to the Intergovernmental Panel on Climate Change (IPCC) forest carbon pools (Table A3–33). Although not shown here, living biomass pools are further subdivided into two sets, for each of hardwood and softwood tree species.

Annual processes and events trigger arrays of carbon transfers between pools as shown in Figure A3–5.

Annual ecosystem processes comprise growth, litter fall, mortality and decomposition and are simulated as carbon transfers executed at each time step (annually) in every inventory record. During annual processes, carbon is taken up in the biomass pool and some biomass carbon is transferred to dead organic matter (DOM) pools. The decay of DOM carbon results in its transfer to another DOM pool (e.g. stem snags to medium deadwood pool), to a slow soil pool or to the atmosphere. More information on pool structure and decay rates is provided in Kurz et al.

12   Salvage cutting (or "salvage logging") is the removal of merchantable timber left after a natural disturbance. Whenever possible, salvage logging is distinguished from conventional harvesting operations.

Table A3–33   Forest Carbon Pools in IPCC and CBM-CFS3

| IPCC Carbon Pools | | Pool Names in CBM-CFS3 |
| --- | --- | --- |
| Living Biomass | Above-ground biomass | Merchantable stemwood<br>Other (submerchantable stemwood, tops, branches, stumps, non-merchantable trees)<br>Foliage |
| | Below-ground biomass | Fine roots<br>Coarse roots |
| Dead Organic Matter (DOM) | Dead wood | Above-ground fast<br>Below-ground fast<br>Medium<br>Softwood stem snag<br>Softwood branch snag<br>Hardwood stem snag<br>Hardwood branch snag |
| | Litter | Above-ground very fast<br>Above-ground slow |
| Soils | Soil organic matter | Below-ground very fast[1]<br>Below-ground slow<br>Black carbon[2]<br>Peat[2] |

Notes:
1. Below-ground very fast pool includes dead and decaying fine roots, which in practice cannot be separated from soil.
2. Black carbon and peat are currently not estimated.

Figure A3–5   Carbon Pools and Transfers Simulated by the CBM-CFS3
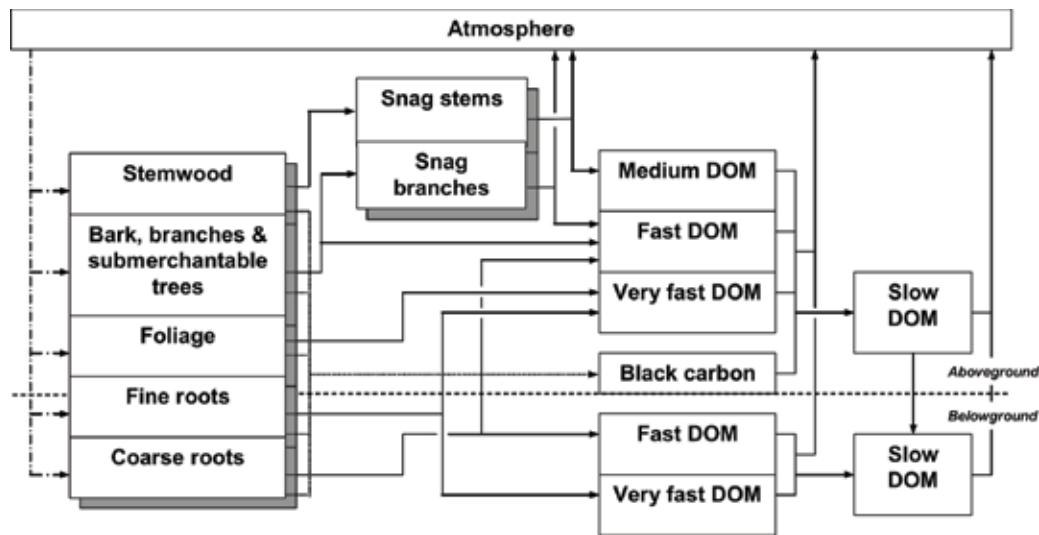


(2009). Rates of carbon transfer are defined for each pool, based on pool-specific turnover rates (for biomass pools) or decay rates (DOM and soil pools). Turnover rates can be very high (e.g. 95% for hardwood foliage) or very low (e.g. < 1% for stemwood). Annual decay rates are defined for a reference mean annual temperature of 10°C and exhibit temperature sensitivity according to defined Q10 relationships; the decay rates vary between 50% (very fast DOM pools, such as dead fine roots) and 0.0032% (slow soil pool).

Growth is simulated as an annual process. Every record in the forest inventory used in each of the 523 analysis units is associated with a yield curve that defines the dynamics of merchantable volume over time. Assignment of an inventory record to the appropriate curve is based on a classifier set that includes province, ecological stratum, leading species, site productivity class and several other classifiers that differ among provinces and territories. Curve libraries for each province and territory in Canada are derived from permanent or temporary sample plots or from forest inventory information.

Conversion of merchantable volume curves to above-ground biomass curves is performed with a set of equations developed for Canada's National Forest Inventory (Boudewyn et al. 2007). These equations derive the above-ground biomass of each stand component from merchantable stemwood volume (per ha), for each province/

territory, ecozone, leading species or forest type. Finally, below-ground biomass pools are estimated using regression equations (Li et al. 2003). Mean annual increments are not used in this derivation.

Disturbances trigger different combinations of carbon transfers, based on the disturbance type and severity, the forest ecosystem affected and the ecological region. For modelling purposes, different practices of forest conversion are also implemented as disturbances. The impact of a disturbance is defined in a disturbance matrix, which specifies for one or more disturbance types the proportion of carbon in each ecosystem pool that is transferred to other pools, released to the atmosphere (in different GHGs) or transferred to harvested wood products. Figure A3–6 illustrates one such matrix, simulating clear-cut harvesting in the Montane Cordillera, during which the wood is harvested and residues (slash) are burned. In the 2011 submission, the simulation uses a total of 84 disturbance matrices to simulate the impact of disturbances. The number of different disturbance matrices is dependent on the availability of activity data (e.g. the spatial and temporal resolution of data sources used to document disturbances) and on the knowledge required to parameterize the matrices for more distinct regions or intensities of disturbance in place of more generically developed parameter sets.

The proportion of $CO_2$-C emitted from each pool, docu-

Figure A3–6    Disturbance Matrix Simulating the Carbon Transfers Associated with Clearcut Harvesting in Reporting Zone 14 (Montane Cordillera)

| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 24 | 25 | Products |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Softwood merchantable | | | | | 0.15 | | | | | 0.85 |
| 2. Softwood foliage | 1 | | | | | | | | | |
| 3. Softwood others | | | 1 | | | | | | | |
| 4. Softwood sub-merch | | | 1 | | | | | | | |
| 5. Softwood coarse roots | | | 0.5 | 0.5 | | | | | | |
| 6. Softwood fine roots | 0.5 | 0.5 | | | | | | | | |
| 7. Hardwood merch | | | | | 0.15 | | | | | 0.85 |
| 8. Hardwood foliage | 1 | | | | | | | | | |
| 9. Hardwood other | | | 1 | | | | | | | |
| 10. Hardwood submerch | | | 1 | | | | | | | |
| 11. Hardwood coarse roots | | | 0.5 | 0.5 | | | | | | |
| 12. Hardwood fine roots | 0.5 | 0.5 | | | | | | | | |
| 13. Above Ground Very Fast soil C | 1 | | | | | | | | | |
| 14. Below Ground Very Fast soil C | | 1 | | | | | | | | |
| 15. Above Ground Fast soil C | | | 1 | | | | | | | |
| 16. Below Ground Fast soil C | | | | 1 | | | | | | |
| 17. Medium Soil C | | | | | 1 | | | | | |
| 18. Above Ground slow soil C | | | | | | 1 | | | | |
| 19. Below Ground Slow soil C | | | | | | | 1 | | | |
| 20. Softwood Stem Snag | | | | | 0.5 | | | | | 0.5 |
| 21. Softwood Branch Snag | | | 1 | | | | | | | |
| 22. Hardwood Stem Snag | | | | | 0.5 | | | | | 0.5 |
| 23. Hardwood Branch Snag | | | 1 | | | | | | | |
| 24. Black C | | | | | | | | 1 | | |
| 25. Peat | | | | | | | | | 1 | |

mented in each disturbance matrix, can be specific to the pool, the types of forest and disturbance intensity, and the ecological zone; there are therefore no $CO_2$ emission factors applicable to all disturbances of a given type, such as fires. With a few exceptions, the proportion of total carbon emitted in each carbon-containing GHG ($CO_2$, CO, and $CH_4$) due to fire is constant: 90% of carbon is emitted as $CO_2$, 9% as CO and 1% as $CH_4$ (Cofer et al. 1998; Kasischke and Bruhwiler 2003).

While the CBM-CFS3 can model carbon fluxes at various spatial scales, generating national estimates involved harmonizing, integrating and ingesting vast quantities of data from a great diversity of sources. The next section documents the key data sources used for this submission

### A3.4.2.2.    Data Sources

**Managed Forest Land**

The Canadian provincial and territorial governments, whose jurisdiction includes natural resource management, provided essential information—notably detailed forest inventory data and, when available, details on forest management activities and practices, disturbances and

disturbance prevention or control, regional yield tables (volume/age curve) for dominant tree species, and site indices—as well as regional expertise (Table A3–34). The forest inventory data in Canada's National Forest Inventory (CanFI 2001) were used for New Brunswick, Manitoba, Saskatchewan, Alberta, Yukon and the Northwest Territories. More recent and higher-resolution inventory data were provided by Prince Edward Island, Newfoundland and Labrador, Nova Scotia, Quebec, Ontario, and British Columbia. Considerable efforts were necessary to harmonize, format and compile the detailed inventory information into input data for the CBM-CFS3. A series of "methods papers" describe the compilation process for each provincial and territorial forest inventory. Since forest inventory data were not collected in the same years, additional steps were necessary to synchronize the inventory data to the year 1990 (Stinson et al. 2006a).

Conceptually, forests are classified as "managed" or "un-managed" based on the occurrence of management activities for timber or non-timber, and on the level of protection against disturbances (Figure A3–7). The estimation of the managed forest area required the spatial delineation and combination of boundaries of many different forest areas, including all operational forest management

Table A3–34    Main Sources of Information and Data, Managed Forests

| Description | Source | Spatial Resolution | Temporal Coverage | Reference |
|---|---|---|---|---|
| Fire data | Canadian Wildland Fire Information System | Spatially explicit | 2004–2009 | http://cwfis.cfs.nrcan.gc.ca/ |
| | Canadian Large Fire Database | Spatially referenced | 1959–2003 | http://cwfis.cfs.nrcan.gc.ca/lfdb |
| Forest inventories | Canada's National Forest Inventory (CanFI) | CanFI grid cell | 1949–2004 | https://nfi.nfis.org/index.php |
| | Alberta | Analysis units | N/A | Yield curves from provincial expert |
| | British Columbia | Analysis units | 1993–2000 | Provincial expert |
| | Newfoundland | Analysis units | 2006 | Provincial expert |
| | Nova Scotia | Analysis units | 2000 | Provincial expert |
| | Ontario | Analysis units | 2000 | Provincial expert |
| | Prince Edward Island | Analysis units | 2000 | Provincial expert |
| | Quebec | Analysis units | 2000 | Provincial expert |
| Harvest data | National Forestry Database | Provincial boundaries | 1990–2009 | http://nfdp.ccfm.org/ |
| | Alberta | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | British Columbia | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | Newfoundland and Labrador | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | Manitoba | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | New Brunswick | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | Northwest Territories | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | Nova Scotia | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | Ontario | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | Prince Edward Island | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | Quebec | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | Saskatchewan | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| | Yukon | Analysis units | 1990–2009 | National Forestry Database http://nfdp.ccfm.org/ |
| Insect data | Forest Insect and Disease Survey | Spatially explicit | 1990–2009 | Atlantic Forestry Centre and Pacific Forestry Centre |
| | Alberta | Spatially explicit | 1970–2009 | http://www.srd.alberta.ca/ManagingPrograms/ForestPests/ForestPestSurveyData.aspx |
| | British Columbia | Spatially explicit | 1990–2009 | Provincial expert |
| | Saskatchewan | Spatially explicit | 1990–2009 | Provincial expert |
| Climate data | CFS | Analysis units | 1961–1990 normals | McKenney (2005) |

Note: N/A = not available

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Figure A3–7    Decision Tree for the Determination of Managed Forest Area

Is
the forest area
managed for timber or
non-timber forest
resources?

No

Is
the forest area
under intensive protection
against natural
disturbances?

Yes

Yes

No

Classify the forest area as
"managed forest"

Classify the forest area as
"unmanaged forest"
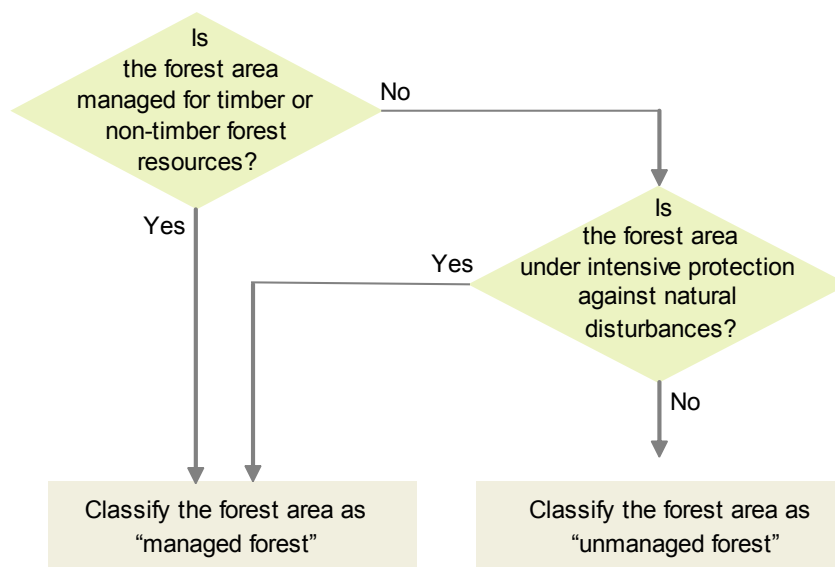
Figure A3–8    Lands with Managed and Un-managed Forests in Canada
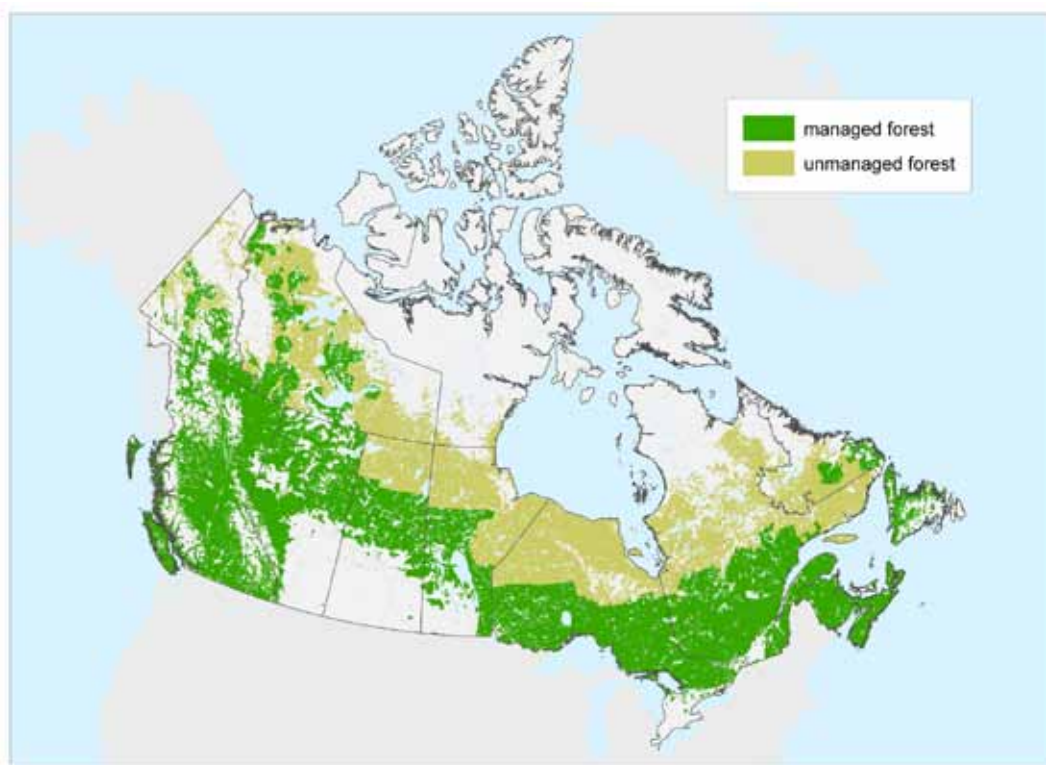
units, timber supply areas, tree farm licences, industrial freehold timberland, private woodlots and any other land in the Forest category where there is active management for timber or non-timber resources, as well as forest areas where there is intensive protection against natural disturbances. All these layers are aggregated and intersected with underlying forest inventory data. The procedures are documented in Stinson et al. (2006b). Figure A3–8 illustrates the location of lands with managed and un-managed forests in Canada, for the purpose of GHG estimation and reporting. In 2009, the total area of managed forests was 229 453 kilohectares (kha), of which 68% lie in four reporting zones: Boreal Shield East, Montane Cordillera, Boreal Plains and Boreal Shield West (see Table A3–32). The managed forest area represents 66% of the total forest area in Canada.

Forest management activities are documented in the National Forestry Database;[13] additional information on specific activities is obtained directly from provincial and territorial forest management agencies.

Historical data on areas disturbed by wildfires were extracted from the Canadian Large Fire Database. These were supplemented by provincial and territorial data for the years 1990 to 2003 and by the Canadian Wildland Fire Information System's National Burn Area Composite (NBAC) product for the years 2004 to 2009 (Table A3.4-4). The NBAC is a composite of low- and medium-resolution remote sensing data and fire mapping data, provided by resource management agencies from across Canada that provides complete mapping of wildfires using the best available data sources. Medium-resolution remote sensing data are used where these are available; data from resource management agencies are given second priority; and low-resolution remote sensing data are only used where no other fire mapping data are available.

Insect disturbances are monitored by aerial surveys (Table A3–34). The gross annual areas are converted into effective impact areas, which represent the area disturbed excluding unaffected forested areas (non-treed areas or treed areas with non-host species). Effective impact areas are assigned to analysis units and, depending on the insect species, are further broken down by three or four levels of impact severity which differ by the amount of mortality and growth reduction (Kurz et al. 2009).

## Forest Conversion

In order to account for the long residual effects of forest conversion, conversion rates were estimated starting in 1970. The approach for estimating forest areas converted to other uses is based on three main information sources: systematic or representative sampling of remote sensing imagery, records and expert judgement/opinion. The basic methods have been tested in several pilot projects (Leckie 2006a), and the methodology has now been implemented across the country.

The core method involves remote sensing mapping of deforestation on samples from Landsat images dated circa 1975, 1990, 2000 and 2008. Change enhancements between two dates of imagery are produced to highlight areas of forest cover change and identify possible forest conversion events (i.e. "candidate events"). The imagery is then interpreted to determine if the land cover of the candidate event was forest initially (at Time 1) and is a land cover change or land-use change at Time 2 (Leckie et al. 2002, 2010a). This deforestation interpretation process is strongly supported by other remote sensing data, including digitized aerial photographs; snow-covered, leaf-off, winter Landsat imagery; secondary Landsat images from other dates and years; ancillary data, such as maps of road networks, settlements, wetlands, woodland coverage and mine and gravel pit locations; and specialized databases giving locations of oil and gas pipelines and well pads (Leckie et al. 2006). When readily available, detailed forest inventory information is also used.

Change imagery is interpreted and analyzed; each forest conversion event larger than 1 ha is manually delineated. The broad forest type prior to deforestation is interpreted,[14] and the post-deforestation land use recorded ("post-class"). Confidence ratings on the land use at the initial time and a later time period are used in subsequent quality control and field validation procedures.

Monitoring of forest conversion activity covers all forest areas of Canada, and is not limited to the managed forest. The entire forested area of Canada is broadly stratified into regions of expected forest conversion level and dominant cause, which dictate the target sampling intensity. Depending on the expected spatial patterns and rates of forest conversion, sampling approaches ranged from complete mapping, to systematic sampling over the entire analysis unit of interest, to a representative selec-

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13    National Forestry Database, available online at http://nfdp.ccfm.org/about_us_e.php

14    See Chapter 7 for the definitional parameters of "forest".

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Figure A3–9    Forest Conversion Strata and Areas Sampled for the 2011 Submission
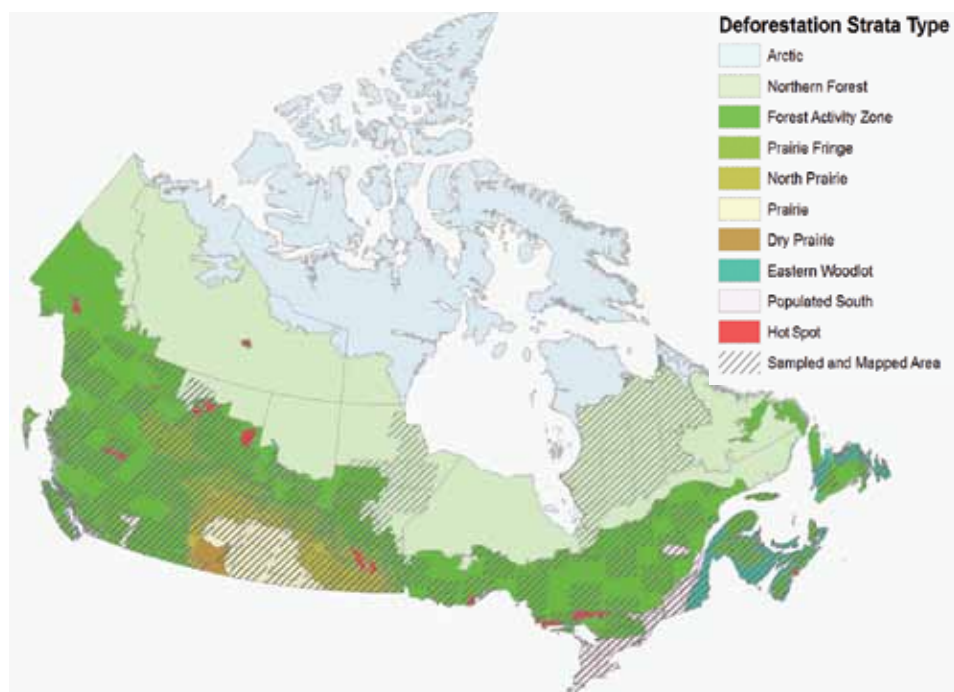


Figure A3–10    Sampling Grids Over Satellite Imagery for Forest Conversion Mapping. Background Imagery: Area Near Kelowna, British Columbia, Landsat TM, Summer 2000

tion of sample cells within a systematic grid. For example, in populated areas of southern Quebec and in the Prairie fringe, a 12% sampling rate was generally achieved, with 3.5 × 3.5-km sample cells at the nodes of a 10-km grid (Figure A3–10). In practice, resource constraints limit the size of the remote sensing sample; wherever possible, a target sampling rate of 12% or 6% was achieved. It is also important to note that different sampling rates may be applied for each time period, in an effort to track differing activity rates between time periods. The total areas, either fully mapped or sampled, cover approximately 346 million hectares (Mha), of which over 16 Mha were mapped for 1975–1990, 40 Mha were mapped for 1990–2000, and 21 Mha were mapped for 2000–2008. Figure A3–9 provides an overview of sampling and mapping for the forest conversion stratification.

Representative samples are used in areas of moderate expected rates of forest conversion (e.g. eastern woodlots in the Maritimes, the Eastern Townships in Quebec, the Lower Mainland of British Columbia, and the south agricultural zone of the Prairies). The forest activity region comprises a large area of Canada with a low population density; the main economic activities consist of forestry and other resource extraction. Again, a representative sampling approach is used, augmented with additional samples (e.g. pilot studies) in Quebec, Ontario and British Columbia. Special cases of known, localized and large forest conversion activities were also identified, such as hydroelectric reservoirs and oil sands development in Alberta. In such cases, the entire areas are handled as single events ("Hot Spot" in Figure A3–9), with spatially complete mapping.

Records were gathered when available. They consist mostly of information on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs (Leckie et al. 2006). The temporal coverage, availability and applicability of these records are assessed to determine the most appropriate information sources (records or imagery). Records data are often used to aid in the validation of estimates made through image interpretation. In particular for British Columbia, records data are used to provide estimates of conversion activity for power lines and oil and gas activity. In northern Quebec, a mix of remote-sensing image interpretation and records data are used to assess the areas of forest converted as a result of hydroelectric development. If the extent of forests affected by land submersion cannot be determined through official records or image interpretation, it is estimated by multiplying the area of land flooded by the proportion of forest cover in

the region surrounding the reservoir, as determined by a Landsat image classification forest cover map (Wulder et al. 2004).

Work with high-resolution imagery has revealed that, although records information may indicate that pipeline right-of-ways are less than 20 metres (m) wide, they are often adjacent to co-disturbance events such as access roads. The resulting total disturbance width is greater than 20m. As a result of this analysis, pipeline records are used in combination with high-resolution sampling to determine the actual impact of pipelines.

Expert opinion is only called upon when remote sensing sampling is insufficient and records data are unavailable or of poor quality. Expert judgement is also used to reconcile differences between records and remote sensing information and to resolve large discrepancies in the 1975–1990, 1990–2000 and 2000–2008 area estimates. In such cases, available expert opinion and data sources are brought together, remote sensing and records data are reviewed, and decisions are made (Leckie 2006b, Leckie et al. 2010b). For most estimates, certainly those where the land-use change categories had the largest impacts, estimates are derived directly from remote sensing samples.

The activity data are compiled and summarized initially by analysis unit. All conversion events are assembled into a database. A compilation is made that summarizes events for detailed post-conversion classes for each reconciliation unit. This compilation process also involves insertion of records data and expert judgement. In the course of these procedures, each event is compiled to yield a local deforestation rate (ha/year) based on the time interval between the images. Since the available imagery was not necessarily dated 1975, 1990, 2000 or 2008, the rates cover different time periods. At the data compilation phase, forest conversion events are assigned to one of three time periods (1975–1990, 1990–2000, 2000–2008), and the corresponding rate of forest conversion is assigned to that period. For example, a 7.0-ha event encountered on imagery from the period 1975–1989 would yield a 0.5 ha/year rate (7.0 ha/14 years) and then would be assigned to the period 1975–1990. The total area interpreted in an analysis unit for that time period is then used to determine a relative rate of forest conversion ((ha/year)/$km_2$ interpreted) for all events of the same type. Relative rates are scaled up for each analysis unit. Data are finally grouped by end-use (e.g. the change rate for agricultural crop or rural residential) and in turn, are summarized by broader

Figure A3–11   Procedure for Developing a Consistent Time Series of Rates of Forest Conversion
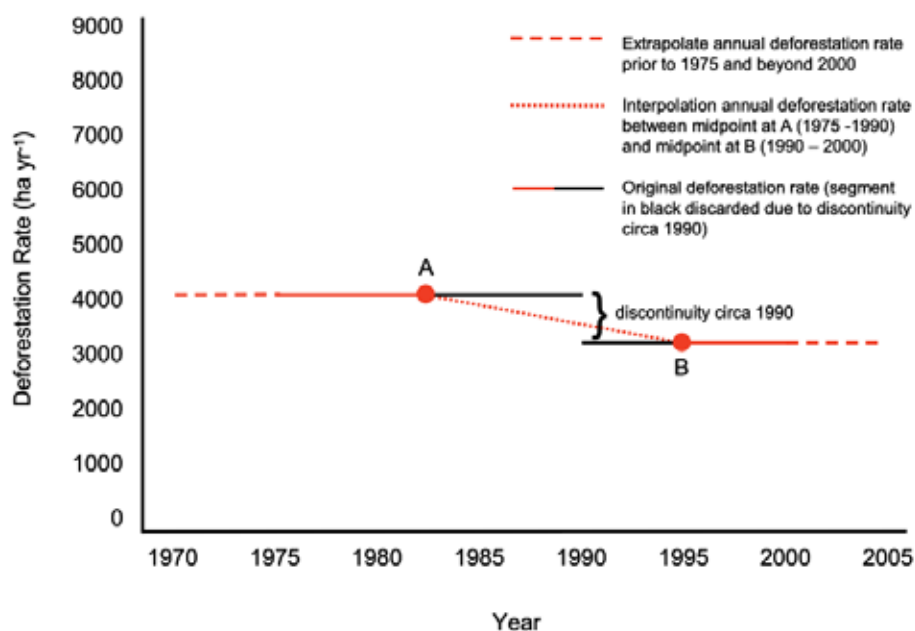


Figure A3–12   Annual Rates of Forest Conversion to Cropland (FLCL) and Forest Conversion to Wetland ([FLWL] reservoir flooding)
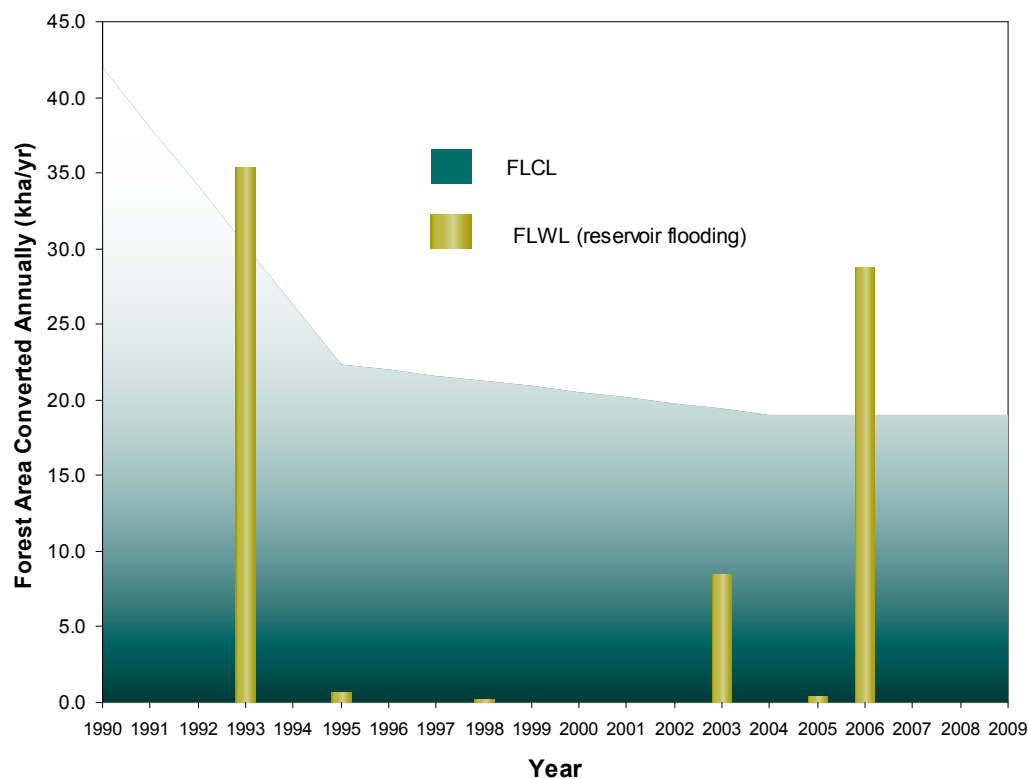
categories when recompiled by reconciliation unit.

The remote sensing data are derived using the imagery from circa 1975, 1990, 2000 and 2008, whereas records data are annual or summarized over time periods. As explained above, the remote sensing core method provides three distinct forest conversion rates—for 1975–1990, 1990–2000 and 2000–2008—but no annual estimates of these rates. The preparation of annual forest conversion rates for 1970–2009 requires the simultaneous application of two procedures: 1) extrapolation of annual rates prior to 1975 and beyond 2008; and 2) interpolation between the 1975–1990, 1990–2000 and 2000–2008 data. In the absence of documented and tested procedures, the simplest approach is to assign the 1975–1990 rate to each year from 1970 to 1983, the 1990–2000 rate to each year from 1983 to 1995, and the 2000–2008 rate to each year from 1995 to 2004. A constant deforestation rate is assumed for the post-2004 period. Information for an additional period will be used to update the process.

A linear interpolation is applied between the three temporal anchor points (1983, 1995 and 2004), which results in an estimate of the annual rate of forest conversion for each intervening year. The procedure is illustrated in Figure A3–11. Noted exceptions to this procedure do occur, and reflect individual large events for which actual disturbance information is known either from records information or detailed mapping activity. One example of this would be the case of hydroelectric reservoirs.

Figure A3–12 displays the annual rates of forest conversion by selected end uses: forest land to cropland (FLCL) and forest land to wetlands (FLWL). The figure helps illustrate the different approaches implemented in developing annual estimates. The conversion to cropland estimate is based on the approach illustrated in Figure A3–11. The estimate of forest conversion to wetlands reflects the use of records and detailed mapping information to account for large unique events. Note that these figures differ from the ones reported in the common reporting format (CRF) tables, which are cumulative areas in the "Land converted to" categories.

### QA/QC of Forest Conversion Data

Great care was taken in understanding the records data, their suitability and their limitations. Documentation of the records data was examined, personnel involved in managing and implementing the data collection and storage were interviewed and, where available, numbers were checked against independent data sources, sampling of high-resolution imagery and the knowledge of experts.

The remote sensing interpretation follows defined procedures (Leckie et al. 2010a), although it is conducted by a variety of organizations, including provincial government forestry or geomatics groups, remote sensing or mapping companies, research and development organizations and in-house government staff. The basic image analysis quality control (QC) process includes internal checks within the mapping agency or company by a senior person; real-time quality assurance (QA) by Canadian Forest Service specialists during interpretation, with feedback provided within days of interpretation of an area; and a final QA or vetting of the interpretation by the Canadian Forest Service. Field validation is conducted on an ongoing basis as resources permit. Each QC point and revision is documented within the Geographic Information System (GIS) database of conversion events (Dyk et al. 2011).

Records of decision as to data used and expert judgement applied, as well as decisions on the resolution of contradictory data, are documented within the overall processing database (Leckie 2006b) and updated for the 2011 submission (Leckie et al. 2010b). Data sources and limitations are recorded, and remote sensing data and interpretations archived.

### Uncertainty of Forest Conversion Data

The development of an uncertainty estimate for forest conversion is a complex and difficult task, because of its spatial and temporal variability. Compared to early ones, current estimates benefit from several years of experience and knowledge gained through the development of previous estimates (Dyk et al. 2010; Leckie 2011). Specific improvements include:

1. Expanded data sets with additional earth observation data, Landsat (MSSS/TM/ETM/Winter), SPOT-5, aerial photography, and high-resolution satellite imagery.

2. Expansion of the sampled area for targeted and other areas.

3. Analysis and validation of records data with high-resolution imagery (for example, co-disturbance of pipelines and access roads).

4. Extending the temporal coverage to the 2000–2008 period, which provides a longer time period to confirm the nature of historical events. This results in

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greater confidence and the reduction of commission and omission[15] errors.

5.   Greater knowledge resulting from increased experience and expertise gained through QC review and validation activity.

These improvements result in enhanced detection, delineation and determination of event size and cause, as well as a more accurate estimate of timing of conversion events.

Two approaches were considered to estimate uncertainties: an empirical approach and an analytical approach. The resulting estimate is based on consideration of these approaches and provides an estimate of uncertainty associated with activity area estimates. The additional sources of uncertainty related to forest type being removed, post-conversion land category and event timing are not considered.

The empirical approach is an attempt to estimate an overall uncertainty in the forest conversion area estimate. This approach provides an overall estimate that considers all of its varied components and their potential interactions.

The empirical estimate was developed by making estimates of extreme low, low, high and extreme high of forest conversion rates for each reconciliation unit and end-use class. These estimates were based on expert knowledge of activity and practices at a regional scale. All of these estimates were then compiled on a national basis. Comparisons between extreme and non-extreme estimates provided some insight into the possible range for which conversion activity could occur. Based on this exercise, an estimate for overall uncertainty for forest conversion was determined to be in the range of ± 20% to ± 30%.

The analytical approach breaks the uncertainty down into subcomponents and then combines these through simple error propagation. The components considered are omission and commission, sampling, and boundary delineation errors.

Omission and commission errors are influenced by a number of factors, but in particular are dependent on the date and quality of pre- and post-imagery. Throughout the time series there is a tendency for omitted events to be smaller in size, whereas commission errors are usually from a misinterpretation rather than an oversight, and thus are

less size-dependent. Commission and omission errors tend to offset each other. For the 2000–2008 time period, commission errors are likely to be greater than omission errors, particularly because of insufficient time lapse to enable post-disturbance conditions to be confirmed.

Uncertainty associated with boundary delineation errors considers the errors resulting from the displacement of the event boundary from the actual or true boundary of the event. Both underestimation and overestimation of area can result. This source of uncertainty is greatly influenced by the quality and resolution of imagery used in the delineation process; improvements made in resolution and image quality reduce this source of uncertainty.

Estimates of sampling uncertainty take into account the uncertainty associated with the sampling process and the scaling of estimates to large regions (strata/reconciliation units). The sampling process is a mixture of wall-to-wall mapping, and regionally focused and systematic sampling. In some areas, the sample coverage and design differed between 1975–1990, 1990–2000 and 2000–2008. The sample error depends on the amount of activity in each region within each time period sampled. In addition, it is dependent on the conversion event size and spatial distribution (Paradine et al. 2004). Uncertainty due to sampling and scaling activity is therefore regionally variable, and, because conversion activity causes may vary by region, the uncertainty is variable.

The results of this analytical approach are consistent with those made based on an empirical approach. Based on these efforts, a conservative estimate is taken, which sets the uncertainty at the higher range of ± 30%. Further work will help improve the current understanding of the various sources of uncertainty, their interaction, and approaches used to combine these components.

This ± 30% uncertainty about the estimate of the total forest area converted annually in Canada places, with 95% confidence, the true value of this area for 2009 as being between 31 and 57 kha. This is an overall estimate considering all time periods, regions and deforestation types. Caution should also be exercised in applying the 30% range to the cumulative area of Forest Land converted to another category over the last 20 years (land areas reported in the CRF tables).

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15   Omission errors are the result of missing true conversion events, and commission errors are the result of including non-conversion disturbances (e.g. forest harvest, burns, beaver flooding).

## Planned Improvements in Forest Conversion

Planned improvements will be incremental, with an emphasis on reducing uncertainties and improving specific estimates. Improvement strategies combine a greater sample coverage, expanded records compilation, improved information processing and system documentation, and additional field verification. Initial image collection and compilation as well as record gathering are underway, to enable extending of estimates for the post-2008 period.

## Land Converted to Forest Land

Records of land conversion to forest land in Canada were available for 1990–2002 from the Feasibility of Afforestation for Carbon Sequestration (FAACS)[16] initiative (White and Kurz 2005). Conversion activities for 1970–1989 and 2003–2008 were estimated based on activity rates observed in the FAACS data. Additional information from the Forest 2020 Plantation Demonstration Assessment[17] was included for 2004 and 2005, and an environmental scan was performed to identify additional sources of information on afforestation rates during 2000–2008. Each event, regardless of date, source, type or location, was converted to an inventory record for the purposes of carbon modelling. All events were compiled in a single data set of afforestation activity in Canada from 1970 to 2008. No new afforestation activity data were identified for the 2009 inventory year. Renewed efforts are underway to obtain additional data on recent afforestation activities in Canada.

For 1990–2008, the area planted was stratified by ecozone, province and species. Total area planted by province and ecozone, in conjunction with the proportion of species planted for each province, was used to calculate area planted by species, resulting in estimates of the area converted to forest, by species, for each reconciliation unit.

Yield curves are not always available for some plantation species or growing conditions (stocking level or site history); those used to estimate growth increments were taken from a variety of sources, most often directly from provincial experts. Where species do not have their own yield curve, they are given the yield curve of another species with similar growth characteristics or the species most likely to have been present in that area. Changes in soil carbon stocks are highly uncertain because of difficulties

in locating data about the carbon stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil carbon at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land-use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

### A3.4.2.3. Estimation of Carbon Stock Changes, Emissions and Removals

At the beginning of each annual time step, the CBM-CFS3 first assigns land-use change activities to inventory records and redistributes these records to ensure that the impacts of land-use change (conversion to forests and conversion of forests) are reported in the new land category. Forest disturbances are simulated only after the land-use conversions have been completed. The selection of forest stands affected by land-use change and non–land-use change disturbances is based on eligibility rules (Kurz et al. 2009).

Once the model has computed the immediate effect of disturbances on all forest stands, it applies the sets of carbon transfers associated with annual processes to all records (managed forest, land converted to forest and land converted from forest), including both stocked and non-stocked stands. As explained above, annual processes combine growth, turnover and decay processes, applied to the entire area of managed forests. The outputs consist of the net GHG balance of managed forests, including growth; immediate emissions due to disturbances (carbon stock changes, carbon losses to the atmosphere and to forest products); and decay of both DOM and soil organic matter, including on stands affected by disturbances. During this stage, inventory records that have been in a "Land converted to" category for 20 years are converted into the "Land remaining" category and the simulation of C dynamics—usually decay—continues in this new category.

The same data output is available on converted forest lands (except tree growth), but is reported in the new land category—e.g. the Land converted to cropland (CRF Table 5.B Row 2), Land converted to wetlands (CRF Table 5.D Row 2), and Land converted to settlements (CRF Table 5.E Row 2) categories. Exceptions consist of estimates of soil organic matter emissions on forest land converted to cropland and peatlands, which are developed separately; methods are described in Sections A3.4.3.3 and A3.4.5.1. Likewise, estimation methods for emissions (as opposed to carbon stock changes) from forest land converted to flooded lands

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16   http://cfs.nrcan.gc.ca/subsite/afforestation/feasibilityafforestation

17   http://cfs.nrcan.gc.ca/subsite/afforestation/forest2020pda/forest-2020pda

Table A3–35    GHG Fluxes To and From Managed Forests, 2009

| Process/Event | GHG Balance (Gg $CO_2$ eq)[1] | | | | |
|---|---|---|---|---|---|
| | Biomass | DOM | Soil | $N_2O$[3] | Ecosystem Net Balance |
| Annual processes | -2 935 937 | 2 110 868 | 614 158 | 0 | -210 910 |
| Harvesting | 105 687 | 15 929 | 0 | 345 | 121 961 |
| Wildfires | 13 652 | 56 423 | 0 | 3 117 | 73 192 |
| Insects[2] | 12 | 0 | 0 | 0 | 12 |
| Total | -2 816 587 | 2 183 220 | 614 158 | 3 462 | -15 746 |

Notes:
1. On a C pool basis, exchanges of GHGs with the atmosphere are not equal to C stock changes.
2. "0" emissions indicate that events do not cause emissions to, or removals from, the atmosphere. Rather, they kill biomass that is transferred to DOM.
3. Carbon in $CH_4$ and CO emissions is included in each pool's assessment, but $N_2O$ emissions are computed separately from total $CO_2$ emissions (see Annex 8).

are described in Section A3.3.5.2.

Note that the immediate effect of disturbances is identifiable in the output data sets for the year of the disturbance. In subsequent years, post-disturbance emissions and removals are simulated as annual processes. The CBM-CFS3 does not distinguish post-disturbance processes from other processes affecting ecosystem C; hence, the long-term impact of disturbances in the managed forests cannot be fully identified.

Table A3–35 gives 2009 estimates of the broad components of the GHG emissions and removals in managed forests generated by the CBM-CFS3. The largest fluxes are carbon uptake by biomass and its release by DOM decay (from heterotrophic respiration). The first is largely influenced by the age-class distribution of the managed forests; organic matter decay is controlled by input from litter fall, mortality and post-disturbance decay. Insect disturbances cause very limited immediate emissions; however, depending on the severity of infestations and insect damage, they may result in 1) reductions in C uptake through growth reductions, 2) large carbon transfers from biomass to DOM and 3) alterations in the long-term trend of organic matter decay (Kurz et al. 2008a).

## A3.4.2.4.    Uncertainties

Good practice recommends the use of numerical methods for assessing uncertainties within complex modelling frameworks with multiple interactions between data and parameters. These methods are data-intensive; computational requirements can quickly become a limiting factor. Not all model parameters or input data have equal influence on model outputs; careful consideration must therefore be given to balance available computing capacity and the inclusion in the uncertainty assessment of input data, parameters and other functions with a large influence on model outputs.

Compared to the previous submission, the uncertainty analysis reported here has been enhanced by allowing more parameters to vary, and adding randomization steps to determine confidence intervals. The general approach to uncertainty assessment remains the same, emphasizing model inputs and parameters as the main sources of uncertainty. The two main uncertainty sources already discussed in previous submissions are forest inventory data and key model parameters. In this assessment, a third one was added: the initialization of soil and dead organic matter C stocks prior to model runs. Additional randomization steps were also fed into the development of confidence intervals, by randomly selecting 10 000 bootstrap samples of the Monte Carlo run outputs. The following paragraphs provide details on the characterization of uncertainty sources.

The forest inventory data used in model simulations are developed for planning and operational purposes. Methods, standards, definitions and quality differ by jurisdiction, depending on their objectives. Although documentation on the different inventory techniques and procedures used across the country is usually available, it seldom contains any quantitative assessment of uncertainty. While it is currently impossible to quantify uncertainties about, for example, managed forest areas, the influence of this uncertainty source can be indirectly built into the uncertainty about the biomass increment simulated by the model. For the purpose of this assessment, a 50% uncertainty about

biomass increment was assumed; in addition to managed forest areas, it incorporated uncertainties about the age-class distribution, yield curves and allometric equations that enter the estimation.

The areas of managed forests affected annually by both natural and anthropogenic disturbances have a large influence on the forest carbon dynamics as a whole. Disturbances affect emissions and removals of C in the short term, and in the long term through residual decay and age-class distribution. Uncertainties of 10% and 25% were assumed on the areas of managed forests subject annually to wildfires and insect infestations respectively.

The uncertainty about the carbon removed in harvested material was spatially refined; it also incorporated error ranges in harvested volume (± 1%), and standard deviations about roundwood specific gravity and bark adjustment factor (Table A3–36). No error was assumed for the carbon proportion of biomass. The annual coefficient of variation was multiplied by 2 to approximate a normal distribution with a triangular one.

Table A3–36   Uncertainty Ranges for Harvested Carbon, by Canadian Province and Territory Source: Metsaranta et al. (2011)

| Province/Territory | Minimum Multiplier | Maximum Multiplier |
|---|---|---|
| Alberta | 0.9 | 1.1 |
| British Columbia | 0.92 | 1.08 |
| Newfoundland | 0.96 | 1.04 |
| Manitoba | 0.86 | 1.14 |
| New Brunswick | 0.92 | 1.08 |
| Northwest Territories | 0.74 | 1.26 |
| Nova Scotia | 0.88 | 1.12 |
| Ontario | 0.92 | 1.08 |
| Prince Edward Island | 0.88 | 1.12 |
| Quebec | 0.86 | 1.14 |
| Saskatchewan | 0.92 | 1.08 |
| Yukon | 0.84 | 1.16 |

As the assessment also provided uncertainties about emissions due to forest conversion, a 30% uncertainty about areas converted annually was used. The "Forest Conversion" section of this annex describes the derivation of this value.

Soil and other slow-decaying DOM pools contain a considerable amount of carbon. Previous work had shown that the initial DOM C stocks, at the beginning of a complete

run, are sensitive to historical disturbance rates. In this assessment, initial C stocks in the soil and DOM pools were allowed to vary by modifying the historical (pre-1990) fire return intervals. Even though the rates of soil organic matter decay modelled by the annual processes are very low, they do, by virtue of the pool size and forest areas, strongly influence emissions from annual processes. A sensitivity analysis of carbon emissions from the dead organic matter and soil pools revealed that the most influential model parameters included decay rates for soil organic matter, and the decay and release to the atmosphere of carbon from very-fast cycling pools, such as dead fine roots and litter (White et al. 2008).

For the purpose of this analysis, 28 model parameters were allowed to vary in the Monte Carlo runs:

- Base decay rates for DOM pools (11 parameters)
- Proportion of decayed material that is oxidized, versus that which is transferred to another DOM pool (5 parameters)
- Turnover rates for biomass pools (12 parameters)

In the absence of evidence to support more complex functions, all input probability distribution functions for biomass increments, activity data on human and natural disturbances and decay parameters were triangular. A gamma probability distribution function was used for fire intervals (Metsaranta et al. 2011).

Significant uncertainty in the modelling framework results from the random selection of forest stands subject to disturbances (Kurz et al. 2008b), which interacts with the uncertainty about forest inventory data. The random effect of stand selection algorithms was included in the analysis, by allowing different seed values to initiate the random selection algorithms.

It is important to note the interactions between input data and parameters. For example, the uncertainty about the age of a forest stand (or age-class structure of a forest landscape) may affect the simulated stand (or landscape) productivity, depending on the yield curves and the particular locations of a given age category along those curves. Emissions due to disturbances—including the conversion of forests to other land categories—are driven not only by the areas affected, but also the pre-conversion standing carbon stocks, the parameters of the disturbance matrices that re-allocate carbon among pools or "release" it to the atmosphere, and the post-conversion decay rates. Hence, uncertainties about estimates cannot be obtained from a

Figure A3–13    Uncertainty Range of Net FLFL CO$_2$ Flux (Full Thin Lines), the Median Value of the 100 Monte Carlo Runs (Dashed Line), and the Estimates of the 2011 Submission (Full Thick Line) for Each Inventory Year in the 1990–2009 Time Series. Source: Metsaranta et al. (2011)
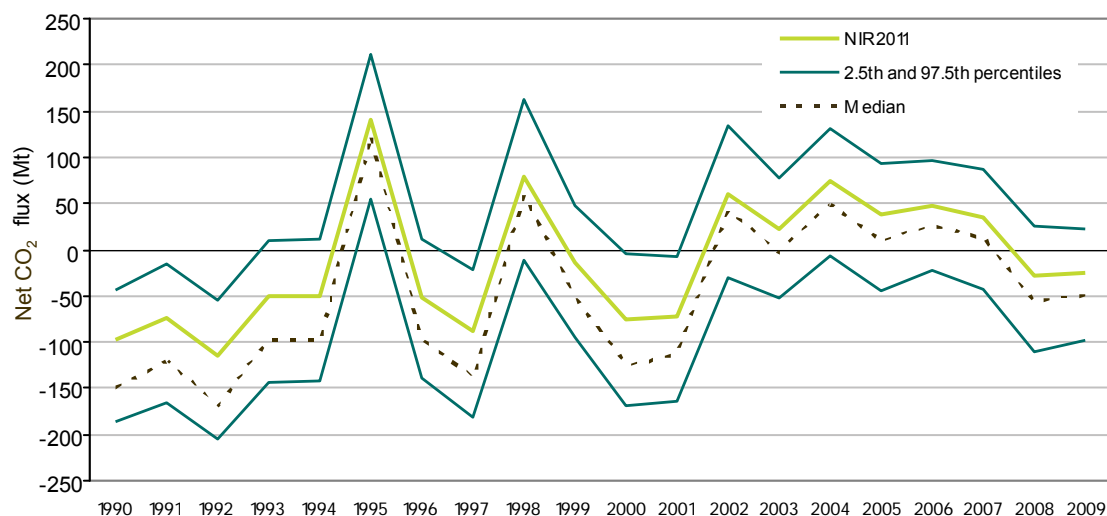


simple combination of "activity data" and "emission factor" uncertainties.

This is the second uncertainty assessment about the net GHG flux estimates for managed forests in Canada. Resulting uncertainty ranges were provided in Chapter 7, and are illustrated below for net CO$_2$ fluxes in Forest Land remaining Forest Land (Figure A3–13). These ranges are generally wider than in the previous submission, because more factors were randomized and error ranges were revised, and because of the additional randomization step due to the re-sampling of run outputs. In some instances, notably forest conversion, the uncertainty about GHG estimates increased even though error ranges about areas were reduced from 38% to 30%.

Not all uncertainty sources have been captured: importantly, the analysis did not consider the impact of processes that are currently not simulated. Hence, the results should not be used to assess potential bias (or accuracy) of estimates. Additional considerations may be warranted to identify the direct human-induced effects, and their uncertainties, on forest carbon dynamics. Improvements are expected to occur over coming years, due to better knowledge, refined procedures and access to more computing capacity.

## A3.4.3.    Cropland

The methodologies described in this section apply to carbon stock changes in mineral soils subject to cropland management and to the conversion of land in the Forest and Grassland categories to the Cropland category; CO$_2$ emissions from liming; CO$_2$ emissions from the cultivation of histosols; changes in the biomass of woody perennial crops; and N$_2$O emissions from soil disturbance upon conversion to cropland. The estimation methodologies for carbon stock changes and GHG emissions from the biomass and DOM pools upon conversion of forest land to cropland are provided in Section A3.4.2.3.

### A3.4.3.1.    Cropland Remaining Cropland

A detailed description of the methodologies used for this category can be found in McConkey et al. (2007a).

**Change in Carbon Stocks in Mineral Soils**

*Changing Management Practices*

The amount of organic carbon retained in soil represents the balance between the rates of input from crop residues and losses through soil organic carbon (SOC) decomposition. How the soil is managed determines whether the amount of SOC stored in a soil is increasing or decreasing. The IPCC (2003) approach, which guided the development of the CO$_2$ estimate methodology, is based on the

premise that, on long-existing cropland, changes in soil C stocks over time occur following changes in soil management that influence the rates of either C additions to, or C losses from, the soil. If no change in management practices occurs, the C stocks are assumed to be at equilibrium, and hence the change in C stocks is deemed zero.

A number of management practices are generally known to increase SOC in cultivated cropland, such as reduction in tillage intensity, intensification of cropping systems, adoption of yield-promoting practices and re-establishment of perennial vegetation (Janzen et al. 1997; Bruce et al. 1999). Adoption of reduced tillage (RT) or no-till (NT) can result in significant accumulation of SOC compared with intensive tillage (IT) (Campbell et al. 1995, 1996a, 1996b; Janzen et al. 1998; McConkey et al. 2003). Many cropping systems can be intensified by increasing the duration of photosynthetic activity through a reduction of summerfallow (Campbell et al. 2000, 2005; McConkey et al. 2003) and greater use of perennial forage (Biederbeck et al. 1984; Bremer et al. 1994; Campbell et al. 1998). Intensification of cropping systems not only increases the amount of C entering the soil, but may also reduce decomposition rates by cooling the soil through shading and by drying the soil. Conversely, switching from conservative to conventional tillage or from intensive to extensive cropping systems will generally reduce C input and increase organic matter decomposition, thereby reducing SOC.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management practices on SOC. This compendium, as well as the availability of activity data from the *Census of Agriculture*, provided the basis for identifying key management practices and management changes used to estimate changes in soil C stocks. Emissions and removals of $CO_2$ from mineral soils are estimated for the following land management changes (LMCs):

1.  Change in mixture of crop type
    a)  Increase in perennial crops
    b)  Increase in annual crops
2.  Change in tillage practices
    a)  IT to RT
    b)  IT to NT
    c)  RT to IT
    d)  RT to NT
    e)  NT to IT
    f)  NT to RT

3.  Change in area of summerfallow
    a)  Increase in area of summerfallow
    b)  Decrease in area of summerfallow

Where nutrients are greatly limiting, proper fertilization can increase SOC; in such conditions, however, fertilizer or other nutrient-enhancing practices are generally applied. Irrigation in semi-arid areas can affect SOC, but the impact is unclear, and the area of irrigated land has been relatively constant in Canada. Therefore, it is assumed that the selected LMCs represent the most important and consistent influences on SOC in mineral soils.

## Carbon Stock Change Factor

To estimate C emissions or removals, an SOC stock change factor specific to each combination of Soil Landscapes of Canada (SLC) polygon (the analysis unit) and management change is multiplied by the area of change. The factor is the average rate of SOC change per year and per unit of area of LMC.

Equation A3–50:

$$\Delta C = F \times A$$

where:

| | | |
|---|---|---|
| $\Delta C$ | = | change in SOC stock for inventory year, Mg C |
| F | = | average annual change in SOC subject to LMC, Mg C/ha/year |
| A | = | LMC area, ha |

Areas of LMC such as changes in tillage, crop type and fallow are obtained from the *Census of Agriculture*. Census data provide information on the net change in area over five-year census periods. In practice, land probably both enters and leaves a land management practice, and combinations of management changes occur. However, because only net change data are available, two assumptions are made: additivity and reversibility of SOC factors. Reversibility assumes that the factor associated with an LMC from A to B is the opposite of that associated with the LMC from B to A. Additivity assumes that the C changes from each individual LMC occurring on the same piece of land are independent and therefore additive. This assumption is supported by the findings of McConkey et al. (2003), who reported that the impact of tillage and crop rotations on SOC is generally additive.

Figure A3–14    Method for Deriving Carbon Factors for Land Management Change of Interest
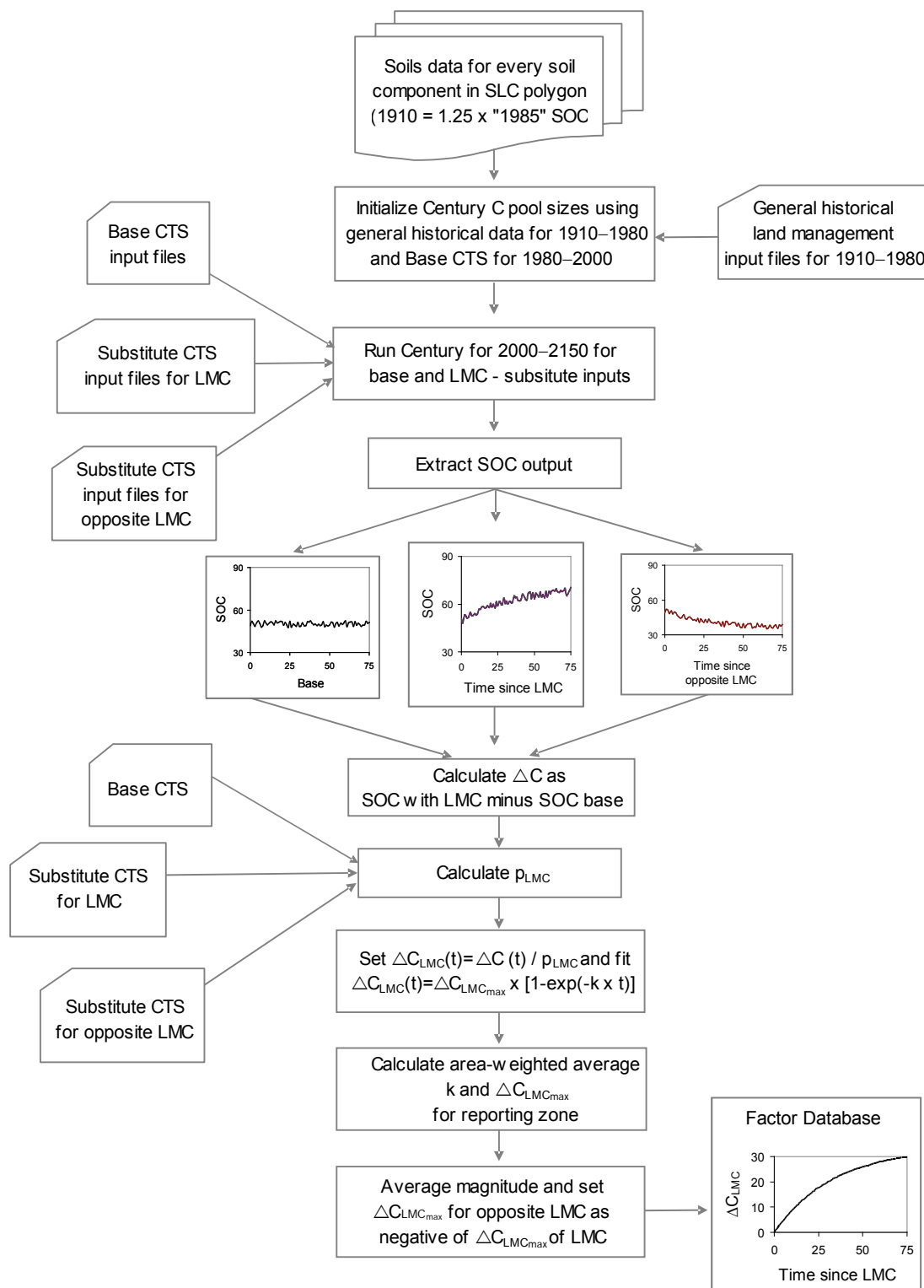


There is a relatively large set of Canadian observations of long-term changes in SOC for LMCs such as adoption of NT and reduced frequency of summerfallow (VandenBygaart et al. 2003; Campbell et al. 2005). However, even this large data set does not cover the whole geographical extent of Canadian agriculture. In addition, there are difficulties in comparing measurements among research sites, in determining the duration of an effect, in estimating full

Figure A3–15   Method for Deriving Land Management Input Files to Use with Century Model to Estimate the Carbon Factor for a Land Management Change of Interest
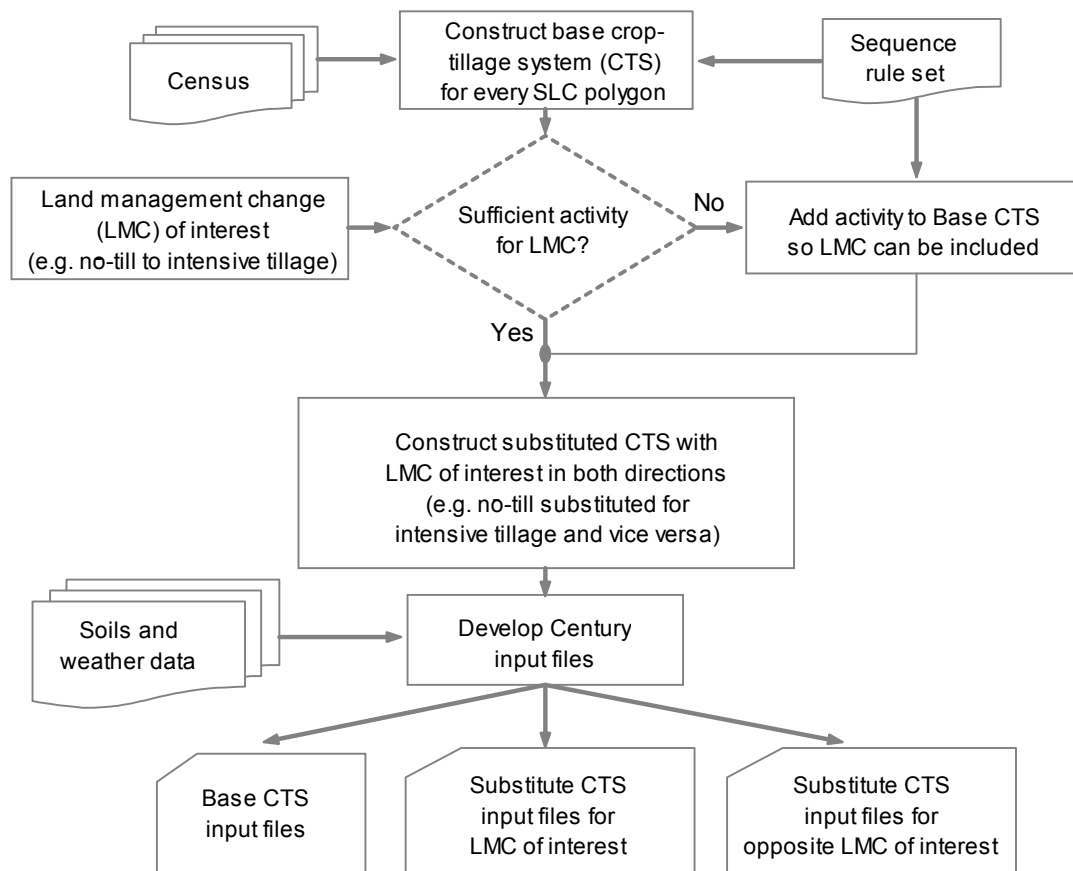


uncertainty from a range of initial soil conditions, and in determining the variability of soil C stocks without management change.

Because of these limitations, a well-calibrated and validated model of SOC dynamics, the Century model (Parton et al. 1987, 1988), is used to derive individual SOC factors for changes between NT and IT, RT and IT, RT and NT, annual and perennial crops, and area of summerfallow. The Century model has been widely used to simulate SOC change for Canadian conditions (Voroney and Angers 1995; Liang et al. 1996; Monreal et al. 1997; Campbell et al. 2000, 2005; Pennock and Frick 2001; Carter et al. 2003; Bolinder 2004).

Smith et al. (1997, 2000, 2001) developed an approach using the Century model to estimate SOC change on agricultural land in Canada. To estimate C change, it was necessary to develop a generalized description of land use and management from 1910 onwards on cropland for a sample of soil types and climates across Canada. These scenarios

were generated from a mixture of expert knowledge and agricultural statistics of land management, including crop types, fallow and fertilizer application (Smith et al. 1997, 2000). These have been used for the first comprehensive assessments of SOC change on agricultural land within a broader assessment of soil health (McCrae et al. 2000).

The general method for developing factors is outlined in Figure A3–14 and Figure A3–15. The starting points were the SOC values in the SLC polygon attribute database (CanSIS). These database SOC values were derived from measurements made for soil surveys and land resource studies (Tarnocai 1997) and were assumed to represent average SOC on cropland in 1985. Initial SOC in 1910 was estimated as 1.25 times the SOC in the SLC polygon. Changes in SOC factors were estimated using the difference in SOC stocks over time between simulation of a generalized land use and management scenario with and without the LMC of interest (Smith et al. 2001).

A 10-year crop-and-tillage system (CTS) was developed for each analysis unit and census year, using data from

the *Census of Agriculture*. The CTS focused on seven crops or crop types (grain, oilseeds, pulses, alfalfa, root crops, perennial crops and summerfallow) and three tillage practices (IT, RT and NT). Essentially, each CTS represents a mix of crops and tillage practices in space as a mix of crops and tillage practices in time. Under this scheme, a polygon with 20% of cropland area in grain and 20% of cropland area in NT, for example, has 2 of 10 years in grain and 2 of 10 years in NT. Temporal sequences of crop and tillage practices are developed from expert-defined rule-sets, such as "summerfallow never follows summerfallow" and "corn typically follows soybeans." The construction allows a base CTS and substitutions of LMCs in the CTS to be readily input to the Century model.

The SOC change factor is determined as Factor = (C for CTS with LMC – C for base CTS) / [(fraction of CTS substituted with the LMC) × (duration considered)]. If a land management system is defined as a particular mix of crops and tillage practices on a specified land area, a change in SOC due to an LMC ($\Delta C_{LMC}$) can be estimated as the difference in SOC stock between two land management systems divided by the proportion of the land area subject to an LMC.

Equation A3–51:

$$\Delta C_{LMC}(t) = \frac{\Delta C}{p_{LMC}}$$

where:

| | | |
|---|---|---|
| $\Delta C_{LMC}(t)$ | = | the difference in SOC between land management systems from year to year (Mg SOC/ha) |
| $p_{LMC}$ | = | the proportion of the land area under a given land management system subject to the LMC |

This proportion ($p_{LMC}$) can be derived as the proportion of the particular LM in the base system less the amount of the LM in the new system after the LMC. That is,

Equation A3–52:

$$p_{LMC} = p_{LMbase} - p_{LMnew}$$

where:

| | | |
|---|---|---|
| $p_{LMbase}$ | = | the proportion of the base land management system |
| $p_{LMnew}$ | = | the proportion of the new land management system |

The following provides an example of Century runs for a Lethbridge loam (Orthic Dark Brown Chernozem) in the Semi-arid Prairies reporting zone. A base model run was

Figure A3–16    Soil Organic Carbon (SOC) for a Base Crop Mix, for Perennial (Alfalfa) Substituted for Annual Crops (Wheat), and for No-Till (NT) Substituted for Intensive Till (IT) Based on Century Runs for a Lethbridge Loam
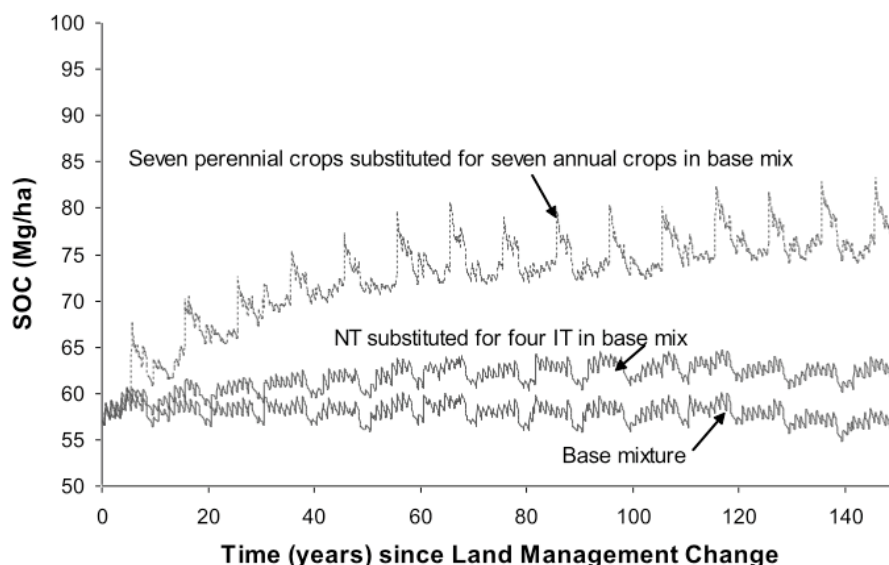
Figure A3–17    Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix
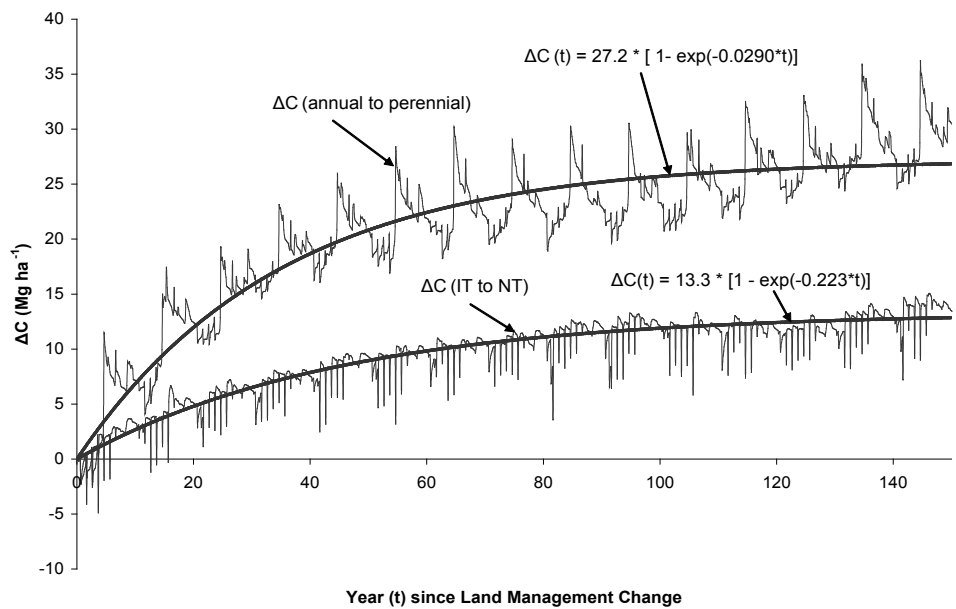


made using a 10-year base mix of crops based on the *1996 Census of Agriculture* and weather data covering the years 1951–2001. Century simulations of SOC were made by substituting perennial crops for the seven annual crops out of ten in the base mixture. As a separate exercise, NT was substituted for IT four years out of ten in the base mixture (Figure A3–16). The next step was to calculate the $\Delta C_{LMC}(t)$ function by subtracting the simulated SOC values for the base mix values from those imposed by the LMC of interest (Equation A3–51). Finally, the $\Delta CLMC(t)$ was calculated as the proportion of area of farming system divided by the pLMC (Equation A3–52); Figure A3–17 illustrates the time series of $\Delta C_{LMC}$. In this particular case the respective values of pLMC for the IT to NT reduction and for the addition of perennial crops were 4/10 and 7/10.

SOC dynamics are believed to be governed by first-order kinetics, and thus C change can be expressed as

Equation A3–53:

$$\Delta C_{LMC}(t) = \Delta C_{LMCmax} \times [1 - exp^{(-k \times t)}]$$

where:

| | | |
|---|---|---|
| $\Delta C_{LMCmax}$ | = | the maximum SOC change induced by the LMC |
| K | = | the rate constant |
| t | = | year |

In practice, the exponential equations are fit statistically using standard statistical analysis software by methods of least squares. The slope of the exponential equation has units of Mg C/ha per year and is the instantaneous factor value. Since the estimation is based on annual changes, the equation used for estimating the factor for annual change from the previous year (i.e. from year t−1 to year t) is

Equation A3–54:

$$F_{LMC}(t) = \Delta C_{LMCmax} \times [exp^{(-k \times [t-1])} - exp^{(-k \times t)}]$$

Since perfect steady-state conditions are never reached, the exponential equation should theoretically apply forever. In practice, however, the exponential equation was truncated when the $F_{LMC}(t)$ dropped to 25 kg C/ha per year. This rate was below a practical measurement limit (Figure A3–18).

## Estimating Mean k and $\Delta C_{LMCmax}$ for Practical Factor Calculations

The $\Delta C_{LMCmax}$ and k parameters were determined for all 11 602 soil components of the CanSIS database and three LMCs (changes in tillage practices, summerfallow and annual-perennial crop mix). These soil components repre-

Figure A3–18    Carbon Factors as a Function of Time
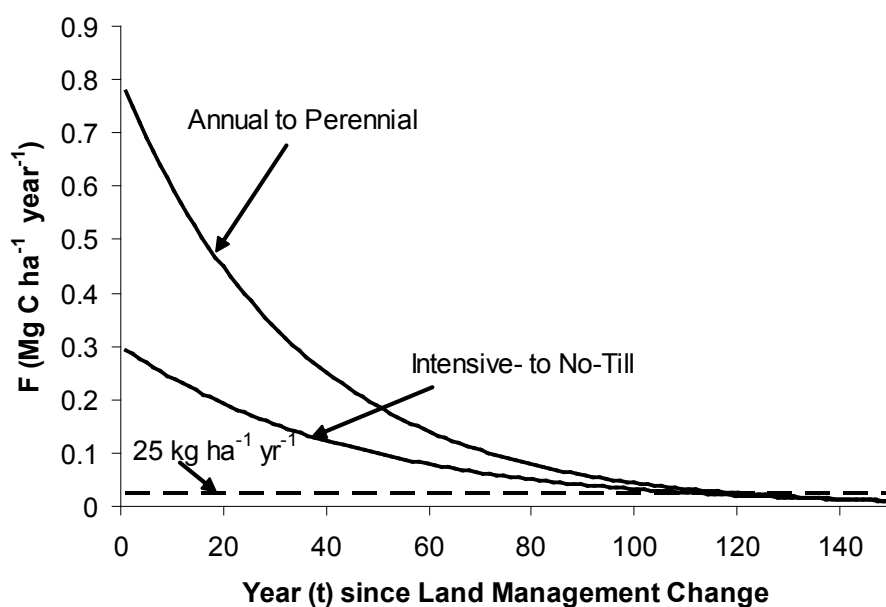


sented a wide range of initial SOC states and combinations of base crop mixtures and amounts of substitutions. The parameter values were estimated for each reporting zone as the mean across these soil components, weighted by area of agriculture on each component (Table A3–37). The geometric mean was used for k, since its distribution was positively skewed. These means were calculated by three general soil texture classes (sandy, loamy and clayey) and applied to each soil component based on its textural class. Occasionally, k values less than 0 or greater than 0.15 resulted from the fit to $\Delta C_{LMC}$; the k and $\Delta C_{LMCmax}$ from these fits were excluded from the reporting zone means.

The dynamics of SOC change in summerfallow have been well studied in Canada. Therefore, rather than using the value for $\Delta C_{LMCmax}$ from the Century simulations, the $\Delta C_{LMCmax}$ value was set so that F was 0.15 Mg C/ha per year (Campbell et al. 2005) at 20 years based on a $p_{LMC}$ of 0.5 (for example a change from 50% fallow to no use of fallow). The k value was derived from the Century simulations as described above.

Generally, rates of SOC losses may be expected to be greater upon an LMC than rates of SOC gain upon the reverse LMC. However, this effect depends greatly on the relative SOC amount at the time of the LMC. Documenting SOC at the time of all LMCs is currently impossible; hence for transparency and simplicity the reversibility assumption was imposed, which requires that the SOC effect of an LMC

in one direction is exactly the negative of the SOC effect of the practice change in the opposite direction.

## Soil Carbon Factor Validation

SOC change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). They showed that empirical data comparing SOC change between IT and NT were highly variable, particularly for eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. The mean IT-NT factor for experiments in the Subhumid Prairies reporting zone was over four times that of the Semi-arid Prairies reporting zone. The mean Century model–derived factor for the Semi-arid Prairies reporting zone was similar to the factor derived from the field experiments. However, the Century-derived IT-NT factor for the Subhumid Prairies reporting zone was about 30% lower than the factor derived from the field experiments.

When considering the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, and this compared favourably with the range of 0.46–0.56 Mg SOC/ha per year in the modelled factors in the Parkland, Semi-arid Prairies and West reporting zones (Table A3–37). In eastern Canada, only two empirical change factors were available in the East Central reporting zone, but they appeared to be in line with the modelled values (0.60–1.07 Mg SOC/ha per year empirical versus

Table A3–37    Generalized Values of Parameters for $F_{LM}C(t) = \Delta C_{LMCmax} \times [1 - \exp^{(-k \times t)}]$ to Predict Change from Land Management Change (LMC) and Effective Linear Coefficients of SOC Change

| Zone[1] | LMC[2] | $\Delta_{CLMCmax}$ (Mg/ha) k/year | Final Year of Effect after LMC[3] | Mean Annual Linear Coefficient over Duration of Effect of LMC (Mg/ha per year) | Mean Annual Linear Coefficient over First 20 years after LMC (Mg/ha per year) |
|---|---|---|---|---|---|
| East Atlantic | IT to NT | 0.0216 | 3.5 | 52 | 0.05 | 0.06 |
|  | IT to RT | 0.0251 | 2.4 | 36 | 0.04 | 0.05 |
|  | RT to NT | 0.0233 | 1.1 | 1 | 0.03 | 0 |
|  | Decrease fallow | 0.0305 | 13.1 | 91 | 0.14 | 0.3 |
|  | Increase perennial | 0.0217 | 43.4 | 167 | 0.25 | 0.77 |
| East Central | IT to NT | 0.025 | 5 | 65 | 0.06 | 0.1 |
|  | IT to RT | 0.0261 | 1.9 | 25 | 0.04 | 0.04 |
|  | RT to NT | 0.0255 | 3.2 | 46 | 0.05 | 0.06 |
|  | Decrease fallow | 0.0305 | 13.1 | 91 | 0.14 | 0.3 |
|  | Increase perennial | 0.0247 | 38.2 | 147 | 0.25 | 0.74 |
| Parkland | IT to NT | 0.0286 | 6.5 | 70 | 0.08 | 0.14 |
|  | IT to RT | 0.0242 | 2.8 | 41 | 0.04 | 0.05 |
|  | RT to NT | 0.0263 | 3.7 | 51 | 0.05 | 0.07 |
|  | Decrease fallow | 0.0305 | 13.1 | 91 | 0.14 | 0.3 |
|  | Increase perennial | 0.0233 | 29.4 | 142 | 0.2 | 0.55 |
| Semi-arid Prairies | IT to NT | 0.0261 | 4.9 | 63 | 0.06 | 0.1 |
|  | IT to RT | 0.0188 | 2.3 | 30 | 0.03 | 0.04 |
|  | RT to NT | 0.0222 | 2.5 | 37 | 0.04 | 0.05 |
|  | Decrease fallow | 0.0305 | 13.1 | 91 | 0.14 | 0.3 |
|  | Increase perennial | 0.0281 | 26.1 | 120 | 0.21 | 0.56 |
| West | IT to NT | 0.0122 | 4.8 | 69 | 0.04 | 0.05 |
|  | IT to RT | 0.0116 | 0.8 | 0 | 0 | 0 |
|  | RT to NT | 0.0119 | 3.9 | 53 | 0.03 | 0.04 |
|  | Decrease fallow | 0.0305 | 13.1 | 91 | 0.14 | 0.3 |
|  | Increase perennial | 0.0155 | 34.4 | 198 | 0.17 | 0.46 |

Notes:

1. Area-weighted summary: East Atlantic is the Atlantic Maritime reporting zone plus the Boreal Shield reporting zone in Newfoundland and Labrador; East Central is the Mixedwood Plains reporting zone plus the Boreal Shield East reporting zone in Ontario and Quebec; Parkland is the Subhumid Prairies, Boreal Shield West and Boreal Plains reporting zones plus those parts of the Montane Cordillera reporting zone with agricultural activity contiguous to agricultural activity within the rest of the Parkland zone; and West is the Pacific Maritime reporting zone plus the Montane Cordillera reporting zone excepting that portion of the latter that is included in the Parkland zone as described above.
2. For LMCs in the opposite direction to that listed, the $F_{LMCmax}$ will be the negative of the value listed.
3. No further C change once the absolute value of the rate of change is less than 25 kg C/ha per year.

0.74–0.77 Mg C/ha per year modelled).

For conversion of crop fallow to continuous cropping, the rate of C storage was more than double the average rate of $0.15 \pm 0.06$ Mg/ha per year derived from two independent assessments of the literature. This difference led to the decision to use empirically based factors for changes in summerfallow in the inventory.

### Estimates of Change in Soil Carbon Stocks

SOC changes as a result of LMC were reported for 1990–2009. Because the effect of LMCs declines over time, a vintage or time when change was deemed to have occurred is maintained for each LMC. The C change factor was multiplied by the area of LMC and summed across soil components to produce an estimate of SOC change for the SLC polygon. This is the smallest georeferenced unit of SOC stocks and SOC stock changes, with accounting using an IPCC Tier 2 approach as follows:

Equation A3–55:

$$\Delta C_{LMC} = \sum_{1951-2009} \sum_{ALL\ SLC} (\Delta C_{TILL} + \Delta C_{SF} + \Delta C_{CROPPING})$$

where:

$\Delta C_{LMC}$ = change in SOC stocks due to LMC for a specific year since 1951

$\Delta C_{TILL}$ = change in SOC stocks due to change in tillage practices from each SLC, since each particular tillage change

$\Delta C_{SF}$ = change in SOC stocks due to the change in summerfallow in each SLC

$\Delta C_{CROPPING}$ = change in soil C stocks due to the change in annual and perennial crops in each SLC

Figure A3–19 provides a schematic of the method for C accounting.

## Data Sources

Carbon stock change estimates rely on C factors and a time series of land management data in the *Census of Agricul-*

*ture*. There are two types of data used for either deriving C factors (modelling) or computing the actual estimates of C stock change. The data mainly used for modelling C factors include SLC, crop-tillage systems derived from the *Census of Agriculture*, and crop yields, climate data and activity data from other surveys and databases. The land management practices from the Census of Agriculture are mainly used for estimating annual C stock changes.

## Land Information and Activity

The SLC is a national-scale spatial database describing the types of soils associated with landforms, displayed as polygons at an intended scale of representation of 1:1 million.[18] The SLC Version 3.0 was chosen for the LULUCF inventory because all SLC polygons are "nested" within the 1995 National Ecological Framework, making it possible to scale up or scale down data and estimates, as required.

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18   Available online at http://sis.agr.gc.ca/cansis/nsdb/slc/v1/intro.html

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Figure A3–19    Method of Using Factors for Land Management Change to Estimate Carbon Change over Large Areas
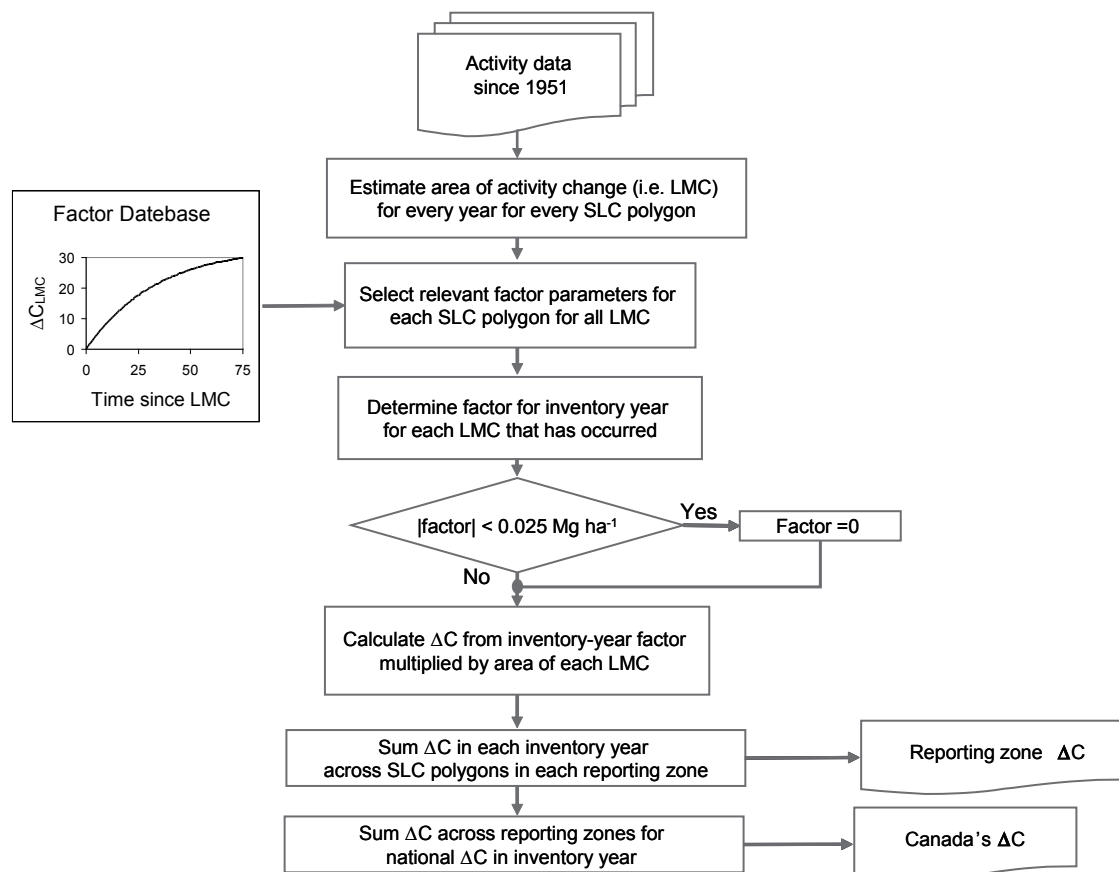
In all provinces within the agricultural region of Canada, detailed soil survey information with map scales greater than 1:1 million was used to delineate the SLC polygons and compile the associated database files. The SLC Component Soil Names Files and Soil Layer Files provided specific input data including soil C content, soil texture, pH, bulk density and soil hydraulic properties for modelling C factors with Century. The SLC polygon provides the spatial basis for allocating land management practices such as tillage practices and cropping systems from the *Census of Agriculture* and Cropland converted from Forest and Grassland to modelled C factors.

## Analysis Units

There are 3264 SLC polygons that have agricultural activities. Since the SLC polygons have several soil landscape components, the finest spatial resolution for analysis of agricultural activities is 11 602 unique combinations of soil components within SLC polygons. These unique combinations represent the basic analysis units. The location of land management and soil components is not spatially explicit but rather spatially referenced to SLC polygons.

A procedure was developed to assign agricultural activities to the SLC based on the suitability of each component of a soil polygon. The soil components have different inherent properties that make them more or less likely to have different types of agricultural activities. Each soil component within the SLC attribute file has a suitability rating of high, moderate or low in terms of its likelihood of being under annual crop production. Annual crop production is linked to those components with a high rating. If there was insufficient area with high likelihood of being under annual cropland for area of annual crops, the remaining annual crop production was linked to components with moderate likelihood of being under annual crop production and, if required, to low-ranked components. After linking the annual crop production area, perennial forages and seeded pasture area were linked to the remaining components in the same manner, starting with components with the highest likelihood of being in annual crops and ending with components with the lowest likelihood of being cropped.

## Crop Yields

Crop yields at an ecodistrict level were developed from Statistics Canada surveys. Statistics Canada conducts annual surveys of up to 31 000 farmers, stratified by region, to compile estimates of the area, yield, production and

stocks of the principal field crops grown in Canada. Eight publications are released at strategic points in the crop year; the first area report contains the planting intentions of producers, whereas the June estimates are made after most of the seeding has been completed. Yields and levels of production by province are estimated twice, based on expectations to the end of harvest, whereas the November estimate is released after the harvest. The data are released at the Census Agricultural Region level, providing crop yields for approximately 70 spatial units in the country. Census Agricultural Region boundaries were overlaid on SLC boundaries in a GIS, and a yield value for each crop in each soil polygon was assigned based on majority proportion. Data used for accounting included 1975–2004 yield data for wheat, barley, oats, corn, soybeans, potatoes and canola. These yields were used to calibrate the Century crop growth submodel.

## Climatic Data

There are 958 weather stations in the weather database archived by Agriculture and Agri-Food Canada (AAFC). Long-term normals of monthly maximum and minimum temperatures (°C) and precipitation (mm) from 1951 to 2001 for all ecodistricts were used for modelling C factors. AAFC-archived weather data were provided by the Meteorological Service of Canada, Environment Canada.

## Census of Agriculture

Activity data for accounting in cropland remaining cropland rely mainly on data from the *Census of Agriculture*.[19] The smallest area for which Statistics Canada will release data externally for confidentiality reasons is the Dissemination/Enumeration Area level (approximately 52 000 in Canada). Agriculture and Agri-Food Canada has reconfigured Census data for 1981, 1986, 1991, 1996, 2001 and 2006 from Dissemination Area units to SLC polygons and higher-level ecostratification units using a procedure involving geographic overlays of the relevant boundary files.

Data on tillage practices were taken from the census according to the following categories: 1) IT—tillage that incorporates most of the crop residue into the soil, 2) RT—tillage that retains most of the crop residue on the surface, and 3) NT—no-till seeding or zero-till seeding. For summerfallow, the following tillage categories were used: 1)

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19    Statistics Canada collects and publishes the Census of Agriculture every five years; the latest in 2006 (2006 Census of Agriculture, Catalogue No. 95-629). Available online at http://www.statcan.ca/english/agcensus2006/index.htm

NT—the area on which chemicals only were used for weed control, 2) IT—the area on which tillage only was used, and 3) RT—the area on which a combination of tillage and chemicals was used. There are two limitations of the census data pertaining to tillage practices that resulted in uncertainties: 1) Statistics Canada and expert opinion indicate that the conservation tillage tends to be underestimated, and 2) tillage distributions as reported for a region must be applied equally to all crops within that region.

### Uncertainty

The derivation of uncertainties about estimates of $CO_2$ emissions or removals requires estimates of uncertainties for LMC areas and C factors of management changes for fallow, tillage and annual/perennial crops (McConkey et al. 2007b).

The uncertainty of area of change was determined for ecodistricts (one level of spatial aggregation above SLC). The average area of agricultural land within an ecodistrict is about 140 kha, i.e., sufficiently large that the areas of different management practice were considered independent of those in others, including adjacent ecodistricts. Errors in the areas of management practices in each ecodistrict were assumed to represent inherent uncertainty that was unaffected by the uncertainty of those in other ecodistricts. Further, the ecodistrict area is sufficiently large that a null report of an activity can be assumed to mean that activity is not occurring within the ecodistrict. Therefore, area uncertainty can be more reliable considered in relative terms for an ecodistrict than for an SLC polygon.

The uncertainty of the area in a management practice at any time for an average ecodistrict was based on the relative proportion of the area of that management practice in that ecodistrict. The relative uncertainty of the area of management practice expressed as standard deviation of an assumed normal population decreased from 10% of the area to 1.25% of the area as the relative area of that practice increased.[20]

The uncertainties associated with C change factors for fallow, tillage and annual/perennial crops were assumed to arise from two main influences: 1) process uncertainty in C change due to inaccuracies in predicting C change even if the situation of the management practice were to be defined perfectly, and 2) situational uncertainty in C change due to variation in the situation of the management practice.

Process uncertainty includes the effect of uncertainty in the model. This includes the uncertainty in the model predictions from uncertain model parameters and from inaccurate and/or incomplete representation of all relevant processes by the model. Where empirical data are used, process uncertainty includes inadequacies in measurement techniques, analysis error, poor representativeness of measurements, and/or components of C change not measured. To estimate the process error, the variation from measured C change for controlled experiments was used. It was assumed that this represents the inherent uncertainty even when the situation is accurately described. Process uncertainty scaling coefficients for tillage and fallow were derived for Canada from VandenBygaart et al. (2003).

Situational uncertainty derives from the inability to accurately describe each situation. This includes the effect of interactions with past or concurrent changes to land use or land management, variability in the weather or soil properties, variability in crop management, and/or continuity of LMCs. The situational uncertainty scaling coefficients for fallow change, tillage change and annual-perennial crop change were estimated from the observed variability of Century-simulated C change for all the soil component-management-climate combinations within the reconciliation unit. There were many combinations of management within which C change was calculated. There was also a range of historical ecodistrict weather that was included in the Century simulations. The situational uncertainty also includes the additional variability of the regional factors introduced by the imposition of reversibility of C change. Average situational uncertainty scaling coefficients were derived for Canada (McConkey et al. 2007b).

Although process and situational uncertainty are expected to interact, given the complexity of the large number of possible interactions between deviations due to process uncertainty and those due to situation uncertainty, it is infeasible to describe their relationship. Hence, it was assumed that the total deviation in total C change was the sum of the deviation from process and situational uncertainty. Details of uncertainty estimate development are provided in McConkey et al. (2007b). Results are provided in Chapter 7.

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20   Huffman T. (Agriculture and Agri-Food Canada). 2006. Personal communication to B.G. McConkey (Agriculture and Agri-Food Canada).

## CO$_2$ Emissions from Agricultural Lime Application

Limestone ($C_aCO_3$) and dolomite ($C_aMg(CO_3)_2$) are often used to neutralize acidic soils; increase the availability of soil nutrients, in particular phosphorus; reduce the toxicity of heavy metals such as aluminium; and improve the crop growth environment. During this neutralization process, $CO_2$ is released in bicarbonate equilibrium reactions that take place in the soil.

The rate of release varies with soil conditions and the types of compounds applied. In most cases lime is applied repeatedly. Thus, for the purposes of the inventory, it is assumed that the annual rate of lime is in near equilibrium with the consumption of lime in previous years. Emissions associated with lime application are calculated from the amount and composition of the lime applied annually.

The amount of C released as a result of limestone application is calculated using the default IPCC Tier 1 approach:

Equation A3–56:

$$C = \sum \left(A_i \times 12/100\right)$$

where:

| | | |
|---|---|---|
| $A_i$ | = | annual limestone consumption in province i, Mg/year |
| 12/100 | = | ratio of molecular weight of C to molecular weight of limestone |

Similarly, the amount of C released as a result of dolomite application is calculated as

Equation A3–57:

$$C = \sum \left(A_i \times 24/184.3\right)$$

where:

| | | |
|---|---|---|
| $A_i$ | = | annual consumption of dolomitic lime in province i, Mg/year |
| 24/184.3 | = | ratio of molecular weight of 2C to molecular weight of dolomite |

There is no single source of data for lime application on agricultural soils. The quantity of lime used for agricultural purposes is not collected by Statistics Canada. Lime usage data were retrieved from Western Canada, Atlantic, Ontario and Quebec Fertilizer Associations.

### *Uncertainty*

The 95% confidence limits associated with annual lime consumption data were estimated to be ±50%.[21] This uncertainty was assumed to include the uncertainty of lime sales, uncertainty in proportion of dolomite to calcite, uncertainty of when lime sold is actually applied, and uncertainty in the timing of emissions from applied lime. The uncertainty in the emission factor was not considered because the chemical conversion is deemed complete, and the maximum value of the emission factor was used.

## CO$_2$ Emissions and Removals from Woody Biomass

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yields. Vineyards are pruned each year, leaving only the trunk and one-year-old stems. Similarly, fruit trees are pruned annually to maintain the desired canopy shape and size. Old plants are replaced on a rotating basis for disease prevention, stock improvement or introduction of new varieties. Typically, Christmas trees are harvested at about 10 years of age. For all three crops, it was assumed that, because of these rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass C within existing farms, as C lost from harvest or replacement would be balanced by gains due to new plant growth. The approach was therefore limited to detecting changes in areas under vineyards, fruit orchards and Christmas tree plantations and estimating the corresponding C stock changes in total biomass.

There are no Canadian studies on the above-ground or below-ground C dynamics of vineyards or fruit trees. However, results from other studies are considered valid inasmuch as varieties, field production techniques and even root stocks are often the same. Canadian literature on Christmas tree plantations is used whenever suitable.

On average, vines are replaced at 28 years of age; the average vine is therefore 14 years old (Mailvaganam 2002). Because of intensive pruning, the biomass of shoots and leaves is set at the constant value of 4 Mg/ha, whereas linear rates of above-ground and below-ground biomass accumulation in trunks and roots were 0.4 and 0.3 Mg/ha per year, respectively (Nendel and Kersebaum 2004). These were converted to C values using a 50% C content in bio-

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mass. Upon a decrease in vineyard areas, an instantaneous loss of 6.9 Mg C/ha is assumed, equal to the average standing biomass for 14-year-old vines (McConkey et al. 2007a).

Because of different standard planting densities, the average biomass of a mature tree ranged between 18 kg for an apple tree and 72 kg for a peach tree. However, the range of standing biomass per area was narrower, between 36 and 40 Mg/ha (McConkey et al. 2007a). This similarity is expected since, regardless of tree size and planting density, the tree shapes and canopies are manipulated to maximize net photosynthesis per area. An annual rate of C sequestration was calculated over a 12-year growth period at 1.6 Mg C/ha per year. The same rate, multiplied by a root: shoot ratio of 0.40 (Bartelink 1998), was used to estimate C sequestration in below-ground biomass. It was assumed that, on new orchard areas, trees accumulate biomass at a linear rate for 10 years (the average tree age on a plantation). Instantaneous C loss upon a decrease of orchards was equal to 50% of the total biomass of a 10-year-old tree (22.4 Mg C/ha).

Christmas trees are marketed at about 10 years of age (McConkey et al. 2007a). Wood accounts for approximately 70% of Christmas tree biomass, and fresh wood has a moisture content of 60-80%. With typical spacing and an expected market mass of 10 kg, a plantation of marketable trees is estimated to have an above-ground biomass density of 17.1 Mg/ha. With a root: shoot ratio of 0.3 (Bartelink 1998; Litton et al. 2003; Xiao and Ceulemans 2004), the total C biomass of a marketable tree plantation is estimated at 11.1 Mg C/ha. Carbon sequestration in biomass of new Christmas tree plantations is calculated for five years at rates of 0.85 and 0.26 Mg C/ha for above-ground and below-ground biomass, respectively. A decrease of plantation area would result in the immediate loss of 5.6 Mg C/ha.

## Uncertainty

Poorly growing plants are regularly removed and replaced. Frequently, fruit trees and vineyards are irrigated to maintain desired growth during dry periods. Consequently, the variability in C stock changes should be less than that for other agricultural activities.

For loss of area, all C in woody biomass is assumed to be immediately released. There are no Canadian-specific data on this uncertainty. Therefore, the default uncertainty of ±75% for woody biomass on Cropland from the IPCC *Good Practice Guidance for Land Use, Land-Use Change and*

*Forestry* (IPCC 2003) was used. If the loss in area of fruit trees, vineyards or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial to annual crop conversion with associated C change uncertainty that contributes to C change uncertainty for a reporting zone.

## Cultivation of Organic Soils

Cultivation of histosols for annual crop production usually involves drainage, tillage and fertilization. All these practices increase decomposition of SOC and, thus, release of $CO_2$ to the atmosphere.

### Methodology

The IPCC Tier 1 methodology is based on the rate of C released per unit land area:

Equation A3–58:

$$C = \sum \left( Ai \times EF \right)$$

where:

Ai   =   area of organic soils that is cultivated for annual crop production in province i, ha

EF   =   C emission factor, Mg C loss/ha per year. The default EF of 5.0 Mg C/ha per year was used (IPCC 2006).

### Data Sources

Areas of cultivated histosols at a provincial level are not included in the *Census of Agriculture*. In the absence of these data, consultations with numerous soil and crop specialists across Canada were undertaken. Based on these consultations, the total area of cultivated organic soils in Canada was estimated at 16 kha (Liang et al. 2004).

### Uncertainty

The uncertainty associated with emissions from this source is due to the uncertainties associated with the area estimates for the cultivated histosols and of the emission factor. The 95% confidence limits associated with the area estimate of cultivated histosols are assessed to be ±50% (Hutchinson et al. 2007). The 95% confidence limits of the emission factor provided in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) is ±90%.

## A3.4.3.2. Grassland Converted to Cropland

Conversion of native grassland to cropland generally results in losses of SOC and soil organic nitrogen (SON) and in turn leads to emissions of $CO_2$ and $N_2O$ to the atmosphere.

A number of studies on changes of SOC and SON in grassland converted to cropland have been carried out on the Brown, Dark Brown and Black soil zones of the Canadian Prairies, and these results are summarized by McConkey et al. (2007a).

### Losses of Soil Organic Carbon

The average loss of SOC based on field observations was 22% (McConkey et al. 2007a). Many of the studies involved comparisons within 30 years of breaking, whereas others were 70 or more years from breaking. Since many of these studies did not specify the period since breaking, it is assumed that the 22% SOC loss would refer to about 50–60 years after breaking.

The SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils (Figure A3–20) can be estimated with the Century model (Version 4.0). Shortly after breaking, there is an increase

in soil organic matter, as below-ground biomass of the grass becomes part of SOC. After a few years, SOC declines below the amount of SOC that existed under grassland. The rate of SOC decline gradually decreases with time. Neglecting the initial SOC increase due to C added from roots, simulated SOC dynamics can be described by the following equation:

Equation A3–59:

$$\Delta C(t) = \Delta C_{Bmax} \times \left[1 - \exp^{(-k \times [t - t_{lag}])}\right]$$

where:

| | | |
|---|---|---|
| $\Delta C(t)$ | = | change in SOC for the $t^{th}$ year after conversion, Mg C/ha |
| $\Delta C_{Bmax}$ | = | maximum ultimate change in SOC from grassland to cropland, Mg C/ha |
| k | = | rate constant for describing the decomposition |
| t | = | time since breaking of grassland, years |
| tlag | = | time lag before $\Delta C$ becomes negative, years |

Assuming that the 22% loss at about 50–60 years after

Figure A3–20    Century-simulated SOC Dynamics after Breaking of Grassland to Cropland for the Brown and Dark Brown Chernozemic Soils



$\Delta C(t) = -1018 \cdot \{1 - \exp[-0.13 \cdot (t-4)]\}$

Dark Brown Chernozem

$\Delta C(t) = -1025 \cdot \{1 - \exp[-0.102 \cdot (t-4)]\}$

Brown Chernozem
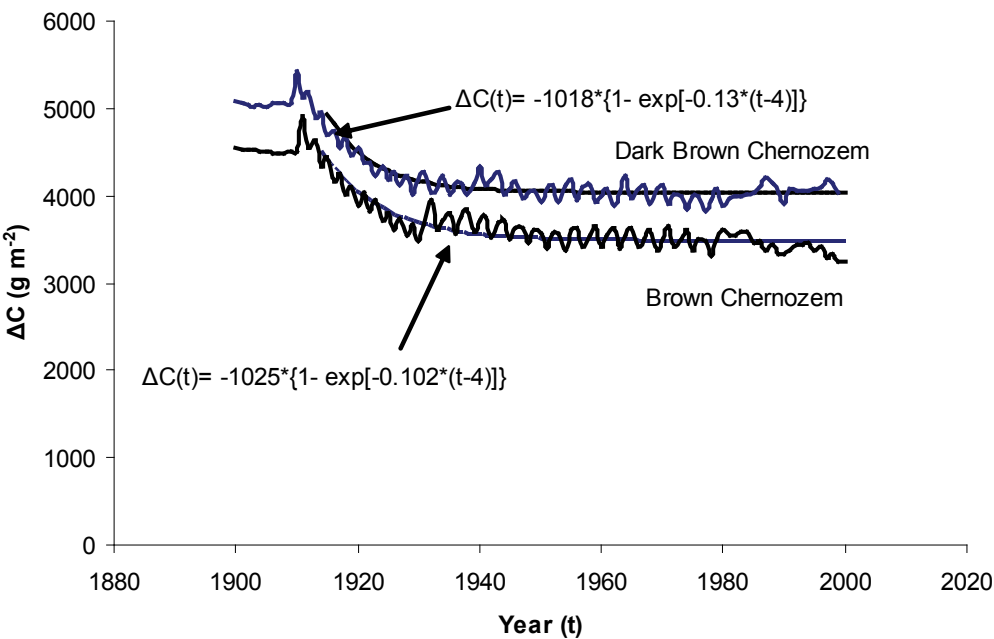
initial breaking represents the total loss, the $\Delta SOC_{Bmax}$ is 0.22/(1−0.22) = 28% of the stabilized SOC under agriculture. Given the uncertainty of actual dynamics, it was assumed that there was no time lag in SOC loss from breaking grassland, so that SOC starts to decline immediately upon breaking. With these assumptions, the general equation for predicting SOC loss from breaking grassland becomes

**Equation A3–60:**

$$\Delta C(t) = 0.28 \times SOC_{agric} \times \left[1 - \exp^{(-0.12 \times t)}\right]$$

where:

| | | |
|---|---|---|
| $\Delta C(t)$ | = | change in SOC for the tth year after conversion, Mg C/ha |
| t | = | time since breaking, years |
| SOCagric | | 0- to 30-cm SOC from the National Soil Database within CanSIS for the soil profile under an agricultural land use (Cropland category), Mg C/ha |

Thus, the total losses of SOC in grassland converted to cropland were calculated using an IPCC Tier 2 approach:

**Equation A3–61:**

$$\Delta C_{GL-CL} = \sum_{1951-2009} \sum_{ALL\ SLC} \sum_{t} (\Delta C_t \times AREA_{GL-CL})$$

where:

| | | |
|---|---|---|
| $\Delta C_{GL-CL}$ | = | losses of SOC in 2009 due to conversion of grassland to cropland since 1951, Mg C |
| ALL SLC | = | all soil polygons that contain grassland |
| t | = | time after grassland conversion, years |
| $\Delta C_t$ | = | change in SOC for the $t^{th}$ year after conversion, Mg C/ha |
| AREAGL-CL | = | area of grassland converted to cropland annually since 1951, ha |

## Losses of Soil Organic N and N₂O Emissions

Change in SON is estimated as a fixed proportion of C losses. Where changes in both SON and SOC were determined, the average change in SON was 0.06 kg N lost/kg C lost (McConkey et al. 2007a). Thus, the emissions of N₂O in grassland converted to cropland were calculated using an IPCC Tier 2 approach:

**Equation A3–62:**

$$N_2O_{GL-CL} = \sum_{1951-2009} \sum_{ALL\ SLC} \sum_{t} (\Delta C_t \times AREA_{GL-CL} \times 0.06 \times EF_{BASE}) \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| N₂OGL-CL | = | emissions of N₂O in 2009 due to the conversion of grassland to cropland since 1951, kt |
| ALL SLC | = | all soil polygons that contain grassland |
| t | = | time after grassland conversion, years |
| ΔCt | = | change in SOC for the $t^{th}$ year after conversion, Mg C/ha |
| AREAGL-CL | = | area of grassland converted to cropland annually since 1951, ha |
| EFBASE | = | base emission factor, defined as a function of long-term climate normals (monthly precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (See Section A3.3.6) |
| 0.06 | = | ratio of ON to OC losses |
| 44/28 | = | coefficient converting N₂O-N to N₂O |

### Data Sources

For the census years of 1981, 1986, 1991, 1996, 2001 and 2006, unimproved pasture areas at the SLC level were obtained by "reconfiguring" the *Census of Agriculture* data to SLC polygons. For 1951, 1961 and 1971, provincial totals for unimproved pasture were disaggregated to SLCs based on the distribution in 1981. Within an SLC, unimproved pasture was allocated to soil components identified as "low" for "likelihood of being cropped." Once allocated to SLC polygons, area totals for unimproved pasture were aggregated to an ecodistrict or reconciliation unit level as required in each year from 1990. Areas of grassland conversion were allocated to the polygons that showed an increase in cropland area for the corresponding time period, while ensuring consistency with the total loss of grassland area within the reconciliation unit.

### Uncertainty

The conversion from the agricultural Grassland category to the Cropland category is allowed, but the conversion in the other direction is not allowed. The uncertainty of the area of this conversion in a given ecodistrict cannot be larger than the uncertainty of the final area of Cropland or the initial area of Grassland. Therefore, the uncertainty of the area of conversion was set to the lower of the uncertainty of the area of land in the Cropland or Grassland cat-

Table A3–38    Soil Organic C for Forested and Agricultural Land in Eastern and Western Canada from the Canadian Soil Information System Database (0- to 30-cm soil depth)

| Soil Texture | Soil Organic Carbon (Mg C/ha) | | Difference (%) |
|---|---|---|---|
| | Forested Land[1] | Cropland[1] | |
| Eastern Canada | | | |
| Coarse | 85 (26) | 68 (42) | -20 |
| Medium | 99 (38) | 77 (35) | -22 |
| Fine | 99 (58) | 78 (36) | -21 |
| Western Canada | | | |
| Coarse | 73 (39) | 74 (38) | 0 |
| Medium | 66 (30) | 73 (30) | 4 |
| Fine | 74 (38) | 77 (25) | 1 |

Note:

1. Standard deviation in parentheses.

egory. The factor scaling coefficient was assumed to be the same as for annual–perennial crop conversions (McConkey et al. 2007b).

### A3.4.3.3.    Forest Converted to Cropland

#### $CO_2$ and $N_2O$ Emissions from Soils

Clearing forest to increase agricultural land is a declining but still significant practice in Canada. This section de-

scribes the methodology for estimating $CO_2$ and $N_2O$ emissions associated with the soil disturbance. The method for estimating emissions from biomass upon conversion is presented in Section A3.4.2.3 For SOC change, there is a need to differentiate between the eastern and the western parts of the country.

Figure A3–21    Century-simulated Soil Organic Carbon Following Conversion of Long-term Deciduous Forest to Cropland



CENTURY-simulated

$\Delta C(t) = -2480*\{1- \exp[-0.035*(t-t_{lag})]\}$

$\Delta C(t) = -2480*[1- \exp(-0.035*t)]$

t is year since deforestation in 2000
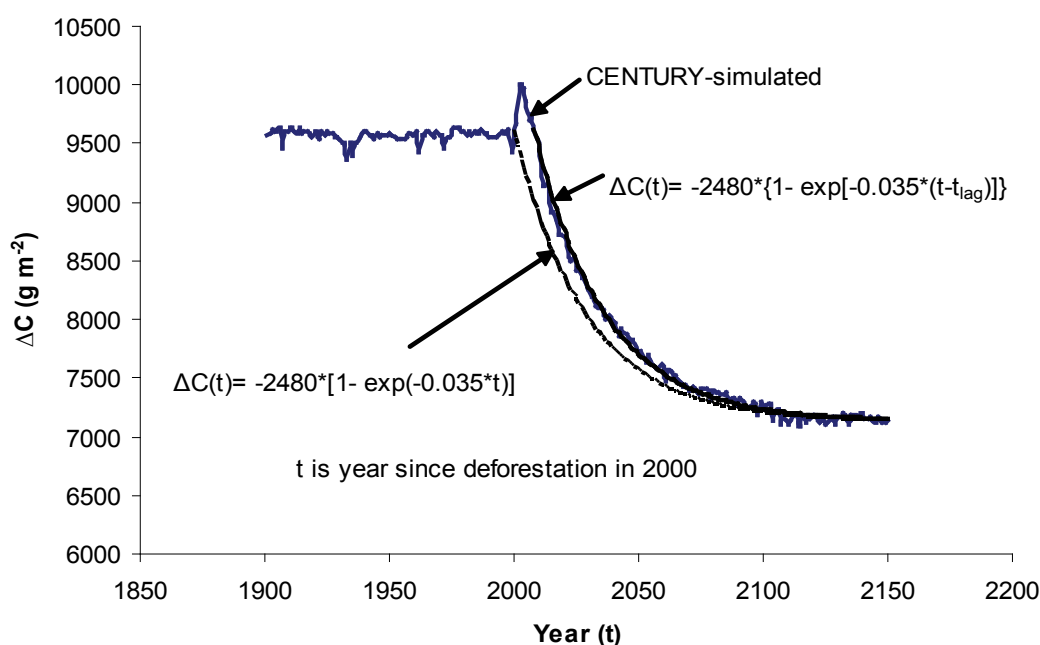
## Eastern Canada

There are many observations that compare SOC for land under forest with adjacent land under agriculture in eastern Canada. The mean loss of C was 20.3% for a depth of approximately 30 cm (McConkey et al. 2007a). This value is comparable with the soil database in CanSIS (Table A3–38), indicating that, on average, SOC for the uppermost 30 cm of soil under agriculture was 20.5% less than under forest.

Although the SOC for forested land in Table A3–38 accounts for C in the litter layer above mineral soil, in practice there is always uncertainty in quantifying the litter layer C and C within soil debris (Paul et al. 2002). Soil erosion, which is generally assumed to increase under agriculture, also reduces measured SOC on agricultural land.

The Century model (Version 4.0) was used to estimate the SOC dynamics from forest conversion, and Figure A3–21 shows an example of such dynamics. In the first years after the conversion, there is an increase in soil organic matter, as litter and above-ground and below-ground DOM become part of SOC. After a few years, SOC declines below the amount of SOC that existed before forest conversion. The rate of SOC decline gradually decreases with time.

The following equation was fit to the Century results in Equation A3–63, neglecting the initial SOC increase:

Equation A3–63:

$$\Delta C(t) = \Delta C_{Dmax} \times \left[1 - \exp^{(-k \times [t - t_{lag}])}\right]$$

where:

| | | |
|---|---|---|
| $\Delta C(t)$ | = | change in SOC for the $t^{th}$ year after conversion, Mg C/ha |
| $\Delta C_{Dmax}$ | = | ultimate change in SOC from forest conversion to agriculture, Mg C/ha |
| k | = | rate constant for describing the de-composition /year |
| t | = | time since land conversion, years |
| $t_{lag}$ | = | time lag before $\Delta C$ becomes negative, years |

For the example shown in Figure A3–21, 25% of C losses occur within 20 years of forest conversion and 90% within 100 years. Given the uncertainty of actual dynamics, it was assumed that there is no time lag in SOC loss from forest conversion, so that SOC starts to decline immediately upon forest conversion: i.e., the fitted SOC loss (Equation A3–63) is used to estimate SOC loss with time lag set to 0 after

fitting. Fitting Equation A3–63 to the simulations shown in Figure A3–21 produces a mean k of 0.0262/year. Using this value, 92.7% of SOC loss would occur by 100 years after forest conversion.

The mean loss of 20.5% of SOC resulting from forest conversion to cropland for eastern Canada, based on CanSIS information, was assumed to correspond to about 100 years after forest conversion; the $\Delta C_{Dmax}$ is therefore 1/0.927 times this value, or 22.1% of SOC under long-term forest. As the CanSIS soil database has more data on SOC for conditions under long-term cropland than on SOC under long-term forest in areas where cropland exists, the maximal SOC losses were calculated relative to stabilized cropland SOC (i.e. loss = 0.221/(1−0.221) × SOC or loss = 0.284 × SOC under agriculture). Therefore, the final equation for estimating SOC loss for forest conversion to cropland in eastern Canada is:

Equation A3–64:

$$\Delta C(t) = 0.284 \times SOC_{agric} \times \left[1 - \exp^{(-0.0262 \times t)}\right]$$

where:

| | | |
|---|---|---|
| $\Delta C(t)$ | = | change in SOC for the $t^{th}$ year after conversion, Mg C/ha |
| $SOC_{agric}$ | = | 0- to 30-cm SOC from CanSIS for a cropland soil profile, Mg C/ha |
| -0.0262 | = | rate constant for describing the de-composition /year |
| t | = | time since conversion, years |

Thus, the total amount of SOC lost from forest land converted to cropland is estimated using the following equation:

Equation A3–65:

$$\Delta C_{FL-CL} = \sum_{1970-2009} \sum_{ALL\ SLC} \sum_{t} (\Delta C_t \times AREA_{FL-CL})$$

where:

| | | |
|---|---|---|
| $\Delta C_{FL-CL}$ | = | total SOC loss in 2009 from the conversion of forest land to cropland since 1970, Mg C/ha |
| t | = | time after the conversion, year |
| ALL SLC | = | all soil polygons that contain forest land converted to cropland |
| $\Delta C_t$ | = | change in SOC for the tth year after conversion, Mg C/ha (See Equation A3–64) |
| $AREA_{FL-CL,t}$ | = | area of forest land converted to cropland annually since 1970, ha |

Note that the SOC loss predicted by Equation A3–65 is in addition to C stock changes in tree biomass and woody DOM that existed in the forest at the time of forest conversion.

Based on the field observations, average N change in eastern Canada was -5.2%, representing 0.4 Mg N/ha (McConkey et al. 2007a). For those comparisons where both N and C losses were determined, the corresponding C loss was 19.9 Mg C/ha, and carbon loss was 50 times N loss. For simplicity, it was assumed that N loss was a constant 2% of C loss. Thus, $N_2O$ emissions from forest land converted to cropland are estimated using the following equation:

Equation A3–66:

$$N_2O_{FL-CL} = \sum_{1970-2009} \sum_{ALL\ SLC} \sum_{t} (\Delta C_t \times AREA_{FL-CL} \times 0.02 \times EF_{BASE}) \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $N_2O_{FL-CL}$ | = | emissions of $N_2O$ subject to conversion of forest to cropland since 1970, kt |
| ALL SLC | = | all soil polygons that contain forest land conversion |
| $\Delta C_t$ | = | change in SOC for the $t^{th}$ year after conversion, Mg C/ha per year |
| $AREA_{FL-CL}$ | = | area of forest land converted to cropland annually since 1970, ha |
| 0.02 | = | conversion of C to N |
| $EF_{BASE}$ | = | base emission factor, defined as a function of long-term climate normals (monthly precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (See Section A3.3.6) |
| 44/28 | = | coefficient converting $N_2O$-N to $N_2O$ |

## Western Canada

Much of the current agricultural soil in western Canada was grassland prior to cultivation. Hence, forest conversion has been primarily of forest that adjoins grassland areas. There is also limited conversion of secondary forest that has grown on former grassland since the suppression of wildfires with agricultural development. Historically, forest conversion has been less important in western Canada than in eastern Canada, and fewer comparisons of SOC under forest and agriculture are available in the literature. Ellert and Bettany (1995) reported that there was no difference in SOC between native aspen forest and long-term pasture that remained uncultivated since clearing for an Orthic Gray Luvisol near Star City, Saskatchewan.

The CanSIS data provide the most numerous comparisons of SOC under forest with that under cropland (Table A3–38). On average, these data indicate that there is no loss of SOC from forest conversion. This suggests that, in the long term, the balance between C input and SOC mineralization remains similar under agriculture to what it was under forest. It is important to recognize that the northern fringe of western Canadian agricultural areas, where most forest conversion is now occurring, is marginal for annual crops, and pasture and forage crops are the primary agricultural uses after clearing. In general, loss of C from forest to agriculture is least where agricultural land contains forages and pastures.

For western Canada, no loss of SOC over the long term was assumed from forest conversion to pasture and forage crops. Therefore, the C loss from land conversion in western Canada would be from losses of C in above- and below-ground tree biomass and coarse woody DOM that existed in the forest at the time of conversion. Similarly, average organic nitrogen change in western Canada for sites at least 50 years from breaking was +52% (McConkey et al. 2007a), reflecting substantial added N in agricultural systems compared with forests. However, recognizing the uncertainty about actual soil C–N dynamics upon conversion, forest land converted to cropland was assumed not to be a source of $N_2O$ from the soil pool. $N_2O$ emissions are reported wherever biomass burning occurs during conversion (see Section A3.4.2.1).

### Data Sources

The approach used to estimate the area of forest land converted to cropland is described in Section A3.4.2.2. The annual forest conversion by reconciliation unit was disaggregated to SLC polygons on the basis of concurrent changes in the area of cropland within SLC polygons. Only polygons that showed an increase in cropland area for the appropriate time period were allocated to forest conversion, and the amount allocated was equivalent to that polygon's proportion of the total cropland increase within the reconciliation unit.

### Uncertainty

The uncertainty of C change in each reporting zone was estimated differently for eastern and western Canada because of differences in C change estimation methods (McConkey et al. 2007b). For western Canada, an uncertainty of C change was estimated, although the mean value of SOC change factor was 0. The assumption was that the

uncertainty of SOC change after forest land to cropland conversion in western Canada would follow a similar pattern as that for eastern Canada.

## A3.4.4.    Grassland

Land in the agricultural Grassland category is defined as "unimproved pasture" used for grazing domestic livestock in geographical areas where grassland would not naturally grow into forest if abandoned: southern Saskatchewan and Alberta and a small area of southern British Columbia. These grasslands developed under millennia of grazing by large animals such as bison and periodic burning. Essentially, "agricultural Grassland" as defined is extensively managed native range.

The primary direct human activities on agricultural grassland in Canada are fire suppression, seeding new plant species into the grassland, and adjusting the amount, duration and timing of grazing by domestic livestock.

### A3.4.4.1.    General Approach and Methods

**State of Grassland**

The Prairie Farm Rehabilitation Administration (2000) conducted an assessment of range in the Prairies ecozone from public land agencies and expert opinion of rangeland professionals and reported that about half of the range in Canada was in poor condition. Range conditions are defined by a range's productivity in terms of grazing and improved biodiversity. They also noted that range management systems had improved over the past several decades. The major challenge is to improve range in poor to good condition as opposed to preventing further decline of range condition. The invasion of grassland by tame grass species is an important problem for Canadian grassland because of negative effects on biodiversity (Bai et al. 2001). However, there is no clear relationship between range condition, invasion of grassland by tame grass species and SOC (McConkey et al. 2007a).

According to the *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003), degraded land in the Grassland category in temperate/boreal regions has 95% of the SOC of non-degraded land, indicating an opportunity to increase SOC by improving conditions of the grassland. However, the IPCC definition of grassland conditions on the basis of SOC differs from the definition used by rangeland professionals and experts in Canada, which is based on productivity. This creates some problems in

applying the IPCC Tier-1 method for estimating soil C stock change in the Canadian grassland.

### Effect of Grassland Management on SOC

There are three methods in the scientific literature to improve grassland conditions: 1) grazing management, 2) fire management, and 3) soil amendments. Much of the potential SOC gain from grazing management on rangeland has been from increasing grazing on grassland that has previously been ungrazed or lightly grazed (Conant et al. 2001; Schuman et al. 2002; Liebig et al. 2005), but that opportunity is relatively small in Canada, as its agricultural grassland is already grazed (Lynch et al. 2005).

There are a number of studies of the effects of grazing versus no grazing on SOC. Although the productivity of heavily grazed pasture is lower, which may lead to a decline in range conditions, this was not related to declines in SOC (Biondini and Manske 1996). The effect of grazing regime is complex, because of the effects of grazing on plant community and effects on C input to soil from both above- and below-ground plant growth (Schuman et al. 2002; Liebig et al. 2005). An additional influence of grazing regime is the increased return of C in fecal matter as stocking rate increases (Baron et al. 2002). Bruce et al. (1999) estimated that there was no opportunity to increase SOC from grazing management improvements on extensively managed rangeland in North America.

Prior to agricultural development, the grassland burned regularly, but burning is now aggressively suppressed. Burning of range increased SOC in Canada (Anderson and Bailey 1980). This effect has been widely observed globally through the production of relatively stable black C (Gonzalez-Perez et al. 2004). However, because of the stability of such black C, which is responsible for net SOC increases from periodic burning, current suppression of fire may be preventing further increases in SOC. Nevertheless, there is no evidence to the effect that fire suppression reduces SOC significantly. Annual $CO_2$ fluxes indicate that grazed grassland with no burning does not appear to be either a source or sink of $CO_2$ in the long term (Frank 2002).

The addition of organic amendments and inorganic fertilizer will increase the productivity of native grassland (Smoliak 1965), suggesting that these practices could increase SOC through greater C inputs. However, such practices are basically of academic interest, as the only economically practical management options for semi-arid grasslands

are altering grazing regime, burning and introducing new plant species (Liebig et al. 2005).

There are no detailed comprehensive activity data over time on management change for Canadian agricultural grassland. However, even if there were such data, there is no indication that this grassland is or will be losing or gaining SOC in response to direct human activity. Therefore, C change on agricultural grassland for Canada remains not estimated.

## A3.4.5.    Wetlands

### A3.4.5.1.    Peatlands

Approximately 12 kha of peatlands are currently managed in Canada for the production of horticultural peat. The cumulative area of peatlands ever managed for this purpose amounts to 23 kha, the difference being peatlands that are no longer under production. The production consists of horticultural peat only; Canada does not produce peat for use as a fuel.

Virtually all peat extraction in Canada relies on the vacuum harvest technology. However, many abandoned peat extraction fields were once exploited with the cut-block method; this influences the post-abandonment dynamics of vegetation regrowth.

Owing to the extraction technology and desired properties of sphagnum peat, at the time of site selection, preference is given, among other factors, to peatlands with thin woody vegetation, which nevertheless meets the definition of "forest" for the purpose of GHG reporting (Canadian Sphagnum Peat Moss Association).[22]

**General Approach and Methods**

Only $CO_2$ emissions from land converted to wetlands (peatlands) and peatlands remaining peatlands were estimated. The estimation included the following sources: vegetation clearing and subsequent decomposition, decay of soil organic matter on sites drained during the inventory year and from fields under production, peat stockpiles, abandoned peat fields, and restored peatlands. In any inventory year, emissions from land converted for peat extraction are expressed by Equation A3–67:

Equation A3–67:

$$CO_2\text{-}C_{L\_Peat} = CO_2\text{-}C_{BIOMASS} + CO_2\text{-}C_{DOM\ residual} + CO_2\text{-}C_{SOILS\ drained} + CO_2\text{-}C_{SOILS\ extraction} + CO_2\text{-}C_{SOILS\ stockpiles}$$

where:

| | | |
|---|---|---|
| $CO_2\text{-}C_{L\_Peat}$ | = | total carbon emissions as $CO_2$ from land converted to wetlands (for peat extraction) |
| $CO_2\text{-}C_{BIOMASS}$ | = | carbon emissions as $CO_2$ from the loss of carbon to forest products upon forest clearing |
| $CO_2\text{-}C_{DOM\ residual}$ | = | carbon emissions as $CO_2$ from the decay of vegetation cleared no more than 20 years prior to the inventory year |
| $CO_2\text{-}C_{SOILS\ drained}$ | = | carbon emissions as $CO_2$ from the oxidation of soil organic matter on peatland drained during the inventory year |
| $CO_2\text{-}C_{SOILS\ extraction}$ | = | carbon emissions as $CO_2$ from the oxidation of soil organic matter on productive peatlands converted for no more than 20 years |
| $CO_2\text{-}C_{SOILS\ stockpiles}$ | = | carbon emissions as $CO_2$ from the oxidation of stockpiled peat on productive peatlands converted for no more than 20 years |

Preconversion biomass (or biomass cleared) is estimated at an average 20 t C/ha, corresponding to the average biomass C density of low-productivity forests. Upon clearing, all biomass carbon is transferred to forest products (estimated at 63% of biomass, which is considered emitted to the atmosphere as $CO_2$ in the year of harvest) or DOM; the latter begins to decay in the same year, following an exponential decay curve as expressed in Equation A3–68.

Equation A3–68:

$$C_{DOM\ (t)} = C_{DOM\ (0)}\ e^{-kt}$$

where:

| | | |
|---|---|---|
| $C_{DOM(t)}$ | = | amount of C in DOM for the $t^{th}$ year after conversion, Mg C/ha |
| $C_{DOM(0)}$ | = | initial amount of C in DOM from forest conversion to peat extraction, Mg C/ha |
| $k$ | = | rate constant for describing the decomposition, year$^{-1}$ |
| $t$ | = | time since land conversion, years |

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22    Available online at http://www.peatmoss.com/pm-harvest.php

A3

On wetlands remaining wetlands (peatlands), emissions are expressed as in Equation A3-20:

**Equation A3–69:**

$$CO_2\text{-}C_{Peat} = CO_2\text{-}C_{DOMresidual} + CO_2\text{-}C_{SOILS\,extraction} + CO_2\text{-}C_{SOILSstockpiles}$$
$$+ CO_2\text{-}C_{SOILS\,abandoned} + CO_2\text{-}C_{SOILS\,restored}$$

where:

| | | |
|---|---|---|
| $CO_2\text{-}C_{Peat}$ | = | total carbon emissions as $CO_2$ from wetlands remaining wetlands (peatlands) |
| $CO_2\text{-}C_{DOM\,residual}$ | = | carbon emissions as $CO_2$ from the decay of biomass cleared more than 20 years ago |
| $CO_2\text{-}C_{SOILS\,extraction}$ | = | carbon emissions as $CO_2$ from the oxidation of soil organic matter on peatlands converted for more than 20 years |
| $CO_2\text{-}C_{SOILS\,stockpiles}$ | = | carbon emissions as $CO_2$ from the oxidation of stockpiled peat on peatlands converted for more than 20 years |
| $CO_2\text{-}C_{SOILS\,abandoned}$ | = | carbon emissions/removals as $CO_2$ resulting from the net ecosystem production on abandoned peatlands |
| $CO_2\text{-}C_{SOILS\,restored}$ | = | carbon emissions/removals as $CO_2$ resulting from the net ecosystem production on restored peatlands |

Soil emissions from a productive peat field, "$CO_2\text{-}C_{SOILS\,extraction}$," are estimated with a single emission factor reflecting peat oxidation rates. Emissions from peat stockpiles are calculated as an exponential decay for half a year.

Abandoned peat fields remain a persistent source of atmospheric $CO_2$ (Waddington and McNeil 2002) until carbon uptake by regrowing vegetation exceeds soil and residual

DOM decay. In the current model, the emission factor on abandoned fields is reduced by a fixed annual amount to reflect the effect of gradual vegetation establishment and the slow decrease of emissions over several decades.

Current restoration practices consist of blocking drainage ditches, sowing the field with fresh moss spores and spreading a layer of straw on abandoned peat fields (to prevent desiccation). In the initial years of restoration, straw decomposition may further increase $CO_2$ emissions until vegetation re-establishes. Net carbon sequestration on restored peat fields is assumed to occur after five years, and its rate is subsequently maintained constant.

It is assumed that the non-growing season is six months long. In that period, emissions represent 15% of the annual total ecosystem $CO_2$ respiration, and gross primary production is zero. Table A3–39 lists the main parameter values applied in estimate development. Uncertainty estimates were obtained from expert judgement.

*Data Sources*

Little information on the area of peat production in Canada is available. The Canadian Sphagnum Peat Moss Association confirmed that 14 kha were under production in 2004 (derived from Cleary 2003), having increased by approximately 76% since 1990.[23] Areas under production in the intervening years were estimated with simple linear regressions fitted to the general trends in total domestic peat production (NRCan 2008). The annual area drained for peat extraction was assumed to be equal to the difference

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23   Hood G, president Canadian Sphagnum Peat Association. 2006. Personal communication dated December 15, 2006, to Dominique Blain, Environment Canada.

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Table A3–39    Parameters and Emission Factors for Estimating $CO_2$-C Emissions from Wetlands (Peatlands)

| Emission Factor/Parameter | Unit | Value | Uncertainty (%) |
|---|---|---|---|
| Biomass cleared | t C/ha | 20 | 100 |
| Exponential decay constant, DOM | | 0.05 | 75 |
| Emission factor on newly drained fields | g $CO_2$-C/m$^2$ per year | 351 | 75 |
| Emission factor on productive fields | g $CO_2$-C/m$^2$ per year | 1019 | 75 |
| Exponential decay constant, stockpiles | | 0.05 | 75 |
| Annual decrease in emission factor, abandoned fields | | | |
| Vacuum-harvested | g $CO_2$-C/m$^2$ per year | 15 | 75 |
| Block-cut | g $CO_2$-C/m$^2$ per year | 35 | 75 |
| Emission factor, restored peatlands | | | |
| First year | g $CO_2$-C/m$^2$ per year | 1753 | 75 |
| >Five years | g $CO_2$-C/m$^2$ per year | -8.00E+01 | 75 |

in total production areas between successive years, minus abandoned and restored peatlands. With the vacuum harvest technology, the average lifetime of a productive peat field is approximately 35 years (Cleary 2003). By default, land converted for more than 20 years is reported in the category Wetlands remaining wetlands.

*Uncertainties*

Emission factors were derived from flux measurements made mostly over abandoned peatlands, which introduces significant uncertainty when applied to actively managed peatlands, and peat stockpiles. All measurements were conducted in eastern Canada, adding uncertainties to estimates in western Canada.

### A3.4.5.2. Flooded Lands

### General Approach and Methods

Following the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003), emissions from land converted to wetlands (creation of flooded lands, namely reservoirs) are estimated for all known reservoirs flooded for 10 years or less. Only $CO_2$ emissions are reported. An IPCC Tier 2 method was used, whereby country-specific $CO_2$ emission factors were developed based on measurements, as described below. Details can be found in Blain et al. (2007). It is believed that the default approach, assuming that all biomass carbon would be emitted upon flooding, would overestimate immediate deforestation emissions from reservoir creation, because the majority of submerged forest biomass does not decay for an extended period of time.

Two complementary estimation methodologies are used to account for GHG fluxes from flooded lands, depending on land conversion practices. When there is evidence of forest clearing and/or burning prior to flooding, immediate and residual emissions from all carbon pools are estimated as in all forest conversion events since 1970, with the CBM-CFS3 (see A3.4.2.1). Note that emissions from forest clearing for infrastructure development are reported under the category Forest converted to settlements.

In the absence of such evidence, it was assumed that all vegetation was simply flooded, leading to the emission—as $CO_2$—of a fraction of the submerged carbon from the surface of the reservoir. The proportion of the area flooded that was previously forested was used to attribute these emissions to either the Forest land converted to wetlands category or the Other land converted to wetlands category.

Since 1993, measurements of $CO_2$ fluxes have been made above some 57 hydroelectric reservoirs in four different provinces: Quebec, Manitoba, British Columbia, and Newfoundland and Labrador (Duchemin 2006). In most studies, the reservoirs were located in watersheds little affected by human activities, with the notable exception of Manitoba. In almost all cases, only diffusive fluxes of $CO_2$, $CH_4$ or $N_2O$ (in order of frequency) were measured. Studies on ebullition, degassing emissions and winter emissions are rare and insufficient to support the development of domestic emission factors. Measurements of diffusive fluxes above the surface of reservoirs were compiled for the entire country. Out of these measured reservoirs, a subset of 25 was selected to develop a national emission curve for the 50-year period following impoundment. These measurements were selected based on the availability of documentation on measurement procedures and measurement comparability. The emission curve was developed from 25 reservoirs and a total of 33 measurements (Figure A3–22). It is important to note that each of these measurements (data points in Figure A3–22) represents, on average, the integration of between 8 and 28 flux samples per reservoir.

Non-linear regression analysis was used to parameterize the emission curve of the form.

Equation A3–70:

$$CO_{2\,rate\,L\_reservoir} = b0 + b1 \times \ln(t)$$

where:

| | | |
|---|---|---|
| $CO_{2\,rate\,L\_reservoir}$ | = | rate of $CO_2$ emissions from land converted to wetlands (reservoirs), mg/m$^2$ per day |
| b0, b1 | = | curve parameters, unitless |
| T | = | time since flooding, years |

Total $CO_2$ emissions from the surface of reservoirs were estimated as the sum of all emissions from reservoirs flooded for 10 years or less:

Figure A3–22    Logarithmic Curve Fit for National Reservoir Emission Factors
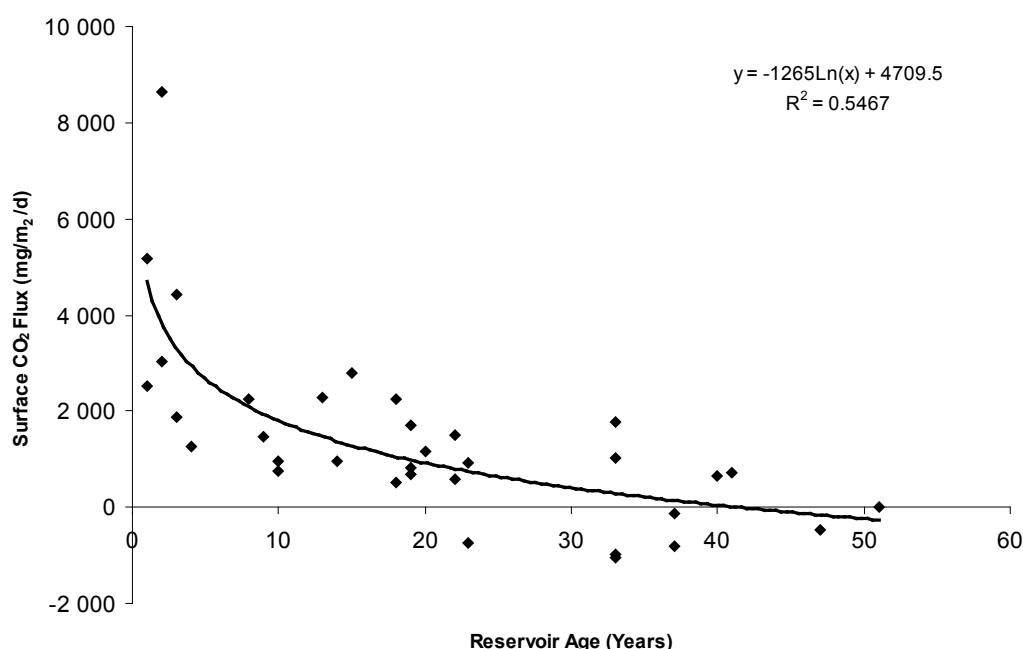


Equation A3–71:

$$CO_{2\,L\_reservoirs} = \sum \left( CO_{2\,rateL\_reservoir} \times A_{reservoir} \times Days_{ice\,free} \times 10^{-8} \right)$$

where:

| | | |
|---|---|---|
| $CO_{2\,L\_reservoirs}$ | = | emissions from lands converted to flooded lands (reservoirs), Gg $CO_2$/year |
| $CO_{2\,rate\,L\_reservoir}$ | = | rate of $CO_2$ emissions for each reservoir, mg/m$^2$ per day |
| $A_{reservoir}$ | = | reservoir area, ha |
| $Days_{ice\,free}$ | = | number of days without ice, days |

$A_{reservoir}$ was used as the best available estimate of the area converted to managed wetlands (reservoirs), although in reality reservoirs may contain islands, i.e., emergent land areas. "Ice-free period" was defined as the average number of days between the observed freeze date and the breakup date of ice cover on a body of water (Magnuson et al. 2000). In the case of hydroelectric reservoirs, locations were mapped and estimates of the ice-free period were generated from the lakes–ice-free period isoline map of Canada (Natural Resources Canada 1974).

Emissions were calculated starting on the year of flooding completion. Reservoirs take a minimum of one year to fill following dam completion, unless otherwise confirmed.

## Data Sources

The three main data sources used to develop area estimates were 1) information on forest conversion due to reservoir impoundment in reporting zones 4, 5 and 8 (see Section A3.4.2.2, Forest Conversion); 2) the Canadian Reservoir Database (Duchemin 2002); and 3) official industry numbers, derived from industry correspondence (Eichel 2006; Tremblay[24]).

The Canadian Reservoir Database contains 421 records of hydro reservoirs dating back to 1876. Of these reservoirs, 110 have a known surface area totalling 3 452 786 ha. The average reservoir size is 31 kha. The distribution of reservoir area is skewed, with 25% of the largest reservoirs representing over 95% of all reservoir area in the database. Information from provincial and private hydroelectric utilities was accessed to update the database and cross-check the date of reservoir construction and the total reservoir area for all these reservoirs. In some instances, the database reported as new facilities some small, refurbished hydroelectric generation sites in the province of Quebec that entered into production under new ownership. As a result, a separate category was added to the database to document both the original construction and commission-

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24    Tremblay A, Hydro-Québec. 2010. Personal communication dated 2010 Nov 19, 2010, to Dominique Blain, Environment Canada.

ing of a dam and the date when a hydroelectric facility was refurbished but no changes occurred to the reservoir area.

As $CO_2$ emissions from the surface of reservoirs are reported only for the 10 years following impoundment, all flooding events since 1980 were used. The trend in area flooded is characterized by two distinct periods (Figure A3–23). The first, prior to 1994, was marked by large-scale flooding, which occurred in the early 1980s and still appeared under the Land converted to wetlands category in the 1990–1993 inventory years. After 10 years, these reservoirs were removed from the accounting, and there was a corresponding decrease in the area to a low in 1994. Emissions were reported from La Forge 3 and La Grande 1 between 1993 and 2002. Three reservoirs (Toulnustouc, Peribonka and Eastmain-1) have been recently created; flooding for Toulnustouc and Eastmain-1 reservoirs was completed in 2005 and 2006, respectively. Accounting of reservoir emissions for Peribonka started in 2008; the 2011 submission includes emissions from both the forest clearing and associated flooding for these three sites.

It is important to note that fluctuations in the area of land converted to wetlands (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but reflect the difference between land areas recently (< 10 years ago) converted to reservoirs and older reservoirs (> 10 years), whose areas are thus transferred out of the accounting. The reporting system does not encompass all the reservoir areas in Canada, which are monitored separately in the Canadian Reservoir Database.

*Uncertainty*

A temporal curve better reflects the decreasing trends of emission rates after impoundment than a unique emission factor. Hence, the domestic approach is believed to reduce the uncertainty in estimation factors. However, there are still important remaining sources of uncertainty:

*Seasonal variability*. Some reservoirs display marked seasonal variability in $CO_2$ fluxes, which are not taken into account in estimate development. Anecdotal evidence suggests that algal bloom in the spring could be associated with this variability, especially in reservoirs subjected to anthropogenic nutrient inputs.

*Reservoir area*. There are variations in reservoir area due to water-level fluctuations during the year.

*Emission pathways*. The omission of potentially important $CO_2$ emission pathways (e.g. degassing).

## Planned Improvements

Planned improvements include developing improved estimates of the preconversion standing biomass, better understanding of conversion practices for both peat extraction and reservoir flooding, and integrating new emission measurements to the curve as they become available.

Figure A3–23   Cumulative Areas in the Lands Converted to Wetlands (Flooded Lands) Category
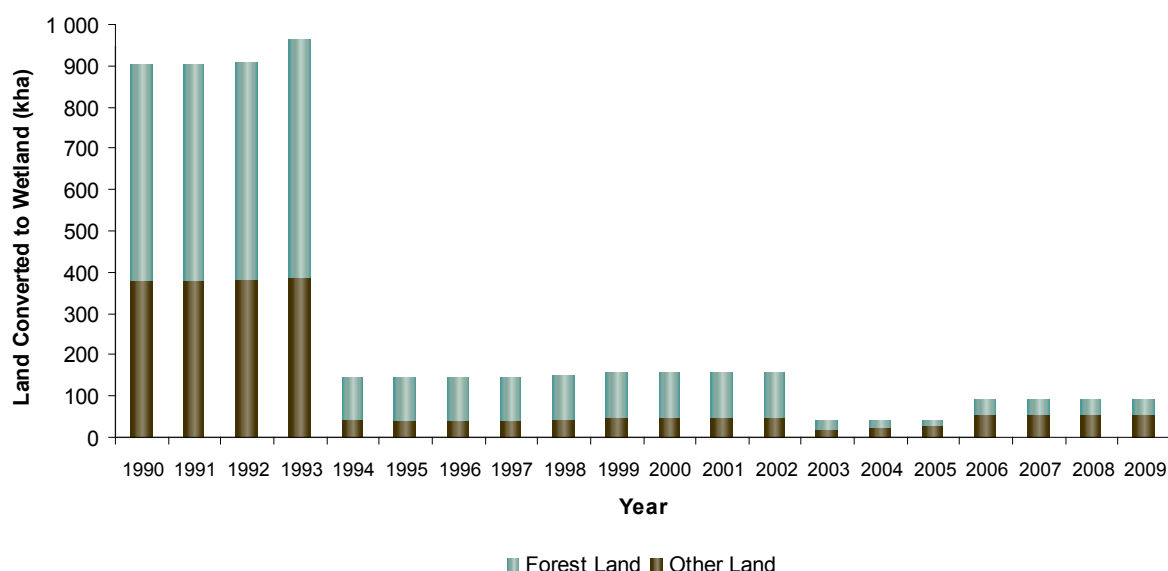
## A3.4.6.    Settlements

Emissions and removals in this category comprise urban tree growth (settlements remaining settlements) and emissions from land conversion to settlements. This submission reports emissions from the conversion of forest land to settlements and of tundra to settlements.

To estimate the very small sink from urban tree growth, a Tier 1 methodology was used. An average growth of 0.05 t biomass/ha per year every year over 1990–2009 was computed and applied to non-built-up urban surface areas (from Statistics Canada 1997).

Approaches, methods and data sources for estimating emissions from the conversion of forest land to settlements are covered in A3.4.2.2. This section describes estimate development for the conversion of non-forest land to settlements in the Canadian Arctic and sub-Arctic.

### A3.4.6.1.    General Approach and Methods

The Canadian northern regions (Arctic and sub-Arctic) cover nearly half of Canada's land mass and include five land categories (IPCC 2003), except Cropland. This assessment covered an area of about 359 million ha and included reporting zones 2, 3, 10, 13, 17 and 18, as well as reporting zones 13 and 18 north of 60°N latitude. The challenge was to capture land-use change and estimate associated emissions in this vast and remote landscape. An approach was developed specifically for this task and included the following components:

1.   Map non-forest land-use change in Canada's Arctic/sub-Arctic prior to and including 1990 and between 1990 and 2000.
2.   Estimate annual GHG emissions (above-ground biomass only) from non-forest land-use change in Canada's Arctic/sub-Arctic for the 1990–2000 period.

A comprehensive, wall-to-wall analysis over this area was clearly impractical, as this would require on the order of 100 Landsat satellite scenes for each date. Similarly, random sampling would likely not capture enough land-use change events to allow a reliable assessment. Instead, GIS data sets denoting the occurrence of cultural, mining and other human development were used to reduce and optimize the domain of investigation, by flagging areas with high probability of occurrence of land-use change. These areas of concentrated land-use change potential were targeted for change detection analysis (change vector analysis – Johnson and Kasischke 1998) using 23 Worldwide

Reference System Landsat frames from circa 1985, 1990 and 2000. The scenes cover more than 8.7 million ha, 56% of the potential land-use change area identified using the GIS data sets, or 70% of potential land-use change area if seismic survey lines are not included.[25] All 23 frames were located in the western Arctic and sub-Arctic regions.

The Land Use Change Mapping System for Canada's North (Butson and Fraser 2005), can be described as a hybrid change detection method based on two separate techniques: change vector analysis for identifying changed areas and constrained signature extension for labelling those changes (Olthof et al. 2005). A detailed description of how the Land Use Change Mapping System for Canada's North was used for the purpose of capturing non-forest land-use change in Canada's north is available in Fraser et al. (2005). The average rate of land-use change between 1985 and 2000 over the assessed area was 666 ha/year, and 70% of land-use change areas occurred in reporting zone 13. Lack of available imagery prevented the implementation of the system beyond 2000; therefore, the same annual rate of land-use change was applied for the years 2001–2009.

A series of above-ground biomass maps in 2000 were developed for the main land-use change areas, using relationships between above-ground biomass and remote sensing data constructed from and calibrated with ground measurements (Figure A3–24). These maps were used to determine $CO_2$ emissions from the clearing of above-ground biomass.

The dominant land cover types in the two study areas are rock, lichen, low to high shrub, grass and sparse woodland.

Multiple regressions were conducted between ln (above-ground biomass) and a combination of image signals for all vegetation covers combined (grass, shrub, sparse woodland). The best least-square approximation had an $r^2 = 0.72$–0.78, dependent on approaches used, a relative mean square error of 75–80%, and a median value of the absolute percentage error of 33–53%. Biomass regressions were applied to the preconversion imagery for all land-use change areas to yield an estimate of the biomass cleared. All land-use change activities involved conversion of tundra vegetation to settlements, and all preconversion biomass carbon was deemed emitted upon clearing.

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25    Recent, low-impact seismic lines have a narrow swath of approximately 2 m in width, as opposed to conventional ones, which were much larger (~8 m). Low-impact seismic lines were widely adopted over the past decade and considerably reduce the environmental impact of seismic exploration.

Figure A3–24    Study Areas for the Determination of Above-Ground Biomass in Canada's Arctic and Sub-Arctic Region



Since the 2007 submission, additional imagery was analyzed with the change detection method used for deforestation area estimation. Reporting zone 4 and part of reporting zone 8 were fully mapped for both forest and non-forest conversion to settlements, adding 55 Mha to the area already mapped. The above-ground biomass of non-forest vegetation was derived from a literature search and estimated at 6 kt/ha (or 3 t C/ha). For this region, there was an average rate of non-forest land-use change of 115 ha/year for the 1990–2006 period.

When only the above-ground biomass component is considered, land-use change activities for the non-forested regions of Canada's north released on average an estimated 153 kt $CO_2$ eq per year in the 1990–2009 period.

### A3.4.6.2.    Uncertainty

The uncertainty in land-use change area covered by the 23 Landsat scenes is estimated to be within 20% (Fraser et al. 2005). The biomass equations developed from field measurements in the Dawson City study area were validated on the other study areas of Yellowknife and the Lupin mine. The median values of the absolute percentage error in above-ground biomass estimation for both study areas are 33–53%.

A Monte Carlo simulation method was used to quantify the overall error in carbon emissions caused by uncertainties in land-use change area and biomass estimation. At the 95% confidence level, the percentage error varies from 218% if there is only one land-use change site within a reporting zone to 15% if a reporting zone has 75 or more land-use change sites. The error in the total above-ground biomass carbon stock change estimate, if considered as one reporting area, is about 15%. A full discussion of uncertainty can be found in Chen et al. (2005, 2009).

### A3.4.6.3.    Planned Improvements

Planned improvements will include efforts to reduce uncertainty associated with the estimates of preconversion biomass in Canada's Arctic and sub-Arctic. Work will be undertaken to update the land-use-change activity estimates for the post-2000 period. For estimates of removals related to urban trees, efforts will be made to improve and update the current estimates of urban area, tree stocks and management practices, which is intended to improve the current estimate approach and the data on which it is based.

A3

## A3.4.7. Estimation of Delayed CO$_2$ Emissions from Harvested Wood Products (HWPs)

In addition to the default method, four alternative approaches for carbon accounting in HWPs have been proposed: stock change, production, atmospheric flow and simple decay. Box A3-1 provides a brief description of each approach. Although these approaches would yield the same net carbon exchange with the atmosphere if applied globally, they differ on a national level in the way in which they account for the time and place of emissions.

As a basis for comparison, the annual emissions of carbon in harvested wood are estimated using the default and three alternative approaches. When warranted, the delayed emissions from domestic wood consumption (stock change and atmospheric flow) or domestic production (production and decay) since 1960 are included. These harvest emissions (HE) are calculated as follows:

IPCC Default:

$$HE_{Default} = RW + Firewood$$

Stock Change:

$$HE_{Stock\ Change} = RW + Firewood − Domestic\ Long\text{-}lived\ Commodity + Inherited\ Emissions\ from\ Long\text{-}lived\ Commodity\ Consumption$$

Production:

$$HE_{Production} = RW + Firewood − Long\text{-}lived\ Commodity\ Production + Inherited\ Emissions\ from\ Long\text{-}lived\ Commodity\ Production$$

Atmospheric Flow

$$HE_{Atm.\ Flow} = Firewood + Processing\ Wastes + Inherited\ Emissions\ from\ Long\text{-}lived\ Commodity\ Consumption$$

where:

| | | |
|---|---|---|
| HE | = | carbon emitted outside managed forests during the inventory year from material harvested and/or consumed in previous and current years |
| RW | = | carbon in industrial roundwood and fuelwood harvested in the current inventory year |
| Firewood | = | carbon in residential firewood consumed in the current inventory year |
| Consumption | = | production + imports − exports |
| Production | = | domestic production |
| Processing Wastes | = | total industrial wood biomass consumption − commodity production |

For Canada, CO$_2$ emissions outside of managed forests in 2009, resulting from either domestically consumed or domestically produced HWPs, varied from 126 Mt for the default IPCC approach (IPCC 2003) to 72 Mt (atmospheric flow), 99 Mt (production) or 113 Mt (stock change), depending on the approach selected.

Note that delay in carbon emissions due to storage in HWPs is taken into account only for long-lived (> 5 years) commodities. The carbon stored in short-lived commodities, including fuelwood and firewood, is assumed to be emitted upon harvest. To date, the calculations have included only semi-processed commodities (e.g. sawnwood, pulpwood, wood-based panels, paper and paperboard, and other industrial roundwood). It is not feasible at present to develop a system that would monitor the paths of carbon stored in HWPs (HWP-C) from harvest to consumer products.

Further elaboration of these approaches is planned, based on the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003) and the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). Work has been initiated in 2007 to update the Forest Product Sector module of the Carbon Budget Model.

Box A3-1

**A3**

**Overview of Approaches to Account for Carbon Storage in Harvested Wood Products**

In the **IPCC default approach**, only the net change in forest carbon stocks is accounted for. Emissions from harvests are treated as though they are 100% released as $CO_2$ to the atmosphere in the year and country of harvest. Carbon storage in wood products is not considered.

The **atmospheric flow** approach tracks carbon emissions and removals associated with the harvest, manufacturing and consumption of wood products within national boundaries. Its intent is similar to the general methodology for estimating fossil fuel emissions, and it provides a more accurate reflection of when and where harvest emissions actually occur.

The **stock change** approach accounts only for the net carbon stock change in the domestic wood product reservoir, e.g., HWP-C in all long-lived commodities within the national territory, after imports and exports. The difference between the stock change and atmospheric flow accounting lies in the treatment of exported products (which are significant in Canada). In the stock change approach, carbon in all exported wood products and commodities exits the domestic stock and hence is considered an emission to the atmosphere.

The **production** approach accounts for the changes in carbon stocks of domestically harvested wood and commodities derived from this domestic wood, regardless of their actual location. The accounting boundaries hence encompass the entire export market; emissions occur both within and outside the producing country (mostly outside in Canada's case).

The **simple decay** approach also accounts for the delayed emissions from all HWP-C from domestically harvested wood, but in a simplified way, by applying decay curves standardized by product categories. This approach uses the same system boundaries as the production one. Equation 12.1 of IPCC (2006) illustrates one implementation of the simple decay approach.

A3

## A3.5. Methodology for Waste

The Waste Sector consists of three sources of emissions: solid waste disposal on land (landfills), wastewater treatment, and waste incineration. This section of Annex 3 details the accounting methodologies that are used to describe the greenhouse gas (GHG) emission estimates for the following categories from the Waste Sector:

- $CH_4$ emissions from solid waste disposal on land;
- $CH_4$ and $N_2O$ emissions from wastewater treatment; and
- $CO_2$, $CH_4$, and $N_2O$ emissions from waste incineration.

### A3.5.1. CH₄ Emissions from Solid Waste Disposal on Land

#### A3.5.1.1. Methodology

Emissions are estimated from two types of landfills in Canada:

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

The Scholl Canyon model is used to estimate $CH_4$ generation from landfills using the following first-order decay equation (IPCC/OECD/IEA 1997):

Equation A3–72:

$$Q_{T,x} = kM_x L_0 e^{-k(T-x)}$$

where:

| | | |
|---|---|---|
| $Q_{T,x}$ | = | the amount of $CH_4$ generated in the current year (T) by the waste Mx, kt $CH_4$/year |
| X | = | the year of waste input |
| $M_x$ | = | the amount of waste disposed of in year x, Mt |
| K | = | $CH_4$ generation rate constant, yr$^{-1}$ |
| $L_0$ | = | $CH_4$ generation potential, kg $CH_4$/t waste |
| T | = | current year |

Figure A3–25   Scholl Canyon Model Representation of Landfill Degradation
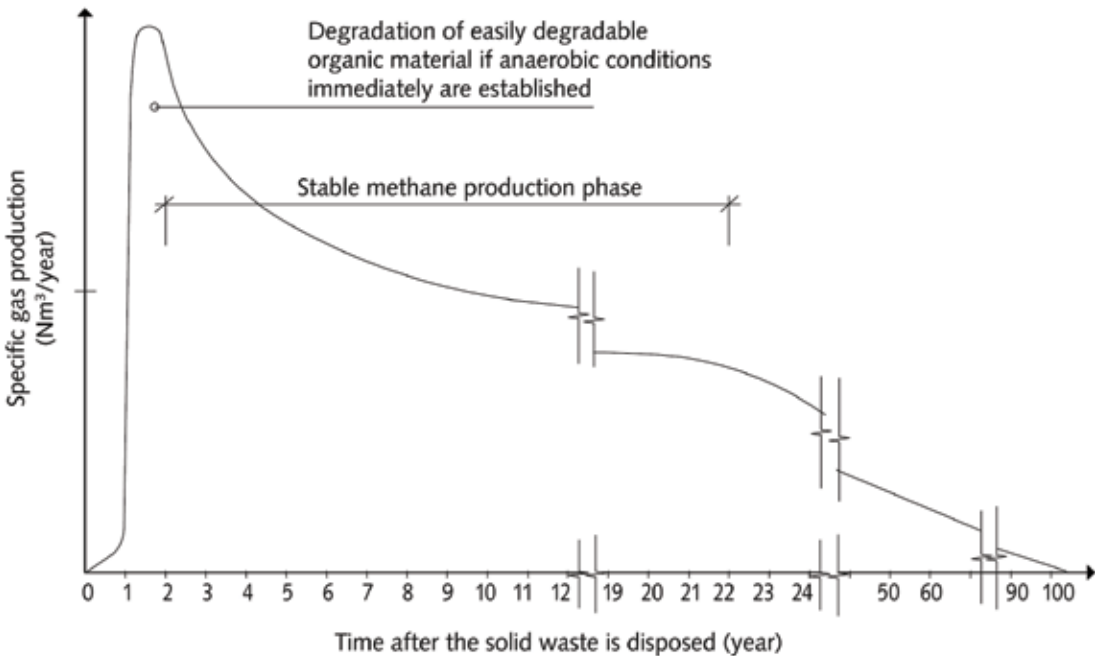


Note:
Figure is from Jensen and Pipatti (2003) and is shown as published without modification.

Equation A3–73:

$$Q_T = \sum Q_{T,x}$$

where:

$Q_T$ = The amount of $CH_4$ generated in the current year (T), kt $CH_4$/year

The Scholl Canyon model assumes that $CH_4$ production is highest in the early phase, followed by a slow steady decline in annual production rates, as shown in Figure A3–25. The Canadian model assumes that the initial lag time where anaerobic conditions are established is negligible, as shown in Figure A3–25.

In order to estimate $CH_4$ emissions from landfills, information on several of the factors described above is needed. To calculate the net emissions for a specific year, the sum of QT,x for every section of waste landfilled in past years is taken, the captured gas quantities subtracted, and the CH4 emitted from the incomplete combustion of the flared portion of captured gas is added. A computerized model has been developed to estimate aggregate emissions on a regional basis in Canada.

## Waste Disposed of Each Year ($M_X$)

### MSW Landfills

Two primary sources are used in obtaining landfill data for the GHG inventory. The amount of MSW landfilled in the years 1941 through 1990 was estimated by Levelton (1991). For the years 1998, 2000, 2002, 2004 and 2006, MSW disposal data are obtained from the *Waste Management Industry Survey*, which is conducted by Statistics Canada on a biennial basis (Statistics Canada, 2000, 2003, 2004, 2007a, 2008a). MSW disposal values for the subsequent odd years (1999, 2001, 2003 and 2005) are obtained by taking an average of the adjacent even years. Disposal, with respect to the Statistics Canada data, refers to the combination of waste incinerated and waste landfilled. Therefore, in order to obtain the amount of waste landfilled, incinerated waste is subtracted from the Statistics Canada disposal values for 1998, 2000, 2002, 2004 and 2006. As well, exported waste is subtracted from the 2000, 2002, 2004 and 2006 Statistics Canada disposal data, since the amount of waste exported is included in the waste disposal values for the Statistics Canada 2000 survey year

and subsequent years.[26, 27]

Over the period 1991–1997 and 2005, with the exception of Prince Edward Island, the Northwest Territories, Nunavut and Yukon, MSW landfill values are estimated by fitting a polynomial to the Levelton (1991) and Statistics Canada (2000, 2003, 2004, 2007a, 2008a) MSW landfill values. The 2007, 2008 and 2009 data were trended from earlier waste quantity values. Data from the 2010 *Waste Management Industry Survey* would have been used to update the 2007 and 2008 waste landfilled quantities, but this publication was not issued in time for the present NIR submission. This information will be revised for the subsequent NIR submission in 2012. To estimate the coefficients in the polynomial, a multiple linear regression application (Microsoft Excel LINEST statistical tool for an array) is used. The choice of how many coefficients to use for the polynomial function depended on how well the data fit the lower-order polynomials. Generally, the polynomial fit was improved with increasing number of coefficients. A polynomial of the order 13 is used in the inventory MSW estimates. This multiple linear regression method of estimation is consistent with the Intergovernmental Panel on Climate Change (IPCC) interpolation method (IPCC 2000). Table A3–40 shows the polynomial coefficients generated by the multiple linear regression method for each of the provinces.

The amounts of MSW landfilled for the years 1991–1997 and 2005 are calculated according to Equation A3–74:

Equation A3–74:

$$M_X = \left(c_{13} \times X^{13}\right) + \left(c_{12} \times X^{12}\right) + \left(c_{11} \times X^{11}\right) + \left(c_{10} \times X^{10}\right) + \left(c_9 \times X^9\right) + \left(c_8 \times X^8\right) + \left(c_7 \times X^7\right)$$
$$+ \left(c_6 \times X^6\right) + \left(c_5 \times X^5\right) + \left(c_4 \times X^4\right) + \left(c_3 \times X^3\right) + \left(c_2 \times X^2\right) + \left(c_1 \times X\right) + c$$

where:

$M_X$ = MSW landfilled in year X, t

$C_i$ = coefficient of the ith order (see Table A3–40)

$x$ = year of interest

26    Marshall J. 2006. Personal communication (February 2006). Manager of the Waste Management Industry Survey: Business and Government Sectors, 2002 Report. Statistics Canada.

27    Marshall J. 2007. Personal communication (email dated February 21, 2006). Manager of the Waste Management Industry Survey: Business and Government Sectors, 2004 Report. Statistics Canada.

Table A3–40    Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of MSW Landfilled for 1991–1997 and 2005

|  | N.L. | N.S. | N.B. | Que. | Ont. | Man. | Sask. | Alta. | B.C. |
|---|---|---|---|---|---|---|---|---|---|
| C | 6.87E+09 | 8.60E+09 | −1.87E+10 | 2.18E+11 | −2.91E+10 | −8.47E+09 | 3.96E+10 | −4.35E+11 | 1.70E+12 |
| C1 | −1.97E+06 | −3.22E+06 | 4.22E+06 | −4.70E+08 | −2.37E+07 | 3.28E+06 | 6.20E+06 | 4.13E+08 | −1.17E+09 |
| C2 | 3.14E+03 | −1.02E+04 | −7.88E+02 | 8.18E+05 | 2.49E+04 | 5.10E+03 | −1.39E+04 | −4.96E+04 | 2.53E+04 |
| C3 | 1.62E+00 | 2.65E+00 | 2.26E+00 | −3.18E+02 | 1.50E+01 | −5.77E−01 | −1.75E+01 | −3.04E+01 | −1.65E+02 |
| C4 | 8.20E−06 | −1.59E−03 | 1.30E−03 | −2.15E−01 | −5.96E−03 | −1.51E−03 | 3.28E−03 | −4.42E−03 | 8.23E−02 |
| C5 | −9.81E−08 | 2.46E−06 | −5.70E−07 | 4.76E−05 | −1.68E−06 | −2.78E−07 | 3.72E−06 | 2.21E−05 | 1.52E−06 |
| C6 | −1.63E−10 | 8.20E−10 | 3.21E−10 | 4.16E−08 | 1.13E−09 | 1.51E−10 | 7.74E−10 | −1.55E−08 | 3.39E−08 |
| C7 | −8.88E−14 | −2.11E−13 | −2.43E−14 | 5.93E−12 | −3.00E−14 | 2.72E−13 | −4.58E−13 | −1.02E−12 | −5.11E−12 |
| C8 | −6.34E−17 | −1.50E−16 | −1.09E−16 | 6.56E−15 | −8.94E−16 | −7.69E−17 | 8.21E−17 | 4.03E−15 | −2.76E−15 |
| C9 | 5.40E−20 | −2.03E−19 | −2.03E−20 | −5.89E−18 | −2.33E−19 | −5.56E−20 | 7.12E−20 | −1.61E−18 | −2.24E−19 |
| C10 | −1.48E−24 | 3.34E−24 | −1.30E−23 | −1.91E−21 | 2.36E−22 | 1.74E−23 | −1.54E−22 | 4.04E−22 | 3.44E−22 |
| C11 | −6.62E−28 | 2.48E−26 | 9.41E−27 | 1.61E−25 | 1.08E−25 | 8.89E−27 | 6.66E−26 | 8.76E−26 | −9.63E−25 |
| C12 | 3.03E−30 | 2.21E−29 | 2.63E−30 | 5.53E−28 | −2.26E−29 | −3.09E−30 | −2.86E−29 | −9.54E−29 | 3.59E−28 |
| C13 | −1.32E−33 | −7.77E−33 | −3.92E−34 | −1.00E−31 | −1.03E−32 | −6.66E−35 | 7.64E−33 | 1.57E−32 | −6.11E−33 |

Notes:

Coefficients have been rounded and may not result in the correct totals for MSW landfilled.

Table A3–41    MSW Landfilled for 1990–2009[4]

| Year | N.L. | P.E.I. | N.S. | N.B. | Que. | Ont.[3] | Man. | Sask. | Alta. | B.C. | Yk. | N.W.T. & Nvt. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990[1] | 366 004 | 51 293 | 493 010 | 462 391 | 3 699 833 | 5 957 104 | 696 174 | 638 942 | 1 577 585 | 1 760 621 | 16 608 | 34 493 |
| 1991 | 400 159 | 68 758 | 540 341 | 489 539 | 4 073 027 | 6 287 557 | 741 706 | 720 035 | 1 790 701 | 1 990 162 | 18 826 | 37 068 |
| 1992 | 402 670 | 74 800 | 533 426 | 488 826 | 4 152 266 | 6 390 940 | 755 034 | 729 362 | 1 837 539 | 2 012 191 | 17 200 | 35 300 |
| 1993 | 403 918 | 72 326 | 523 456 | 485 805 | 4 230 976 | 6 479 872 | 767 869 | 736 993 | 1 881 860 | 2 028 235 | 20 392 | 39 083 |
| 1994 | 403 775 | 74 801 | 510 179 | 480 262 | 4 309 123 | 6 552 824 | 780 167 | 742 752 | 1 923 350 | 2 037 746 | 19 677 | 40 378 |
| 1995 | 402 110 | 76 727 | 493 335 | 471 972 | 4 386 673 | 6 608 214 | 791 881 | 746 453 | 1 961 687 | 2 040 161 | 20 487 | 41 527 |
| 1996 | 398 783 | 79 338 | 472 655 | 460 706 | 4 463 598 | 6 644 405 | 802 966 | 747 906 | 1 996 538 | 2 034 895 | 21 500 | 42 343 |
| 1997 | 393 651 | 80 034 | 447 861 | 446 225 | 4 539 872 | 6 659 708 | 813 373 | 746 914 | 2 027 558 | 2 021 350 | 21 940 | 42 427 |
| 1998[2] | 366 280 | 104 825 | 407 095 | 425 626 | 4 568 910 | 5 963 525 | 855 666 | 780 700 | 1 874 276 | 1 789 252 | 24 104 | 49 469 |
| 1999 | 369 650 | 80 397 | 357 703 | 387 656 | 4 799 511 | 6 202 392 | 875 695 | 741 743 | 2 006 801 | 1 843 849 | 20 845 | 42 392 |
| 2000[2] | 373 020 | 92 586 | 308 311 | 349 685 | 5 030 113 | 6 441 259 | 895 724 | 702 786 | 2 139 327 | 1 898 445 | 21 290 | 43 694 |
| 2001 | 364 808 | 81 111 | 306 549 | 354 002 | 5 057 953 | 6 375 459 | 857 145 | 711 293 | 2 193 015 | 1 882 820 | 20 175 | 43 612 |
| 2002[2] | 356 595 | 82 280 | 304 787 | 358 318 | 5 085 793 | 6 309 660 | 818 566 | 719 801 | 2 246 704 | 1 867 196 | 18 920 | 38 830 |
| 2003 | 367 700 | 82 195 | 310 242 | 366 047 | 5 429 638 | 6 021 626 | 839 020 | 716 748 | 2 346 984 | 1 962 272 | 21 046 | 45 971 |
| 2004[2] | 378 804 | 90 075 | 315 698 | 373 776 | 5 773 482 | 5 733 593 | 859 475 | 713 696 | 2 447 264 | 2 057 347 | 20 712 | 42 509 |
| 2005 | 382 441 | 83 815 | 315 785 | 377 185 | 5 937 451 | 5 790 051 | 903 996 | 731 122 | 2 742 529 | 2 120 093 | 22 062 | 47 471 |
| 2006[2] | 386 077 | 83 553 | 315 872 | 380 593 | 6 101 419 | 5 846 509 | 948 518 | 748 549 | 3 037 794 | 2 182 838 | 22 464 | 47 691 |
| 2007 | 382 710 | 84 021 | 272 933 | 350 787 | 6 236 765 | 5 784 974 | 866 338 | 698 631 | 2 836 066 | 2 160 704 | 22 781 | 48 357 |
| 2008 | 384 910 | 86 711 | 262 871 | 346 560 | 6 423 385 | 5 726 843 | 866 915 | 693 430 | 2 942 694 | 2 203 076 | 23 371 | 48 745 |
| 2009 | 387 110 | 89 726 | 252 810 | 342 333 | 6 610 004 | 5 668 712 | 867 493 | 688 229 | 3 049 322 | 2 245 448 | 23 950 | 49 210 |

Notes:
1. 1990 data obtained from Levelton (1991).
2. 1998, 2000, 2002, 2004 and 2006 data obtained from Statistics Canada disposal data (Statistics Canada 2000, 2003, 2004, 2007a, 2008a).
3. Exported MSW subtracted from the Statistics Canada disposal data (Bruce Pope, Waste Management Analyst, Waste Management Policy Branch, Ontario Ministry of Environment, personal communication, February 2006, January 2007; Jim Hiraishi, Senior Engineer, Waste Management Policy Branch, Ontario Ministry of Environment, personal communication, November 30, 2007).
4. The data represented above were chosen from selected years. MSW landfill data from 1941 to 1990 (Levelton 1991) were used in the multiple linear regression method for estimation of MSW landfilled for 1991–2006.

Statistics Canada MSW disposal data are unavailable for Prince Edward Island,the Northwest Territories, Nunavut and Yukon. Thus, MSW landfill values for this province and these territories for the period 1991–2009 are obtained by trending historical landfill data with the provincial populations for 1971–2009 (Statistics Canada 2006). Three sources of landfill data are used to estimate the MSW landfill amounts for 1991–2009. The first set of data was provided by Levelton (1991) for 1971–1990. The second set of landfill data was provided by the Hazardous Waste Branch of Environment Canada for 1992 (Environment Canada 1996b). The third set of landfill data involves multiplying the 1992 percentage of waste landfilled for Prince Edward Island, the Northwest Territories, Nunavut and Yukon (Environment Canada 1996b) by the surplus of waste landfilled provided by Statistics Canada for 1998, 2000, 2002, 2004 and 2006 (Statistics Canada 2000, 2003, 2004, 2007a, 2008a). The surplus of waste landfilled for 1998, 2000, 2002, 2004 and 2006 is calculated by subtracting the sum of the provided provincial landfill values from the total Canadian landfill value. Table A3–41 shows the amount of MSW landfilled for the period 1990–2009.

## Wood Waste Landfills

The amount of wood waste landfilled in the years 1970 through 1992 is estimated at a national level based on the National Wood Residue Data Base (NRCan 1997). Data for the years 1998 and 2004 are provided in subsequent publications (NRCan 1999, 2005). A linear regression trend analysis is conducted to interpolate the amount of wood residue landfilled in the years 1993–1997, 1999–2003 and 2005–2009. This interpolation method has been selected because it is most suitable for the data distribution.

The breakdown in the amount of wood residue disposed of (defined as residue that is not further used in a product, used as a source of fuel, or converted into a chemical) for the solid wood operations and the pulp and paper industries is estimated based on information from a study of pulp and paper mill waste (MWA Consultants Paprican 1998). The proportion of wood waste disposal is estimated at 80% for solid wood operations and 20% for pulp and paper mills.

The breakdown of the portion of the wood residue directed to landfills from the solid wood and pulp and paper industry operations is estimated based on the National

Table A3–42    Wood Waste Generated and Landfilled in Canada for 1990–2009

| Year | Wood Waste Disposed of (bone dry tonnes) | | Wood Waste Landfilled (bone dry tonnes) | | |
|---|---|---|---|---|---|
| | Pulp & Paper | Solid Wood Industry | Pulp & Paper | Solid Wood Industry | Total |
| 1990 | 1 811 062 | 7 244 248 | 1 557 513 | 1 086 637 | 2 644 151 |
| 1991 | 1 811 062 | 7 244 248 | 1 557 513 | 1 086 637 | 2 644 151 |
| 1992 | 1 811 062 | 7 244 248 | 1 557 513 | 1 086 637 | 2 644 151 |
| 1993 | 1 537 557 | 6 150 226 | 1 322 299 | 922 534 | 2 244 833 |
| 1994 | 1 447 245 | 5 788 981 | 1 244 631 | 868 347 | 2 112 978 |
| 1995 | 1 356 934 | 5 427 736 | 1 166 963 | 814 160 | 1 981 124 |
| 1996 | 1 266 623 | 5 066 491 | 1 089 296 | 759 974 | 1 849 269 |
| 1997 | 1 176 311 | 4 705 246 | 1 011 628 | 705 787 | 1 717 415 |
| 1998 | 1 080 000 | 4 320 000 | 928 800 | 648 000 | 1 576 800 |
| 1999 | 995 689 | 3 982 755 | 856 292 | 597 413 | 1 453 706 |
| 2000 | 905 378 | 3 621 510 | 778 625 | 543 227 | 1 321 851 |
| 2001 | 815 066 | 3 260 265 | 700 957 | 489 040 | 1 189 997 |
| 2002 | 724 755 | 2 899 020 | 623 289 | 434 853 | 1 058 142 |
| 2003 | 634 444 | 2 537 775 | 545 622 | 380 666 | 926 288 |
| 2004 | 547 561 | 2 190 244 | 470 902 | 328 537 | 799 439 |
| 2005 | 453 821 | 1 815 284 | 390 286 | 272 293 | 662 579 |
| 2006 | 363 510 | 1 454 039 | 312 618 | 218 106 | 530 724 |
| 2007 | 273 198 | 1 092 794 | 234 951 | 163 919 | 398 870 |
| 2008 | 182 887 | 731 549 | 157 283 | 109 732 | 267 015 |
| 2009 | 92 576 | 370 303 | 79 615 | 55 546 | 135 161 |

Wood Residue Data Base (NRCan 1997). The allocation of wood waste landfilled in private landfills is estimated at 15% for solid wood operations and 86% for pulp and paper mills. To avoid double counting, since emissions from public landfills are already accounted for in the emissions from MSW landfills, the ratio of wood waste landfilled in private versus public landfills, obtained from NRCan (1997) is used to isolate the quantity landfilled in dedicated private wood waste landfills. This portion is assumed to be also true for the years 1970–2009. Table A3–42 shows the amount of wood waste disposed of and landfilled for the period 1990–2009.

## CH₄ Generation Rate Constant (k)

The $CH_4$ generation rate constant k represents the first-order rate at which $CH_4$ is generated after waste has been landfilled. The value of k is affected by four factors: moisture content, availability of nutrients, pH and temperature. In calculating provincial decay rates, however, the ambient temperature should not be considered, as the landfill temperature is independent of the ambient temperature at depths exceeding 2 m. The moisture content should be the sole parameter considered (Maurice and Lagerkvist 2003; Thompson and Tanapat 2005).

### MSW Landfills

The k values used to estimate emissions from MSW landfills were obtained from a study conducted by Environment Canada's Greenhouse Gas Division that employed provincial precipitation data from 1941 to 2007 (Environment Canada, 1941–2007). The provincial locations at which the average annual precipitations calculated were those indicated in the Levelton study where major landfills were located over the 1941 to 1990 period (Levelton

1991), with additional data for British Columbia from a study performed by Golder Associates Ltd. (2008). From these precipitation values, k values were determined using a relationship prepared by the Research Triangle Institute (RTI) for the U.S. Environmental Protection Agency (RTI 2004). RTI assigns default decay values of less than 0.02/year, 0.038/year and 0.057 /year to areas with an annual precipitation of less than 20 inch/year (< 500 mm), between 20 and 40 inch/year (500 to 1000 (average 750) mm) and greater than 40 inch/year (> 1000 mm), respectively. The plot of these decay values and precipitation data showed a linear relationship: $k (yr^{-1}) = 7 \times 10^{-5} \times$ precipitation (mm)$-0.0172$. Using this relationship and Environment Canada's average provincial precipitation data for 1941–1975, 1976–1989 and 1990–2007, average provincial landfill decay rates were calculated (Environment Canada 1941–2007). The U.S. k values are related to precipitation, assuming that the moisture content of a landfill is a direct function of the annual precipitation. Based on both the U.S. k values and precipitation data and the average annual precipitation at Canadian landfills surveyed by Levelton (1991), k values were assigned to each of the provinces for the three respective time series: 1941–1975, 1976–1989 and 1990–2007. These three time intervals were selected to match those used to derive the provincial $L_o$ values in order to better represent the changing conditions over the 1941–2009 time series. It is assumed that the conditions for which the 1990–2007 k values were derived were also valid for 2008 and 2009.

Table A3–43 shows the mean annual precipitation and decay values assigned for each of the provincial landfill sites selected by Levelton (1991) and Golder Associates Ltd. (2008).

Table A3–43    Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites

| Region | Annual Precipitation (mm) from Environment Canada's Historical Climate Data | | | Rate constant k (yr-1) | | |
|---|---|---|---|---|---|---|
| | 1941–1975 | 1976–1989 | 1990–2007 | 1941–1975 | 1976–1989 | 1990–2007 |
| **British Columbia** | | | | | | |
| Campbell River | 1 521.4 | 1 370.2 | 1 507.0 | 0.089 | 0.079 | 0.088 |
| Chilliwack | 1 674.4 | 1 736.9 | 1 678.0 | 0.100 | 0.104 | 0.100 |
| Courtney | 1 465.7 | 1 387.9 | 1 441.3 | 0.085 | 0.080 | 0.084 |
| Kamloops | 270.1 | 273.9 | 296.5 | 0.002 | 0.002 | 0.004 |
| Matsqui | 1 537.1 | 1 480.1 | 1 571.6 | 0.090 | 0.086 | 0.093 |
| Port Alberni | 1 954.2 | 1 870.8 | 2 050.1 | 0.120 | 0.114 | 0.126 |
| Prince Rupert | 2 636.2 | 3 082.7 | 2 538.7 | 0.167 | 0.199 | 0.161 |
| Vancouver | 1 846.0 | 1 599.8 | 1 564.5 | 0.112 | 0.095 | 0.092 |
| Vernon | 393.2 | 415.3 | 429.7 | 0.010 | 0.012 | 0.013 |
| Victoria | 864.6 | 978.6 | 1 197.7 | 0.043 | 0.051 | 0.067 |
| **Average** | **1 416.3** | **1 419.6** | **1 427.5** | **0.082** | **0.082** | **0.083** |
| **Alberta** | | | | | | |
| Calgary | 429.9 | 406.8 | 426.5 | 0.013 | 0.011 | 0.013 |
| Edmonton | 451.9 | 480.2 | 446.8 | 0.014 | 0.016 | 0.014 |
| Fort McMurray | 441.1 | 445.8 | 417.9 | 0.014 | 0.014 | 0.012 |
| Lethbridge | 427.5 | 396.4 | 385.8 | 0.013 | 0.011 | 0.010 |
| Medicine Hat | 344.1 | 332.5 | 338.9 | 0.007 | 0.006 | 0.007 |
| Red Deer | 450.9 | 463.5 | 487.4 | 0.014 | 0.015 | 0.017 |
| **Average** | **424.2** | **420.9** | **417.2** | **0.012** | **0.012** | **0.012** |

Table A3-43   Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites   (cont'd)

| Region | Annual Precipitation (mm) from Environment Canada's Historical Climate Data | | | Rate constant k (yr-1) | | |
|---|---|---|---|---|---|---|
| | 1941–1975 | 1976–1989 | 1990–2007 | 1941–1975 | 1976–1989 | 1990–2007 |
| **Saskatchewan** | | | | | | |
| Moose Jaw | 388.9 | 329.7 | 468.4 | 0.010 | 0.006 | 0.016 |
| Prince Albert | 333.2 | 425.9 | 458.7 | 0.006 | 0.013 | 0.015 |
| Regina | 390.2 | 359.9 | 404.2 | 0.010 | 0.008 | 0.011 |
| Saskatoon | 360.0 | 332.9 | 356.3 | 0.008 | 0.006 | 0.008 |
| Swift Current | 385.1 | 359.8 | 409.1 | 0.010 | 0.008 | 0.011 |
| Yorkton | 440.7 | 440.1 | 435.1 | 0.014 | 0.014 | 0.013 |
| **Average** | **383.0** | **374.7** | **422.0** | **0.010** | **0.009** | **0.012** |
| **Manitoba** | | | | | | |
| Brandon | 464.8 | 434.7 | 480.8 | 0.015 | 0.013 | 0.016 |
| Portage la Prairie | 540.4 | 533.8 | 562.4 | 0.021 | 0.020 | 0.022 |
| Thompson | 566.8 | 517.5 | 500.7 | 0.022 | 0.019 | 0.018 |
| Winnipeg | 534.1 | 487.7 | 540.9 | 0.020 | 0.017 | 0.021 |
| **Average** | **526.5** | **493.4** | **521.2** | **0.020** | **0.017** | **0.019** |
| **Ontario** | | | | | | |
| Barrie | 894.6 | 952.3 | 927.6 | 0.045 | 0.049 | 0.048 |
| Belleville | 868.3 | 898.7 | 920.6 | 0.044 | 0.046 | 0.047 |
| Brantford | 741.3 | 815.8 | 857.1 | 0.035 | 0.040 | 0.043 |
| Brockville | 961.2 | 977.2 | 1 013.0 | 0.050 | 0.051 | 0.054 |
| Cornwall | 934.7 | 969.0 | 1 044.9 | 0.048 | 0.051 | 0.056 |
| Guelph | 839.6 | 915.3 | 900.5 | 0.042 | 0.047 | 0.046 |
| Hamilton | 750.2 | 945.3 | 889.1 | 0.035 | 0.049 | 0.045 |
| Kingston | 810.3 | 975.2 | 964.2 | 0.040 | 0.051 | 0.050 |
| Kitchener | 885.9 | 985.5 | 844.0 | 0.045 | 0.052 | 0.042 |
| London | 921.5 | 997.8 | 993.3 | 0.047 | 0.053 | 0.052 |
| North Bay | 979.2 | 1 015.2 | 1 050.3 | 0.051 | 0.054 | 0.056 |
| Oshawa | 843.5 | 941.3 | 866.4 | 0.042 | 0.049 | 0.043 |
| Ottawa-Hull | 868.4 | 939.2 | 937.7 | 0.044 | 0.049 | 0.048 |
| Peterborough | 749.4 | 862.8 | 856.5 | 0.035 | 0.043 | 0.043 |
| St. Catharines | 806.7 | 860.2 | 866.5 | 0.039 | 0.043 | 0.043 |
| Sarnia | 752.4 | 842.6 | 972.8 | 0.035 | 0.042 | 0.051 |
| Sudbury | 760.6 | 907.7 | 911.6 | 0.036 | 0.046 | 0.047 |
| Thunder Bay | 734.8 | 696.1 | 578.4 | 0.034 | 0.032 | 0.023 |
| Timmins | 780.4 | 864.6 | 809.7 | 0.037 | 0.043 | 0.039 |
| Toronto | 794.4 | 843.2 | 808.1 | 0.038 | 0.042 | 0.039 |
| Windsor | 839.8 | 921.8 | 927.0 | 0.042 | 0.047 | 0.048 |
| **Average** | **834.2** | **910.8** | **901.9** | **0.041** | **0.047** | **0.046** |
| **Quebec** | | | | | | |
| Montréal | 952.8 | 935.2 | 1 018.8 | 0.049 | 0.048 | 0.054 |
| Québec | 1 137.9 | 1 174.9 | 1 148.6 | 0.062 | 0.065 | 0.063 |
| Rimouski | 773.0 | 955.7 | 961.3 | 0.037 | 0.050 | 0.050 |
| Saint-Étienne | 1 021.0 | 994.2 | 981.4 | 0.054 | 0.052 | 0.051 |
| Saint-Tite-des-Caps | 1 009.7 | 1 102.4 | 1 178.3 | 0.053 | 0.060 | 0.065 |
| Ste-Cécile | 1 113.5 | 1 218.6 | 1 245.1 | 0.061 | 0.068 | 0.070 |
| Ste-Sophie | 1 047.3 | 1 031.2 | 1 063.4 | 0.056 | 0.055 | 0.057 |
| **Average** | **1 007.9** | **1 058.9** | **1 085.3** | **0.053** | **0.057** | **0.059** |
| **New Brunswick** | | | | | | |
| Bathurst | 958.1 | 1 067.5 | 1 123.4 | 0.050 | 0.058 | 0.061 |
| Campbellton | 1 002.6 | 1 002.6 | 1 002.6 | 0.053 | 0.053 | 0.053 |
| Edmundston | 1 078.3 | 1 053.3 | 992.1 | 0.058 | 0.057 | 0.052 |
| Fredericton | 1 077.4 | 1 182.5 | 995.7 | 0.058 | 0.066 | 0.053 |
| Moncton | 1 159.4 | 1 116.7 | 1 172.1 | 0.064 | 0.061 | 0.065 |
| Saint John | 1 339.3 | 1 477.4 | 1 245.5 | 0.077 | 0.086 | 0.070 |
| **Average** | **1 102.5** | **1 150.0** | **1 088.6** | **0.060** | **0.063** | **0.059** |
| **Prince Edward Island** | | | | | | |
| Charlottetown | 1 116.0 | 1 218.3 | 1 096.2 | 0.061 | 0.068 | 0.060 |
| Summerside | 987.6 | 1 052.7 | 1 149.1 | 0.052 | 0.056 | 0.063 |
| **Average** | **1 051.8** | **1 135.5** | **1 122.6** | **0.056** | **0.062** | **0.061** |
| **Nova Scotia** | | | | | | |
| Dartmouth | 1 492.8 | 1 449.5 | 1 349.6 | 0.087 | 0.084 | 0.077 |
| Halifax | 1 492.8 | 1 449.5 | 1 349.6 | 0.087 | 0.084 | 0.077 |
| Lunenburg | 1 456.2 | 1 475.2 | 1 559.5 | 0.085 | 0.086 | 0.092 |
| New Glasgow | 1 076.8 | 1 120.5 | 1 106.7 | 0.058 | 0.061 | 0.060 |
| Sydney | 1 359.1 | 1 514.9 | 1 413.0 | 0.078 | 0.089 | 0.082 |
| Truro | 1 087.7 | 1 226.1 | 1 110.8 | 0.059 | 0.069 | 0.061 |
| **Average** | **1 327.6** | **1 372.6** | **1 314.9** | **0.076** | **0.079** | **0.075** |
| **Newfoundland** | | | | | | |
| Carbonear | N/A | N/A | N/A | N/A | N/A | N/A |
| Corner Brook | 1 127.1 | 1 255.9 | 1 196.1 | 0.062 | 0.071 | 0.067 |
| St. John's | 1 502.4 | 1 525.2 | 1 515.3 | 0.088 | 0.090 | 0.089 |
| **Average** | **1 314.8** | **1 390.5** | **1 355.7** | **0.075** | **0.080** | **0.078** |
| **Yukon** | | | | | | |
| Whitehorse | 264.2 | 261.7 | 271.8 | 0.001 | 0.001 | 0.002 |
| **Average** | **264.2** | **261.7** | **271.8** | **0.001** | **0.001** | **0.002** |
| **Northwest Territories** | | | | | | |
| Yellowknife | 261.2 | 273.0 | 287.0 | 0.001 | 0.002 | 0.003 |
| **Average** | **261.2** | **273.0** | **287.0** | **0.001** | **0.002** | **0.003** |
| **Nunavut** | | | | | | |
| Iqaluit | 420.1 | 448.9 | 372.1 | 0.012 | 0.014 | 0.009 |
| **Average** | **420.1** | **448.9** | **372.1** | **0.012** | **0.014** | **0.009** |
| **Average (N.W.T. and Nvt.)** | **340.6** | **360.9** | **329.5** | **0.007** | **0.008** | **0.006** |

Note: N/A =  not available.

Table A3–44    Provincial and Territorial MSW Landfill k ($Yr^{-1}$)Value Estimates

| Year | Provinces and Territories | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N.L. | P.E.I. | N.S. | N.B. | Que. | Ont. | Man. | Sask. | Alta. | B.C. | Yk. | N.W.T. & Nvt. |
| 1941–1975 | 0.075 | 0.056 | 0.076 | 0.06 | 0.053 | 0.041 | 0.020 | 0.01 | 0.012 | 0.082 | 0.001 | 0.001 |
| 1976–1989 | 0.080 | 0.062 | 0.079 | 0.063 | 0.057 | 0.047 | 0.017 | 0.009 | 0.012 | 0.082 | 0.001 | 0.002 |
| 1990–2007 | 0.078 | 0.061 | 0.075 | 0.059 | 0.059 | 0.046 | 0.019 | 0.012 | 0.012 | 0.083 | 0.002 | 0.003 |

The k values used to estimate emissions from MSW landfills at a provincial level are derived from taking the average of k value estimates for each province for each of the three time series. These values are provided in Table A3–44.

*Wood Waste Landfills*

Based upon the default value for estimating wood products industry landfill $CH_4$ emissions recommended by the National Council for Air and Stream Improvement Inc., a k value of 0.03/year was assumed to represent the $CH_4$ generation rate constant for all of the wood waste landfills in Canada (NCASI 2003).

## $CH_4$ Generation Potential ($L_0$)

*MSW Landfills*

The $CH_4$ generation potential ($L_0$) represents the amount of $CH_4$ that could be theoretically produced per tonne of waste landfilled. As presented in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Equation A3–75, is used to calculate the $CH_4$ generation potential for MSW landfills (IPCC/OECD/IEA 1997):

Equation A3–75:

$$L_0 = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \times 1000 \frac{kgCH_4}{tCH_4}$$

where:

| | | |
|---|---|---|
| $L_0$ | = | $CH_4$ generation potential, kg $CH_4$/t waste |
| MCF | = | $CH_4$ correction factor, fraction |
| DOC | = | degradable organic carbon, t C/t waste |
| $DOC_F$ | = | fraction of DOC dissimilated |
| F | = | fraction of $CH_4$ in landfill gas |
| 16/12 | = | stoichiometric factor to convert $CH_4$ to carbon |

The methane conversion factor (MCF) accounts for the proportion of managed to un-managed solid waste disposal

sites. Un-managed solid waste disposal sites produce less $CH_4$, since a larger fraction of waste decomposes aerobically in the top layers of the site. The IPCC default value for MCF for managed landfill sites is chosen to represent the MCF for MSW landfills, since it is assumed that all landfills covered by the data collected are engineered landfills. The IPCC default values for MCF are shown in Table A3–45 (IPCC/OECD/IEA 1997).

Table A3–45    Solid Waste Disposal Site $CH_4$ Correction Factors

| Type of Site | MCF Default Values |
|---|---|
| Managed | 1.0 |
| Unmanaged: deep (≥ 5 m waste) | 0.8 |
| Unmanaged: shallow (< 5 m waste) | 0.4 |
| Default value: uncategorized solid waste disposal sites | 0.6 |

The IPCC default value for the fraction of $CH_4$ in landfill gas (F) ranges between 0.4 and 0.6. It can vary based on certain factors, including waste age and composition and potential air dilution effects that can lower the actual concentration of $CH_4$ in the landfill gas. The average value 0.5 is chosen for the fraction of $CH_4$ in landfill gas.

$DOC_F$ represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal site. It accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. A value of 0.6 was selected from the IPCC $DOC_F$ default range, for waste that includes lignin, of 0.5 to 0.6 (IPCC 2000). This value, taken from the upper end of this range, i.e., more easily degraded, best represents the Canadian situation where the majority of the wood wastes, that by definition have high lignin concentrations, from saw mills and pulp

and paper industries, are disposed of in dedicated private landfills.

DOC represents the amount of organic carbon that is accessible to biochemical decomposition and is based on the composition of the waste. Waste composition percentages from across Canada are used to calculate the provincial DOC values according to Equation A3–76 (IPCC/OECD/IEA 1997).

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Equation A3–76:

$$\% \text{ DOC (by wet weight)} = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D)$$

where:

| | | |
|---|---|---|
| A | = | % of MSW that is paper and textiles |
| B | = | % of MSW that is garden or park waste |
| C | = | % of MSW that is food waste |
| D | = | % of MSW that is wood or straw |

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The provincial and territorial DOCs were calculated from waste disposal composition values for three distinct time periods: 1941–1975, 1976–1989 and 1990–2006. Using waste composition data obtained from a Natural Resources Canada (NRCan) study, which were based on the 2002 data year (NRCan 2006), DOC values were derived and assumed to be constant over the period 1990 to 2009. Since

the waste diversion programs were not significant prior to 1990, a second set of DOCs was developed to represent the waste composition at disposal from 1976 to 1989 by adding the NRCan landfill data to the 2004 Statistics Canada recycled waste composition data (Statistics Canada 2007a). A third set of DOCs was developed from a 1967 national study to cover the period from 1941 to 1975 (CRC Press 1973). Provincial and territorial DOC and $L_0$ values are summarized in Table A3–46.

From the NRCan 2006 document, the quantities for each standard category of waste from residential and ICI origins were added together to reflect the true composition at disposal at the MSW landfill sites. Therefore, by this methodology, the ICI biodegradability as well as that of the residential waste are accounted for in the MSW waste composition. The NRCan report uses a consistent methodology to estimate the MSW waste composition at disposal for all provinces and territories.

Since significant results from waste diversion projects only began to be made manifest in the early 1990s in Canada, as supported by this document and expert opinion in the field, these provincial/territorial DOCs are used in the estimation of $L_0$ values and ultimately in the provincial/territorial specific methane emission generation for the period 1990–2009, inclusively.

Table A3–46   Provincial and Territorial $CH_4$ Generation Potential ($L_0$) Values

| Province/Territory | 2002 Organic Waste Diversion[1] (%) | 1941 to 1975 | | 1976 to 1989 | | 1990 to Present | |
|---|---|---|---|---|---|---|---|
| | | DOC | $L_0$ (kg $CH_4$/t waste) | DOC | $L_0$ (kg $CH_4$/t waste) | DOC | $L_0$ (kg $CH_4$/t waste) |
| Newfoundland | N/A | 0.28 | 112.62 | 0.18 | 73.28 | 0.18 | 73.35 |
| Prince Edward Island | N/A | 0.27 | 108.74 | 0.17 | 67.19 | 0.16 | 64.63 |
| Nova Scotia | 29.7 | 0.25 | 100.89 | 0.16 | 62.35 | 0.16 | 64.1 |
| New Brunswick | 19.8 | 0.23 | 93.91 | 0.16 | 65.91 | 0.16 | 63.22 |
| Quebec | 13.7 | 0.36 | 144.45 | 0.21 | 82.52 | 0.2 | 81.23 |
| Ontario | 16.4 | 0.36 | 143.74 | 0.21 | 82.75 | 0.21 | 83 |
| Manitoba | 4.9 | 0.33 | 131.37 | 0.19 | 76.82 | 0.19 | 76.59 |
| Saskatchewan | 4.3 | 0.36 | 143.92 | 0.22 | 86.39 | 0.22 | 86.75 |
| Alberta | 16.7 | 0.39 | 157.63 | 0.26 | 104.46 | 0.18 | 71.87 |
| British Columbia | 23.3 | 0.28 | 111.86 | 0.17 | 69.89 | 0.16 | 63.71 |
| Territories (Yk., N.W.T. & Nvt.) | N/A | 0.22 | 87.59 | 0.15 | 58.54 | 0.16 | 65.13 |

Notes:
Sources: Derived from data obtained from NRCan (2006), Statistics Canada (2007a) and CRC Press (1973).
1. Thompson et al. (2006).
N/A = Not available.

For the period 1976–1989, DOC values were calculated based on the assumption that the waste composition at disposal could be represented by the generation waste composition for the year 2002. This was accomplished by summing the MSW (residential and ICI) waste quantities (NRCan 2006) at disposal for each waste category with the recycled quantities for the corresponding category for each province and territory. The latter data were obtained from Statistics Canada report *Waste Management Industry Survey: Business and Government Sectors 2004* (Statistics Canada 2007a). Where gaps were identified in the Statistics Canada report, due to confidentiality issues, regional factors (western, central and maritime provinces and northern territories) were used to populate the missing data.

The years 1941 to 1975 are covered by an $L_0$ developed by a third set of DOC values, based on national waste compositions provided in Table 1.1-9 of CRC Press (1973) The data from this table are derived from the article "World Survey Finds Less Organic Matter" (Anon. 1967a). Waste audit data for the time series 1976 to 1998 were obtained from Table 1: Waste Composition Data for Ontario, of the report *Residential Waste Composition Study*, Ontario Waste composition Study – Vol. 1 (Ontario Ministry of the Environment 1991). The waste audit studies were conducted in 1976, 1978 and 1980 and gave paper, wood, food wastes, textile and yard waste average percentages of 40%, 2.6%, 22%,

3.4% and 13%, respectively. These are comparable to those from the 2002 generated estimates used for the 1976 to 1989 period. The 1967 article data (Anon. 1967a) gave paper and organic matter compositions of 70% and 10%, respectively. Therefore, 1975–1976 was judged to be an appropriate transition point to use to allow for a realistic change between the significantly different 1967 data set and the data derived from the 2002 waste composition without waste diversion employed to represent the waste composition for the late 1970s and 1980s. The breakdown of organic matter percentage (10%), obtained from Table 1.1-9: Summary of international Refuse Composition, into food and yard waste was based upon the waste composition (10.2% and 8.6%, respectively) given for Montréal, Quebec, from the same CRC Press (1973) text, Table 1.1-10: Composition of Household Garbage, where the data were obtained from a separate 1967 article (Anon. 1967b). The information on percentage of wood (2.4%) came from an article by the American Public Works Association (1964), and was presented in Table 1.1-2.8: Composition and Analysis of Average Municipal Refuse (CRC Press 1973).

A provincial profile was developed from the 1967 national average by pro-rating each of its DOC waste categories to match the same provincial profile as for the 1976 to 1989 period. Table A3–47 presents the landfilled waste composition by the categories defined in the Revised IPCC 1996

Table A3–47    Provincial and Territorial CH₄ Generation Potential ($L_0$) Values

| British Columbia | | DOC Parameters 1941–1975 | DOC Parameters 1976–1989 | DOC Parameters 1990–2009 |
|---|---|---|---|---|
| | | % | % | % |
| | A | 64.2 | 29.7 | 34.2 |
| | B | 4.8 | 15.7 | 7.9 |
| | C | 4.7 | 15.1 | 7.6 |
| | D | 0.0 | 0.0 | 0.0 |
| | DOC | 0.28 | 0.175 | 0.159 |
| | $L_0$ | 111.9 | 69.9 | 63.7 |

| Alberta | | DOC Parameters 1941–1975 | DOC Parameters 1976–1989 | DOC Parameters 1990–2009 |
|---|---|---|---|---|
| | | % | % | % |
| | A | 87.4 | 40.4 | 27 |
| | B | 7.5 | 24.6 | 17 |
| | C | 9.3 | 30 | 20.7 |
| | D | 6 | 4.2 | 3.9 |
| | DOC | 0.394 | 0.261 | 0.18 |
| | $L_0$ | 157.6 | 104.5 | 71.9 |

Table A3-48    Provincial and Territorial CH$_4$ Generation Potential (L$_0$) Values

| Manitoba | | DOC Parameters 1941–1975 | DOC Parameters 1976–1989 | DOC Parameters 1990–2009 |
|---|---|---|---|---|
| | | % | % | % |
| | A | 76.7 | 35.5 | 32.7 |
| | B | 3.8 | 12.6 | 15.1 |
| | C | 4.8 | 15.4 | 18.4 |
| | D | 2.7 | 1.9 | 2.4 |
| | DOC | 0.328 | 0.192 | 0.191 |
| | L$_0$ | 131.4 | 76.8 | 76.6 |

| Ontario | | DOC Parameters 1941–1975 | DOC Parameters 1976–1989 | DOC Parameters 1990–2009 |
|---|---|---|---|---|
| | | % | % | % |
| | A | 83.2 | 38.5 | 37.2 |
| | B | 4.2 | 13.9 | 14.8 |
| | C | 4.1 | 13.4 | 14.2 |
| | D | 4.4 | 3.1 | 4.1 |
| | DOC | 0.359 | 0.207 | 0.207 |
| | L$_0$ | 143.7 | 82.7 | 83 |

| Quebec | | DOC Parameters 1941–1975 | DOC Parameters 1976–1989 | DOC Parameters 1990–2009 |
|---|---|---|---|---|
| | | % | % | % |
| | A | 84.7 | 39.2 | 35 |
| | B | 4.2 | 13.8 | 17.2 |
| | C | 4.1 | 13.2 | 16.6 |
| | D | 3 | 2.1 | 3 |
| | DOC | 0.361 | 0.206 | 0.203 |
| | L$_0$ | 144.4 | 82.5 | 81.2 |

| New Brunswick | | DOC Parameters 1941–1975 | DOC Parameters 1976–1989 | DOC Parameters 1990–2009 |
|---|---|---|---|---|
| | | % | % | % |
| | A | 53.2 | 24.6 | 26.4 |
| | B | 6.3 | 20.7 | 16 |
| | C | 6.2 | 19.8 | 15.4 |
| | D | 0.7 | 0.5 | 0.7 |
| | DOC | 0.235 | 0.165 | 0.158 |
| | L$_0$ | 93.9 | 65.9 | 63.2 |

| Nova Scotia | | DOC Parameters 1941–1975 | DOC Parameters 1976–1989 | DOC Parameters 1990–2009 |
|---|---|---|---|---|
| | | % | % | % |
| | A | 59.6 | 27.5 | 32.3 |
| | B | 4.4 | 14.6 | 9.9 |
| | C | 4.3 | 14 | 9.5 |
| | D | 0 | 0 | 0 |
| | DOC | 0.252 | 0.156 | 0.16 |
| | L$_0$ | 100.9 | 62.4 | 64.1 |

Table A3-48   Provincial and Territorial $CH_4$ Generation Potential ($L_0$) Values

| Prince Edward Island | DOC Parameters 1941–1975 | DOC Parameters 1976–1989 | DOC Parameters 1990–2009 |
|---|---|---|---|
| | % | % | % |
| A | 64.2 | 29.7 | 34.2 |
| B | 4.8 | 15.7 | 7.9 |
| C | 4.7 | 15.1 | 7.6 |
| D | 0 | 0 | 0 |
| DOC | 0.272 | 0.168 | 0.162 |
| $L_0$ | 108.7 | 67.2 | 64.6 |

| Newfoundland and Labrador | DOC Parameters 1941–1975 | DOC Parameters 1976–1989 | DOC Parameters 1990–2009 |
|---|---|---|---|
| | % | % | % |
| A | 64.7 | 29.9 | 30.9 |
| B | 5.9 | 19.3 | 18 |
| C | 5.7 | 18.5 | 17.3 |
| D | 1.4 | 1 | 1.1 |
| DOC | 0.282 | 0.183 | 0.183 |
| $L_0$ | 112.6 | 73.3 | 73.4 |

| Yukon, Nunavut and Northwest Territories | DOC Parameters 1941–1975 | DOC Parameters 1976–1989 | DOC Parameters 1990–2009 |
|---|---|---|---|
| | % | % | % |
| A | 50.7 | 23.5 | 26.1 |
| B | 5.1 | 16.7 | 18.6 |
| C | 5 | 16.1 | 17.9 |
| D | 0 | 0 | 0 |
| DOC | 0.219 | 0.146 | 0.163 |
| $L_0$ | 87.6 | 58.5 | 65.1 |

Guidelines for National Greenhouse Gas Inventories for the provinces and territories as derived from the data sources.

### Wood Waste Landfills

Equation A3–75 as presented in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, is used to calculate the $CH_4$ generation potential for wood waste landfills (IPCC/OECD/IEA 1997). The IPCC default value for MCF for unmanaged deep landfill sites (0.8) is chosen to represent the MCF, as it best represents industry practices.

The value 0.5 is chosen for the fraction of $CH_4$ in landfill gas (F) from the IPCC default range of 0.4 to 0.6.

$DOC_F$ represents the amount of organic carbon that is ultimately degraded and released from the solid waste

disposal sites. It accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. The *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) provides default values in the order of 0.5–0.6 for waste sites that include lignin. The lower end of this range, 0.5, is used in the calculation for the $CH_4$ generation potential to better represent the high lignin content in wood waste (IPCC/OECD/IEA 1997).

DOC represents the amount of organic carbon that is accessible to biochemical decomposition. Equation A3–75 is used to calculate the national wood waste DOC value, assuming a 100% wood composition (IPCC/OECD/IEA 1997).

Based on these considerations, a $L_0$ of 80 kg CH4/t of wood waste is calculated from Equation A3–75.

## Captured Landfill Gas

At many large MSW landfill facilities, landfill gas is captured to be flared or utilized, or both. Owing to the relatively high concentration of $CH_4$ in the landfill gas, the gas can be combusted for electricity or heat generation. To a lesser extent, in recent years, the captured gas is simply collected and vented. If not utilized, the captured landfill gas is flared. For the purposes of the inventory, captured gas includes only the gas that is flared or utilized. In order to calculate the net $CH_4$ emissions from landfills, the amount of captured $CH_4$ is subtracted from the $CH_4$ generated as estimated by the Scholl Canyon model, and then this value is added to the portion of $CH_4$ emitted from the flaring operation. GHG emissions affiliated with the use of landfill gas for energy recovery are accounted for in the Energy Sector. The calculation of net $CH_4$ emissions is shown in the following equation:

Equation A3–77:

$$CH_{4(NET)} = CH_{4(generated)} - CH_{4(captured)} + CH_{4(emitted-F)}$$

where:

| | | |
|---|---|---|
| $CH_{4(NET)}$ | = | net $CH_4$ emissions from MSW landfills, t |
| $CH_{4(generated)}$ | = | $CH_4$ emissions generated from MSW landfills, t |
| $CH_{4(captured)}$ | = | $CH_4$ emissions captured from MSW landfills, t |
| $CH_{4(emitted-F)}$ | = | $CH_4$ emissions emitted from flaring of captured MSW landfill gas, t |

A flaring emission control efficiency of 99.7% is used to determine the amount of $CH_4$ emitted. This value is obtained from Table 2.4-3 of Chapter 2.4 of EPA AP 42 (US EPA 1995). The amount of $CH_4$ emitted from flaring of landfill gas is calculated as follows:

Equation A3–78:

$$CH_{4(emitted-F)} = CH_{4(flared)} \times \left(1 - Eff_{(flare-control)}\right)$$

where:

| | | |
|---|---|---|
| $CH_{4(emitted-F)}$ | = | $CH_4$ emissions emitted from flaring of MSW $CH_4$ gas, t/year |
| $CH_{4(flared)}$ | = | $CH_4$ gas flared, t/year |
| $Eff_{(flare-control)}$ | = | flare emission control efficiency, fraction |

The quantities of $CH_4$ gas collected from 1983 to 1996 were obtained from ad hoc surveys conducted by

Environment Canada[28] and for the years 1997–2003 were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 2003a). $CH_4$ gas capture data for 2005 were obtained through a study prepared for Environment Canada (Environment Canada 2007). $CH_4$ gas capture and utilization data for 2006 and 2007 as well as 2008 and 2009 were obtained through survey studies conducted by the Greenhouse Gas Division of Environment Canada in 2008 and 2010 (Environment Canada 2009, 2011). Prior to the 2008 data collection survey, the landfill gas capture data were collected every odd year, and therefore, for the purposes of the national GHG inventory, the landfill gas capture data for the subsequent even years were averaged from the odd years starting from 1997. However, the subsequent biennial surveys collected data for two data years from the facilities; these data were employed for the 2011 NIR submission estimates. Table A3–48 shows the amount of $CH_4$ captured and flared from 1990 to 2009.[29]

### 3.5.1.2. Data Sources

Waste disposal data are collected from a Statistics Canada biennial waste survey (Statistics Canada 2000, 2003, 2004, 2007a, 2008a). The Statistics Canada data for 1998, 2000, 2002, 2004 and 2006 waste disposal are used in developing its MSW estimates for the national GHG inventory.

Landfill gas capture and flare data for 1997–2003 were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 2003a). $CH_4$ gas capture data for 2005 were obtained through the study entitled "An Inventory of Landfill Gas Recovery and Utilization in Canada," prepared for Environment Canada (Environment Canada 2007). $CH_4$ gas capture data for 2006 and 2007 as well as for 2008 and 2009 were collected through the subsequent study conducted by the Greenhouse Gas Division (Environment Canada 2009, 2011).

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28  Perkin. Personal communication (letter dated July 1998). National Office of Pollution Prevention, Environment Canada

29  Where data were not made available from the landfill gas capture facilities, data from previous surveys were employed.

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Table A3–48    Estimated MSW CH$_4$ Captured, Flared, and Emitted for 1990–2009

| Year | CH$_4$ Generated (kt) | CH$_4$ Captured (kt) | CH$_4$ Flared (kt) | CH$_4$ Emitted from Flare (kt) | CH$_4$ Emitted (kt) |
|---|---|---|---|---|---|
| 1990 | 925.72 | 192.66 | 23.61 | 0.07 | 733.13 |
| 1991 | 942.04 | 195.64 | 27.18 | 0.08 | 746.48 |
| 1992 | 958.53 | 204.78 | 35.29 | 0.11 | 753.85 |
| 1993 | 975.02 | 209.39 | 44.46 | 0.13 | 765.77 |
| 1994 | 991.41 | 223.36 | 56.73 | 0.17 | 768.22 |
| 1995 | 1 007.55 | 243.44 | 69.36 | 0.21 | 764.32 |
| 1996 | 1 023.30 | 264.55 | 78.67 | 0.24 | 758.99 |
| 1997 | 1 038.51 | 267.80 | 81.00 | 0.24 | 770.95 |
| 1998 | 1 048.90 | 271.82 | 90.80 | 0.27 | 777.36 |
| 1999 | 1 060.81 | 275.83 | 100.59 | 0.30 | 785.28 |
| 2000 | 1 074.29 | 294.29 | 117.90 | 0.35 | 780.36 |
| 2001 | 1 086.89 | 312.74 | 135.21 | 0.41 | 774.55 |
| 2002 | 1 098.70 | 312.56 | 137.06 | 0.41 | 786.55 |
| 2003 | 1 111.28 | 312.38 | 139.34 | 0.42 | 799.32 |
| 2004 | 1 124.58 | 312.95 | 146.92 | 0.44 | 812.07 |
| 2005 | 1 138.92 | 313.52 | 154.49 | 0.46 | 825.86 |
| 2006 | 1 154.26 | 304.70 | 130.80 | 0.39 | 849.95 |
| 2007 | 1 168.47 | 329.96 | 164.90 | 0.49 | 839.01 |
| 2008 | 1 182.93 | 347.87 | 213.40 | 0.64 | 835.71 |
| 2009 | 1 197.62 | 349.24 | 217.13 | 0.65 | 849.04 |

Note: 2008 values were assumed to be constant from 2007.

## A3.5.2.    CH$_4$ Emissions from Wastewater Treatment

### A3.5.2.1.    Methodology

**Municipal Wastewater Treatment**

The IPCC default method for calculating CH$_4$ emissions from domestic wastewater handling is not used, because the required data (i.e. volumes of wastewater treated) are not available. Instead, a method similar to the IPCC methodology, developed for Environment Canada (AECOM Canada 2010a), is used to calculate an emission factor. A new maximum methane-producing capacity (Bo) was derived. In past submissions, a methane emission factor developed by ORTECH (1994), 0.22 kg CH$_4$/kg five-day biological oxygen demand (BOD5), was used. Following the 2009 centralized review, this value was questioned, because the default 2000 IPCC greenhouse gas emission factor (GHG EF) is given as 0.6 kg CH$_4$/kg BOD5. Further to the expert review team (ERT) report, and having identified a problem with the derivation of the IPCC default Bo value, AECOM

was commissioned to review the current data and confirm the EF to be used. The Bo recommended by AECOM is 0.36 kg CH$_4$ per kg BOD5. It was also recommended that the methane conversion factor (MCF) be changed from a percent of population served by anaerobic treatment to the product of a combined MCF (septic systems, facultative lagoons, anaerobic lagoons and direct discharge) and the provincial population served by these systems, i.e., not served by a centralized treatment system. An MCF of 0.3 was recommended, as it best reflected the reality of the distribution of the Canadian municipal wastewater treatment units for the best data available.

Therefore, an emission factor of 0.108 was derived from the product of a Bo of 0.36 kg CH4 per kg BOD5 and an MCF of 0.3. To provide the EF in units of kg CH$_4$/capita/yr., the following relation was used, given an organic loading rate of 0.050 kg BOD5/person/day:

Equation A3–79:

$$EF_{CH_4} \text{ (kg CH}_4 \text{ / capita per year)} = \text{(per capita BOD}_5 \text{ loading rate)} \times \text{(CH}_4 \text{ generation rate)}$$

$$= \left(0.05\frac{\text{kg BOD}_5}{\text{capita} \times \text{day}}\right) \times \left(365\frac{\text{days}}{\text{year}}\right) \times \left(0.108\frac{\text{kg CH}_4}{\text{kg BOD}_5}\right)$$

$$= \left(1.971\frac{\text{kg CH}_4}{\text{capita} \times \text{year}}\right)$$

The percentage of wastewater that is treated aerobically for each province is derived from the product of the percentage of rural population, obtained from an appendix to the AECOM report (AECOM 2010b) and the population of the province or territory. It is assumed that anaerobic primary and secondary wastewater treatment, septic tanks and out-falls where the effluent is discharged without treatment, where $CH_4$ emissions are not captured, are present in rural areas. Canadian urban municipalities can be assumed to be serviced by aerobic treatment systems and/or anaerobic systems that have full capture of the biogases where they are utilized or flared with near-complete combustion. Using the Statistics Canada definition of an urban area[30] and the 2006 census data, which give the provincial populations, the percentage of rural population is obtained.

Emissions are calculated by multiplying the emission factor by the population of the respective province (Statistics Canada 2006, 2010) and the fraction of wastewater that is anaerobically treated.

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30    Statistics Canada definition of urban area: "An urban area has a minimum population concentration of 1000 persons and a population density of at least 400 persons per square kilometre, based on the current census population count. All territory outside urban areas is classified as rural. Taken together, urban and rural areas cover all of Canada."

Equation A3–80:

$$CH_{4(x)} = EF_{CH_4} \times P_x \times Frac_{AN(x)}$$

where:

| | | |
|---|---|---|
| $CH_{4(x)}$ | = | $CH_4$ emissions from wastewater treatment for province x, t/year |
| $EF_{CH4}$ | = | $CH_4$ emission factor for wastewater treatment, t/capita per year |
| $P_x$ | = | population of province x |
| $Frac_{AN(x)}$ | = | fraction of wastewater treated anaerobically for province x |

Table A3–49 shows the percentage of wastewater treated anaerobically, including untreated wastewater for 1990–2009. The remaining percentage of wastewater is treated aerobically (primary and secondary wastewater treatment).

## Industrial Wastewater Treatment – CH$_4$ & N$_2$O

In past submissions, the emissions from this subcategory, although identified, were not estimated. In order to correct this incompleteness, data were collected through an in-house survey of industrial facilities that were suspected or known to employ anaerobic units to treat their effluent on-site. The information gained allowed for the estimation of emissions for each site.

Emissions from industrial wastewater handling at a plant-site level are typically difficult to quantify, due to confidentiality issues and the variety of biological treatment units available that focus on biodegradable organics or nitrogen removal, or that can serve both functions.

Based on the responses to inquiries submitted to industrial associations and provincial ministries of the environment, which indicated that anaerobic industrial wastewater units were relatively rare in Canada, it was decided to implement a Tier 3 approach to collect information from the individual facilities directly. To use the default data and methodology—without knowledge about those industry sectors using anaerobic treatment, the existence of

Table A3–49    Percentage of Wastewater Treated Anaerobically by Province for the 1990–2009 Time Series

| Wastewater Treatment (% Anaerobic) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N.L. | P.E.I. | N.S. | N.B. | Que. | Ont. | Man. | Sask. | Alta. | B.C. | N.W.T. & Nvt. | Yk. |
| 1.600 | 0.400 | 2.900 | 2.300 | 23.400 | 38.900 | 3.700 | 3.000 | 10.500 | 13.000 | 0.100 | 0.100 |

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biogas recovery systems, and the quantities actually recovered—would invite an unacceptable overestimation of methane emissions.

As recommended by the I*PCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), the Decision Tree for $CH_4$ Emissions from Industrial Wastewater Handling was followed as a framework for the Tier 3 approach. Using the information gathered for previous National Inventory Reports (NIRs), detailed in Annex 3.5 of Canada's original 2010 submission, for industries with large volumes of wastewater produced, industry sectors were prioritized for the plant-specific data, to be collected through surveys, in order of importance as: pulp and paper, chemicals and chemical products, food, beverages, petroleum and coal products, rubber products, plastic products, and total textiles.

The following industrial sectors were ruled out based on confirmations from industry representatives that anaerobic treatment was not taking place at facilities in their sectors: chemicals and chemical products,[31] beverages,[32] petroleum and coal products,[33] rubber products,[34] plastic products,[35,36] and total textiles.[37]  Requests were submitted to the Canadian Chemical Producers' Association (CCPA), Canadian Soft Drink Association (CSDA), Canadian Association of Petroleum Producers (CAPP) and Rubber Association of Canada (RAC) to obtain a confirmation for recent years, but at the time of the re-submission, not all their members had replied—though none of the members who had replied had confirmed use of an anaerobic system. Nineteen facilities were identified to have anaerobic sys-

tems: two in the pulp and paper sector, fifteen in the food industry and two in the beverage industry. Lecture notes from a seminar in 2004 show the existence of 13 sites (Crolla A et al. 2004), so it may be assumed that the coverage for this sector is complete. Of all the subject industry sectors, the two pulp and paper facilities treat by far the largest portion of process water.

From Internet searches and direct communications with the facilities, we identified only two pulp and paper facilities in Canada using anaerobic treatment. This was confirmed by the industry sector association, i.e., the Forest Products Association of Canada (FPAC).[38] These facilities directly provided the methane production in volumetric units. These quantities were converted to mass units using the density of methane at 25°C and 1 atm. Fugitive losses from the digesters and the piping system were estimated to be 0.5%, which was an average of the 0.6% for losses in pipelines and leakage at the end user for processing, transmission and distribution of natural gas, and 0.4% for leakage from residential and commercial sectors as given in the IPCC Reference Manual, Table 1.6, page 1.29 (IPCC/OECD/IEA 1997). However, a representative from the engineering design firm for one of the systems confirmed that there should not be any leaks, because the system was under negative pressure and oxygen sensors were provided in the system to alert the operators of a breach. Therefore, these emissions should be non-existent if the other facility used a similar system. Methane emissions from the inefficiencies of the flare and utilization devices were also accounted for. These methane-destruction efficiencies were 0.995 for an enclosed flare and 0.98 for a boiler (Climate Action Reserve 2009). Therefore, the total emissions were the sum of the piping losses and the quantities of methane circumventing combustion in the flare and boiler.

Similarly, the emissions for the food industry were calculated. However, where no production data were made available (i.e. from a cheese manufacturer, potato processor and candy bar manufacturer), design parameters (process wastewater volumes, chemical oxygen demand [COD]) were used from the engineering firm that supplied the units to these facilities in conjunction with the default IPCC EF (IPCC/OECD/IEA 1997), to generate gas quantities. As it is known that the gas is collected, it was assumed that

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31    CCPA. Personal communication (email dated December 4, 2006). Bruce Caswell, Canadian Chemical Producers' Association, to Paula Critchley, Waste Sector, Greenhouse Gas Division.

32    CSDA. Personal communication (telephone conversation dated December 2006). Canadian Soft Drink Association and Paula Critchley, Waste Sector, Greenhouse Gas Division.

33    CAPP. Personal communication (email dated October 24, 2006). Sonia Simard, Canadian Association of Petroleum Producers, to Paula Critchley, Waste Sector, Greenhouse Gas Division.

34    RAC. Personal communication (telephone conversation dated December 2006). Rubber Association of Canada and Paula Critchley, Waste Sector, Greenhouse Gas Division.

35    CPIA. Personal communication (email dated December 4, 2006). Ray Kelsey, Canadian Plastics Industry Association, to Paula Critchley, Waste Sector, Greenhouse Gas Division.

36    CPIA. Personal communication (email dated October 6, 2010). Fred Edgecombe, Canadian Plastics Industry Association, to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division.

37    Lincoln Fabrics. Personal communication (email dated October 4, 2010). Steve Thistle, Plant Manager of Lincoln Fabrics Ltd., to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division.

38    FPAC. Personal communication (email dated October 4, 2010). Roger Cook, Forest Products Association of Canada, to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division.

Table A3–50    COD Values Used in CH$_4$ Emission Estimates per Industry Type

| Industry Group | IPCC Industry Type | IPCC Degradable Organic Component—COD (g/L) |
|---|---|---|
| Food | Vegetables, Fruits & Juices | 5 |
| Beverages | Soft Drinks | 2 |
| Rubber Products | Organic Chemicals | 3 |
| Plastic Products | Plastics and Resins | 3.7 |
| Primary Textiles & Textile Products | Textiles (Natural) | 0.9 |
| Wood Products | N/A | N/A |
| Paper & Allied Products | Pulp & Paper (Combined) | 9 |
| Primary Metals | N/A | N/A |
| Fabricated Metals | N/A | N/A |
| Transportation Equipment | N/A | N/A |
| Non-Metallic Mineral Products | N/A | N/A |
| Petroleum & Coal Products | Petroleum Refineries | 1 |
| Chemicals & Chemical Products | Organic Chemicals | 3 |

Notes:

Sources: IPCC (2000), except for Industry Group, which is from Environment Canada (1986, 1991, 1996a).

N/A = not available.

the losses, i.e., emissions, would consist of piping losses and utilization by a boiler.

Table A3–50 shows the industry sectors included within the Environment Canada surveys (Environment Canada 1986, 1991, 1996a) and the corresponding IPCC default COD values that are chosen to represent the industry sectors (IPCC 2000).

### A3.5.2.2.    Data Sources

Volumes of biogas collected, the fraction of CH$_4$ in the biogas, and information on the combustion of the collected biogas (utilization and/or flaring) were provided directly from the industrial facility. Where the information was not available, design specifications obtained from the engineering firms that designed the specific systems or that were made available from the facility were used to derive the emissions, which would be conservative estimations.

### A3.5.3.    N$_2$O Emissions from Wastewater Treatment

### A3.5.3.1.    Methodology

The N$_2$O emissions from municipal wastewater treatment facilities are calculated using the IPCC default method (IPCC/OECD/IEA 1997). This method estimates emissions based on the amount of nitrogen in sewage and the

Table A3–51    Canadian Protein Consumption

| Year | Protein Consumption (g/capita per day) |
|---|---|
| 1990 | 65.26 |
| 1991[1] | 66.19 |
| 1992 | 66.55 |
| 1993 | 67.2 |
| 1994 | 67.86 |
| 1995 | 68.52 |
| 1996[1] | 68.59 |
| 1997 | 69.87 |
| 1998 | 70.56 |
| 1999 | 71.25 |
| 2000 | 71.95 |
| 2001[1] | 72.97 |
| 2002 | 72.79 |
| 2003[1] | 71.76 |
| 2004[1] | 72.18 |
| 2005[2] | 71.12 |
| 2006[2] | 71.03 |
| 2007[2] | 71.79 |
| 2008[2] | 70.25 |
| 2009[2] | 69.85 |

Sources

1.  Statistics Canada (2008b), Food Statistics, Catalogue No. 21-020-X: the data have been adjusted for retail, household cooking and plate loss.
2.  Statistics Canada (2010b), Food Statistics, Catalogue No. 21-020-X: the data have been adjusted for retail, household cooking and plate loss.

assumption that 0.01 kg $N_2O$-N/kg sewage nitrogen will be generated.

To estimate the amount of nitrogen in sewage, it is assumed that protein is 16% nitrogen (IPCC/OECD/IEA 1997). The Canadian protein consumption is obtained from the annual food statistics publication (Statistics Canada 2007b, 2008b, 2010b), as shown in Table A3–51. Data are provided for the years 1991, 1996 and 2001–2009. Protein consumption data for missing years are estimated by applying a multiple linear regression application to the Statistics Canada data.

The $N_2O$ emission factor is calculated as follows:

Equation A3–81:

$$EF_{N_2O} = PC \times EF_{N_2O-N} \times Frac_{NPR} \times \frac{44}{28}$$

where:

| | | |
|---|---|---|
| $EF_{N2O}$ | = | emission factor: kg $N_2O$/capita per year |
| PC | = | annual per capita protein consumption, kg/capita per year (Statistics Canada 2007b, 2008b, 2010b) |
| $EF_{N2O-N}$ | = | emission factor: default 0.01 (0.002–0.12) kg $N_2O$-N/kg sewage nitrogen produced |
| $Frac_{NPR}$ | = | fraction of nitrogen in protein: default = 0.16 kg N/kg protein |
| 44/28 | = | stoichimetric factor to convert nitrogen to $N_2O$ |

Emissions are calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada 2006, 2010a):

Equation A3–82:

$$N_2O_s = EF_{N_2O} \times NR_{PEOPLE}$$

where:

| | | |
|---|---|---|
| $N_2O_s$ | = | $N_2O$ emissions from human sewage, kg $N_2O$/year |
| $EF_{N2O}$ | = | emission factor: kg $N_2O$/capita per year (Equation A3–81). |
| $NR_{PEOPLE}$ | = | number of people in country |

### 3.5.3.2.   Data Sources

The Canadian protein consumption data are obtained from the annual food statistics publication (Statistics Canada 2008b, 2010).

The provincial populations are obtained from Statistics Canada (Statistics Canada 2006b, 2010a).

## A3.5.4.   CO$_2$ Emissions from Municipal Waste Incineration

### A3.5.4.1.   Methodology

The IPCC decision tree in Figure 5.5 of IPCC (2000) for CO2 emissions from waste incineration defines good practice in adapting the methods in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). Country-specific carbon contents are not available; thus, Box 2 of the decision tree in Figure 5.5 (IPCC 2000) is the chosen methodology for calculation of CO2 emissions.

The following steps detail the methodology for the estimation of CO$_2$ emissions from waste incineration:

*Calculating the Amount of Waste Incinerated*: The amount of waste incinerated each year is based on two primary sources. The amount of MSW incinerated in the year 1992 was estimated based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The amount of MSW incinerated for the years 1999, 2000, and 2001 was estimated based on the study "Municipal Solid Waste Incineration in Canada: An Update on Operations 1999–2001, performed by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b). A polynomial curve-fitting equation is employed to estimate the amount of MSW incinerated over the period 1991–1998 based on the values provided by A.J. Chandler & Associates Ltd. and Environment Canada. To estimate the coefficients in the polynomial, a multiple linear regression application (Microsoft Excel LINEST statistical tool for an array) is used. A polynomial of the order 13 provides the best fit. This multiple linear regression method of estimation is consistent with the IPCC interpolation method (IPCC 2000). To estimate the amount of MSW incinerated for 2002–2009, a trend extrapolation was performed with the A.J. Chandler & Associates Ltd. and Environment Canada MSW incineration values for all relevant provinces except Quebec and Ontario, for which only the former MSW incineration values were used. In the province of Ontario, one of the incineration plants closed at the end of 2001. Therefore, the amount of waste incinerated in Ontario for the period 2002–2009 is estimated by trending the A.J. Chandler & Associates Ltd. incineration values for 1999–2001 with population (Statistics Canada

Table A3–52    Estimated MSW Incinerated by Province for 1990–2009

| Year | MSW Incinerated (t) | | | | | |
|------|------|------|------|------|------|------|
| | N.L. | P.E.I. | N.S. | Que. | Ont. | B.C. |
| 1990 | 0 | 32 000 | 76 500 | 619 522 | 258 700 | 239 752 |
| 1991 | 0 | 32 000 | 53 458 | 564 219 | 266 361 | 252 214 |
| 1992 | 35 500 | 29 800 | 56 700 | 541 100 | 277 000 | 257 500 |
| 1993 | 0 | 32 000 | 57 953 | 530 107 | 255 272 | 262 964 |
| 1994 | 0 | 32 000 | 57 564 | 508 308 | 251 779 | 265 179 |
| 1995 | 0 | 32 000 | 55 924 | 483 314 | 249 873 | 265 668 |
| 1996 | 0 | 32 000 | 53 421 | 455 098 | 249 719 | 264 723 |
| 1997 | 0 | 32 000 | 50 443 | 423 631 | 251 484 | 262 637 |
| 1998 | 0 | 32 000 | 47 385 | 388 882 | 255 337 | 259 705 |
| 1999 | 0 | 32 212 | 45 000 | 298 904 | 258 429 | 254 800 |
| 2000 | 0 | 33 000 | 42 000 | 303 887 | 270 811 | 256 400 |
| 2001 | 0 | 32 224 | 42 000 | 303 910 | 281 671 | 246 700 |
| 2002 | 0 | 32 662 | 41 487 | 307 715 | 165 060 | 251 949 |
| 2003 | 0 | 32 824 | 39 079 | 310 700 | 178 747 | 251 718 |
| 2004 | 0 | 33 036 | 37 246 | 314 041 | 192 169 | 251 406 |
| 2005 | 0 | 33 214 | 38 641 | 317 108 | 204 647 | 251 009 |
| 2006 | 0 | 33 151 | 38 574 | 320 418 | 217 032 | 250 563 |
| 2007 | 0 | 33 264 | 40 730 | 324 145 | 228 578 | 249 933 |
| 2008 | | 33 913 | 39 812 | 328 407 | 241 189 | 249 225 |
| 2009 | | 34 640 | 37 491 | 333 544 | 253 189 | 248 497 |

Note: Ontario incineration plant closed as of 2001 year end.

2006, 2010), assuming that the Ontario incineration plant was closed for this period.

MSW incineration estimates for the period 1990–2009 are shown in Table A3–52.

*Developing Emission Factors:* Provincial $CO_2$ emission factors are developed based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The $CO_2$ emission factors are founded on the assumption that carbon contained in waste undergoes complete oxidation to $CO_2$.

The provincial breakdown in the type of waste incinerated for 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The quantity of waste incinerated was divided into three categories: paper, plastics and organics. Consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997), only $CO_2$ emissions resulting from the incineration of carbon in waste of fossil origin (e.g. plastics, certain textiles, rubber, liquid solvents and waste oil) are included in emission estimates (IPCC

2000). Therefore, it is necessary to estimate the fossil origin portion of the waste in order to develop an emission factor that excludes emissions due to the incineration of biomass. The breakdown in organic composition is estimated by averaging waste composition data from three published documents (Environment Canada 1994a, 1995a, 1995b). Table A3–53 shows the averaged breakdown in organic composition.

The amount of fossil fuel-based carbon available in the

Table A3–53    Estimated MSW Organic Composition

| Component | % Composition of Total Organics |
|-----------|--------------------------------|
| Yard/Garden Waste | 41 |
| Food Waste | 31 |
| Wood Waste | 16 |
| Textiles | 10 |
| Rubber | 2 |
| Other | 0 |
| Total Organics | 100 |

waste incinerated is determined using typical percent weight carbon content values. Carbon and moisture content values were provided by Tchobanoglous et al. (1993) and Peavy et al. (1985). The amount of carbon per tonne of waste is estimated by subtracting the moisture content from the mass of fossil origin waste and multiplying by the carbon content value of the waste type. The fossil origin portion of the organic waste is determined by multiplying the organic waste by the percent fossil origin composition as follows:

Equation A3–83:

$$WasteType_{Fossil-Origin} = M_{Total} \times \left(1 - \% \, Organic_{Comp}\right)$$

where:

| | | |
|---|---|---|
| WasteTypeFossil-Origin | = | amount of fossil fuel–based waste incinerated, t |
| $M_{Total}$ | = | amount of waste incinerated, t (1992 data provided by Environment Canada [1996b]) |
| %OrganicComp | = | % organic composition per waste type (Environment Canada 1994a, 1995a, 1995b) |

The amount of fossil fuel-based carbon is converted to tonnes of $CO_2$ per tonne of waste by multiplying by the ratio of the molecular mass of $CO_2$ to that of carbon. The derivation of the $CO_2$ emission factor is shown in the following equations:

Equation A3–84:

$$C_{Avail(y)} = \left(WasteType_{Fossil-Origin}\right) \times \left(1 - \% \, Moisture\right) \times \% \, C_{WasteType}$$

where:

| | | |
|---|---|---|
| $C_{Avail\,(y)}$ | = | available carbon per waste type for province y, t |
| WasteTypeFossil-Origin | = | amount of fossil fuel-based waste incinerated, t (1992 data provided by Environment Canada [1996b]) |
| % Moisture | = | % moisture content per waste type (Tchobanoglous et al. 1993) |
| % $C_{WasteType}$ | = | % carbon content per waste type (dry basis) (Tchobanoglous et al. 1993) |

Equation A3–85:

$$EF_{CO_2-1992\,(y)} = \left(\frac{\sum C_{Avail(y)}}{M_{Inc(y)}}\right) \times \frac{44}{12}$$

where:

| | | |
|---|---|---|
| EFCO2–1992(y) | = | 1992 $CO_2$ emission factor for incineration for province y, t $CO_2$/t waste incinerated |
| CAvail(y) | = | available carbon per waste type for province y, t (See Equation A3–84) |
| MInc (y) | = | total mass waste incinerated in 1992 for province y, t |
| 44/12 | = | stoichimetric factor to convert carbon to $CO_2$ |

*Calculating $CO_2$ Emissions*: Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

Equation A3–86:

$$CO_{2(x)} = EF_{CO_2-1992} \times \left(M_{Inc(x)/province}\right)$$

where:

| | | |
|---|---|---|
| $CO_2(x)$ | = | $CO_2$ emissions from waste incineration in year x, t/province per year |
| EFCO2–1992 | = | 1992 provincial $CO_2$ emission factor for incineration, t $CO_2$/t incinerated |
| MInc(x)/province | = | mass waste incinerated per province in year x, t/year |

## A3.5.4.2.   Data Sources

The amount of MSW incinerated in the year 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The amount of MSW incinerated for the years 1999, 2000, and 2001 was estimated by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

The amount of fossil fuel-based carbon available in the waste incinerated is determined using typical percent weight carbon constants. Carbon constants and moisture contents were provided by Tchobanoglous et al. (1993) and Peavy et al. (1985).

## A3.5.5. N$_2$O Emissions from Waste Incineration

### A3.5.5.1. Methodology

**Municipal Solid Waste Incineration**

Emissions of N$_2$O from MSW incineration are estimated using the assumption that the IPCC five-stoker facility factors are most representative. The average N$_2$O emission factor over the range given as IPCC default values for MSW five-stoker facilities is 0.148 kg/t waste incinerated (IPCC/OECD/IEA 1997). To estimate emissions, the calculated factor is multiplied by the amount of waste incinerated by each province. The national emission values are then determined as the summation of these emissions for all provinces.

Equation A3–87:

$$N_2O_{MSW} = M_{MSW} \times EF_{N_2O-MSW}$$

where:

| | | |
|---|---|---|
| N$_2$O$_{MSW}$ | = | N$_2$O emissions from municipal solid waste incineration, t/year |
| M$_{MSW}$ | = | mass of municipal solid waste incinerated, t/year |
| EF$_{N2O-MSW}$ | = | MSW N$_2$O emission factor (0.148 kg N$_2$O/t MSW incinerated / 1000 kg/t) |

**Sewage Sludge Incineration**

Emissions of N$_2$O from sewage sludge incineration are estimated using the IPCC default emission factor for fluidized beds, 0.8 kg/t of dried sewage sludge incinerated (IPCC 2000). To estimate emissions, the calculated factor is multiplied by the amount of waste incinerated by each province. The national emission values are then determined as the summation of these emissions for all provinces.

Equation A3–88:

$$N_2O_{SS} = M_{SS} \times EF_{N_2O-SS}$$

where:

| | | |
|---|---|---|
| N$_2$O$_{SS}$ | = | N$_2$O emissions from sewage sludge incineration, t/year |
| M$_{SS}$ | = | mass of dried sewage sludge incinerated, t/year |
| EF$_{N2O-SS}$ | = | sewage sludge N$_2$O emission factor (0.8 kg N$_2$O/t dried sludge incinerated / 1000 kg/t) |

### A3.5.5.2. Data Sources

Data sources for MSW incineration are described in Section A3.5.4.2.

Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

## A3.5.6. CH$_4$ Emissions from Waste Incineration

### A3.5.6.1. Methodology

CH$_4$ emissions from the incineration of MSW are assumed to be negligible. However, waste incineration of the biosolids resulting from municipal wastewater treatment does produce CH$_4$ emissions. The IPCC does not provide a methodology for CH$_4$ emissions from waste incineration, but recommends that national experts use existing published methods (IPCC 2000).

Emissions of CH$_4$ are estimated based on emission factors obtained from the U.S. Environmental Protection Agency (US EPA 1995). The emission factors are 1.6 t/kt of total dried solids for fluidized bed sewage incinerators and 3.2 t/kt of dried solids for multiple hearth incinerators, both equipped with venturi scrubbers. It is assumed that all incinerators are of the fluidized bed type.

CH$_4$ emissions from sewage sludge incineration are dependent on the amount of dried solids incinerated. To calculate the CH$_4$ emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor. Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994 (Environment Canada 1994b). Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000, and 2001 are

Table A3–54   Estimated Sewage Sludge Incinerated for 1990–2009

| Year | Sewage Sludge Incinerated (t, dry basis) | | | | |
|---|---|---|---|---|---|
| | Que. | Ont. | Sask. | Alta. | National Total |
| 1990 | 49 200 | 222 795 | 1 840 | 0 | 273 835 |
| 1991 | 59 400 | 222 795 | 1 840 | 0 | 284 035 |
| 1992 | 79 800 | 222 795 | 1 840 | 0 | 304 435 |
| 1993 | 64 833 | 129 125 | 71 | 0 | 194 029 |
| 1994 | 100 181 | 93 072 | 59 | 0 | 193 311 |
| 1995 | 101 356 | 113 985 | 152 | 0 | 215 493 |
| 1996 | 93 276 | 112 697 1 | 70 | 0 | 206 043 |
| 1997 | 15 424 | 0 | 0 | 4 885 | 20 310 |
| 1998 | 18 341 | 0 | 0 | 4 951 | 23 292 |
| 1999 | 22 032 | 0 | 0 | 0 | 22 032 |
| 2000 | 24 651 | 0 | 0 | 0 | 24 651 |
| 2001 | 27 960 | 0 | 0 | 0 | 27 960 |
| 2002 | 31 096 | 0 | 0 | 0 | 31 096 |
| 2003 | 34 234 | 0 | 0 | 0 | 34 234 |
| 2004 | 37 373 | 0 | 0 | 0 | 37 373 |
| 2005 | 40 511 | 0 | 0 | 0 | 40 511 |
| 2006 | 43 649 | 0 | 0 | 0 | 43 649 |
| 2007 | 46 787 | 0 | 0 | 0 | 46 787 |
| 2008 | 49 925 | 0 | 0 | 0 | 49 925 |
| 2009 | 53 064 | 0 | 0 | 0 | 53 064 |

Note:

A large step change is observed in the quantities of sewage sludge incinerated in Ontario for the period 1996–1997. This is as a result of two pilot projects that were approved in the mid-1990s for the non-incineration waste disposal of sewage sludge. The first project involved the spreading of treated sewage sludge on farmers' fields outside of Toronto, and the second project involved the transportation of sewage sludge to be spread on mine tailings. Both projects proved to have difficulties, owing to odour problems and the large quantities of waste that were to be spread on farmers' fields. From 1996 to 2000, Toronto sludge was stored during periods when excess quantities of waste were unable to be applied on land. In 2001, a new contract commenced that involved the spread of biosolids on Ontario farmers' fields, with excess biosolids being shipped to U.S. landfill sites.

taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b). To estimate the amount of sewage sludge incinerated in the years 2002–2009, a linear regression analysis is completed using the A.J. Chandler & Associates Ltd. and Compass Environmental Inc. MSW incineration values.

In view of the relatively small number of facilities that incinerate sewage sludge in Canada, we believe that all relevant facilities were contacted, and we expect that the activity data collected from all three sources of information are complete. As such, our approach in estimating the amount of sewage sludge incinerated over the time series years is consistent.

Sewage sludge incineration estimates for the period 1990–2009 are shown in Table A3–54.

$CH_4$ emissions are calculated as follows:

Equation A3–89:

$$CH_{4(s)} = S_{Inc} \times EF_{CH_4\text{-}FB}$$

where:

| | | |
|---|---|---|
| $CH_{4(s)}$ | = | $CH_4$ emissions from waste incineration, t/year |
| $S_{Inc}$ | = | sewage sludge incinerated, dry t/year |
| $EF_{CH4\text{-}FB}$ | = | $CH_4$ emission factor for fluidized bed incinerators: 1.6 t $CH_4$/kt sewage sludge incinerated / 1000 kg/t |

### A3.5.6.2. Data Sources

Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

A3

# Annex 4

## Comparison of Sectoral and Reference Approaches

This annex covers the energy and the $CO_2$ emission results from the reference approach (RA), a comparison of the results from the RA with those estimated by the sectoral approach (SA), and a summary of the national energy balance, which is the main energy data source for both the RA and the SA.

### A4.1. Comparison of Reference Approach with Sectoral Approach

Results from the RA were compared with the SA as a check of energy consumed and $CO_2$ emissions from the combustion of fossil fuels. The check was performed for all years from 1990 to 2009 and is an integral part of reporting to the United Nations Framework Convention on Climate Change (UNFCCC).

Direct comparisons of the results of the RA and SA show significant discrepancies, since the SA total for combustion does not include the energy and the fossil fuel-derived $CO_2$ from the non-energy use of fossil fuels and feedstocks, as presented in Table A4–1. Direct comparison of the RA and SA shows a 10.5 to 13.6% variation in energy and a 5.5 to 8.7% variation in emissions.

In Canada, large amounts of fossil fuels are used as a feedstock in various industrial processes, such as aluminium production, ammonia production, ethylene production, and iron and steel production. Since the RA's net carbon values are calculated based on a top-down approach of production, export, import, stock change data and carbon stored, this will result in the inclusion of carbon emitted from feedstock and non-energy use. This is corrected by excluding the non-combustion energy and emissions of feedstocks to ensure that the RA and the SA are comparing similar sources for Canada.

When the RA energy amounts include adjustments for non-energy use of fossil fuels, the difference between the SA and adjusted RA varies from 0.9 to 4.1%, while the emissions difference varies between -1.52 and 0.9%. Table A4–1 shows a comparison of the adjusted RA and SA.

Table A4–1    Comparison of Adjusted Reference Approach and Sectoral Approach for Canada

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Overall Energy Comparison** | | | | | | | | | | | | | | | | | | | | |
| Reference Approach (PJ) | 7 150 | 7 000 | 7 196 | 7 240 | 7 474 | 7 640 | 7 902 | 8 077 | 8 156 | 8 443 | 8 759 | 8 716 | 8 811 | 9 117 | 9 236 | 9 142 | 8 995 | 9 430 | 9 240 | 8 811 |
| Sectoral Approach (PJ) | 6 399 | 6 240 | 6 478 | 6 487 | 6 713 | 6 870 | 7 063 | 7 193 | 7 281 | 7 565 | 7 916 | 7 829 | 7 977 | 8 248 | 8 223 | 8 085 | 7 916 | 8 452 | 8 191 | 7 847 |
| Percentage Difference without Adjustment (%) | 11.7 | 12.2 | 11.1 | 11.6 | 11.3 | 11.2 | 11.9 | 12.3 | 12.0 | 11.6 | 10.7 | 11.3 | 10.5 | 10.5 | 12.3 | 13.1 | 13.6 | 11.6 | 12.8 | 12.3 |
| **Non-Energy Use of Fossil Fuels and Feedstocks** | | | | | | | | | | | | | | | | | | | | |
| Non-Energy Use of Liquid Fuels (PJ) | 328 | 308 | 319 | 324 | 328 | 353 | 382 | 406 | 397 | 404 | 392 | 381 | 399 | 409 | 460 | 424 | 458 | 454 | 457 | 401 |
| Non-Energy Use of Solid Fuels (PJ) | 157 | 171 | 170 | 165 | 165 | 164 | 165 | 161 | 163 | 171 | 177 | 170 | 168 | 171 | 176 | 182 | 187 | 184 | 170 | 132 |
| Non-Energy Use of Gaseous Fuels (PJ) | 157 | 176 | 167 | 187 | 194 | 193 | 197 | 209 | 202 | 205 | 190 | 160 | 149 | 156 | 165 | 158 | 157 | 156 | 145 | 109 |
| Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ) | 6 508 | 6 345 | 6 540 | 6 563 | 6 787 | 6 931 | 7 157 | 7 302 | 7 395 | 7 663 | 8 000 | 8 005 | 8 096 | 8 381 | 8 435 | 8 379 | 8 193 | 8 635 | 8 468 | 8 169 |
| **Percentage Difference with Adjustment - 100% x (RA-SA)/SA** | 1.70 | 1.68 | 0.95 | 1.17 | 1.10 | 0.88 | 1.33 | 1.51 | 1.57 | 1.30 | 1.06 | 2.25 | 1.49 | 1.61 | 2.58 | 3.64 | 3.50 | 2.17 | 3.38 | 4.09 |

## Table A4-1 Comparison of Adjusted Reference Approach and Sectoral Approach for Canada

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Overall Emission Comparison** | | | | | | | | | | | | | | | | | | | | |
| Reference Approach (Gg CO$_2$) | 447 146 | 437 485 | 446 416 | 445 663 | 457 908 | 468 649 | 483 002 | 497 792 | 501 304 | 518 193 | 540 323 | 534 945 | 536 029 | 557 076 | 557 490 | 554 589 | 539 135 | 565 544 | 555 550 | 527 280 |
| Sectoral Approach (Gg CO$_2$) | 412 541 | 402 533 | 416 246 | 413 667 | 426 343 | 437 361 | 448 720 | 459 719 | 466 461 | 482 803 | 505 603 | 501 596 | 508 060 | 526 033 | 523 322 | 514 360 | 502 392 | 533 745 | 518 214 | 490 057 |
| Percentage Difference without Adjustment (%) | 8.39 | 8.68 | 7.25 | 7.73 | 7.40 | 7.15 | 7.64 | 8.28 | 7.47 | 7.33 | 6.87 | 6.65 | 5.51 | 5.90 | 6.53 | 7.82 | 7.31 | 5.96 | 7.20 | 7.60 |
| **Carbon dioxide emissions from non-energy use of fossil fuel and feedstocks** | | | | | | | | | | | | | | | | | | | | |
| Liquid (Gg CO$_2$) | 14 288 | 13 257 | 13 499 | 13 614 | 14 109 | 14 368 | 15 433 | 16 905 | 16 723 | 16 878 | 16 314 | 16 130 | 16 625 | 17 189 | 18 680 | 18 484 | 19 181 | 18 591 | 18 842 | 18 166 |
| Solid (Gg CO$_2$) | 12 216 | 13 467 | 13 488 | 13 171 | 13 006 | 13 100 | 13 099 | 12 694 | 12 766 | 13 378 | 13 893 | 13 281 | 13 100 | 13 391 | 13 728 | 14 193 | 14 662 | 14 467 | 13 559 | 10 465 |
| Gaseous (Gg CO$_2$) | 6 339 | 7 062 | 6 713 | 7 498 | 7 668 | 7 714 | 7 889 | 8 334 | 8 035 | 8 202 | 7 616 | 6 381 | 5 947 | 6 199 | 6 569 | 6 282 | 6 260 | 6 208 | 5 765 | 4 335 |
| Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ) | 414 303 | 403 700 | 412 716 | 411 381 | 423 125 | 433 467 | 446 580 | 459 859 | 463 780 | 479 736 | 502 501 | 499 153 | 500 357 | 520 297 | 518 514 | 515 631 | 499 031 | 526 278 | 517 384 | 494 313 |
| **Percentage Difference with Adjustment - 100% x (RA-SA)/SA** | 0.43 | 0.29 | -0.85 | -0.55 | -0.75 | -0.89 | -0.48 | 0.03 | -0.57 | -0.64 | -0.61 | -0.49 | -1.52 | -1.09 | -0.92 | 0.25 | -0.67 | -1.40 | -0.16 | 0.87 |
| **Specific details on carbon dioxide emissions from non-energy use of fossil fuel and feedstocks** | | | | | | | | | | | | | | | | | | | | |
| **Liquid Fuels** | | | | | | | | | | | | | | | | | | | | |
| Reference Approach (Gg CO$_2$) | 194 093 | 182 099 | 178 257 | 180 900 | 185 086 | 185 830 | 192 537 | 203 363 | 202 790 | 205 850 | 209 929 | 212 700 | 205 267 | 219 552 | 225 486 | 227 458 | 216 292 | 221 089 | 221 661 | 217 246 |
| Carbon dioxide emissions from non-energy use of fossil fuel and feedstocks | | | | | | | | | | | | | | | | | | | | |
| Non-Energy Consumption of Naphtha | 167 | 176 | 160 | 126 | 98 | 73 | 79 | 96 | 74 | 72 | 132 | 83 | 66 | 66 | 60 | 44 | 42 | 36 | 34 | 27 |
| Non-Energy Consumption of Bitumen | 10 393 | 9 460 | 9 625 | 9 360 | 9 734 | 9 535 | 9 865 | 10 965 | 11 272 | 11 503 | 10 868 | 10 760 | 10 985 | 11 060 | 11 394 | 11 574 | 11 708 | 11 054 | 11 210 | 11 283 |
| Non-Energy Consumption of Lubricants | 1 318 | 1 223 | 1 215 | 1 272 | 1 400 | 1 427 | 1 425 | 1 554 | 1 495 | 1 507 | 1 549 | 1 451 | 1 693 | 1 734 | 1 684 | 1 735 | 1 592 | 1 615 | 1 549 | 1 438 |
| Non-Energy Consumption of Petrochemical Feedstock | 1 898 | 1 768 | 1 933 | 1 916 | 1 827 | 2 186 | 2 301 | 2 275 | 2 293 | 2 436 | 2 278 | 2 122 | 2 310 | 2 218 | 2 574 | 1 929 | 2 327 | 2 384 | 2 338 | 1 500 |
| Non-Energy Use of Other Products | 512 | 630 | 565 | 940 | 1 050 | 1 148 | 1 763 | 2 015 | 1 589 | 1 360 | 1 487 | 1 714 | 1 572 | 2 110 | 2 967 | 3 201 | 3 512 | 3 502 | 3 710 | 3 918 |
| Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (Gg CO$_2$) | 179 804 | 168 842 | 164 758 | 167 286 | 170 978 | 171 461 | 177 104 | 186 458 | 186 067 | 188 972 | 193 615 | 196 570 | 188 641 | 202 363 | 206 806 | 208 974 | 197 110 | 202 498 | 202 819 | 199 079 |
| Sectoral Approach (Gg CO$_2$) | 178 311 | 167 354 | 168 093 | 168 978 | 173 259 | 174 579 | 178 714 | 185 233 | 189 550 | 191 505 | 194 668 | 195 551 | 193 820 | 206 796 | 211 520 | 209 375 | 201 775 | 209 262 | 206 266 | 200 078 |
| **Percentage Difference with Adjustment - 100% x (RA-SA)/SA** | 0.84 | 0.89 | -1.98 | -1.00 | -1.32 | -1.79 | -0.90 | 0.66 | -1.84 | -1.32 | -0.54 | 0.52 | -2.67 | -2.14 | -2.23 | -0.19 | -2.31 | -3.23 | -1.67 | -0.50 |
| **Solid Fuels** | | | | | | | | | | | | | | | | | | | | |
| Reference Approach (Gg CO$_2$) | 100 616 | 104 211 | 107 474 | 100 021 | 103 573 | 106 027 | 107 245 | 112 544 | 118 707 | 120 173 | 128 788 | 128 415 | 126 946 | 130 140 | 124 566 | 123 678 | 121 257 | 124 296 | 124 312 | 104 510 |
| Carbon dioxide emissions from non-energy use of fossil fuel and feedstocks | | | | | | | | | | | | | | | | | | | | |
| Coke Oven Gas | 1 490 | 1 463 | 1 404 | 1 267 | 1 429 | 1 254 | 1 328 | 1 339 | 1 266 | 1 316 | 1 314 | 1 346 | 1 319 | 1 312 | 1 367 | 1 341 | 1 354 | 1 344 | 1 014 | 900 |
| Non-Energy Use of Anthracite | 173 | 132 | 172 | 198 | 197 | 232 | 278 | 278 | 274 | 257 | 273 | 187 | 149 | 163 | 158 | 153 | 155 | 112 | 110 | 99 |
| Non-Energy Use of Canadian Bituminous | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 464 | 210 | 258 | 570 | 318 |
| Non-Energy Use of Coke (iron and steel & other) | 8 056 | 9 273 | 9 219 | 8 882 | 8 194 | 8 522 | 8 308 | 8 119 | 8 328 | 8 523 | 8 531 | 7 936 | 7 782 | 7 705 | 7 877 | 7 694 | 8 409 | 8 420 | 8 227 | 5 968 |
| Non-Energy Use of Foreign Bituminous | 467 | 418 | 372 | 399 | 438 | 486 | 472 | 487 | 503 | 458 | 521 | 419 | 504 | 572 | 612 | 513 | 583 | 500 | 3 | 3 |
| Non-Energy Use of Lignite | 123 | 127 | 123 | 196 | 151 | 167 | 186 | 189 | 154 | 119 | 197 | 204 | 200 | 215 | 238 | 267 | 267 | 230 | 201 | 201 |
| Non-Energy Use of Petroleum coke | 1 907 | 2 053 | 2 199 | 2 229 | 2 596 | 2 439 | 2 527 | 2 281 | 2 241 | 2 704 | 3 057 | 3 188 | 3 146 | 3 425 | 3 475 | 3 761 | 3 684 | 3 603 | 3 434 | 2 975 |

A4

Table A4-1   Comparison of Adjusted Reference Approach and Sectoral Approach for Canada

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Specific details on carbon dioxide emissions from non-energy use of fossil fuel and feedstocks (cont'd) | | | | | | | | | | | | | | | | | | | |
| **Solid Fuels (cont'd)** | | | | | | | | | | | | | | | | | | | | |
| Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (Gg CO$_2$) | 88 400 | 90 744 | 93 986 | 86 851 | 90 567 | 92 927 | 94 146 | 99 849 | 105 941 | 106 796 | 114 896 | 115 135 | 113 847 | 116 748 | 110 839 | 109 485 | 106 595 | 109 828 | 110 753 | 94 045 |
| Sectoral Approach (Gg CO$_2$) | 90 679 | 93 141 | 96 625 | 89 939 | 94 203 | 96 565 | 98 013 | 104 119 | 109 974 | 110 705 | 119 743 | 119 795 | 118 380 | 121 246 | 115 863 | 113 643 | 110 496 | 115 369 | 111 925 | 94 367 |
| **Percentage Difference with Adjustment - 100% x (RA-SA)/SA** | **-2.51** | **-2.57** | **-2.73** | **-3.43** | **-3.86** | **-3.77** | **-3.94** | **-4.10** | **-3.67** | **-3.53** | **-4.05** | **-3.89** | **-3.83** | **-3.71** | **-4.34** | **-3.66** | **-3.53** | **-4.80** | **-1.05** | **-0.34** |
| | | | | | | | | | | | | | | | | | | | | |
| **Gaseous Fuels** | | | | | | | | | | | | | | | | | | | | |
| Reference Approach (Gg CO$_2$) | 152 306 | 151 026 | 160 517 | 164 556 | 168 871 | 176 485 | 182 905 | 181 733 | 179 574 | 191 942 | 201 338 | 193 573 | 203 425 | 207 011 | 207 023 | 203 152 | 201 266 | 219 739 | 209 147 | 205 094 |
| Carbon dioxide emissions from non-energy use of fossil fuel and feedstocks | | | | | | | | | | | | | | | | | | | | |
| Non-Energy Consumption of Natural Gas | 6 339 | 7 062 | 6 713 | 7 498 | 7 668 | 7 714 | 7 889 | 8 334 | 8 035 | 8 202 | 7 616 | 6 381 | 5 947 | 6 199 | 6 569 | 6 282 | 6 260 | 6 208 | 5 765 | 4 335 |
| Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (Gg CO$_2$) | 145 967 | 143 964 | 153 805 | 157 059 | 161 203 | 168 771 | 175 016 | 173 399 | 171 538 | 183 740 | 193 722 | 187 192 | 197 478 | 200 812 | 200 454 | 196 870 | 195 006 | 213 531 | 203 382 | 200 759 |
| Sectoral Approach (Gg CO$_2$) | 143 418 | 141 888 | 151 360 | 154 564 | 158 504 | 165 909 | 171 679 | 170 214 | 166 703 | 180 364 | 190 923 | 185 993 | 195 469 | 197 617 | 195 524 | 191 040 | 189 804 | 208 699 | 199 599 | 195 188 |
| **Percentage Difference with Adjustment - 100% x (RA-SA)/SA** | **1.78** | **1.46** | **1.61** | **1.61** | **1.70** | **1.73** | **1.94** | **1.87** | **2.90** | **1.87** | **1.47** | **0.64** | **1.03** | **1.62** | **2.52** | **3.05** | **2.74** | **2.32** | **1.90** | **2.85** |

## A4.2.   Reference-approach Methodology

The RA for the most part follows the Intergovernmental Panel on Climate Change (IPCC) designated method with the use of country-specific energy conversion factors (in higher heating value [HHV]/gross calorific value [GCV]) and emission factors. In Canada, as in the United States, HHV is used to record the energy content of fuels. Fuel quantities from the *Report on Energy Supply–Demand in Canada* (RESD; Statistics Canada catalogue no. 57-003-XIB) and the *Energy Statistics Handbook* (Statistics Canada 2010) are entered in their physical units, with the exception of international bunkers. A discussion of the data for international bunkers is presented in the following sections: 3.4.1, International Bunker Fuels; A2.4.2.3, Civil Aviation; and A2.4.2.4, Navigation. For primary fuels (crude oil, coal and natural gas), the stock change data have been adjusted to account for inter-product transfers, stock variation and other adjustments, and are then transformed to other fuels to determine the apparent consumption values. The stock change data for secondary fuels take into consideration imports, exports, international bunkers, stock variations and other adjustments.

Once the apparent consumption is determined, country-specific energy conversion factors and carbon emission factors are used to calculate the carbon content and emissions. These factors are taken from the following sources: Statistics Canada's annual *Report on Energy Supply–Demand in Canada* (RESD #57-003); C*anada's Greenhouse Gas Emissions: Estimates for 1990* (Jaques 1992); the *1998 Fossil Fuel and Derivative Factors* (McCann 2000); and Measurement Canada, an Industry Canada agency. For the majority of fossil fuels, the applied emission factors and oxidation factors are from McCann (2000), Jaques (1992) and from IPCC/OECD/IEA (1997).

Table A4–2 presents the applied emission factor, energy conversion factor and oxidation value in the RA. Energy conversion factors are taken directly from the RESD, with the exception of crude oil, natural gas, petroleum coke and still gas, where weighted factors have been developed to account for the quantity and variation of energy content at the point of consumption such as commercial usage or self-generated usage. For example, for provinces with natural gas production, there are two emission factors for natural gas: marketable natural gas, which is sold to consumers, and non-marketable natural gas, which is consumed directly by the producers of natural gas.

Table A4–2   Reference Approach Energy Conversion and Emission Factors for Canada

| Fuel Types | | | Energy Conversion Factor, GCV | | | Carbon Emission Factor, (t C/TJ GCV) | | Oxidation Factors (IPCC Default) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | 2009 Value | Unit | Reference | 2009 Value | Reference | | |
| **Liquid Fossil** | Primary Fuels | Crude Oil | 39.79 | TJ/ML | Refer to Comments | 19.25 | Refer to Comments | 0.99 | 1) Energy values associated with LPG (for butane and propane), with refinery still gas and with petroleum coke have been allocated to the Gaseous and Solid Fossil fuel category.<br>2) Weighted energy conversion and emission factor are based on country-specific data. |
| | | Orimulsion | NA | – | – | NA | – | 0.99 | |
| | | Natural Gas Liquids | 17.22 | TJ/ML | 4 | 15.61 | 2 | 0.99 | 1) Report use of ethane from natural gas liquid.  2) Use of butane and propane have been allocated to the Gaseous Fossil fuel category. |
| | Secondary Fuels | Gasoline | 35 | TJ/ML | 4 | 17.84 | 2 | 0.99 | |
| | | Jet Kerosene | 37.4 | TJ/ML | 4 | 18.67 | 2 | 0.99 | Use of aviation turbo fuel. |
| | | Other Kerosene | 37.68 | TJ/ML | 4 | 18.53 | 2 | 0.99 | |
| | | Shale Oil | NA | – | – | NA | – | – | |
| | | Gas/Diesel Oil | 38.3 | TJ/ML | 4 | 18.86 | 2 | 0.99 | Use of diesel fuel oil. |
| | | Residual Fuel Oil | 42.5 | TJ/ML | 4 | 20.07 | 2 | 0.99 | Use of heavy fuel oil. |
| | | LPG | IE | – | – | IE | – | – | Propane and butane from refineries have been allocated to Gaseous Fossil fuel category. |
| | | Ethane | 17.22 | TJ/ML | 4 | 15.61 | 2 | 0.995 | 1)Use of ethane from NGL.<br>2) Total available ethane is consumed as a feedstock in industrial processes. |
| | | Naphtha | 35.17 | TJ/ML | 4 | 19.33 | 3 | 0.99 | |
| | | Bitumen | 44.46 | TJ/ML | 4 | 21.11 | 3 | 0.99 | Use of asphalt. |
| | | Lubricants | 39.16 | TJ/ML | 4 | 19.66 | 3 | 0.99 | |
| | | Petroleum Coke | IE | – | – | IE | – | – | Allocated to the Solid Fossil fuel category. |
| | | Refinery Feedstocks | 35.17 | TJ/ML | 4 | 19.33 | 3 | 0.99 | Use of petrochemical feedstock in industrial processes |
| | | Other Oil | 38.8 | TJ/ML | 4 | 19.15 | 2 | 0.99 | Use of light fuel oil. |
| | Other Liquid Fuels | Aviation Gasoline | 33.52 | TJ/ML | 4 | 19.25 | 3 | 0.99 | |
| | | Other Product Feedstocks | 39.82 | TJ/ML | 4 | 19.84 | 3 | 0.99 | |
| **Solid Fossil** | Primary Fuels | Anthracite | 27.7 | TJ/kt | 4 | 23.74 | 3 | 0.99 | |
| | | Coking Coal | 28.83 | TJ/kt | 4 | 23.69 | 2 | 0.99 | |
| | | Other Bituminous Coal | 27.11 | TJ/kt | 4 | 22.67 | 5 | 0.99 | Use of Canadian bituminous coal |
| | | Sub-bituminous Coal | 19.15 | TJ/kt | 4 | 24.69 | 5 | 0.99 | |
| | | Lignite | 15 | TJ/kt | 4 | 25.99 | 5 | 0.99 | |
| | | Oil Shale | NA | – | – | NA | – | – | |
| | | Peat | NA | – | – | NA | – | – | |
| | Secondary Fuels | BKB & Patent Fuel | NA | – | – | NA | – | – | |
| | | Coke Oven Gas | IE | – | – | IE | – | – | Allocated to the Gaseous Fossil fuel category. |
| | Other Solid Fuels | Petroleum Coke – Refinery and Upgrader | 44.6 | TJ/ML | 4 | 22.74 | - | 0.99 | Country-specific weighted emission factors based on available emission factors for refining and upgrading (of oil sands to synthetic crude oil). |

Table A4-2   Reference Approach Energy Conversion and Emission Factors for Canada   (cont'd)

| Fuel Types | | | Energy Conversion Factor, GCV | | | Carbon Emission Factor, (t C/TJ GCV) | | Oxidation Factors (IPCC Default) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | 2009 Value | Unit | Reference | 2009 Value | Reference | | |
| **Solid Fossil (cont'd)** | Other Solid Fuels (cont'd) | Foreign Bituminous Coal | 29.82 | TJ/kt | 4 | 22.82 | 5 | 0.99 | |
| **Gaseous Fossil** | | Natural Gas | 38.26 | TJ/GL | 4 | 14.12 | 2 | 0.995 | Country specific weighted emission factor based on proportion of marketable and non-marketable natural gas. |
| | Other Gaseous Fuels | Propane | 25.31 | TJ/ML | 4 | 16.35 | 2 | 0.995 | Includes consumption of NGL-propane. |
| | | Coke Oven Gas | 19.14 | TJ/ML | 4 | 12.52 | 2 | 0.99 | |
| | | Butane | 28.44 | TJ/ML | 4 | 16.67 | 2 | 0.995 | Includes consumption of NGL-butane. |
| | | Still Gas – Refinery and Upgrader Fuel Gas | 39.24 | TJ/ML | 4 | 13.25 | - | 0.99 | Country-specific weighted emission factor based on factors from refinery and from upgrading (of crude from oil sands to synthetic crude oil) activities. |
| **Biomass** | | Solid Biomass | 18 | TJ/kt | 4 | 28.41 | - | 0.99 | 1) Consists of industrial and residential biomass consumption. 2) Assumed 99% oxidation. |
| | | Liquid Biomass | 14.86 | TJ/kt | 4 | 18.91 | 3 | 0.952 | 1) Consists of spent pulping liquor, ethanol and biodiesel. 2) Weighted oxidation factor approximately 95%. |
| | | Gas Biomass | 35.9 | TJ/1000m$^3$ | 1 | 14.97 | 1 | 0.99 | 1) Consists of landfill gas. 2) Assumed a 99% oxidation factor. |

References: (1) IPCC/OECD/IEA (1997); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada, #57-003 (2003 data); (5) EC Coal Study.
NA = Not applicable; BKB = Charcoal briquettes; NGL = natural gas liquids; LPG = liquified petroleum gas; IE = included elsewhere.

To adjust the RA for comparison with the SA, non-energy use of fossil fuels and feedstocks and the corresponding carbon dioxide emitted must be calculated using the storage and emission factors for industrial processes presented in Annex 8 of the NIR.

## A4.3.  National Energy Balance

Statistics Canada provides Environment Canada with a large portion of the underlying activity data to estimate GHG emissions for the Energy Sector and the Industrial Processes Sector. Statistics Canada's Manufacturing and Energy Division (MED) is responsible for the collection, compilation and dissemination of the energy balance in the RESD (#57-003). The objective of MED is to ensure that the information as collected under the authority of the *Statistics Act* and used in the development of the energy balance meets the following quality criteria: completeness, consistency, coherency and accuracy. The quality management system for the energy balance also includes an inter-

nal and external review process. MED's quality assurance framework and methodological reports are documented and made available through Statistics Canada's Integrated Meta Database.

The energy balance is an accounting of all available energy forms in Canada from import and export activities through production and domestic consumption (refer to Figure A4–1 for a sample of an energy flow diagram). Energy and fossil fuel data are collected by various methods, such as a mix of annual or monthly surveys and some censuses from industry, federal agencies (such as the National Energy Board [NEB], the Energy Resources Conservation Board [ERCB] and the Alberta Utilities Commissions [AUC]), provincial energy departments, and from the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC). Refer to Figure A4–2 for a sample of the energy and fossil fuel data input to MED and what information is provided by each of the data sources or respondents. Oil and gas information as provided by the ERCB is highly accurate, since it is tied to oil and gas exploitation permits and to federal and provincial royalty schemes.

Figure A4–1    Sample of an Energy Balance Flow Diagram for Canada (RESD)
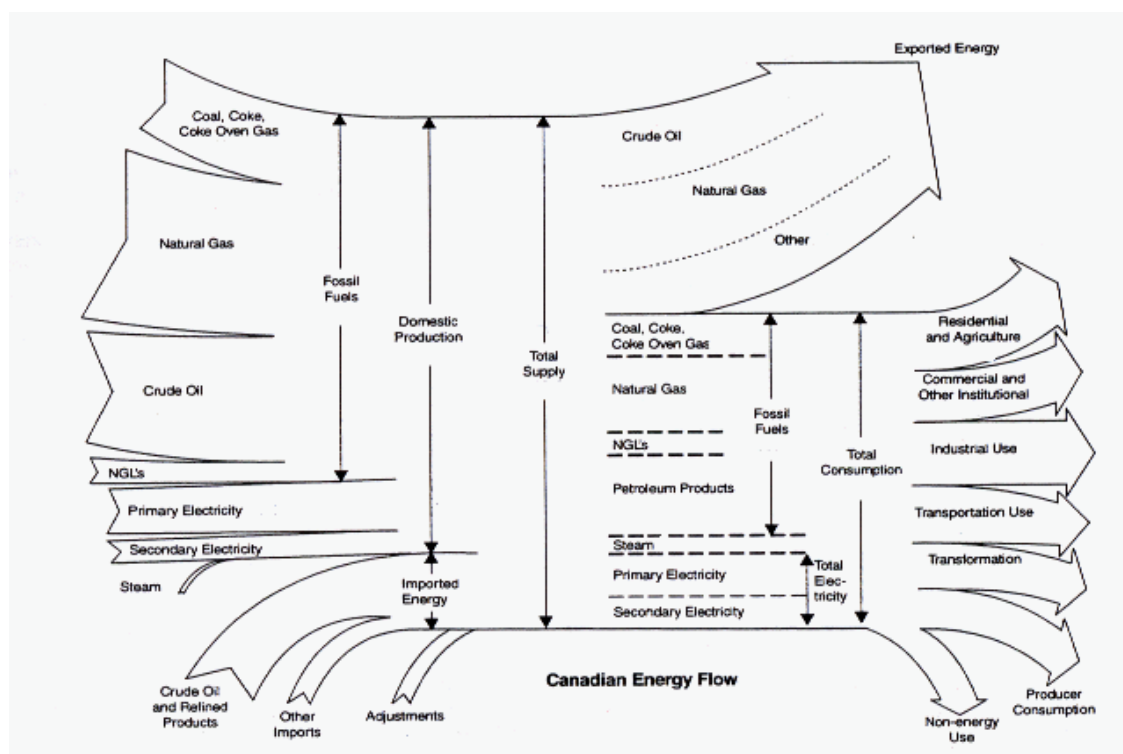


Figure A4–2    Fossil Fuel and Energy Data Input

**A4**
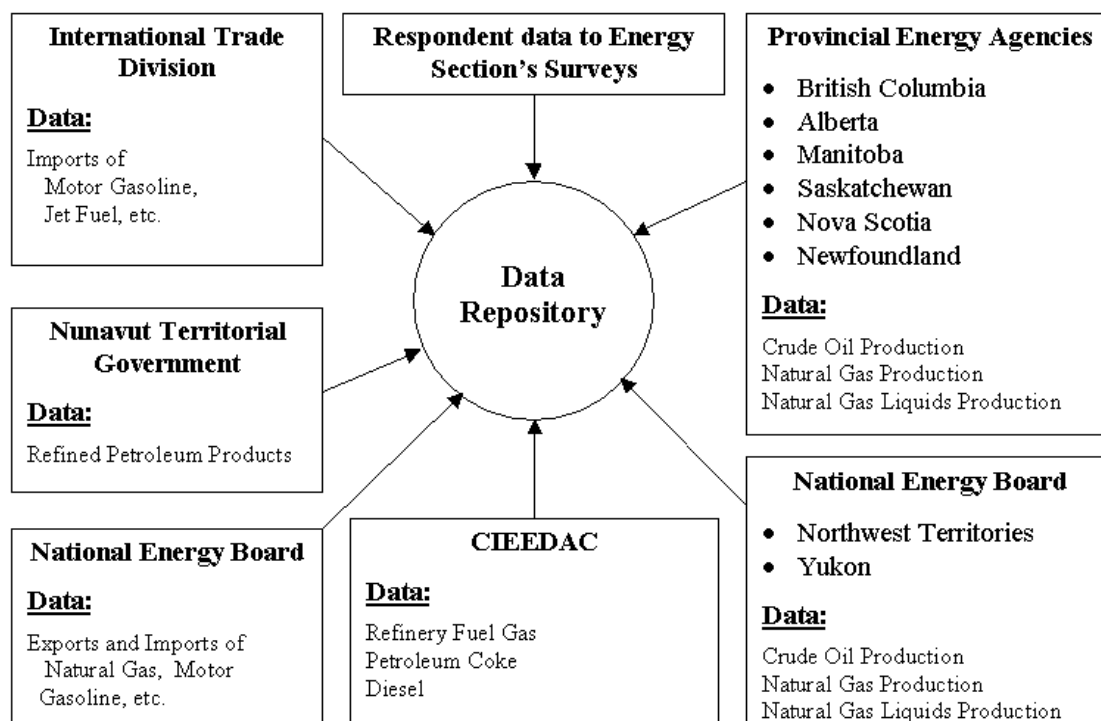
There are also other internal data quality checks of the information collected through provincial energy departments and from various supply, disposition and consumption surveys. For example, the quantity of crude oil shipped as reported by the producer is verified against report receipts from pipeline companies, and the information as reported by pipelines is verified against refinery receipts. MED also applies both a top-down approach through the supply and disposition surveys and a bottom-up approach through the Industrial Consumption of Energy survey to verify the quality of the data for manufacturing industries, including the petroleum refining industry. In addition, technical information on energy characteristics is collected to verify reported fuels in physical and energy units.

The energy balance consists of information on crude oil, natural gas, coal, refined petroleum product (RPPs), electricity, steam, non-energy use of fossil fuels, feedstock and other secondary energy forms for all Canadian industrial sectors and other energy use, such as the transportation, residential and commercial sectors.

Both the Industrial Consumption of Energy product and the energy balance are used by various federal departments for energy efficiency programs, policy development, reporting to the International Energy Agency, energy and emission forecasting, and reporting to the UNFCCC. As such, MED has established partnerships with various federal government departments, provincial energy ministries, industrial associations and centres of excellence to assist with their quality assurance process.

For example, a "work-in-progress" review has been established with Environment Canada and Natural Resources Canada (NRCan) to review the industrial consumption of energy estimates and the energy balance prior to their official release. Canadian industrial members also participate in the review of industrial data through the Canadian Industrial Program for Energy Conservation group. The Canadian Industrial Energy End-Use Data and Analysis Centre also participates in the review of refinery data and the industrial energy statistics.

Owing to the complexity of energy data, a working group on energy statistics was established to provide advice, direction and recommendations. The working group consists of members from Statistics Canada, Environment Canada, Industry Canada, Transport Canada, Foreign Affairs Canada and Natural Resources Canada. Its mandate is to identify and address issues related to the collection of a comprehensive set of energy data for various sectors of the economy and to improve existing energy statistics.

## A4.4.    IPCC Fuel Categorization

In its Common Reporting Format (CRF) data tables, Canada characterizes fuels according to their physical state at time of use, which does not in all cases match IPCC fuel categorizations. To ensure that information submitted to the UNFCCC is transparent, complete, consistent and comparable, $CO_2$ implied emission factors (IEF) from combustion activities are presented following physical state and IPCC fuel groupings (refer to Table A4–4 to Table A4–6 for specific details).

Presented in Table A4–3 are the fuel types that are consumed in Canada, grouped according to their physical state and the IPCC categorization.

The allocation of fuels based on their physical state at point of usage with similar carbon content, heating value and density helps to ensure that aggregated implied emission factors are comparable. This approach also reduces the impact of highly variable fuels (such as internally generated, non-commercial fuels produced by oil sands upgraders and refineries) that may skew the resultant IEFs when compared to Annex I Parties that consume mostly commercial-grade fuels, such as diesel (with less variability in fuel properties). As an example, the $CO_2$ IEF of solid fuels for petroleum refining following IPCC categorization of Annex I Parties ranged from a low of 40.85 t/TJ to a high of 257.18 t/TJ due to the variability of the carbon content and the quantity of each type of coal, coke oven gas and solid waste fuel that is consumed. This makes it difficult to compare and to assess the accuracy of reported emissions and IEFs, especially for large fossil-fuel-producing Parties with a mix of conventional and unconventional sources of fossil fuels.

It is important to note that for Canada, the impact on the $CO_2$ IEF based on the allocation of fuels by physical states as compared to the IPCC categorization is minimal for stationary combustion sources such as Public Electricity and Heat Production; Non-ferrous Metals; Chemicals; Pulp, Paper and Print; Mining; Commercial/Institutional; and the Residential subcategory as presented in Table A4–4 for the Energy Industries, Table A4–5 for the

Table A4–3    Fuel Type Categories for Stationary Combustion Methodology

| Fuel Types | Physical Categorization | IPCC Categorization |
|---|---|---|
| Liquid Fuels | Motor gasoline<br>Kerosene and stove oil<br>Diesel fuel oil<br>Light fuel oil<br>Heavy fuel oil<br>Aviation gasoline<br>Aviation turbo fuel | Motor gasoline<br>Kerosene and stove oil<br>Diesel fuel oil<br>Light fuel oil<br>Heavy fuel oil<br>Aviation gasoline<br>Aviation turbo fuel<br>Ethane<br>Propane<br>Butane<br>Petroleum Coke – Refineries, Upgraders & Others<br>Still Gas – Refinery fuel gas, Upgraders fuel gas & Others |
| Solid Fuels | Coke (coal)<br>Canadian bituminous<br>Sub-bituminous (foreign & domestic)<br>Lignite<br>Anthracite<br>Foreign bituminous<br>Petroleum Coke–Refineries, Upgraders & Others<br>Waste fuel - tires | Coke (coal)<br>Canadian bituminous<br>Sub-bituminous (foreign & domestic)<br>Lignite<br>Anthracite<br>Foreign bituminous<br>Waste fuel – tires<br>Coke oven gas |
| Gaseous Fuels | Natural Gas<br>Coke oven gas<br>Propane<br>Butane<br>Ethane<br>Still Gas–Refineries, Upgraders & Others | Natural Gas |

Manufacturing Industries and Construction and in Table A4–6 for the Other Sectors.

In other cases, the allocation of fuels by physical characteristics results in a closer alignment of Canada's $CO_2$ IEF when compared to the overall average value of all Parties (based on 2009 submissions). For example, the 2008 iron and steel's $CO_2$ IEF for solid fuels is about 46.65 t/TJ following IPCC categorization (as shown in Table A4-7) which is at the low end of the range. But it is 84.01 t/TJ when allocated based on physical state, which is much closer to the overall average IEF value of 111.87 t/TJ for Annex I Parties.

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Table A4–4    Energy Industries' $CO_2$ Implied Emission Factors

| | 1990 | 1995 | 2000 | 2005 | 2008 | 2009 |
|---|---|---|---|---|---|---|
| | | | | *t/TJ* | | |
| **1.A.1. Energy Industries** | | | | | | |
| a.  Public Electricity and Heat Production | | | | | | |
| Liquid Fuels | | | | | | |
| Physical categorization | 74.4 | 74.3 | 73.3 | 73.3 | 73.1 | 73.1 |
| IPCC categorization | 74.7 | 74.8 | 71.6 | 73.2 | 73.7 | 73.7 |
| Solid Fuels | | | | | | |
| Physical categorization | 88.3 | 90.0 | 87.8 | 89.0 | 89.2 | 89.1 |
| IPCC categorization | 88.3 | 90.0 | 87.8 | 89.1 | 89.4 | 89.4 |
| Gaseous Fuels | | | | | | |
| Physical categorization | 50.5 | 49.8 | 49.8 | 49.4 | 49.5 | 49.4 |
| IPCC categorization | 50.5 | 49.8 | 49.8 | 49.4 | 49.5 | 49.4 |
| b.  Petroleum Refining | | | | | | |
| Liquid Fuels | | | | | | |
| Physical categorization | 73.8 | 73.3 | 73.3 | 72.8 | 71.9 | 71.6 |
| IPCC categorization | 56.8 | 59.4 | 59.3 | 60.8 | 60.2 | 60.1 |
| Solid Fuels | | | | | | |
| Physical categorization | 84.7 | 85.1 | 80.1 | 82.3 | 82.4 | 82.3 |
| IPCC categorization | NO | NO | NO | NO | NO | NO |
| Gaseous Fuels | | | | | | |
| Physical categorization | 45.1 | 47.3 | 46.4 | 46.9 | 46.9 | 47.2 |
| IPCC categorization | 45.3 | 48.7 | 45.9 | 44.4 | 45.9 | 45.3 |
| d.  Manufacture of Solid Fuels and Other Energy Industries | | | | | | |
| Liquid Fuels | NA | NA | NA | NA | NA | NA |
| Solid Fuels | | | | | | |
| Physical categorization | 87.8 | 87.7 | 85.7 | 86.0 | 86.0 | 86.0 |
| IPCC categorization | 72.0 | 71.9 | 84.2 | 84.2 | 84.2 | 84.4 |
| Gaseous Fuels | | | | | | |
| Physical categorization | 61.3 | 59.3 | 60.5 | 59.3 | 59.3 | 58.2 |
| IPCC categorization | 62.5 | 61.9 | 62.3 | 61.5 | 61.5 | 61.2 |

Note:
NO = not occurring; NA = not applicable

Table A4–5   Manufacturing Industries and Construction's CO$_2$ Implied Emission Factors

| | 1990 | 1995 | 2000 | 2005 | 2008 | 2009 |
|---|---|---|---|---|---|---|
| | | | | t/TJ | | |
| **1.A.2 Manufacturing Industries and Construction** | | | | | | |
| a.  Iron and Steel | | | | | | |
|     Liquid Fuels | | | | | | |
|       Physical categorization | 74.86 | 74.86 | 73.51 | 73.51 | 73.51 | 73.50 |
|       IPCC categorization | 74.87 | 75.38 | 73.56 | 73.51 | 73.61 | 73.65 |
|     Solid Fuels | | | | | | |
|       Physical categorization | 87.54 | 85.55 | 85.44 | IE | 84.01 | 84.69 |
|       IPCC categorization | 47.62 | 47.66 | 46.58 | 45.92 | 46.65 | 47.08 |
|     Gaseous Fuels | | | | | | |
|       Physical categorization | 48.8 | 48.8 | 48.6 | 48.2 | 48.2 | 48.2 |
|       IPCC categorization | 49.8 | 49.3 | 49.4 | 49.1 | 49.1 | 49.1 |
| b.  Non-ferrous Metals | | | | | | |
|     Liquid Fuels | | | | | | |
|       Physical categorization | 74.7 | 74.1 | 73.4 | 73.4 | 73.4 | 73.4 |
|       IPCC categorization | 76.3 | 76.1 | 74.2 | 74.5 | 75.5 | 75.5 |
|     Solid Fuels | | | | | | |
|       Physical categorization | 82.9 | 83.9 | 85.3 | 85.3 | 84.8 | 85.0 |
|       IPCC categorization | 82.7 | 83.7 | 85.8 | 85.8 | 85.2 | 85.8 |
|     Gaseous Fuels | | | | | | |
|       Physical categorization | 49.9 | 49.5 | 49.6 | 49.3 | 49.4 | 49.5 |
|       IPCC categorization | 49.9 | 49.5 | 49.6 | 49.3 | 49.4 | 49.5 |
| c.  Chemicals | | | | | | |
|     Liquid Fuels | | | | | | |
|       Physical categorization | 74.9 | 74.9 | 73.5 | 73.5 | 73.5 | 73.5 |
|       IPCC categorization | 75.8 | 76.0 | 74.5 | 75.0 | 75.5 | 75.9 |
|     Solid Fuels | | | | | | |
|       Physical categorization | 84.7 | 85.1 | 80.1 | 82.4 | 82.4 | 82.4 |
|       IPCC categorization | NO | NO | NO | 79.6 | 79.6 | 79.6 |
|     Gaseous Fuels | | | | | | |
|       Physical categorization | 50.4 | 50.0 | 50.2 | 49.9 | 49.9 | 50.0 |
|       IPCC categorization | 50.4 | 50.0 | 50.2 | 49.9 | 49.9 | 50.0 |
| d.  Pulp, Paper and Print | | | | | | |
|     Liquid Fuels | | | | | | |
|       Physical categorization | 74.8 | 74.8 | 73.5 | 73.5 | 73.4 | 73.4 |
|       IPCC categorization | 74.8 | 74.8 | 73.5 | 73.5 | 73.4 | 73.4 |
|     Solid Fuels | | | | | | |
|       Physical categorization | 86.8 | 87.3 | 87.6 | 89.4 | 89.3 | 91.8 |
|       IPCC categorization | 86.8 | 87.3 | 87.6 | 89.4 | 89.3 | 91.8 |
|     Gaseous Fuels | | | | | | |
|       Physical categorization | 50.0 | 49.7 | 49.8 | 49.5 | 49.5 | 49.5 |
|       IPCC categorization | 50.0 | 49.7 | 49.8 | 49.5 | 49.5 | 49.5 |
| e.  Food Processing, Beverages and Tobacco | IE | IE | IE | IE | IE | IE |
| f.  Other | | | | | | |
|     1.AA.2.F.i Cement | | | | | | |
|     Liquid Fuels | | | | | | |
|       Physical categorization | 74.9 | 74.9 | 73.5 | 73.5 | 73.5 | 73.5 |
|       IPCC categorization | 82.4 | 83.4 | 78.7 | 81.2 | 81.7 | 81.4 |
|     Solid Fuels | | | | | | |
|       Physical categorization | 83.8 | 83.2 | 82.4 | 83.9 | 84.1 | 84.3 |
|       IPCC categorization | 83.3 | 82.2 | 82.8 | 84.4 | 84.8 | 84.6 |
|     Gaseous Fuels | | | | | | |
|       Physical categorization | 50.4 | 50.1 | 50.3 | 49.4 | 49.4 | 49.4 |
|       IPCC categorization | 50.4 | 50.1 | 50.3 | 49.4 | 49.4 | 49.4 |

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Table A4-5   Manufacturing Industries and Construction's CO$_2$ Implied Emission Factors  (cont'd)

| | 1990 | 1995 | 2000 | 2005 | 2008 | 2009 |
|---|---|---|---|---|---|---|
| | | | | t/TJ | | |
| f.  Other (cont'd) | | | | | | |
| 1.AA.2.F.ii Mining | | | | | | |
| Liquid Fuels | | | | | | |
| Physical categorization | 73.4 | 73.4 | 72.4 | 71.7 | 72.2 | 71.8 |
| IPCC categorization | 72.9 | 69.6 | 63.7 | 61.7 | 61.3 | 60.9 |
| Solid Fuels | | | | | | |
| Physical categorization | 86.9 | 87.2 | 86.0 | 86.5 | 83.7 | 83.9 |
| IPCC categorization | 86.0 | 86.0 | 86.0 | 86.7 | 83.4 | 83.5 |
| Gaseous Fuels | | | | | | |
| Physical categorization | 50.9 | 51.2 | 51.1 | 50.8 | 50.7 | 50.5 |
| IPCC categorization | 50.3 | 49.7 | 49.9 | 49.8 | 49.9 | 49.8 |
| 1.AA.2.F.iii Construction | | | | | | |
| Liquid Fuels | | | | | | |
| Physical categorization | 71.2 | 70.8 | 70.6 | 71.4 | 70.4 | 71.3 |
| IPCC categorization | 64.8 | 65.4 | 65.5 | 66.7 | 64.1 | 65.4 |
| Gaseous Fuels | | | | | | |
| Physical categorization | 52.5 | 51.9 | 51.2 | 50.5 | 50.7 | 50.9 |
| IPCC categorization | 50.0 | 49.6 | 49.6 | 49.3 | 49.2 | 49.1 |
| 1.AA.2.F.iv Other Manufacturing | | | | | | |
| Liquid Fuels | | | | | | |
| Physical categorization | 74.4 | 73.2 | 72.4 | 72.4 | 72.1 | 72.2 |
| IPCC categorization | 71.3 | 72.1 | 71.0 | 68.0 | 67.2 | 67.0 |
| Solid Fuels | | | | | | |
| Physical categorization | 85.0 | 84.9 | 83.4 | 84.4 | 84.4 | 84.6 |
| IPCC categorization | 85.1 | 84.8 | 85.3 | 85.6 | 85.8 | 85.9 |
| Gaseous Fuels | | | | | | |
| Physical categorization | 50.3 | 49.8 | 50.0 | 49.8 | 49.9 | 49.9 |
| IPCC categorization | 50.0 | 49.7 | 49.8 | 49.4 | 49.4 | 49.4 |

Note:
NO = not occurring; IE = included elsewhere.

Table A4–6   Other Sectors – CO$_2$ Implied Emission Factors

| | 1990 | 1995 | 2000 | 2005 | 2008 | 2009 |
|---|---|---|---|---|---|---|
| | | | | t/TJ | | |
| **1.A.4  Other Sectors** | | | | | | |
| a.  Commercial/Institutional | | | | | | |
|    Liquid Fuels | | | | | | |
|       Physical categorization | 70.9 | 70.7 | 70.8 | 71.4 | 71.4 | 71.5 |
|       IPCC categorization | 68.8 | 66.4 | 67.4 | 69.5 | 68.8 | 69.2 |
|    Solid Fuels | | | | | | |
|       Physical categorization | 81.4 | 71.8 | 84.2 | NO | NO | 86.1 |
|       IPCC categorization | 81.4 | 71.8 | 84.2 | NO | NO | 86.1 |
|    Gaseous Fuels | | | | | | |
|       Physical categorization | 50.4 | 50.5 | 50.4 | 49.9 | 50.0 | 49.9 |
|       IPCC categorization | 50.0 | 49.7 | 49.7 | 49.4 | 49.4 | 49.4 |
| b.  Residential | | | | | | |
|    Liquid Fuels | | | | | | |
|       Physical categorization | 70.2 | 70.2 | 70.0 | 70.1 | 70.1 | 70.2 |
|       IPCC categorization | 69.1 | 69.2 | 69.2 | 68.9 | 68.3 | 68.3 |
|    Solid Fuels | | | | | | |
|       Physical categorization | 87.9 | 85.3 | 88.4 | 89.5 | 91.8 | 91.4 |
|       IPCC categorization | 87.9 | 85.3 | 88.4 | 89.5 | 91.8 | 91.4 |
|    Gaseous Fuels | | | | | | |
|       Physical categorization | 50.3 | 49.9 | 49.9 | 49.6 | 49.6 | 49.6 |
|       IPCC categorization | 50.0 | 49.6 | 49.7 | 49.4 | 49.4 | 49.4 |
| c.  Agriculture/Forestry/Fisheries | | | | | | |
|    Liquid Fuels | | | | | | |
|       Physical categorization | 70.5 | 70.3 | 70.5 | 71.8 | 72.0 | 71.2 |
|       IPCC categorization | 67.4 | 66.8 | 67.1 | 66.1 | 65.8 | 63.8 |
|    Gaseous Fuels | | | | | | |
|       Physical categorization | 51.5 | 51.7 | 51.2 | 51.8 | 51.8 | 51.5 |
|       IPCC categorization | 49.9 | 49.3 | 49.6 | 49.0 | 49.1 | 49.0 |

Note:
NO = not occurring.

Table A4–7   Examples of Improved Comparability of CO$_2$ Implied Emission Factors Based on Physical Categorization

| | | 1990 | 2008 |
|---|---|---|---|
| | | t/TJ | |
| **1.A.1. Energy Industries** | | | |
| c.  Manufacture of Solid Fuels and Other Energy Industries | | | |
|    Solid Fuels | | | |
|       Physical categorization | | 87.8 | 86.0 |
|       IPCC categorization | | 72.0 | 84.2 |
|       CRF Locator - Outliers | *Low* | 40.8 | 31.9 |
| | *Average* | 92.1 | 86.3 |
| | *High* | 163.2 | 158.8 |
|    Gaseous Fuels | | | |
|       Physical categorization | | 61.3 | 59.3 |
|       IPCC categorization | | 62.5 | 61.5 |
|       CRF Locator | *Low* | 26.8 | 49.8 |
| | *Average* | 56.8 | 61.2 |
| | *High* | 81.6 | 185.1 |
| **1.A.2 Manufacturing Industries and Construction** | | | |
| a.  Iron and Steel | | | |
|    Solid Fuels | | | |
|       Physical categorization | | 87.5 | 84.0 |
|       IPCC categorization | | 47.6 | 46.7 |
|       CRF Locator | *Low* | 20.4 | 20.5 |
| | *Average* | 113.7 | 111.9 |
| | *High* | 248.0 | 221.3 |

# Annex 5

# Assessment of Completeness

Although this inventory report serves as a comprehensive assessment of anthropogenic greenhouse gas (GHG) emissions and removals in Canada, some categories have not been included or have been included with other categories for reasons explained in the common reporting format (CRF) tables and in this annex.

## A5.1.    Energy

Overall, the Energy Sector of the national inventory provides a full estimate of all significant sources. $CH_4$ and $N_2O$ emissions from the combustion of waste fuels are not currently estimated, but this does not affect the completeness of the inventory owing to its relatively small contribution.

### A5.1.1.    Emissions from Combustion of Waste Fuels

Although carbon dioxide emissions from waste fuels are included in the inventory, emissions of $CH_4$ and $N_2O$ have not been included, due to a lack of emission factors or measured data on such emissions from these fuels.

## A5.2.    Industrial Processes

Overall, the Industrial Processes Sector of the national inventory provides a comprehensive estimate of all significant sources. Discussed in the following subsections are sources that are not currently estimated and that may represent a source in their particular subsector. However, their magnitudes are assumed to be small and to not affect the overall completeness of the GHG inventory.

### A5.2.1.    Mineral Products

$CO_2$ emissions from asphalt roofing and road paving with asphalt are not estimated. There is currently no country-specific information on this. However, based on Chapter 5, Volume 3 of the 2006 IPCC Guidelines (IPCC 2006), $CO_2$ emissions from this category are thought to be negligible.

Only $CO_2$ emissions from glass production coming from the use of limestone, dolomite and soda ash are currently estimated. These emissions are reported under 2.A.3 Limestone and Dolomite Use, and 2.A.4 Soda Ash Production and Use. Emissions other than those coming from these minerals are not estimated and are considered to be minor based on Chapter 2, Volume 3 of the 2006 IPCC Guidelines (IPCC 2006).

Soda ash was produced in Canada until 2001. The Solvay process in which soda ash was produced results in some $CO_2$ emissions. However, as $CO_2$ is also a necessary component in the process reactions, it is most commonly recovered for reuse. Hence, the quantity of recovered $CO_2$ is estimated in the inventory for the years 1990–2001, but the net amount of non-recovered (i.e. emitted) $CO_2$ coming from soda ash production is not estimated and is considered to be minimal.

### A5.2.2.    Chemical Production

$N_2O$ emissions associated with the production of chemicals other than nitric acid, adipic acid and ethylene are reported as "Not Estimated." However, according to a recent study (Cheminfo Services 2010), production of chemicals, such as ammonia, ethylene and methanol, is not a large source of $N_2O$ emissions (i.e. not more than 10 kt $CO_2$ eq/year). Complete results on $N_2O$ emission estimation found in this study will be included in the next inventory.

$CH_4$ emissions from production of carbide, carbon black, ethylene, methanol, ethylene dichloride and styrene are now included in the inventory.

Process-related $CO_2$ emissions from adipic acid production are not inventoried (i.e. not estimated) and are considered negligible in comparison with the amount of $CO_2$ emitted from fuel combustion.[1]

### A5.2.3.    Metal Production

Process $CH_4$ emissions associated with the production of metals are currently reported as "Not Estimated." However,

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1    Lauridsen S. 2005. Personal communication (email dated November 3, 2005). Invista Canada.

a recent study (Cheminfo Services 2010) has determined that the contribution of estimated $CH_4$ and $N_2O$ emissions to the total process GHGs is approximately 1%. Complete results of the study will be included in the next inventory.

### A5.2.4. Production and Consumption of Halocarbons and $SF_6$

Since data on perfluorocarbons (PFCs) used in aerosols are currently unavailable, the associated emissions are not inventoried (i.e. not estimated). Hydrofluorocarbon (HFC) emissions from electronic industries are reported under the category 2.F.5 Solvents, not 2.F.9 Other (Contained and Emissive Emissions from Electronic Industries), in the CRF reporter, since it is not possible for this submission to separate HFC consumption as solvent in electronic industries from other types of solvent use. There are also some PFCs emitted from the electronic industry, and these emissions are reported under 2.F.9 Other (Contained and Emissive Emissions from Electronic Industries). HFC emissions coming from electrical equipment are reported as "Not Estimated" because there is no known use of HFCs for electrical insulation and arc quenching in equipment used in the electricity industry. According to the electricity industry, $CF_4$ has been used in some outdoor electrical equipment. Specifically, it is found in gas mixtures with $SF_6$, since $SF_6$ alone cannot function properly as an insulating gas in low temperatures. There are ongoing discussions with the industry, so that $CF_4$ use and emission data can be collected and reported by Environment Canada in future inventories.

Potential emissions of $SF_6$, which should be derived from the information on imports and exports of $SF_6$ (in bulk and in product), and $SF_6$ destruction are reported as "Not Estimated" since there is currently no comprehensive information on $SF_6$ exports in products. Based on information provided by major $SF_6$ gas distributors, there is no bulk $SF_6$ exported from Canada. The electricity industry has also indicated that destruction or recycling of $SF_6$ found in electrical equipment is done in the United States.

### A5.2.5. Other and Undifferentiated Production

$CO_2$ emissions from the non-energy use of hydrocarbons are estimated using two types of emission factors. The first type was developed by simply converting the national carbon contents for non-energy fuel types to GHG emission factors, while the second type was derived based on both national carbon contents and IPCC default fractions of carbon stored. The IPCC default fractions of carbon stored take into account the release of carbon from the use or destruction of the manufactured products over a short term only. $CO_2$ emissions from the combustion of waste fuels (made from non-energy use of hydrocarbons) need to be researched further. This, to understand to what extent the IPCC default fraction of carbon stored represents the release of carbon from use or destruction of the product in the short term (versus the long term). Please see comments in A5.1 on this as well.

### A5.3. Solvent and Other Product Use

In this sector, only $N_2O$ emissions associated with the use of anaesthetics and propellants are estimated. Emissions from use of solvents in dry cleaning, printing, metal degreasing, and a variety of industrial applications as well as household use are not estimated because, according to the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997), GHGs are not emitted in significant amounts from these types of uses. Also, according to a recent study (Cheminfo Services 2010), there has been no $N_2O$ used in fire extinguishers because the decomposition of $N_2O$ provides a source of oxygen for flammable materials that would sustain, not suppress, any fire. As such, $N_2O$ from fire extinguishers (category 3.D.2 in the CRF) is reported as "not occurring."

### A5.4. Agriculture

Overall, the Agriculture Sector of the national inventory provides a complete estimate of the significant sources. The following list includes sources that are not currently estimated. These are considered to be minor sources.

### A5.4.1. Enteric Fermentation and Manure Management

Some minor animal categories, such as ranched deer, wild boar, elk, rabbit, ostrich and ducks, have not yet been included. Complete IPCC default emission factors and parameters are unavailable for these categories, and they have relatively low populations. Mules, asses and camels are reported as not occurring because there is no known commercial production of these animals. At this time, in-

formation on animal waste manure systems using anaerobic lagoons, daily spread and dry lot, by livestock category, is not available. These manure management systems are considered minor by Canadian experts when compared with liquid/slurry and solid and dry lot storage. Information on animal waste management systems, including distributions for anaerobic lagoons, daily spread and dry lot, will be collected and, in the mid term or long term, will be reported from these sources.

### A5.4.2. Prescribed Burning of Savanna

Prescribed Burning of Savanna is not a relevant reporting category for Canada.

### A5.4.3. Rice Production

$CH_4$ emissions from rice production are not currently inventoried, as rice production is not occurring in Canada.

## A5.5. Land Use, Land-Use Change and Forestry

With the major methodological improvements implemented in the 2006 submission, the completeness of the LULUCF inventory has considerably improved through increased coverage of carbon pools and improvement in the resolution of activity data. Uncertainty ranges are provided for estimates in the Forest Land and Cropland categories, and for the area of forest conversion to other land categories. They are under preparation for all other land categories.

### A5.5.1. Forest Land

Forest land estimates are provided for both forest land remaining forest land and land converted to forest land. These estimates include carbon stock changes and emissions from all pools (biomass, dissolved organic matter (DOM) and soil) in managed forests resulting from growth and mortality, fire and insect disturbances, and management activities. Emissions of $CO_2$, $CH_4$, CO and $N_2O$ are estimated. Emissions of $NO_x$ are not estimated. CO emissions occur during biomass burning only; they are reported as $CO_2$ emissions in the CRF Biomass Burning tables. Carbon stock changes and emissions reported from forest soils are assumed to include both mineral and organic soils, as specific data on organic soils are not readily available.

### A5.5.2. Cropland

Estimates of cropland remaining cropland include soil and partial biomass estimates. Estimates for mineral soils capture the major land management changes (crop mixture, tillage practices, and summerfallow). Other practices, such as irrigation, manure application and fertilization, which are also known to have some positive impacts on soil organic carbon (SOC), are not represented. The current estimate in the land converted to cropland category includes $CO_2$ emissions from all pools and $N_2O$ emissions due to forest and grassland conversion to cropland. Non-$CO_2$ emissions ($CH_4$, CO, $N_2O$) from biomass burning during land conversion are also reported; $NO_x$ estimates have not been estimated. GHG emissions and removals from the conversion of wetlands and settlements to cropland have not been estimated.

### A5.5.3. Grassland

Emissions and removals from grassland remaining grassland are not estimated. In Canada's definitional framework of land use, land-use change and forestry (LULUCF) land categories (refer to Chapter 7), grasslands exclude improved pastures, which are captured under the Cropland category. The challenge resides in that there are no detailed and comprehensive activity data on change in management practices on unimproved pastures that would allow the implementation of the IPCC methodology. Moreover, there is no scientific evidence that these lands have been losing or gaining soil organic carbon as a result of human activity. Note also that, according to the land category definitions, the conversion of forest land to grassland cannot occur. Cropland conversion to grassland is not occurring. Emissions from the conversion of wetlands to grassland have not been estimated.

### A5.5.4. Wetlands

GHG emissions in land converted to flooded land, land converted to (managed) peatland, and (managed) wetlands remaining wetlands have been prepared but cannot be reported separately in the CRF tables. $CO_2$ estimates were developed in all categories; non-$CO_2$ ($CH_4$, CO, and $N_2O$) estimates associated with biomass burning are reported in forest land converted to flooded land. Emissions of $NO_x$ have not been estimated. Cropland and grassland converted to wetlands were not estimated; however, emissions from land converted to flooded land would include

those arising from the flooding of unmanaged wetlands and grassland (tundra), which are reported in the category "Other Land converted to Wetlands".

## A5.5.5.   Settlements

The current estimates in the land converted to settlements category include forest loss to settlements and the conversion of tundra to settlements in the Canadian north. Non-$CO_2$ emissions ($CH_4$, CO, and $N_2O$) are reported only when biomass burning has occurred in the course of conversion activities. Emissions of $NO_x$ have not been estimated. Emissions and removals from the conversion of cropland, agricultural grassland, wetlands, and other land to settlements have not been estimated. $CO_2$ estimates in settlements remaining settlements include only net carbon sequestration in the above-ground biomass of urban trees.

## A5.6.   Waste

This category is for the most part complete, with the exception of the following.

### A5.6.1.   Unmanaged Solid Waste Disposal

For the purpose of complying with the completeness principle, emissions from unmanaged landfills are given the "Not Estimated" notation. Current data on unmanaged landfills are neither readily available nor reliable, and in addition, the needed historical data are non-existent.

The majority of the larger landfills are managed engineered landfills. Typically, even small communities are served by a managed landfill, as provincial regulations require some form of management. It is assumed that the unmanaged landfills are shallow, i.e., aerobic biodegradation prevails, with relatively insignificant waste placement quantities. Thus, the emission contribution would be negligible in comparison with the managed landfills. The present estimation method results in a conservative estimate, as it is assumed that all wastes landfilled are placed in managed landfills.

The disposed waste quantities are obtained from Statistics Canada's Waste Management Industry Survey, a biennial publication (Statistics Canada 2000, 2003, 2004, 2007, 2008). Disposal facilities are surveyed directly and, for those small rural areas not covered by the survey, an estimate is derived from the product of the provincial per

capita disposal rate and the known population for those under-covered municipalities. Therefore, the present activity data are complete and the $CH_4$ emission estimates are conservative for the reasons provided above. However, a study is underway to attempt to isolate the waste quantities placed in unmanaged landfills. These estimates will be reported in the next NIR submission on condition that the accuracy of the present estimates can be improved upon, while still ensuring that correct allocation (managed versus unmanaged landfills—deep to shallow) is supportable and double counting can be avoided.

### A5.6.2.   Domestic and Commercial Wastewater

The notation for $N_2O$ emissions from the Wastewater subsector is NE ("Not Estimated"), to be consistent with the domestic and commercial wastewater without the human sewage–sludge subcategory. No methodology is provided for the estimation of $N_2O$ emissions from domestic and commercial wastewater without human sewage in the Revised 1996 IPCC Guidelines or the IPCC Good Practice Guidance documents. Recovery of $CH_4$ from these wastewater treatment operations has not been confirmed, but is not expected to occur. $CH_4$ emissions from the sludge subcategory are reported as NE, because the data required to evaluate the quantities captured from specific sites are not available at this time.

### A5.6.3.   Industrial Wastewater

The notation "Not Estimated" (NE) is used for $N_2O$ emissions from industrial wastewater, as this information is not readily available from facilities and no methodology to estimate these emissions is provided in the Revised 1996 IPCC Guidelines or the IPCC Good Practice Guidance. $CH_4$ emissions from this subsector were noted in previous submissions as NE, but now are given estimated emission values from a facility-level survey that was conducted in 2010. $CH_4$ emissions from industrial wastewater sludge are noted as not occurring. The majority of pulp and paper sludges are disposed of in landfills, and food processing sludges are either landfilled or land-applied to degrade aerobically. $N_2O$ emissions from industrial wastewater sludge treatment is noted as NE, since this information is not readily available from facilities and no methodology is provided in the Revised 1996 IPCC Guidelines or the IPCC Good Practice Guidance to estimate these emissions.

### A5.6.4.    Waste Incineration

$CH_4$ emissions from municipal solid waste (MSW) incineration are considered to be negligible and have not been estimated. Approximately less than 5% of all MSW is incinerated in Canada. Therefore, $CH_4$ emissions from this source are not expected to contribute significantly to the national inventory and are reported as "Not Estimated." A study is underway to assess $CH_4$ emissions from this source. This study will quantify the emissions or at least to confirm that the quantities are in the trace range for the next NIR submission.

A5

# Annex 6

# Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) procedures are an integral part of the inventory development and submission processes. These procedures ensure that Canada is able to meet the United Nations Framework Convention on Climate Change (UNFCCC) requirements of transparency, consistency, comparability, completeness and accuracy. The Government of Canada is committed to improving data and methods in collaboration with industry, provinces and territories, academia and the international community to ensure that a credible and defensible inventory is developed, and that Canada meets its international obligations.

## A6.1. Characteristics of the QA/QC Plan for the National Inventory

Canada has developed a quality assurance / quality control (QA/QC) plan that uses an integrated approach to managing the inventory quality and works towards achieving continuously improved emission and removal estimates. It is designed so that QA/QC procedures are implemented throughout the entire inventory development process, from initial data collection through development of emission and removal estimates to publication.

The plan, originally developed in 2006, incorporates a system of continuous improvement that includes, but is not limited to, procedures to capture lessons learned as part of the inventory cycle; the use of QA/QC and other tools as a means to identify and prioritize improvements; and processes to ensure that improvements identified are incorporated into the operating procedures.

The plan also includes a schedule for multi-year implementation such that, in every submission year, all key categories (and categories where a significant methodological change has occurred) will be subject to Tier 1 QC. Over a three-year cycle, all categories will undergo a Tier 1 QC. Some Tier 2 QC, QA and verification activities will be performed every year based on a multi-year schedule with the objective of providing more comprehensive quality assessments of the entire inventory over a seven-year timeframe. The implementation of the multi-year cycle has started and is expected to ramp up over the next few years. Until this final objective can be met, annual interim targets are set each year by a Prioritization and Planning Committee. In addition, the committee is responsible for approving the implementation of methodological changes, ensuring adequate resources, and applying due diligence and guidance for overall project management of the inventory.

Documentation of QA/QC procedures is at the core of the system. Standard checklists are used for the consistent, systematic documentation of all QA/QC activities in the annual inventory preparation and submission. QC checks are completed during each annual inventory preparation and archived along with other procedural and methodological documentation, by inventory category and by submission year. The plan requires the coordination of QA/QC activities, with outside agencies and organizations providing activity data and/or developing greenhouse gas (GHG) emission and removal estimates for Environment Canada.

## A6.2. Annual Inventory Development Process

The inventory development is built around a continuous process of methodological improvements, data collection, refinements and review. During the early portions of the project cycle (May to October), collection of the required data begins while the new inventory schedule is prepared. By the end of October, the methodologies are finalized and the data collection process is near completion.

Between November and January, estimates and the NIR text are prepared by sector experts. Emissions are calculated by inventory experts (dedicated to a specific sector) and QC checks are conducted and signed off by sectoral managers before the report and national totals are prepared. This process also involves key category assessment, recalculations, uncertainty analysis, QC and documentation preparation.

Over February and March, the compiled inventory is reviewed internally and select components are reviewed externally by experts, government agencies and provincial/territorial governments. Comments received are

documented and, where appropriate, incorporated into the final draft. Once the submission is approved by senior officials, the inventory is submitted to the UNFCCC by April 15. The inventory is then archived and the NIR is translated into French and published.

The inventory archives consist of both electronic and hard-copy archives. The hard-copy archives are in the form of a reference library that contains hard-copy references cited within the NIR. The reference library is populated on an annual basis with updated references from the most recent submission. The electronic archives consist of a shared networked drive with a standard folder system designed specifically to contain all relevant information required to rebuild the inventory, including information on QA/QC procedures and their results. The electronic archives are also updated on an annual basis and contain information and records from the most recent inventory.

The inventory cycle is completed by lesson-learned meetings held at the end of April each year. These meetings are held internally and with partners to review the procedures in order to continually improve the process.

## A6.3.    QC Procedures

QC is designed to provide routine technical checks to measure and control the quality of the inventory; to ensure data consistency, integrity, correctness and completeness; and to identify and address errors and omissions. Its scope covers a wide range of inventory processes, from data acquisition and handling and application of approved procedures and methods, to calculation of estimates and documentation.

### A6.3.1.    Tier 1 QC

A series of systematic Tier 1 QC checks are performed annually on at least the key categories and across sectors by staff in the inventory agency. Tier 1 QC follows the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), including (but not limited to)

- preventing easily avoidable data errors, e.g., during data flow, use of appropriate units and basic calculations;
- consistency checks among data used in multiple sectors;
- basic trend analysis and comparison with previous estimates;

- proper documentation of assumptions; expert credentials; and selection criteria for emission factors, parameters, methodologies; and
- completeness checks.

Checks on the documentation and archiving of all the information required to produce the national emission estimates are performed, focusing on the key categories. The QC checklists include a record of any corrective action taken and refer to supporting documentation. Minor updates to the QC checklist were made in 2010. Formal cross-cutting QC checks on final products are performed and documented prior to submission.

### A6.3.2.    Tier 2 QC

A Tier 2 quality control assessment is an opportunity to review and investigate improvements of a specific category or categories. There is a need for a comprehensive assessment to ensure that the category will remain current and relevant for a number of years beyond the year of analysis. The investigation is broad and uses a variety of approaches, including

- making assessments of applicability of methods, emission factors (EFs), activity data, uncertainty, etc;
- understanding the flow of information, secondary data and data inputs, and being able to trace inputs to their root sources;
- cleaning and updating documentation (not covered by Tier I checks); and
- laying the foundation for future activities, including making and prioritizing recommendations for improvement and making preparations for subsequent quality assurance.

Documentation of the Tier 2 QC checks may be done through a standard checklist or with an in-depth study to complete a comprehensive assessment.

## A6.4.    QA Procedures

QA generally consists of review activities by independent experts to ensure that the inventory represents the best possible estimates of emissions and removals and to support the effectiveness of the QC program. As with QC, QA is undertaken every year on components of the inventory. Pertinent sections of the draft inventory are reviewed by members of a formal provincial and territorial expert working group on emissions. Sections are also reviewed at the same time by experts and scientists in other government departments.

Selected underlying data and methods are independently assessed each year by various groups or individual experts in industry, academia and government. QA is undertaken for the assessment of the activity data, methodology and emission factor utilized for developing estimates, and is preferably done prior to making a decision on implementing a methodological change.

## A6.5. Verification

Verification is the use of third-party information to confirm the veracity of the inventory. For example, where appropriate facility-level GHG data exist from Canada's facility-level Greenhouse Gas Emissions Reporting Program, analysis is undertaken to perform bottom-up versus top-down comparisons.

## A6.6. Key QA/QC Achievements in the 2011 Inventory Submission

Ongoing measurement to improve quality and the implementation of the quality framework was a key focus for 2010.

QA/QC achievements for 2010 include

- conducting a lessons-learned review to identify potential improvements and risks for the inventory;
- making further improvements to the project timeline to advance the inventory schedule;
- continued regular coordination with Environment Canada, Statistics Canada and Natural Resources Canada to review timing, quality and technical issues related to the *Report on Energy Supply-Demand in Canada* (RESD) and the *Industrial Consumption of Energy* (ICE) data developed by Statistics Canada (i.e. energy data);
- review and implementation of 21 methodological changes;
- revised QC checklists for 2011 and a random audit of QC checklists used in the 2010 NIR;
- improved tracking of improvements, notably those recommended by an external review team; and
- initiating an overhaul to the quality manual. This is expected to be an ongoing activity extending beyond a single inventory year.

For the 2011 submission, Tier 1 QC procedures were implemented and the results documented by the experts who prepared these category estimates. Cross-cutting checks on the NIR and CRF were also performed prior to submission.

# Annex 7

# Uncertainty

## A7.1.    Introduction

In their respective National Inventory Reports, all Annex I parties shall report estimated uncertainties associated with both annual estimates of emissions, and with emission trends over time. According to the Intergovernmental Panel on Climate Change (IPCC), uncertainty estimates are an essential element of an inventory. They help to prioritize improvements of future inventories and to guide decisions on methodological choice (IPCC 2000). Canada performed a first uncertainty assessment of its 1990 estimates in 1994 (McCann 1994). In 2003–2004, Canada embarked on a comprehensive study to perform an Approach 2 (Monte Carlo) uncertainty assessment associated with the source categories included in the 2001 GHG inventory (the latest inventory estimates available at the time of the study); the results of this assessment were discussed in several subsequent submissions (Environment Canada 2009). Since 2004, many methodological changes, refinements and updates, including updates to uncertainty parameters themselves, have been made; uncertainty estimates have also been developed in the LULUCF Sector (see Chapter 7). The overall results of the previous assessment are not longer applicable to the inventory as a whole.

In this submission, Canada used the Approach 1 (error propagation) method for combining uncertainty estimates by completing Table 6.1 at the source category level—using methodology specified in Chapter 6 of the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). Uncertainty estimates about each source/sink category were either; retained from the previous studies; improved upon on the basis of these studies; or derived independently as in the Land Use, Land-Use Change and Forestry (LULUCF) Sector.

## A7.2.    Uncertainty Assessment on 2008 Greenhouse Gas Emissions and Removals

Table A7-1 presents the uncertainty assessment for Canadian GHG emissions. Separate analyses were conducted for the inventory as a whole with and without LULUCF. The calculation of uncertainties about trends was only performed without the LULUCF Sector. Given the high interannual variability in the LULUCF estimates, and the fact that it is primarily driven by natural factors (wildfires in the managed forests), it was decided that this sector should not be considered in the analysis of uncertainties about trends in anthropogenic GHG emissions and removals.

The uncertainty for the national inventory, not including the LULUCF Sector, is ±3.9%, consistent with the previously reported ranges of -3% to +6%. The Energy Sector had the lowest uncertainty, at ±2.4%, while the Agriculture Sector had the highest uncertainty, at 39%. The Industrial Processes Sector, the Solvent and Other Product Use Sector, and the Waste Sector had uncertainties of ±7.6, ±19.3 and ±34.4%, respectively.

The categories that made the largest contribution to uncertainty at the national level were Agriculture – indirect agricultural soils $N_2O$; Energy – fuel combustion – other transportation (off-road) $N_2O$; Agriculture – direct agricultural soils $N_2O$; Energy – fuel combustion – public electricity and heat combustion $CO_2$; and Waste – solid waste disposal on land $CH_4$.

The trend uncertainty, not including LULUCF, was found to be 0.71%. Therefore, the total increase in emissions since 1990 has a 95% chance of being in the range of 16.2–17.6%.

The uncertainty when the LULUCF emissions and removals are included in the national total was found to be 6.1% (see Table A7-2). The top five contributors influencing the national uncertainty when LULUCF is included are LULUCF – forest land $CO_2$; Agriculture – indirect agricultural soils $N_2O$; Energy – fuel combustion – other transportation (off-road) $N_2O$; Agriculture – direct agricultural soils $N_2O$; and Waste – solid waste disposal on land $CH_4$.

Although a full uncertainty assessment is presented, it should be noted that, in accordance with information provided in previous submissions, Canada intends to improve its uncertainty assessment, incrementally, over several years. In many instances the available information for the uncertainty assessment did not conform to the assumption of non-correlated, normally distributed parameters and therefore required simplification for the purposes of this analysis. For example, in some cases uncertainty values for the emission estimates—based on the previous uncertainty assessments performed using Monte Carlo technique—were adapted for use in the error propagation model. The full impact of these simplifications, i.e., whether leading to an underestimation or overestimation of uncertainty, was not evaluated as part of this submission. However, the assumptions are expected to be reviewed and/or updated in future submissions in conjunction with Canada's quality assurance / quality control (QA/QC) program. For further details on uncertainty related to specific sectors see the uncertainty sections throughout Chapters 3–8.

## A7.3.  Planned Improvements

Planned improvements for uncertainty include the development of a program to provide incremental improvements to Canada's uncertainty assessment on an annual basis. Some efforts at capacity building have been undertaken and applied in the short term. Canada will most likely build on previous methods and databases, including making use of the Monte Carlo simulation data and methods performed in 2003–2004 while ensuring that any new methodological changes and refinements consider the impact on uncertainty prior to implementation. In addition, many sectors have plans to improve the uncertainty estimates within their respective areas of expertise.

Canada notes that the expert reviews of previous submissions have identified several needs: performing uncertainty analyses on a regular basis; developing in-house capacity to perform uncertainty analyses and make full use of the results; and performing Tier 2 key category analysis. All these steps will help to further integrate QA/QC, key category analysis and uncertainty analysis in order to prioritize improvements. Canada's longer-term vision with respect to performing uncertainty assessments is consistent with these expert recommendations.

Table A7–1    Uncertainty Assessment Level and Trend without LULUCF

| IPCC Source Category | Gas | Base Year Emissions 1990 | 2009 Year Emissions | Activity Data Uncetainty | Emission Factor Uncertainty | Combined Uncertainty | Activity Data Uncertainty as % of 2009 TOTAL | Emission Factor Uncertainty as % of 2009 TOTAL | Combined Uncertainty as % of 2009 TOTAL | Type A Sensitivity | Type B Sensitivity | Uncertainty in Trend in National Emissions Introduced by Emission Factor Uncertainty | Uncertainty in Trend in National Emissions Introduced by Activity Data Uncertainty | Uncertainty Introduced into the Trend in Total National Emissions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | kt CO$_2$ eq | kt CO$_2$ eq | % | % | % | | | % | % | % | % | % | % |
| | TOTALS | 590 417 | 690 044 | 0.51 | 3.85 | 3.88 | | | | | | Assumption: Emission factors are fully correlated between years | Assumption: Activity data is fully correlated between years | 0.71 |
| 1.A.1.a | Fuel Combustion - Public Electricity and Heat Production | CO$_2$ | 91011 | 97181 | 0.5 | 7.9 | 7.9 | 0.08 | 1.11 | 1.11 | -0.0155 | 0.1646 | -0.1220 | -0.0084 | 0.1223 |
| 1.A.1.a | Fuel Combustion - Public Electricity and Heat Production | CH$_4$ | 37 | 103 | 0.8 | 31.4 | 31.4 | 0.00 | 0.00 | 0.00 | 0.0001 | 0.0002 | 0.0032 | 0.0001 | 0.0032 |
| 1.A.1.a | Fuel Combustion - Public Electricity and Heat Production | N$_2$O | 532 | 572 | 0.5 | 49.0 | 49.0 | 0.00 | 0.04 | 0.04 | -0.0001 | 0.0010 | -0.0042 | 0.0000 | 0.0042 |
| 1.A.1.b | Fuel Combustion - Petroleum Refining | CO$_2$ | 17657 | 19909 | 0.9 | 13.2 | 13.2 | 0.03 | 0.38 | 0.38 | -0.0012 | 0.0337 | -0.0162 | -0.0011 | 0.0163 |
| 1.A.1.b | Fuel Combustion - Petroleum Refining | CH$_4$ | 6 | 6 | 0.7 | 57.8 | 57.8 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1.A.1.b | Fuel Combustion - Petroleum Refining | N$_2$O | 38 | 24 | 0.7 | 53.4 | 53.4 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | -0.0018 | 0.0000 | 0.0018 |
| 1.A.1.c | Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries | CO$_2$ | 31912 | 41451 | 0.9 | 5.0 | 5.0 | 0.06 | 0.30 | 0.30 | 0.0070 | 0.0702 | 0.0349 | 0.0065 | 0.0355 |

**A7**

Table A7- 1:   Uncertainty Assessment Level and Trend without LULUCF   (cont'd)

| IPCC Source Category | | Gas | Base Year Emissions 1990 | 2009 Year Emissions | Activity Data Uncertainty | Emission Factor Uncertainty | Combined Uncertainty | Activity Data Uncertainty as % of 2009 TOTAL | Emission Factor Uncertainty as % of 2009 TOTAL | Combined Uncertainty as % of 2009 TOTAL | Type A Sensitivity | Type B Sensitivity | Uncertainty in Trend in National Emissions Introduced by Emission Factor Uncertainty | Uncertainty in Trend in National Emissions Introduced by Activity Data Uncertainty | Uncertainty Introduced into the Trend in Total National Emissions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | kt CO₂ eq | kt CO₂ eq | % | % | % | | | % | % | % | % | % | % |
| 1.A.1.c | Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries | CH₄ | 1583 | 1921 | 1.0 | 41.8 | 41.8 | 0.00 | 0.12 | 0.12 | 0.0001 | 0.0033 | 0.0050 | 0.0001 | 0.0050 |
| 1.A.1.c | Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries | N₂O | 250 | 290 | 0.9 | 84.9 | 84.9 | 0.00 | 0.04 | 0.04 | 0.0000 | 0.0005 | -0.0004 | 0.0000 | 0.0004 |
| 1.A.2 | Fuel Combustion - Manufacturing Industries and Construction | CO₂ | 63861 | 74094 | 2.0 | 4.1 | 4.5 | 0.21 | 0.44 | 0.49 | -0.0009 | 0.1255 | -0.0038 | -0.0018 | 0.0042 |
| 1.A.2 | Fuel Combustion - Manufacturing Industries and Construction | CH₄ | 52 | 63 | 4.2 | 13.9 | 15 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0001 | 0.0001 | 0.0000 | 0.0001 |
| 1.A.2 | Fuel Combustion - Manufacturing Industries and Construction | N₂O | 616 | 792 | 4.1 | 18.5 | 19 | 0.00 | 0.02 | 0.02 | 0.0001 | 0.0013 | 0.0022 | 0.0005 | 0.0023 |
| 1.A.3.a | Fuel Combustion - Civil Aviation | CO₂ | 7152 | 7081 | 0.0 | 0.6 | 0.6 | 0.00 | 0.01 | 0.01 | -0.0022 | 0.0120 | -0.0013 | 0.0000 | 0.0013 |
| 1.A.3.a | Fuel Combustion - Civil Aviation | CH₄ | 10 | 8 | 0.0 | 61.0 | 61.0 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | -0.0005 | 0.0000 | 0.0005 |
| 1.A.3.a | Fuel Combustion - Civil Aviation | N₂O | 70 | 66 | 0.0 | 545.0 | 545.0 | 0.00 | 0.05 | 0.05 | 0.0000 | 0.0001 | -0.0153 | 0.0000 | 0.0153 |
| 1.A.3.b | Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane) | CO₂ | 93216 | 127541 | 0.0 | 0.5 | 0.5 | 0.00 | 0.08 | 0.08 | 0.0314 | 0.2160 | 0.0142 | 0.0000 | 0.0142 |
| 1.A.3.b | Fuel Combustion - Road Transporta-tion (Gas, Diesel, Natural Gas, Propane) | CH₄ | 304 | 216 | 0.0 | 62.0 | 62.0 | 0.00 | 0.02 | 0.02 | -0.0002 | 0.0004 | -0.0146 | 0.0000 | 0.0146 |
| 1.A.3.b | Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane) | N₂O | 3195 | 3734 | 0.0 | 27.4 | 27.4 | 0.00 | 0.15 | 0.15 | 0.0000 | 0.0063 | 0.0000 | 0.0000 | 0.0000 |
| 1.A.3.c | Fuel Combustion - Railways | CO₂ | 6159 | 6114 | 0.0 | 1.7 | 1.7 | 0.00 | 0.02 | 0.02 | -0.0018 | 0.0104 | -0.0031 | 0.0000 | 0.0031 |
| 1.A.3.c | Fuel Combustion - Railways | CH₄ | 7 | 7 | 0.0 | 65.0 | 65.0 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0001 |
| 1.A.3.c | Fuel Combustion - Railways | N₂O | 790 | 785 | 0.0 | 280.0 | 280.0 | 0.00 | 0.32 | 0.32 | -0.0002 | 0.0013 | -0.0656 | 0.0000 | 0.0656 |
| 1.A.3.d | Fuel Combustion - Navigation | CO₂ | 4693 | 4774 | 0.0 | 3.0 | 3.0 | 0.00 | 0.02 | 0.02 | -0.0012 | 0.0081 | -0.0036 | 0.0000 | 0.0036 |
| 1.A.3.d | Fuel Combustion - Navigation | CH₄ | 7 | 7 | 0.0 | 140.5 | 140.5 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | -0.0002 | 0.0000 | 0.0002 |
| 1.A.3.d | Fuel Combustion - Navigation | N₂O | 339 | 283 | 0.0 | 282.0 | 282.0 | 0.00 | 0.12 | 0.12 | -0.0002 | 0.0005 | -0.0539 | 0.0000 | 0.0539 |
| 1.A.3.e | Fuel Combustion - Other Transportation (Off-Road) | CO₂ | 21464 | 30048 | 0.0 | 1.0 | 1.0 | 0.00 | 0.04 | 0.04 | 0.0084 | 0.0509 | 0.0082 | 0.0000 | 0.0082 |
| 1.A.3.e | Fuel Combustion - Other Transportation (Off-Road) | CH₄ | 204 | 216 | 0.0 | 116.6 | 116.6 | 0.00 | 0.04 | 0.04 | 0.0000 | 0.0004 | -0.0044 | 0.0000 | 0.0044 |
| 1.A.3.e | Fuel Combustion - Other Transportation (Off-Road) | N₂O | 1833 | 2965 | 0.0 | 272.4 | 272.4 | 0.00 | 1.17 | 1.17 | 0.0014 | 0.0050 | 0.3794 | 0.0000 | 0.3794 |
| 1.A.3.e | Fuel Combustion - Pipeline Transport | CO₂ | 6652 | 6136 | 1.0 | 3.0 | 3.1 | 0.01 | 0.03 | 0.03 | -0.0028 | 0.0104 | -0.0082 | -0.0027 | 0.0087 |
| 1.A.3.e | Fuel Combustion - Pipeline Transport | CH₄ | 141 | 130 | 1.0 | 40.0 | 40.0 | 0.00 | 0.01 | 0.01 | -0.0001 | 0.0002 | -0.0024 | -0.0001 | 0.0024 |
| 1.A.3.e | Fuel Combustion - Pipeline Transport | N₂O | 57 | 53 | 0.9 | 85.3 | 85.3 | 0.00 | 0.01 | 0.01 | 0.0000 | 0.0001 | -0.0019 | 0.0000 | 0.0019 |
| 1.A.4 | Fuel Combustion - Other Sectors | CO₂ | 68763 | 75730 | 1.1 | 1.6 | 2.0 | 0.12 | 0.18 | 0.22 | -0.0078 | 0.1283 | -0.0129 | -0.0086 | 0.0155 |
| 1.A.4 | Fuel Combustion - Other Sectors | CH₄ | 2117 | 2194 | 19.7 | 88.5 | 90.7 | 0.06 | 0.28 | 0.29 | -0.0005 | 0.0037 | -0.0421 | -0.0094 | 0.0432 |
| 1.A.4 | Fuel Combustion - Other Sectors | N₂O | 701 | 810 | 8.8 | 47.8 | 48.6 | 0.01 | 0.06 | 0.06 | 0.0000 | 0.0014 | -0.0008 | -0.0001 | 0.0008 |
| 1.B.1.a | Fugitive Sources - Coal Mining | CH₄ | 1914 | 709 | 0.0 | 57.5 | 57.5 | 0.00 | 0.06 | 0.06 | -0.0026 | 0.0012 | -0.1488 | 0.0000 | 0.1488 |
| 1.B.2. (a+b) | Fugitive Sources - Oil & Gas | CO₂ | 117 | 271 | 0.0 | 15.0 | 15.0 | 0.00 | 0.01 | 0.01 | 0.0002 | 0.0005 | 0.0034 | 0.0000 | 0.0034 |

Table A7- 1:   Uncertainty Assessment Level and Trend without LULUCF   (cont'd)

| | IPCC Source Category | Gas | Base Year Emissions 1990 | 2009 Year Emissions | Activity Data Uncetainty | Emission Factor Uncertainty | Combined Uncertainty | Activity Data Uncertainty as % of 2009 TOTAL | Emission Factor Uncertainty as % of 2009 TOTAL | Combined Uncertainty as % of 2009 TOTAL | Type A Sensitivity | Type B Sensitivity | Uncertainty in Trend in National Emissions Introduced by Emission Factor Uncertainty | Uncertainty in Trend in National Emissions Introduced by Activity Data Uncertainty | Uncertainty Introduced into the Trend in Total National Emissions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | kt CO$_2$ eq | kt CO$_2$ eq | % | % | % | | | % | % | % | % | % | % |
| 1.B.2. (a+b) | Fugitive Sources - Oil & Gas | CH$_4$ | 15456 | 24612 | 0.0 | 11.0 | 11.0 | 0.00 | 0.39 | 0.39 | 0.0111 | 0.0417 | 0.1220 | 0.0000 | 0.1220 |
| 1.B.2. (a+b) | Fugitive Sources - Oil & Gas | N$_2$O | 31 | 31 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 1.B.2.c | Fugitive Sources - Venting | CO$_2$ | 6992 | 10171 | 0.0 | 22.0 | 22.0 | 0.00 | 0.32 | 0.32 | 0.0034 | 0.0172 | 0.0745 | 0.0000 | 0.0745 |
| 1.B.2.c | Fugitive Sources - Flaring | CO$_2$ | 4352 | 6296 | 0.0 | 16.0 | 16.0 | 0.00 | 0.15 | 0.15 | 0.0020 | 0.0107 | 0.0328 | 0.0000 | 0.0328 |
| 1.B.2.c | Fugitive Sources - Venting & Flaring | CH$_4$ | 13219 | 18596 | 0.0 | 17.5 | 17.5 | 0.00 | 0.47 | 0.47 | 0.0053 | 0.0315 | 0.0933 | 0.0000 | 0.0933 |
| 1.B.2.c | Fugitive Sources - Venting & Flaring | N$_2$O | 0 | 13 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2.A.1 | Industrial Processes - Cement Production | CO$_2$ | 5436 | 5108 | 0.0 | 28.0 | 28.0 | 0.00 | 0.21 | 0.21 | -0.0021 | 0.0087 | -0.0590 | 0.0000 | 0.0590 |
| 2.A.2 | Industrial Processes - Lime Production | CO$_2$ | 1759 | 1214 | 0.0 | 8.0 | 8.0 | 0.00 | 0.01 | 0.01 | -0.0014 | 0.0021 | -0.0114 | 0.0000 | 0.0114 |
| 2.A.3 | Industrial Processes - Limestone and Dolomite Use | CO$_2$ | 734 | 281 | 0.0 | 19.3 | 19.3 | 0.00 | 0.01 | 0.01 | -0.0010 | 0.0005 | -0.0188 | 0.0000 | 0.0188 |
| 2.A.4 | Industrial Processes - Soda Ash Production and Use | CO$_2$ | 211 | 99 | 0.0 | 10.2 | 10.2 | 0.00 | 0.00 | 0.00 | -0.0002 | 0.0002 | -0.0025 | 0.0000 | 0.0025 |
| 2.A.7.2 | Industrial Processes - Magnesite Use | CO$_2$ | 147 | 69 | 0.0 | 8.1 | 8.1 | 0.00 | 0.00 | 0.00 | -0.0002 | 0.0001 | -0.0014 | 0.0000 | 0.0014 |
| 2.B.1 | Industrial Processes - Ammonia Production | CO$_2$ | 4994 | 6212 | 0.0 | 7.1 | 7.1 | 0.00 | 0.06 | 0.06 | 0.0006 | 0.0105 | 0.0045 | 0.0000 | 0.0045 |
| 2.B.2 | Industrial Processes - Nitric Acid Production | N$_2$O | 1012 | 1150 | 0.0 | 10.2 | 10.2 | 0.00 | 0.02 | 0.02 | -0.0001 | 0.0019 | -0.0006 | 0.0000 | 0.0006 |
| 2.B.3 | Industrial Processes - Adipic Acid Production | N$_2$O | 10718 | 662 | 0.0 | 10.8 | 10.8 | 0.00 | 0.01 | 0.01 | -0.0201 | 0.0011 | -0.2165 | 0.0000 | 0.2165 |
| | Industrial Processes - Petrochemical Production | CH$_4$ | 99 | 55 | 0.0 | 26.9 | 26.9 | 0.00 | 0.00 | 0.00 | -0.0001 | 0.0001 | -0.0028 | 0.0000 | 0.0028 |
| | Industrial Processes - Petrochemical Production | N$_2$O | 8 | 7 | 0.0 | 21.1 | 21.1 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0001 |
| 2.C.1 | Industrial Processes - Iron and Steel Production | CO$_2$ | 10193 | 7646 | 0.0 | 5.4 | 5.4 | 0.00 | 0.06 | 0.06 | -0.0072 | 0.0130 | -0.0387 | 0.0000 | 0.0387 |
| 2.C.3 | Industrial Processes - Aluminium Production | CO$_2$ | 2715 | 5026 | 0.0 | 7.1 | 7.1 | 0.00 | 0.05 | 0.05 | 0.0031 | 0.0085 | 0.0224 | 0.0000 | 0.0224 |
| 2.C.3 | Industrial Processes - Aluminium Production | PFCs | 6539 | 2163 | 0.0 | 9.1 | 9.1 | 0.00 | 0.03 | 0.03 | -0.0093 | 0.0037 | -0.0845 | 0.0000 | 0.0845 |
| 2.C.4.1 | Industrial Processes - Aluminium Production | SF$_6$ | 59 | 14 | 0.0 | 3.3 | 3.3 | 0.00 | 0.00 | 0.00 | -0.0001 | 0.0000 | -0.0003 | 0.0000 | 0.0003 |
| 2.C.4.2 | Industrial Processes - Magnesium Production | SF$_6$ | 3106 | 193 | 0.0 | 4.0 | 4.0 | 0.00 | 0.00 | 0.00 | -0.0058 | 0.0003 | -0.0232 | 0.0000 | 0.0232 |
| 2.C.5 | Industrial Processes - Magnesium Casting | SF$_6$ | 0 | 0 | 0.0 | 4.0 | 4.0 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2.E | Industrial Processes - Production of Halocarbons | HFCs | 767 | 0 | 0.0 | 35.7 | 35.7 | 0.00 | 0.00 | 0.00 | -0.0015 | 0.0000 | -0.0543 | 0.0000 | 0.0543 |
| 2.E | Industrial Processes - Production of Halocarbons | PFCs | 0 | 0 | 0.0 | 23.5 | 23.5 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2.E | Industrial Processes - Production of SF$_6$ | SF$_6$ | 0 | 0 | 0.0 | 32.0 | 32.0 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**A7**

Table A7- 1:   Uncertainty Assessment Level and Trend without LULUCF   (cont'd)

| IPCC Source Category | | Gas | Base Year Emissions 1990 | 2009 Year Emissions | Activity Data Uncertainty | Emission Factor Uncertainty | Combined Uncertainty | Activity Data Uncertainty as % of 2009 TOTAL | Emission Factor Uncertainty as % of 2009 TOTAL | Combined Uncertainty as % of 2009 TOTAL | Type A Sensitivity | Type B Sensitivity | Uncertainty in Trend in National Emissions Introduced by Emission Factor Uncertainty | Uncertainty in Trend in National Emissions Introduced by Activity Data Uncertainty | Uncertainty Introduced into the Trend in Total National Emissions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | kt CO$_2$ eq | kt CO$_2$ eq | % | % | % | | | % | % | % | % | % | % |
| 2.F | Industrial Processes - Consumption of Halocarbons | HFCs | 0 | 6786 | 0.0 | 35.7 | 35.7 | 0.00 | 0.35 | 0.35 | 0.0115 | 0.0115 | 0.4108 | 0.0000 | 0.4108 |
| 2.F | Industrial Processes - Consumption of Halocarbons | PFCs | 0 | 9 | 0.0 | 23.5 | 23.5 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | 0.0003 | 0.0000 | 0.0003 |
| 2.F.7 | Industrial Processes - Consumption of SF$_6$ for Semi-Conductor | SF$_6$ | 207 | 180 | 0.0 | 32.0 | 32.0 | 0.00 | 0.01 | 0.01 | -0.0001 | 0.0003 | -0.0034 | 0.0000 | 0.0034 |
| 2.F.8 | Industrial Processes - Consumption of SF$_6$ for Electrical Equipment | SF$_6$ | 15 | 5 | 0.0 | 45.3 | 45.3 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | -0.0010 | 0.0000 | 0.0010 |
| 2.G | Industrial Processes - Other (Undifferentiated Processes) | CO$_2$ | 8030 | 9435 | 0.0 | 20.9 | 20.9 | 0.00 | 0.29 | 0.29 | 0.0001 | 0.0160 | 0.0018 | 0.0000 | 0.0018 |
| 3.D | Solvent and Other Product Use | N$_2$O | 179 | 260 | 0.0 | 19.3 | 19.3 | 0.00 | 0.01 | 0.01 | 0.0001 | 0.0004 | 0.0017 | 0.0000 | 0.0017 |
| 4.A | Agriculture - Enteric Fermentation | CH$_4$ | 16294 | 19325 | 5 | 19 | 20 | 0.13 | 0.53 | 0.55 | 0.0005 | 0.0327 | 0.0091 | 0.0032 | 0.0096 |
| 4.A | Agriculture - Manure Management | CH$_4$ | 2546 | 2682 | 3 | 26 | 26 | 0.01 | 0.10 | 0.10 | -0.0005 | 0.0045 | -0.0130 | -0.0021 | 0.0131 |
| 4.A | Agriculture - Manure Management | N$_2$O | 3121 | 3878 | 24 | 96 | 99 | 0.14 | 0.54 | 0.56 | 0.0004 | 0.0066 | 0.0375 | 0.0133 | 0.0398 |
| 4.D.1 | Agriculture - Direct Agricultural Soils | N$_2$O | 15964 | 19030 | 11 | 35 | 36 | 0.30 | 0.96 | 1.00 | 0.0006 | 0.0322 | 0.0219 | 0.0097 | 0.0239 |
| 4.D.3 | Agriculture - Indirect Agricultural Soils | N$_2$O | 8736 | 10898 | 16 | 180 | 180 | 0.26 | 2.84 | 2.85 | 0.0012 | 0.0185 | 0.2093 | 0.0269 | 0.2110 |
| 4.F | Field Burning of Agricultural Residues | CH$_4$ | 148 | 33 | 50 | 40 | 64 | 0.00 | 0.00 | 0.00 | -0.0002 | 0.0001 | -0.0096 | -0.0169 | 0.0194 |
| 4.F | Field Burning of Agricultural Residues | N$_2$O | 57 | 12 | 50 | 50 | 71 | 0.00 | 0.00 | 0.00 | -0.0001 | 0.0000 | -0.0046 | -0.0065 | 0.0079 |
| 6.A | Waste - Solid Waste Disposal on Land | CH$_4$ | 17925 | 20345 | 0.0 | 36.5 | 36.5 | 0.00 | 1.08 | 1.08 | -0.0010 | 0.0345 | -0.0374 | 0.0000 | 0.0374 |
| 6.B | Waste - Wastewater Handling | CH$_4$ | 269 | 338 | 0.0 | 42.5 | 42.5 | 0.00 | 0.02 | 0.02 | 0.0000 | 0.0006 | 0.0017 | 0.0000 | 0.0017 |
| 6.B | Waste - Wastewater Handling | N$_2$O | 514 | 670 | 0.0 | 62.5 | 62.5 | 0.00 | 0.06 | 0.06 | 0.0001 | 0.0011 | 0.0073 | 0.0000 | 0.0073 |
| 6.C | Waste - Waste Incineration | CO$_2$ | 267 | 200 | 0.0 | 34.5 | 34.5 | 0.00 | 0.01 | 0.01 | -0.0002 | 0.0003 | -0.0066 | 0.0000 | 0.0066 |
| 6.C | Waste - Waste Incineration | CH$_4$ | 9 | 2 | 0.0 | 60.0 | 60.0 | 0.00 | 0.00 | 0.00 | 0.0000 | 0.0000 | -0.0009 | 0.0000 | 0.0009 |
| 6.C | Waste - Waste Incineration | N$_2$O | 124 | 55 | 0.0 | 85.0 | 85.0 | 0.00 | 0.01 | 0.01 | -0.0002 | 0.0001 | -0.0130 | 0.0000 | 0.0130 |

Table A7–2   Uncertainty Assessment with LULUCF

| | IPCC Source Category | Gas | 2009 Year Emissions | Combined Uncertainty |
|---|---|---|---|---|
| | | | kt CO$_2$ eq | % |
| | TOTALS | | 677 944 | 6.1 |
| 1.A.1.a | Fuel Combustion - Public Electricity and Heat Production | CO$_2$ | 97181 | 7.9 |
| 1.A.1.a | Fuel Combustion - Public Electricity and Heat Production | CH$_4$ | 103 | 31.4 |
| 1.A.1.a | Fuel Combustion - Public Electricity and Heat Production | N$_2$O | 572 | 49.0 |
| 1.A.1.b | Fuel Combustion - Petroleum Refining | CO$_2$ | 19909 | 13.2 |
| 1.A.1.b | Fuel Combustion - Petroleum Refining | CH$_4$ | 6 | 57.8 |
| 1.A.1.b | Fuel Combustion - Petroleum Refining | N$_2$O | 24 | 53.4 |
| 1.A.1.c | Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries | CO$_2$ | 41451 | 5.0 |
| 1.A.1.c | Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries | CH$_4$ | 1921 | 41.8 |
| 1.A.1.c | Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries | N$_2$O | 290 | 84.9 |
| 1.A.2 | Fuel Combustion - Manufacturing Industries and Construction | CO$_2$ | 74094 | 0.0 |
| 1.A.2 | Fuel Combustion - Manufacturing Industries and Construction | CH$_4$ | 63 | 14.0 |
| 1.A.2 | Fuel Combustion - Manufacturing Industries and Construction | N$_2$O | 792 | 18.5 |
| 1.A.3.a | Fuel Combustion - Civil Aviation | CO$_2$ | 7081 | 0.6 |
| 1.A.3.a | Fuel Combustion - Civil Aviation | CH$_4$ | 8 | 61.0 |
| 1.A.3.a | Fuel Combustion - Civil Aviation | N$_2$O | 66 | 545.0 |
| 1.A.3.b | Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane) | CO$_2$ | 127541 | 0.5 |
| 1.A.3.b | Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane) | CH$_4$ | 216 | 62.0 |
| 1.A.3.b | Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane) | N$_2$O | 3734 | 27.4 |
| 1.A.3.c | Fuel Combustion - Railways | CO$_2$ | 6114 | 1.7 |
| 1.A.3.c | Fuel Combustion - Railways | CH$_4$ | 7 | 65.0 |
| 1.A.3.c | Fuel Combustion - Railways | N$_2$O | 785 | 280.0 |
| 1.A.3.d | Fuel Combustion - Navigation | CO$_2$ | 4774 | 3.0 |
| 1.A.3.d | Fuel Combustion - Navigation | CH$_4$ | 7 | 140.5 |
| 1.A.3.d | Fuel Combustion - Navigation | N$_2$O | 283 | 282.0 |
| 1.A.3.e | Fuel Combustion - Other Transportation (Off-Road) | CO$_2$ | 30048 | 1.0 |
| 1.A.3.e | Fuel Combustion - Other Transportation (Off-Road) | CH$_4$ | 216 | 116.6 |
| 1.A.3.e | Fuel Combustion - Other Transportation (Off-Road) | N$_2$O | 2965 | 272.4 |
| 1.A.3.e | Fuel Combustion - Pipeline Transport | CO$_2$ | 6136 | 3.1 |
| 1.A.3.e | Fuel Combustion - Pipeline Transport | CH$_4$ | 130 | 40.0 |
| 1.A.3.e | Fuel Combustion - Pipeline Transport | N$_2$O | 53 | 85.3 |
| 1.A.4 | Fuel Combustion - Other Sectors | CO$_2$ | 75730 | 2.0 |
| 1.A.4 | Fuel Combustion - Other Sectors | CH$_4$ | 2194 | 90.7 |
| 1.A.4 | Fuel Combustion - Other Sectors | N$_2$O | 810 | 48.6 |
| 1.B.1.a | Fugitive Sources - Coal Mining | CH$_4$ | 709 | 57.5 |
| 1.B.2.(a+b) | Fugitive Sources - Oil & Gas | CO$_2$ | 271 | 15.0 |
| 1.B.2.(a+b) | Fugitive Sources - Oil & Gas | CH$_4$ | 24612 | 11.0 |
| 1.B.2.(a+b) | Fugitive Sources - Oil & Gas | N$_2$O | 31 | 0.0 |
| 1.B.2.c | Fugitive Sources - Venting | CO$_2$ | 10171 | 22.0 |
| 1.B.2.c | Fugitive Sources - Flaring | CO$_2$ | 6296 | 16.0 |
| 1.B.2.c | Fugitive Sources - Venting & Flaring | CH$_4$ | 18596 | 17.5 |
| 1.B.2.c | Fugitive Sources - Venting & Flaring | N$_2$O | 13 | 0.0 |
| 2.A.1 | Industrial Processes - Cement Production | CO$_2$ | 5108 | 28.0 |
| 2.A.2 | Industrial Processes - Lime Production | CO$_2$ | 1214 | 8.0 |
| 2.A.3 | Industrial Processes - Limestone and Dolomite Use | CO$_2$ | 281 | 19.3 |
| 2.A.4 | Industrial Processes - Soda Ash Production and Use | CO$_2$ | 99 | 10.2 |
| 2.A.7.2 | Industrial Processes - Magnesite Use | CO$_2$ | 69 | 8.1 |
| 2.B.1 | Industrial Processes - Ammonia Production | CO$_2$ | 6212 | 7.1 |
| 2.B.2 | Industrial Processes - Nitric Acid Production | N$_2$O | 1150 | 10.2 |
| 2.B.3 | Industrial Processes - Adipic Acid Production | N$_2$O | 662 | 10.8 |
| | Industrial Processes - Petrochemical Production | CH$_4$ | 55 | 26.9 |
| | Industrial Processes - Petrochemical Production | N$_2$O | 7 | 21.1 |
| 2.C.1 | Industrial Processes - Iron and Steel Production | CO$_2$ | 7646 | 5.4 |
| 2.C.3 | Industrial Processes - Aluminium Production | CO$_2$ | 5026 | 7.1 |
| 2.C.3 | Industrial Processes - Aluminium Production | PFCs | 2163 | 9.1 |
| 2.C.4.1 | Industrial Processes - Aluminium Production | SF$_6$ | 14 | 3.3 |
| 2.C.4.2 | Industrial Processes - Magnesium Production | SF$_6$ | 193 | 4.0 |
| 2.C.5 | Industrial Processes - Magnesium Casting | SF$_6$ | 0 | 4.0 |
| 2.E | Industrial Processes - Production of Halocarbons | HFCs | 0 | 35.7 |
| 2.E | Industrial Processes - Production of Halocarbons | PFCs | 0 | 23.5 |
| 2.E | Industrial Processes - Production of SF$_6$ | SF$_6$ | 0 | 32.0 |
| 2.F | Industrial Processes - Consumption of Halocarbons | HFCs | 6786 | 35.7 |
| 2.F | Industrial Processes - Consumption of Halocarbons | PFCs | 9 | 23.5 |
| 2.F.7 | Industrial Processes - Consumption of SF$_6$ for Semi-Conductor | SF$_6$ | 180 | 32.0 |
| 2.F.8 | Industrial Processes - Consumption of SF$_6$ for Electrical Equipment | SF$_6$ | 5 | 45.3 |
| 2.G | Industrial Processes - Other (Undifferentiated Processes) | CO$_2$ | 9435 | 20.9 |
| 3.D | Solvent and Other Product Use | N$_2$O | 260 | 19.3 |
| 4.A | Agriculture - Enteric Fermentation | CH$_4$ | 19325 | 20 |
| 4.A | Agriculture - Manure Management | CH$_4$ | 2682 | 26 |
| 4.A | Agriculture - Manure Management | N$_2$O | 3878 | 99 |
| 4.D.1 | Agriculture - Direct Agricultural Soils | N$_2$O | 19030 | 36 |
| 4.D.3 | Agriculture - Indirect Agricultural Soils | N$_2$O | 10898 | 180 |

**A7**

Table A7- 2:   Uncertainty Assessment with LULUCF  (cont'd)

| IPCC Source Category | | Gas | 2009 Year Emissions | Combined Uncertainty |
|---|---|---|---|---|
| | | | kt $CO_2$ eq | % |
| 4.F | Field Burning of Agricultural Residues | $CH_4$ | 33 | 64 |
| 4.F | Field Burning of Agricultural Residues | $N_2O$ | 12 | 71 |
| 5.A | Forest Land $CO_2$ | $CO_2$ | -25585 | 124.7 |
| 5.A | Forest Land $CH_4$ | $CH_4$ | 5580 | 35.6 |
| 5.A | Forest Land $N_2O$ | $N_2O$ | 3462 | 35.6 |
| 5.B | Cropland $CO_2$ | $CO_2$ | -12406 | 18.6 |
| 5.D | Wetlands $CO_2$ | $CO_2$ | 2048 | 0.0 |
| 5.E | Settlements $CO_2$ | $CO_2$ | -12 | 0.0 |
| | Conversion of Forest Land $CO_2$ | $CO_2$ | 14446 | 11.7 |
| | Conversion of Forest Land  $CH_4$ | $CH_4$ | 226 | 28.0 |
| | Conversion of Forest Land  $N_2O$ | $N_2O$ | 140 | 27.8 |
| 6.A | Waste - Solid Waste Disposal on Land | $CH_4$ | 20345 | 36.5 |
| 6.B | Waste - Wastewater Handling | $CH_4$ | 338 | 42.5 |
| 6.B | Waste - Wastewater Handling | $N_2O$ | 670 | 62.5 |
| 6.C | Waste - Waste Incineration | $CO_2$ | 200 | 34.5 |
| 6.C | Waste - Waste Incineration | $CH_4$ | 2 | 60.0 |
| 6.C | Waste - Waste Incineration | $N_2O$ | 55 | 85.0 |

# Annex 8

# Emission Factors

This annex summarizes the development and selection of emission factors for use in estimating greenhouse gas emissions. Additional details on sector-specific methodologies for the use of these factors are presented in Annex 2 and Annex 3.

## A8.1.    Fuel Combustion

### A8.1.1.    Natural Gas and Natural Gas Liquids

#### A8.1.1.1.    $CO_2$

$CO_2$ emission factors for fossil fuel combustion are dependent primarily on fuel properties such as carbon content, density and heating value and, to a lesser extent, on the combustion technology.

For natural gas, there are two major qualities of fuel combusted in Canada: marketable fuel (processed for commercial sale) and non-marketable fuel (unprocessed for internal use). As of 2007, there are nine regions in Canada that produce natural gas for commercial sale and/or for internal consumption, resulting in regional variations of marketable and non-marketable natural gas. Provincial and territorial emission factors (Table A8–1) have been developed based on data from chemical analysis of representative natural gas samples (McCann 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC/OECD/IEA 1997). Non-marketable natural gas emission factors are higher than those of marketable fuels as a result of its raw nature, which may include ethane, propane and butane in addition to methane in the fuel mix.

$CO_2$ emission factors (Table A8–3) for natural gas liquids (NGL) such as ethane, propane and butane were developed based on chemical analysis data for marketable fuels (McCann 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC/OECD/IEA 1997). These emission factors are

lower than those developed on the assumption of pure fuels (Jaques 1992) owing to the presence of impurities in the fuels.

#### A8.1.1.2.    $CH_4$

Emissions of $CH_4$ from fuel combustion are technology-dependent. Sectoral emission factors (Table A8–2 and Table A8–3) have been developed based on technologies typically used in Canada. The factors were developed based on a broad review of emission factors for combustion technologies (SGA Energy 2000). The emission factor for producer consumption of natural gas was developed based on a technology split for the upstream oil and gas industry (CAPP 1999) and technology-specific emission factors from the U.S. EPA report AP 42 (EPA 1996a).

#### A8.1.1.3.    $N_2O$

Emissions of $N_2O$ from fuel combustion are technology-dependent. Emission factors (Table A8–2 and Table A8–3) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

Table A8–1    $CO_2$ Emission Factors for Natural Gas

| Province | Emission Factor[3] (g/m³) | |
| --- | --- | --- |
| | Marketable[1] | Non-marketable[2] |
| Newfoundland and Labrador | 1 891 | 2 482 |
| Nova Scotia | 1 891 | 2 482 |
| New Brunswick | 1 891 | NO |
| Quebec | 1 878 | NO |
| Ontario | 1 879 | NO |
| Manitoba | 1 877 | NO |
| Saskatchewan | 1 820 | 2 429 |
| Alberta | 1 918 | 2 380 |
| British Columbia | 1 916 | 2 151 |
| Yukon | NO | 2 389 |
| Northwest Territories | 2 454 | 2 454 |

Notes:

NO = Not occurring

1.    The term "marketable" applies to fuel consumed by the Electric Utilities, Manufacturing Industries, Residential/Commercial and Transport subsectors.

2.    The term "non-marketable" applies to raw gas consumption, mainly by natural gas producers.

3.    Adapted from McCann (2000)

Table A8–2    $CH_4$ and $N_2O$ Emission Factors for Natural Gas

| Source | Emission Factor (g/m³) | |
|---|---|---|
| | $CH_4$ | $N_2O$ |
| Electric Utilities | 0.49 | 0.049 |
| Industrial | 0.037 | 0.033 |
| Producer Consumption (Non-marketable) | 6.5 [1, 2] | 0.06 |
| Pipelines | 1.9 | 0.05 |
| Cement | 0.037 | 0.034 |
| Manufacturing Industries | 0.037 | 0.033 |
| Residential, Construction, Commercial/Institutional, Agriculture | 0.037 | 0.035 |

Notes:

1. EPA (1996)

2. CAPP (1999)

Table A8–3    Emission Factors for Natural Gas Liquids

| Source | Emission Factor (g/L) | | |
|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ |
| Propane | | | |
| Residential | 1 510[1] | 0.027[2] | 0.108[2] |
| All Other Uses | 1 510[1] | 0.024 [2] | 0.108[2] |
| Ethane | 976[1] | N/A | N/A |
| Butane | 1 730[1] | 0.024 [2] | 0.108 [2] |

Notes:

1. Adapted from McCann (2000)

2. SGA Energy (2000)

N/A = Not available

## A8.1.2.    Refined Petroleum Products

### A8.1.2.1.    $CO_2$

$CO_2$ emission factors for fossil fuel combustion are dependent primarily on fuel properties and, to a lesser extent, on the combustion technology.

Emission factors have been developed for each major class of refined petroleum products (RPP) based on their heating value, carbon content and destiny (McCann 2000) with an assumed fuel combustion efficiency of 99% (IPCC/OECD/IEA 1997), to ensure consistency with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*.

The composition of petroleum coke is process-specific. Factors have been developed for both refinery (catalytic cracker) derived cokes and coke used in upgrading facilities. These factors (Table A8–5) have been developed based on data provided by industry to the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC) in their *Review of Energy Consumption* reports on the refining and upgrading industry (CIEEDAC 2003, 2010). The bulk of the coke consumed by refineries is catalytic cracker-derived, and the emission factor is an average of petroleum coke and catalytic cracker coke emission factors. Factors were provided by industry on a mass basis and were converted to a volumetric basis for comparability with the national energy data using the density of coke provided by Statistics Canada.

Factors for still gas (Table A8–5) from refining operations and upgrading facilities were also developed based on data provided by industry and reported by CIEEDAC (CIEEDAC 2003, 2010).

### A8.1.2.2.    $CH_4$

Emissions of $CH_4$ from fuel combustion are technology-dependent. Emission factors have been developed (Table A8–4) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

The emission factor for petroleum coke was assumed to be the same for both catalytic cracker-derived cokes and coke used in upgrading facilities. An emission factor for still gas is not available, according to the 2000 SGA Energy study.

### A8.1.2.3.    $N_2O$

Emissions of $N_2O$ from fuel combustion are technology-dependent. Emission factors for RPPs, with the exception of petroleum coke, have been developed (Table A8–4) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000). Emission factors for petroleum coke (Table A8–6) were based on 2006 IPCC default emission factors and were calculated on an annual basis using energy conversion factors provided by Statistics Canada (2008).

Table A8–4    Emission Factors for Refined Petroleum Products

| Source | Emission Factor (g/L) | | |
|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ |
| **Light Fuel Oil** | | | |
| Electric Utilities | 2 725 [1] | 0.18 [2] | 0.031 [2] |
| Industrial | 2 725 [1] | 0.006 [2] | 0.031 [2] |
| Producer Consumption | 2 643 [1] | 0.006 [2] | 0.031 [2] |
| Residential | 2 725 [1] | 0.026 [2] | 0.006 [2] |
| Forestry, Construction, Public Administration and Commercial/Institutional | 2 725 [1] | 0.026 [2] | 0.031 [2] |
| **Heavy Fuel Oil** | | | |
| Electric Utilities | 3 124 [1] | 0.034 [2] | 0.064 [2] |
| Industrial | 3 124 [1] | 0.12 [2] | 0.064 [2] |
| Producer Consumption | 3 158 [1] | 0.12 [2] | 0.064 [2] |
| Residential, Forestry, Construction, Public Administration and Commercial/Institutional | 3 124 [1] | 0.057 [2] | 0.064 [2] |
| **Kerosene** | | | |
| Electric Utilities | 2 534 [1,3] | 0.006 [2] | 0.031 [2] |
| Industrial | 2 534 [1,3] | 0.006 [2] | 0.031 [2] |
| Producer Consumption | 2 534 [1,3] | 0.006 [2] | 0.031 [2] |
| Residential | 2 534 [1,3] | 0.026 [2] | 0.006 [2] |
| Forestry, Construction, Public Administration and Commercial/Institutional | 2 534 [1,3] | 0.026 [2] | 0.031 [2] |
| **Diesel** | 2 663 [1] | 0.133 [2] | 0.4 [2] |
| **Petroleum Coke** | (see Table-A8-5) | 0.12 [2] | (see Table A8–5) |
| **Still Gas** | (see Table-A8-5) | N/A | 0.00002[2] |

Notes:
1. Adapted from McCann (2000)
2. SGA Energy (2000)
3. Assumed McCann (2000) aviation turbo fuel emission factor
N/A = Not available

Table A8–5    $CO_2$ Emission Factors for Petroleum Coke and Still Gas

| | Emission Factor | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001-2009 |
| **Petroleum Coke** | g/L | | | | | | | | | | | |
| Upgrading Facilities[1] | 3 556 | 3 556 | 3 556 | 3 556 | 3 554 | 3 551 | 3 585 | 3 538 | 3 528 | 3 507 | 3 481 | 3 494 |
| **Still Gas** | g/m³ | | | | | | | | | | | |
| Upgrading Facilities[1] | 2 310 | 2 310 | 2 310 | 2 310 | 2 280 | 2 090 | 2 210 | 2 320 | 2 300 | 2 110 | 2 120 | 2 140 |
| | 1990-1993 | 1997 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| **Petroleum Coke** | g/L | | | | | | | | | | | |
| Refineries & Others[2] | 3 766 | 3 756 | 3 711 | 3 763 | 3 812 | 3 834 | 3 806 | 3 814 | 3 817 | 3 820 | 3 817 | 3 816 |
| **Still Gas** | g/m³ | | | | | | | | | | | |
| Refineries & Others[2] | 1 678 | 1 779 | 1 683 | 1 652 | 1 667 | 1 700 | 1 707 | 1 719 | 1 753 | 1 760 | 1 705 | 1 723 |

Notes:
1. CIEEDAC (2003)
2. CIEEDAC (2010)

Table A8–6    N$_2$O Emission Factors for Petroleum Coke

| | Emission Factor | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001-2009 |
| **Petroleum Coke** | g/m³ | | | | | | | | | | | |
| Upgrading Facilities[1] | 20.1 | 20.3 | 20.6 | 20.8 | 21.1 | 20.8 | 20.8 | 21.1 | 21.7 | 21.8 | 22.3 | 22.2 |
| Refineries & Others[2] | 18.5 | 18.7 | 19.0 | 19.2 | 19.4 | 19.2 | 19.2 | 19.4 | 19.5 | 19.6 | 20.0 | 19.9 |

Notes:
1. IPCC (2006)
2. Energy content from Statistics Canada Cat. No. 57-003 (2008)

Table A8–7    CO$_2$ Emission Factors for Coal

| Province | Coal Type | Source | Emission Factor (kg CO$_2$/tonne)[1,2,3] | | | |
|---|---|---|---|---|---|---|
| | | | Average | Low | High | Moisture (wt %) |
| P.E.I., Quebec | Canadian Bituminous (Eastern) | Assume Nova Scotia | 2 320 | 2 100 | 2 590 | 3.2 |
| Nova Scotia | Canadian Bituminous (Eastern) | Nova Scotia | 2 320 | 2 100 | 2 590 | 3.2 |
| New Brunswick | Canadian Bituminous (Eastern) | New Brunswick | 2 310 | 2 180 | 2 400 | 3.2 |
| Atlantic[4] | Foreign Bituminous | Non-U.S. | 2 540 | 2 480 | 2 600 | 8.3 |
| Ontario | Canadian Bituminous (Western) | Assume Alberta | 2 190 | 2 060 | 2 390 | 7.6 |
| Ontario, Quebec | Foreign Bituminous | U.S. (Pennsylvania)[5] | 2 430 | N/A | N/A | N/A |
| Ontario, Manitoba | Foreign Sub-bituminous | U.S. (Wyoming)[5] | 1 820 | N/A | N/A | N/A |
| Saskatchewan | Lignite | Saskatchewan | 1 390 | 1 330 | 1 440 | 36 |
| Alberta, Saskatchewan, B.C. | Canadian Sub-bituminous (Western) | Alberta | 1 720 | 1 610 | 1 890 | 19 |
| Alberta, Saskatchewan, B.C. | Canadian Bituminous (Western) | Alberta | 2 190 | 2 060 | 2 390 | 7.6 |
| All Provinces & Territories | Anthracite | -- | 2 390 | N/A | N/A | N/A |

Notes:
1. Factors presented on a "wet basis." Moisture content shown is that for the "average" emission factor.
2. Radovan R, Sanei H. 2010. Statistical Analysis of Coal Carbon Content in Canada. Unpublished report. Ottawa (ON): Environment Canada, Greenhouse Gas Division.
3. High and low values represent the upper and lower bounds of the inter-quartile range, which were determined through statistical analysis of Canadian coal data.
4. Atlantic refers to the Maritime provinces and Newfoundland & Labrador.
5. U.S. factors adapted from Annex 2 of the U.S. EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008 (April 2010), converted to 99% oxidation.
 N/A = not available

## A8.1.3.    Coal and Coal Products

### A8.1.3.1.    CO$_2$

CO$_2$ emission factors for coal combustion are dependent primarily on the properties of the fuel and, to a lesser extent, on the combustion technology. Coal emission factors (Table A8–7) have been developed for each province based on the rank of the coal and the region of supply. Emission factors have been developed based on data from chemical analysis of coal samples for electric utilities, which account for the vast majority of coal consumption, and a fuel combustion efficiency of 99.0% (Jaques 1992). The factors were completely revised and updated for the current submission through a multi-year project carried out in collaboration between Environment Canada and the Geological Survey of Canada.

Factors presented in Table A8–7 were developed based on the statistical analysis of over 3000 analytical samples for a variety of coal types and producing/consuming regions. The analysis and uncertainty calculations were conducted using the @Risk software package. The coal emission factors are presented as a range, based on the uncertainty, because the supply and quality of coal can vary over time. The average coal carbon and moisture content for each coal type was used to develop CO$_2$ emission factors. Lower and upper ranges are provided based on the inter-quartile range of the modelled statistical distributions. Factors for coal imported from the United States are from Annex 2 of

the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008 (US EPA 2010).

Coke and coke oven gas emission factors are presented in Table A8–8. The coke emission factor was developed based on industry data (Jaques 1992). It is representative of coke use in the cement, non-ferrous metal and other manufacturing industries. The coke oven gas emission-factor value is from the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) and is primarily representative of use in the iron and steel industry.

### A8.1.3.2.    $CH_4$

Emissions of $CH_4$ from fuel combustion are technology-dependent. Emission factors for sectors (Table A8–9) have been developed based on technologies typically used in

Table A8–8    $CO_2$ Emission Factors for Coal Products[1]

| Coal Product - Fuel Type | Emission Factor |
|---|---|
| Coke Oven Gas[1] | 878.9 g/m³ |
| Coke[2] | 2 480 g/kg |

Notes:

1. Revised IPCC 1996 Guidelines
2. Adapted from Jaques (1992)

Table A8–9    $CH_4$ and $N_2O$ Emission Factors for Coals [1]

| Source | Emission Factor | |
|---|---|---|
| | $CH_4$ | $N_2O$ |
| | g/kg | g/kg |
| **Coal** | | |
| Electric Utilities | 0.022 | 0.032 |
| Industry and Heat & Steam Plants | 0.03 | 0.02 |
| Residential, Public Administration | 4 | 0.02 |
| **Coke** | 0.03 | 0.02 |
| **Coke Oven Gas (g/m³)** | 0.037 | 0.035 |

Note:
1. SGA Energy (2000)

Table A8–10    Emission Factors for Alternative Fuels

| Source | Fuel | Emission Factor (kg/GJ) | | |
|---|---|---|---|---|
| | | $CO_2$ | $CH_4$ | $N_2O$ |
| Cement | Tires | 85 | N/A | N/A |

Notes:

A $CO_2$ emission factor for tires consumed by the cement industry was developed by the World Business Council for Sustainable Development (WBCSD 2005) on a gross-calorific-value energy basis.

N/A = Not available

Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

### A8.1.3.3.    $N_2O$

Emissions of $N_2O$ from fuel combustion are technology-dependent. Emission factors for sectors (Table A8–9) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

## A8.1.4.    Other Fuels

### A8.1.4.1.    $CO_2$

Alternative fuels such as tires, refuse, and waste oil and solvents are used by some industries to offset combustion of purchased fuels like coal, oil or natural gas. $CO_2$ emissions associated with the stationary combustion of waste fuels are included in the National Inventory Report where data are available. The cement industry in particular is known to consume "tire-derived fuel" (TDF) (Cement Association of Canada 2007) and it is assumed that the emission factor for TDF is appropriate for all waste fuel combustion (Table A8–10).

### A8.1.4.2.    $CH_4$

$CH_4$ emission factors for alternative fuels (specifically TDF) are not currently available.

### A8.1.4.3.    $N_2O$

$N_2O$ emission factors for alternative fuels (specifically TDF) are not currently available.

## A8.1.5.    Mobile Combustion

### A8.1.5.1.    $CO_2$

$CO_2$ emission factors for mobile combustion are dependent on fuel properties and are generally the same as those used for stationary combustion fuels.

### A8.1.5.2.    $CH_4$

Emissions of $CH_4$ from fuel combustion are technology-dependent. Mode-specific $CH_4$ emission factors have been developed based on technologies typically used in Cana-

### Table A8–11   Emission Factors for Energy Mobile Combustion Sources

| Mode[†] | Emission Factor (g/L fuel) | | |
|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ |
| **Road Transport** | | | |
| Gasoline Vehicles | | | |
| Light-duty Gasoline Vehicles (LDGVs) | | | |
| Tier 2 | 2 289[1] | 0.14[2] | 0.022[3] |
| Tier 1 | 2 289[1] | 0.23[4] | 0.47[4] |
| Tier 0 | 2 289[1] | 0.32[5] | 0.66[6] |
| Oxidation Catalyst | 2 289[1] | 0.52[7] | 0.20[5] |
| Non-catalytic Controlled | 2 289[1] | 0.46[7] | 0.028[5] |
| Light-duty Gasoline Trucks (LDGTs) | | | |
| Tier 2 | 2 289[1] | 0.14[2] | 0.022[3] |
| Tier 1 | 2 289[1] | 0.24[4] | 0.58[4] |
| Tier 0 | 2 289[1] | 0.21[7] | 0.66[6] |
| Oxidation Catalyst | 2 289[1] | 0.43[7] | 0.20[5] |
| Non-catalytic Controlled | 2 289[1] | 0.56[5] | 0.028[5] |
| Heavy-duty Gasoline Vehicles (HDGVs) | | | |
| Three-way Catalyst | 2 289[1] | 0.068[7] | 0.20[7] |
| Non-catalytic Controlled | 2 289[1] | 0.29[5] | 0.047[5] |
| Uncontrolled | 2 289[1] | 0.49[5] | 0.084[5] |
| Motorcycles | | | |
| Non-catalytic Controlled | 2 289[1] | 0.77[2] | 0.041[2] |
| Uncontrolled | 2 289[1] | 2.3[5] | 0.048[5] |
| Diesel Vehicles | | | |
| Light-duty Diesel Vehicles (LDDVs) | | | |
| Advanced Control* | 2 663[1] | 0.051[5] | 0.22[5] |
| Moderate Control | 2 663[1] | 0.068[5] | 0.21[5] |
| Uncontrolled | 2 663[1] | 0.10[5] | 0.16[5] |
| Light-duty Diesel Trucks (LDDTs) | | | |
| Advanced Control* | 2 663[1] | 0.068[5] | 0.22[5] |
| Moderate Control | 2 663[1] | 0.068[5] | 0.21[5] |
| Uncontrolled | 2 663[1] | 0.085[5] | 0.16[5] |
| Heavy-duty Diesel Vehicles (HDDVs) | | | |
| Advanced Control | 2 663[1] | 0.11[8] | 0.151[8] |
| Moderate Control | 2 663[1] | 0.14[5] | 0.082[5] |
| Uncontrolled | 2 663[1] | 0.15[5] | 0.075[5] |
| Natural Gas Vehicles | 1.89[1] | 9E-03[5] | 6E-05[5] |
| **Propane Vehicles** | 1 510[1] | 0.64[5] | 0.028[5] |
| **Off-road** | | | |
| Off-road Gasoline | 2 289[1] | 2.7[5] | 0.050[5] |
| Off-road Diesel | 2 663[1] | 0.15[5] | 1.1[5] |
| **Railways** | | | |
| Diesel Train | 2 663[1] | 0.15[5] | 1.1[5] |
| **Marine** | | | |
| Gasoline Boats | 2 289[1] | 1.3[5] | 0.066[5] |
| Diesel Ships | 2 663[1] | 0.15[5] | 1.1[5] |
| Light Fuel Oil Ships | 2 725[1] | 0.26[5] | 0.073[5] |
| Heavy Fuel Oil Ships | 3 124[1] | 0.28[5] | 0.079[5] |
| **Aviation** | | | |
| Aviation Gasoline | 2 342[9] | 2.2[9] | 0.23[9] |
| Aviation Turbo Fuel | 2 534[1] | 0.028[10] | 0.071[11] |
| **Renewable Fuels** | | | |
| Ethanol | 1 494[12] | ** | ** |
| Biodiesel | 2 449[12,13] | *** | *** |

Notes:

† In the context of Transportation Modes, Tiers 0–2 refer to increasingly stringent U.S. EPA emission standards, enabled through advancements in emission control technologies. It should not be confused with IPCC GHG estimation methodologies. EPA Tiers apply to on-road vehicles under the following model year breakdown, with some overlap due to technology penetration (refer to Figure A2-2 of Annex 2 for more details): Tier 0: 1980–1995; Tier 1: 1994–2003; Tier 2: 2004–2009.

1. Adapted from McCann (2000)
2. Adapted from Environment Canada ERMD Report 04-44 (2006)
3. Adapted from Environment Canada ERMD Report 04-44 (2006) and Graham et al. (2009)
4. Adapted from Environment Canada ERMS Report 07-14A (2009)

5. SGA (2000)
6. Adapted from Barton & Simpson (1994)
7. ICF (2004)
8. Graham et al. (2008)
9. Jaques (1992)
10. National overall average emission factor based on 2006 IPCC Guidelines (IPCC 2006). Refer to Section A2.4.2.3 of Annex 2 for further information.
11. IPCC (2006)
12. Refer to Section 3.4.2.3 and 3.4.2.4 of Chapter 3 for further information.
13. BioMer (2005)

* Advanced control diesel emission factors are used for Tier 2 diesel vehicle populations.
** Gasoline $CH_4$ and $N_2O$ emission factors (by mode and technology) are used for ethanol.
*** Diesel $CH_4$ and $N_2O$ emission factors (by mode and technology) are used for biodiesel.

da, and are summarized in Table A8–11. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies (SGA Energy 2000).

Existing on-road $CH_4$ emission factors were re-evaluated in 2010 (Franchi 2011) and compared to a compilation of recently acquired Canadian and U.S. emissions test results (Environment Canada 2006, 2009; Graham et al. 2008). The existing emission factors were assessed for calculation accuracy, supporting assumptions and sample size. These results were compared against the newly acquired emission factor test data, which were typically found to be more representative of Canadian on-road vehicle emission control technologies. Consequently, six on-road $CH_4$ emission factors were updated for light-duty gasoline vehicles (LDGVs), light-duty gasoline trucks (LDGTs), motorcycles and heavy-duty diesel vehicles (HDDVs).

Over 50 updated aircraft-specific aviation-turbo-fuel $CH_4$ emission factors from the 2006 IPCC Guidelines (IPCC 2006) were introduced into the Tier 3 civil aviation model (Aviation Greenhouse Gas Emission Model - AGEM); Table A8–11 displays a national overall average implied emission factor, for conciseness. Refer to Section A2.4.2.3 for more information on AGEM.

### A8.1.5.3.    $N_2O$

Emissions of $N_2O$ from fuel combustion are technology-dependent. Mode-specific $N_2O$ emission factors have been developed based on technologies typically used in Canada. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies (SGA Energy 2000).

Similar to the $CH_4$ emission factor study of Section A8.1.5.2, the existing on-road $N_2O$ emission factors from the SGA Energy study were reviewed in 2010 (Franchi 2011), and weighed against a compilation of recently acquired Canadian and U.S. emissions test results (Environment Canada 2006, 2009; Graham et al. 2008, 2009). The calculation accuracy, sample sizes and supporting assumptions of the existing emission factors were compared to the newly acquired emission factor test data, which were typically found to be more representative of Canadian on-road vehicle emission control technologies.

In particular, the updated test data highlighted the effect of high-sulphur gasoline on $N_2O$ emission factors: vehicles fuelled with high-sulphur gasoline for the majority of their useful lives generally emitted higher levels of $N_2O$ than those run on low-sulphur gasoline (Environment Canada 2009). Because Canadian vehicles consumed high-sulphur gasoline prior to the introduction of low-sulphur fuel regulations in 2005 (Environment Canada 2001), six on-road $N_2O$ emission factors were updated for LDGVs, LDGTs, motorcycles and HDDVs.

The Tier 1 aviation-turbo-fuel $N_2O$ emission factor from the 2006 IPCC Guidelines (IPCC 2006) is applied in the Tier 3 civil aviation model (AGEM), replacing the emission factor previously originating from Jaques (Jaques 1992). Refer to Section A2.4.2.3 for more information on AGEM.

Table A8–12    Carbon Dioxide ($CO_2$) Emission Factors for Mineral Products

| Category | Mineral Product | Emission Factor (g $CO_2$/kg of mineral product) |
|---|---|---|
| Cement Production | Clinker | 507.1[1] |
| Lime Production | High-Calcium Lime | 751[2] |
| | Dolomitic lime | 889[2] |
| Limestone and Dolomite Use | Limestone | 418[3] |
| | Dolomite | 468[3] |
| Soda Ash Use | Soda Ash | 415[3] |
| Magnesite Use | Magnesite | 506[3] |

Notes:
1. IPCC/OECD/IEA (1997)
2. Developed based on information provided by W. Kenefick 2008. Personal communication (e-mail from Kenefick W. to Amy Shen dated October 7, 2008). Canadian Lime Institute (CLI).
3. AMEC (2006)

## A8.2.    Industrial Processes

### A8.2.1.    Mineral Products

To estimate emissions from the production and use of mineral products, many parameters have been used as emission factors; they are all listed in Table A8–12.

## A8.2.2.    Chemical Industry

Shown in Table A8–13, Table A8–14 and Table A8–15 are the emission factors used for categories included under the Chemical Industry, as well as the sources from which these factors were obtained.

Table A8–13    Emission Factors for Ammonia and Adipic Acid Production

| Category | Process Description | Emission Factor (tonne per tonne (t/t) of chemical product) | |
|---|---|---|---|
| | | $CO_2$ | $N_2O$ |
| Ammonia Production | Natural gas reforming which produces hydrogen needed for ammonia manufacturing | 1.56[1] | NA |
| Adipic Acid Production | Oxidation reaction of cyclohexanone and cyclohexanol mixture without $N_2O$ abatement | NA | 0.3[2] |

Notes:
1. Jaques (1992)
2. IPCC (2000)

NA = Not applicable

Table A8–14    $N_2O$ Emission Factors for Nitric Acid Production

| Category | Process Description | $N_2O$ Emission Factor (kg/t) |
|---|---|---|
| Nitric Acid Production | Dual-pressure plants with extended absorption "Type 1" | 9.4[1] |
| | Dual-pressure plants with extended absorption "Type 2" | 12[1] |
| | High-pressure plants with non-selective catalytic reduction | 0.66[1] |
| | High-pressure plants with selective catalytic reduction | 8.5[2] |

Notes:
1. Collis G. (1992). Personal communication (letter dated March 23, 1992). Canadian Fertilizer Institute
2. IPCC (2000)

Table A8–15    Emission Factors for Petrochemical Products

| Petrochemical Product | Emission Factor | Type |
|---|---|---|
| Silicon Carbide | 11.6 kg $CH_4$ / t (tonne) product | **IPCC default[1]** |
| Calcium Carbide | 4.8 kg $CH_4$ / t product | Derived from IPCC data[2] |
| Carbon Black | 1.29 kg $CH_4$ / t product | Sector-wide weighted average[3] |
| Ethylene | 0.013 kg $CH_4$ / t product | Sector-wide weighted average[3] |
| | 0.0055 kg $N_2O$ / t product | Sector-wide weighted average[3] |
| Ethylene Dichloride | 0.4 kg $CH_4$ / t product | IPCC default[1] |
| Styrene | 4 kg $CH_4$ / t product | IPCC default[1] |
| Methanol | 0.031 kg $CH_4$ / t product | Sector-wide weighted average[3] |

Notes:
1. Default value from IPCC (2006)
2. Derived from IPCC (2006) data. See section 4.10.2 for details.
3. Cheminfo Services (2010)

## A8.2.3.   Metal Production

Tier 1-type emission factors for the category of aluminium production and the sources from which these emission factors were obtained are shown in Table A8–16. The parameter values of other tier types, which were also used in the estimation of emissions from aluminium production, are found in Section 4.17.2 of Chapter 4.

Table A8–17 shows the values of the parameters used for estimating emissions from iron and steel production.

Table A8–16   Tier 1 Emission Factors for Aluminium Production

| Cell Technology Type | Emission Factor[1] (kg /t product) | | |
|---|---|---|---|
| | $CO_2$ | Carbon Tetrafluoride (CF$_4$) | Carbon Hexafluoride (C$_2$F$_6$) |
| Side-worked pre-baked | 1600 | 1.6 | 0.4 |
| Centre-worked pre-baked | 1600 | 0.4 | 0.04 |
| Horizontal stud Söderberg | 1700 | 0.4 | 0.03 |
| Vertical stud Söderberg | 1700 | 0.8 | 0.04 |

Notes:
1. IAI (2006)

Table A8–17   $CO_2$ Emission Factors for Iron and Steel Industry

| Parameter | Emission Factor | Unit |
|---|---|---|
| Iron ore reduction with coke | 3.2–3.3[1] | t $CO_2$/t (tonne) coke used |
| Electrode consumption in electric arc furnaces | 4.53[2] | kg $CO_2$/ t steel |
| Electrode consumption in basic oxide furnaces | 0.23[2] | kg $CO_2$/ t steel |

Notes:
1.   Year-specific emission factors provided in Cheminfo Services (2010).
2.   Provided by the Canadian Steel Producers Association. Chan K. 2009. Personal communication (email from Chan K to Maryse Pagé, Greenhouse Gas Division, dated July 21, 2009). Canadian Steel Producers Association.

Table A8–18   Emission Factors for Consumption of HFCs in 1995

| Application | Emission Factor (kg loss/ g consumed) | Assumptions |
|---|---|---|
| Aerosols | 0.8 | For aerosol products, the IPCC (2000) suggests a default emission factor of 50% of the initial charge per year. It was assumed that 1994 production was 50% of that of 1995, meaning that emissions from 1994 production that occurred in 1995 would be equivalent to 25% of production in 1995. Therefore, the emission factor applied to the 1995 production was 75% or 80% (rounded). |
| Foams | 1 | For foam blowing, it was assumed that all HFCs used for foam blowing in 1995 were for the open cell type. According to the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*[1] emissions equal 100% of the quantity sold for blowing open cell foam. |
| AC OEM | 0.04 | For AC OEM, a typical range of 2–5% loss rate is mentioned in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.*[1] Therefore, a loss rate of 4% was assumed here. |
| AC Service | 1 | For AC service, it was assumed that most service HFCs were used to replace operating losses. In other words, it was assumed that service HFCs replace an identical amount of HFCs that was previously vented. Hence, the loss rate was 100%. |
| Refrigeration | 0.1 | As shown in Equation 4-18 of Chapter 4, the emission factor for refrigeration is (0.17/1.17), which equals roughly 0.1. |
| Total Flooding Systems | 0.35 | For total flooding systems, the default loss rate, as shown in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*,[1] is 35%. |

Notes:
1. IPCC/OECD/IEA (1997)

## A8.2.4.    Consumption of Halocarbons

The use of halocarbons in various applications, such as air conditioning (AC), refrigeration, aerosols, foam blowing, solvents, fire extinguishing and semiconductor manufacturing (for PFCs only), can result in hydrofluorocarbon / perfluorocarbon (HFC/PFC) emissions.

As mentioned in Chapter 4 of this report, detailed 1995 HFC activity data were not available. Therefore, a modified Tier 1, instead of Tier 2, methodology was used to estimate 1995 HFC emissions for the following use types: aerosols, foam blowing, AC original equipment manufacturing (OEM), AC servicing, refrigeration and total flooding systems. Shown in Table A8–18 are the emission factors used in the modified Tier 1 estimation method and the assumptions made to derive and to use these factors.

Table A8–19 summarizes emission rates used to estimate 1996–2009 HFC emissions and 1995–2009 PFC emissions.

## A8.2.5.    Other and Undifferentiated Production

The use of fossil fuels as feedstock or for other non-energy uses may result in emissions during the life of manufactured products. To estimate $CO_2$ emissions from non-energy use of natural gas, an emission factor of 1522 g $CO_2/m^3$ was used (Cheminfo Services 2005). Table A8–20 shows the emission factors used to develop $CO_2$ emission estimates for non-energy applications of natural gas liquids and non-energy petroleum producs, respectively. Please refer to the emission factor for petroleum coke, refineries & others in Table A8–5 for the emission factor associated with non-energy use of petroleum coke, and to Table A8–7 for emission factors for non-energy use of coal and coal products.

Table A8–19    Emission Rates for Consumption of HFCs and PFCs [1]

| Application | HFC Emission Rate (%) | PFC Emissions Rate (%) |
|---|---|---|
| **Assembly** | | |
| Residential Refrigeration Equipment | 2% (of charge) | 3.5% (of charge) [2] |
| Commercial Refrigeration Equipment | 3.5% (of charge) [2] | |
| Stationary AC Equipment | 3.5% (of charge) [2] | 3.5% (of charge) [2] |
| Mobile AC Equipment | 4.5% (of charge) [3] | 4.5% (of charge) [3] |
| **Operation** | | |
| Residential Refrigeration Equipment | 1% (of stock in existing systems) | 17% (of stock in existing systems) |
| Commercial Refrigeration Equipment | 17% (of stock in existing systems) | |
| Stationary AC Equipment | 17% (of stock in existing systems) | 17% (of stock in existing systems) |
| Mobile AC Equipment | 15% (of stock in existing systems) [4] | 30% (of stock in existing systems) |
| **Other Applications** | | |
| Foam Blowing - open cell | 100% (of use) | 100% (of use) |
| Foam Blowing - closed cell | 10% of charge released during manufacturing and 4.5% of the original quantity charge released per year over the product's lifetime | 10% of charge released during manufacturing and 4.5% of the original quantity charge released per year over the product's lifetime |
| Fire Extinguishing – portable | 60% (of HFC use in new systems) | NA |
| Fire Extinguishing – total flooding systems | 35% (of HFC use in new systems) | NA |
| Aerosol Products | 50% (of use) in the first year and the other 50% (of use) in the second year | NA |
| Solvents | 50% (of use) in the first year and the other 50% (of use) in the second year | 50% (of use) in the first year and the other 50% (of use) in the second year |
| Other Products – contained | NA | 1% of the quantity sold is emitted during manufacturing and 2% of stock is emitted per year during the product's lifetime |
| Other Products – emissive | NA | 50% (of use) in the first year and the other 50% (of use) in the second year |

Notes:
1.  IPCC/OECD/IEA (1997)
2.  The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories provide two ranges for values: 2–3% and 4–5%. The mid-point of the two ranges was used.
3.  The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories provide a range of 4–5% as values. The average value was used.
4.  The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories provide a range of 10–20% as values. The average value was used.
NA = Not applicable

Table A8–20  CO$_2$ Emission Factors for Non-energy Use of Natural Gas Liquids and Petroleum Products

| Product | Fraction of Carbon Stored in Product | CO$_2$ Emission Factor (g CO$_2$/L) |
|---|---|---|
| Natural Gas Liquids | | |
| Propane | 0.8[1] | 303[2] |
| Butane | 0.8[1] | 349[2] |
| Ethane | 0.8[1] | 197[2] |
| Petroleum Products | | |
| Petrochemical Feedstocks[3] | 0.8[1] | 500[7] |
| Naphthas[4] | 0.75[1] | 625[7] |
| Lubricating Oils and Greases[5] | 0.5[1] | 1 410[7] |
| Petroleum Used for Other Products[6] | 0.5[1] | 1 450[7] |

Notes:
1. IPCC/OECD/IEA (1997)
2. McCann (2000)
3. Carbon factor for Petrochemical Feedstocks is 680 g C/L (Jaques 1992)
4. Carbon factor for Napthas is 680 g C/L (Jaques 1992)
5. Carbon factor for Lubricating Oils and Greases is 770 g C/L (Jaques 1992)
6. Carbon factor for Petroleum Used in Other Products is 790 g C/L (Jaques 1992)
7. The resulting CO$_2$ emission factor is calculated by multiplying the carbon factor for each product by the molecular weight ratio between CO$_2$ and Carbon (44/12) and by (1-fraction of carbon stored in product).

Table A8–21  Emission Factors for Solvent and Other Product Use

| Product | Application | N$_2$O Emission Rate (%) |
|---|---|---|
| N$_2$O Use | Anaesthetic Usage | 100 |
| | Propellant Usage | 100 |

Source: IPCC (2006)

Table A8–22  Methane Emission Factors for Enteric Fermentation for Non-cattle Animals

| Non-cattle Animal Category | Enteric Fermentation Emission Factor[1] (kg CH$_4$/head per year) |
|---|---|
| **Pigs** | |
| Boars | 1.5 |
| Sows | 1.5 |
| Pigs < 20 kg | 1.5 |
| Pigs 20–60 kg | 1.5 |
| Pigs > 60 kg | 1.5 |
| **Other Livestock** | |
| Sheep | 8 |
| Lambs | 8 |
| Goats | 5 |
| Horses | 18 |
| Buffalo | 55 |
| **Poultry** | |
| Chickens | N/A |
| Hens | N/A |
| Turkeys | N/A |

Notes:
1. IPCC Tier 1 default emission factors (IPCC/OECD/IEA 1997)
N/A = Not available

## A8.3.  Solvent and Other Product Use

$N_2O$ emissions can result from the use of $N_2O$ as an anaesthetic and propellant. The development of the emission factors shown in Table A8–21 is described in the Solvent and Other Product Use chapter of the Inventory Report (Chapter 5).

## A8.4.  Agriculture

The sources of agricultural greenhouse gas emissions are enteric fermentation, manure management and agricultural soils. Methodologies for generating country-specific $CH_4$ emission factors for enteric fermentation (cattle only) and manure management emission estimates are detailed in Section A3.3. Other emission factors and related information are provided below, in Table A8–22 to Table A8–25.

Table A8–23   Maximum Methane-Producing Potential (B0) by animal category[1]

| Animal Category | Maximum $CH_4$ Producing Potential ($B_0$) ($m^3$/kg VS)[4] |
|---|---|
| Dairy Cattle[2] | 0.24 |
| Non-dairy Cattle[3] | 0.19 |
| Sheep | 0.19 |
| Goats | 0.18 |
| Horses | 0.30 |
| Swines | 0.48 |
| Hens | 0.39 |
| Broilers | 0.36 |
| Turkeys | 0.36 |

Notes:
1. Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9
2. Dairy cattle include dairy cows and dairy heifers.
3. The non-dairy cattle value is also used for buffalo.
4. VS = volatile solids

Table A8–24   Methane Conversion Factors (MCFs) by Animal Category and Manure Management System[1]

| Animal Categories | Liquid Systems (MCFL) | Solid Storage and Drylot (MCFSSD) | Pasture, Range and Paddock (MCFPRP) | Other Systems (MCFO) |
|---|---|---|---|---|
| Dairy Cattle | 0.20 | 0.02 | 0.01 | 0.01 |
| Non-dairy Cattle[2] | 0.20 | 0.02 | 0.01 | 0.01 |
| Swine | 0.20 | 0.02 | NA | 0.01 |
| Poultry | 0.015 | 0.015 | 0.015 | NA |
| Horses | NA | 0.01 | 0.01 | NA |
| Goats | NA | 0.01 | 0.01 | NA |
| Sheep | NA | 0.01 | 0.01 | NA |
| Lambs | NA | 0.01 | 0.01 | NA |

Notes:
1. Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9 (cool climate, average annual temperature 12°C)
2. Non-dairy cattle values are also used for buffalo.
3. NA = Not applicable

Table A8–25    Emission Factors (EFs) for  Manure Nitrogen (N) Lost as $N_2O$-N by Animal Category and Animal Waste Management Systems (IPCC/OECD/IEA 1997) )

| Animal Category | % of Manure N Lost as $N_2O$-N | | | |
|---|---|---|---|---|
| | Liquid Systems ($EF_L$) | Solid Storage and Drylot ($EF_{SSD}$) | Pasture, Range and Paddock ($EF_{PRP}$) | Other Systems ($EF_O$) |
| Non-dairy Cattle | 0.001 | 0.02 | 0.02 | 0.005 |
| Dairy Cattle | 0.001 | 0.02 | 0.02 | 0.005 |
| Poultry | 0.001 | 0.02 | 0.02 | 0.005 |
| Sheep and Lambs | 0.001 | 0.02 | 0.01 | 0.005 |
| Swine | 0.001 | 0.02 | 0.02 | 0.005 |
| Goats | 0.001 | 0.02 | 0.01 | 0.005 |
| Horses | 0.001 | 0.02 | 0.01 | 0.005 |
| Buffalo | 0.001 | 0.02 | 0.02 | 0.005 |

Source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Uses, Table 11.1

# A8.5.    Biomass Combustion

## A8.5.1.    $CO_2$

Emissions of $CO_2$ from the combustion of biomass (whether for energy use, from prescribed burning or from wildfires) are not included in National Inventory totals. These emissions are estimated and recorded as a loss of biomass stock in the Land Use, Land-use Change and Forestry (LULUCF) Sector.

The emissions related to energy use are reported as memo items in the common reporting format (CRF) tables as required by the United Nations Framework Convention on Climate Change (UNFCCC). Emission factors for residential combustion (Table A8–26) are technology-dependent. Emission factors for $CO_2$ are from an Environment Canada study (ORTECH Corporation 1994) and assume a moisture content of 50%.

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The $CO_2$ emission factor (Table A8–26) for industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (EPA 2003). The U.S. EPA data were converted to kg/tonne at 50% moisture content (m.c.) using a higher heating value (HHV) of 10.47 MJ/kg at 50% m.c., which was developed from an internal review of available moisture content and heating value data. The emission factor for spent pulping liquor is calculated from data collected by the National Council for Air and Stream Improvement (NCASI), based on carbon content assuming a 1% correction for unoxidized carbon (NCASI 2010). The NCASI emission factors were reported in units of kg/GJ HHV, which was converted to kg/tonne at 50% m.c. based on the same HHV vs. moisture convert wood waste.

$CO_2$ emissions occur during forest wildfires and from controlled burning during forest conversion activities. The carbon emitted as $CO_2$ ($CO_2$-C) during forest fires is considered in the forest carbon balance, whereas the $CO_2$-C emitted during controlled burns is reported under the new land-use categories. There is no unique $CO_2$ emission factor applicable to all fires, as the proportion of $CO_2$-C emitted for each pool can be specific to the pool, the type of forest and disturbance, and the ecological zone (see Section A3.4.2).

## A8.5.2.    $CH_4$

Emissions of $CH_4$ from residential combustion of firewood are technology-dependent. The emission factors (Table A8–26) were chosen based on a review of emission factors for combustion technologies (SGA Energy 2000). The factors are taken from the U.S. EPA AP 42 Supplement B (EPA 1996b).

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The emission factor (Table A8–26) for $CH_4$ from industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (EPA 2003) and converted to kg/tonne at 50% m.c. as discussed in section A8.5.1 above. The emission factor for $CH_4$ from spent pulping liquor is from the IPCC

Table A8–26   Emission Factors for Biomass

| Source [1] | Description | Emission Factor (g/kg fuel) | | |
|---|---|---|---|---|
| | | CO$_2$ | CH$_4$ | N$_2$O |
| Wood Fuel / Wood Waste | Industrial Combustion | 840[4] | 0.09[4] | 0.02[4] |
| Forest Wildfires | Open Combustion | NA | NA[2] | NA[3] |
| Controlled Burning | Open Combustion | NA | NA[2] | NA[3] |
| Spent Pulping Liquor | Industrial Combustion | 891[5] | 0.02[6] | 0.02[6] |
| Stoves and Fireplaces | Residential Combustion | | | |
|    Conventional Stoves | | 1 500[7] | 15[8] | 0.16[8] |
|    Conventional Fireplaces and Inserts | | 1 500[7] | 15[8] | 0.16[8] |
|    Stoves/Fireplaces with Advanced Technology or Catalytic Control [9] | | 1 500[7] | 6.9[8] | 0.16[8] |
|    Other Wood-burning Equipment | | 1 500[7] | 15[8] | 0.16[8] |

Notes:

1. CO$_2$ emissions from biomass combusted for energy purposes are not included in inventory totals, whereas CH4 and N2O emissions from these sources are inventoried under the Energy Sector. All greenhouse gas (GHG) emissions, including CO2 from biomass burned in managed forests (wildfires and controlled burning), are reported under Land Use, Land-Use Change and Forestry (LULUCF) and excluded from national inventory totals.

2. Emission ratio for CH$_4$ is 1/90th CO$_2$. See Section A3.4 in Annex 3.

3. Emission ratio for N$_2$O is 0.017% CO$_2$. See Section A3.4 in Annex 3.

4. No CH$_4$ or N$_2$O emission factors were available for spent pulping liquor therefore the emission factor for Industrial Fuelwood was used in its place.

5. The CH$_4$ emission factor used is an average of the Non-Catalyst Stove and Catalyst Stove Emission factors

6. SGA Energy (2000)

7. EPA (1996)

8. Jaques (1992)

9. ORTECH (1994)

NA = not applicable

Table A8–27   Emission Factors for Landfill Gas Combustion

| Source | Description | Emission Factor (kg / terajoule) | | |
|---|---|---|---|---|
| | | CO$_2$ | CH$_4$ | N$_2$O |
| Landfill Gas | Industrial Combustion | 54,600 | 1.0 | 0.1 |

Source: IPCC (2006)

(2006). It is converted from the units reported in the IPCC (kg/TJ lower heating value [LHV]) to kg/tonne at 50% m.c. based on the assumption that the LHV is 20% lower than the HHV along with the same HHV vs. moisture content relationship discussed in A8.5.1.

Emission factors from landfill gas (Table A8–27) are from the IPCC (2006).

Emissions of carbon as CH$_4$ (CH$_4$-C) from wildfires and controlled burning are always equal to 1/90th of CO$_2$-C emissions.

## A8.5.3.   N$_2$O

Emissions of N$_2$O from residential combustion of fire-wood are technology-dependent. The emission factors (Table A8–26) were chosen based on a review of emission factors for combustion technologies and an analysis of combustion technologies typically used in Canada (SGA Energy 2000). The factors are taken from the U.S. EPA AP 42 Supplement B (EPA 1996b).

Emissions from industrial combustion of biomass are de-pendent primarily on the characteristics of the fuel being combusted. Emission factors (Table A8–26) for industrial wood waste have been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMB-TU (EPA 2003) and converted to kg/tonne at 50% m.c. as

discussed in section A8.5.2 above. The emission factor for $CH_4$ from spent pulping liquor is from the IPCC (2006). It is converted from the units reported in the IPCC (kg/TJ LHV) to kg/tonne at 50% m.c. based on the assumption that the LHV is 20% lower than the HHV along with the same HHV vs. moisture content relationship discussed in A8.5.1.

Emission factors for landfill gas (Table A8–27) are from the IPCC (2006).

$N_2O$ emissions from wildfires and controlled burning are equal to 0.017% vol/vol of $CO_2$ emissions. Since both gases have the same molecular weight, the same ratio can be applied on a mass basis (see Section A3.4.2).

# A8.6.    Waste

## A8.6.1.    Municipal Wastewater Handling – Wastewater

### A8.6.1.1.    $CH_4$

Emissions from municipal wastewater handling are dependent upon the organic loading of the effluent stream, population and the type of wastewater treatment provided. The emission factor in this case is the product of the methane correction factor (MCF), which is an estimate of the fraction of biological oxygen demand (BOD) that will ultimately degrade anaerobically (MCF) and the maximum methane-producing capacity ($B_o$), which is expressed in terms of kg $CH_4$/kg BOD removed. From a recent study by AECOM Canada (2010), commissioned by Environment Canada, it is recommended that the following country-specific values be used: an MCF of 0.3, which is a blended category that represents the Canadian proportion of septic tanks, anaerobic lagoons and untreated effluents as well as the degree of degradation of the organics expected of the treatment or discharge and a $B_o$ of 0.36 kg $CH_4$/kg $BOD_5$. Therefore, the emission factor is 0.108 kg $CH_4$/kg $BOD_5$.

The IPCC default emission factor of 0.6 kg $CH_4$/kg BOD was not used, as the AECOM study confirmed that its derivation from the 0.25 kg CH4/kg COD was erroneous, where COD is the chemical oxygen demand.

## A8.6.2.    Municipal Wastewater Handling - Human Sewage

### A8.6.2.1.    $N_2O$

$N_2O$ emissions from human sewage are a function of protein consumption per capita, population and the nitrogen content in protein. The emission factor used is the IPCC default value of 0.01 kg $N_2O$-N kg sewage-N (IPCC/OECD/IEA 1997).

## A8.6.3.    Waste Incineration

### A8.6.3.1.    $CH_4$

$CH_4$ emissions from sewage sludge incinerators are estimated from an emission factor of 1.6 kg $CH_4$/tonne of dry sludge, which is obtained from the U.S. EPA (1995).

### A8.6.3.2.    $N_2O$

The emission estimates from municipal solid waste (MSW) incineration are calculated from an average IPCC default emission factor for MSW five-stoker facilities of 0.148 kg $N_2O$/tonne of waste (IPCC/OECD/IEA 1997). For wastewater sludge incineration, the emission factor is taken from the IPCC Good Practice Guidance and has the value of 0.8 kg $N_2O$/tonne of dry sludge.

# Annex 9

# Rounding Protocol

A rounding protocol has been developed for the emission and removal estimates in order to reflect their uncertainty levels. The accuracy of a value is reflected by presenting the emission and removal estimates rounded to an appropriate number of significant figures based on the uncertainty of the category in question. The number of significant figures to which each source and sink category has been rounded, using the rounding rules provided in this protocol, can be found in Table A9–1.

A large number of the uncertainty ranges that are used for the various categories were developed using Monte Carlo analysis, as performed by ICF Consulting (ICF Consulting 2004, 2005), using the 2001 inventory estimates submitted in the NIR 2003. Default uncertainty values published by the IPCC (IPCC/OECD/IEA 1997; IPCC 2001) and those resulting from expert elicitation were also utilized for some ranges. Uncertainty ranges have been calculated around the mean values, as determined by Monte Carlo analysis. In cases where uncertainty ranges are asymmetric about the mean, the range with a greater absolute distance from the mean has been employed to represent that uncertainty.

Recently developed uncertainty values have been adopted for certain categories in all sectors. These new uncertainty estimates have been considered in developing Table A9–1. For a more complete description of the analysis of uncertainty in Canada's emission estimates, please refer to Annex 7, which includes tables of current uncertainty values. Recent updates to uncertainty estimates are provided in the respective sectoral chapters.

The following uncertainty ranges have been used to establish the number of significant figures to which the estimates have been rounded:

- one significant figure: uncertainty equal to and greater than 50%;
- two significant figures: uncertainty between 10% and 50%; and
- three significant figures: uncertainty equal to and less than 10%.

The LULUCF Sector was not formally assessed for uncertainty in the 2004 ICF Consulting study. Since then, new methodologies have been used to develop uncertainty estimates in the Cropland and Deforestation[1] categories (Chapter 7, sections 4 and 8 respectively). The number of significant figures for the remaining categories was determined by expert opinion.

All calculations, including the summing of emission totals, were made using unrounded data. The rounding protocol was applied only after the calculations had been completed. The reader should also note that formatting in Annex 12 and Annex 15 limits the maximum number of decimal places and, therefore, even though a zero entry is recorded, some emissions may exist in that category (zero emissions are identified with a dash "-"). Because of these procedures, individual values in the emission tables may not add up to the subtotals and/or overall totals.

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1   Kyoto category – see Chapter 7.

Table A9–1   Number of Significant Figures Applied to GHG Summary Tables

| GHG Source/Sink Categories | | $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | $SF_6$ | TOTAL |
|---|---|---|---|---|---|---|---|---|
| TOTAL | | 3 | 2 | 2 | 2 | 2 | 2 | 3 |
| ENERGY | | 3 | 2 | 1 | | | | 3 |
| a. | Stationary Combustion Sources | 3 | 1 | 1 | | | | 3 |
| | Electricity and Heat Generation | 3 | 2 | 1 | | | | 3 |
| | Fossil Fuel Industries | 3 | 1 | 1 | | | | 2 |
| | Petroleum Refining and Upgrading | 2 | 1 | 1 | | | | 2 |
| | Fossil Fuel Production | 3 | 1 | 1 | | | | 2 |
| | Mining & Oil and Gas Extraction | 3 | 1 | 1 | | | | 3 |
| | Manufacturing Industries | 3 | 1 | 1 | | | | 3 |
| | Iron and Steel | 3 | 1 | 1 | | | | 3 |
| | Non-ferrous Metals | 3 | 1 | 1 | | | | 3 |
| | Chemical | 3 | 2 | 1 | | | | 3 |
| | Pulp and Paper | 3 | 1 | 1 | | | | 3 |
| | Cement | 3 | 1 | 1 | | | | 3 |
| | Other Manufacturing | 3 | 1 | 1 | | | | 3 |
| | Construction | 3 | 1 | 1 | | | | 3 |
| | Commercial & Institutional | 3 | 1 | 1 | | | | 3 |
| | Residential | 3 | 1 | 1 | | | | 2 |
| | Agriculture & Forestry | 3 | 1 | 1 | | | | 3 |
| b. | Transportation | 3 | 1 | 1 | | | | 3 |
| | Domestic Aviation | 3 | 1 | 1 | | | | 2 |
| | Road Transportation | 3 | 2 | 2 | | | | 3 |
| | Light-duty Gasoline Vehicles | 3 | 2 | 2 | | | | 3 |
| | Light-duty Gasoline Trucks | 3 | 2 | 2 | | | | 3 |
| | Heavy-duty Gasoline Vehicles | 3 | 2 | 2 | | | | 3 |
| | Motorcycles | 3 | 2 | 2 | | | | 3 |
| | Light-duty Diesel Vehicles | 3 | 1 | 1 | | | | 3 |
| | Light-duty Diesel Trucks | 3 | 1 | 1 | | | | 3 |
| | Heavy-duty Diesel Vehicles | 3 | 1 | 1 | | | | 3 |
| | Propane & Natural Gas Vehicles | 3 | 1 | 1 | | | | 2 |
| | Railways | 3 | 1 | 1 | | | | 1 |
| | Domestic Marine | 3 | 1 | 1 | | | | 2 |
| | Others | 2 | 1 | 1 | | | | 2 |
| | Off-road Gasoline | 2 | 1 | 1 | | | | 2 |
| | Off-road Diesel | 2 | 1 | 1 | | | | 2 |
| | Pipelines | 3 | 2 | 1 | | | | 3 |
| c. | Fugitive Sources | 3 | 3 | 1 | | | | 3 |
| | Coal Mining | | 1 | | | | | 1 |
| | Oil and Natural Gas | 3 | 3 | 1 | | | | 3 |
| | Oil | 2 | 3 | 1 | | | | 3 |
| | Natural Gas | 3 | 3 | | | | | 3 |
| | Venting | 3 | 3 | 1 | | | | 3 |
| | Flaring | 2 | 2 | 1 | | | | 2 |
| INDUSTRIAL PROCESSES | | 2 | | 3 | 2 | 2 | 2 | 3 |
| a. | Mineral Production | 2 | | | | | | 2 |
| | Cement Production | 2 | | | | | | 2 |
| | Lime Production | 2 | | | | | | 2 |
| | Mineral Product Use | 3 | | | | | | 3 |
| b. | Chemical Industry | 2 | | 3 | | | | 2 |
| | Ammonia Production | 2 | | | | | | 2 |
| | Nitric Acid Production | | | 3 | | | | 3 |
| | Adipic Acid Production | | | 2 | | | | 2 |
| | Petrochemical Production | | 2 | 2 | | | | 2 |
| c. | Metal Production | 3 | | | | 2 | 3 | 3 |
| | Iron and Steel Production | 3 | | | | | | 3 |
| | Aluminium Production | 2 | | | | 2 | 3 | 2 |
| | $SF_6$ Used in Magnesium Smelters and Casters | | | | | | 3 | 3 |
| d. | Consumption of Halocarbons and $SF_6$ | | | | 2 | 1 | 2 | 2 |
| e. | Other & Undifferentiated Production | 2 | | | | | | 2 |
| SOLVENT AND OTHER PRODUCT USE | | | | 2 | | | | 2 |
| AGRICULTURE | | | 2 | 2 | | | | 2 |
| a. | Enteric Fermentation | | 2 | | | | | 2 |
| b. | Manure Management | | 2 | 2 | | | | 2 |
| c. | Agricultural Soils | | | 2 | | | | 2 |
| | Direct Sources | | | 2 | | | | 2 |
| | Pasture, Range, and Paddock Manure | | | 2 | | | | 2 |
| | Indirect Sources | | | 1 | | | | 1 |
| d. | Field Burning of Agricultural Residues | | 2 | 2 | | | | 2 |
| WASTE | | 2 | 2 | 1 | | | | 2 |
| a. | Solid Waste Disposal on Land | | 2 | | | | | 2 |
| b. | Wastewater Handling | | 2 | 1 | | | | 2 |
| c. | Waste Incineration | 2 | 1 | 1 | | | | 2 |
| LAND USE, LAND-USE CHANGE AND FORESTRY | | 2 | 2 | 2 | | | | 2 |
| a. | Forest Land | 2 | 2 | 2 | | | | 2 |
| b. | Cropland | 2 | 1 | 1 | | | | 2 |
| c. | Grassland | | | | | | | |
| d. | Wetlands | 1 | 1 | 1 | | | | 1 |
| e. | Settlements | 1 | 1 | 1 | | | | 1 |

# Annex 10

## Ozone and Aerosol Precursors

The 2009 national summary table for carbon monoxide (CO), nitrogen oxides ($NO_x$), non-methane volatile organic compounds (NMVOC) and sulphur oxides ($SO_x$) is included in this annex (Table A10-1). These gases are reported to the United Nations Economic Commission for the Environment under the Convention on Long-range Transboundary Air Pollution. As recommended by the Conference of the Parties to the UNFCCC (FCCC/SBSTA/2006/9), Annex I Parties should provide information on indirect GHGs such as CO, $NO_x$, NMVOC and $SO_x$ in the NIR.

While these gases do not have a direct global warming effect, they either influence the creation and destruction of tropospheric and stratospheric ozone or affect the terrestrial radiation absorption, as in the case of $SO_x$. These gases can impact the climate by acting as short-lived GHGs, alter atmospheric lifetimes of other GHGs and form GHGs, as in the case of CO reacting with a hydroxyl radical to form $CO_2$ in the atmosphere. These emissions are produced by a number of sources, such as fossil fuel combustion in the energy and transportation sectors, industrial production and biomass combustion.

Table A10–1  Carbon Monoxide, Nitrogen Oxides, Non-Methane Volatile Organic Compounds and Sulphur Oxides 2009 Emissions Summary for Canada

| NFR Sectors Reported to LRTAP[1] | | CO | NO$_x$ | NMVOC | SO$_x$ |
|---|---|---|---|---|---|
| | | | | kt | |
| 1 A 1 a | Public Electricity and Heat Production | 40.82 | 205.35 | 2.63 | 374.34 |
| 1 A 1 b | Petroleum Refining | 16.35 | 19.81 | 0.90 | 53.89 |
| 1 A 1 c | Manufacture of Solid Fuels and Other Energy Industries | 463.41 | 411.02 | 62.81 | 265.46 |
| 1 A 2 a | Stationary Combustion in Manufacturing Industries and Construction: Iron and Steel | 1.68 | 5.59 | 0.01 | 7.47 |
| 1 A 2 b | Stationary Combustion in Manufacturing Industries and Construction: Non-ferrous Metals | 9.19 | 1.77 | 0.04 | 1.56 |
| 1 A 2 c | Stationary Combustion in Manufacturing Industries and Construction: Chemicals | 0.95 | 4.33 | 0.38 | 3.64 |
| 1 A 2 d | Stationary Combustion in Manufacturing Industries and Construction: Pulp, Paper and Print | 324.88 | 24.63 | 23.94 | 24.05 |
| 1 A 2 e | "Stationary Combustion in Manufacturing Industries and Construction: Food Processing, Beverages and Tobacco" | 0.23 | 0.76 | 0.01 | 0.48 |
| 1 A 2 f i | Stationary Combustion in Manufacturing Industries and Construction: Other | 47.48 | 35.93 | 2.55 | 28.96 |
| 1 A 2 f ii | Mobile Combustion in Manufacturing Industries and Construction | IE | IE | IE | IE |
| 1 A 3 a ii (i) | Civil Aviation (Domestic, LTO) | 27.37 | 8.65 | 7.25 | 0.92 |
| 1 A 3 a i (i) | International Aviation (LTO) | IE | IE | IE | IE |
| 1 A 3 b i | Road Transport: Passenger Cars | 1767.96 | 82.95 | 99.61 | 0.66 |
| 1 A 3 b ii | Road Transport: Light-duty Vehicles | 1858.58 | 101.69 | 102.32 | 0.76 |
| 1 A 3 b iii | Road Transport: Heavy-duty Vehicles | 127.91 | 228.24 | 15.43 | 0.65 |
| 1 A 3 b iv | Road Transport: Mopeds & Motorcycles | 20.48 | 1.44 | 3.36 | 0.00 |
| 1 A 3 b v | Road Transport: Gasoline Evaporation | NA | NA | IE | NA |
| 1 A 3 b vi | Road Transport: Automobile Tyre and Brake Wear | NA | NA | NA | NA |
| 1 A 3 b vii | Road Transport: Automobile Road Abrasion | NA | NA | NA | NA |
| 1 A 3 c | Railways | 16.06 | 98.83 | 2.82 | 2.24 |
| 1 A 3 d i (ii) | International Inland Waterways | IE | IE | IE | IE |
| 1 A 3 d ii | National Navigation (Shipping) | 9.98 | 119.37 | 3.94 | 82.77 |
| 1 A 3 e | Pipeline Compressors | IE | IE | IE | IE |
| 1 A 4 a i | Commercial / Institutional: Stationary | 19.68 | 35.18 | 1.47 | 39.38 |
| 1 A 4 a ii | Commercial / Institutional: Mobile | IE | IE | IE | IE |
| 1 A 4 b i | Residential: Stationary Plants | 704.07 | 43.52 | 153.59 | 8.77 |
| 1 A 4 b ii | Residential: Household and Gardening (mobile) | IE | IE | IE | IE |
| 1 A 4 c i | Agriculture/Forestry/Fishing: Stationary | IE | IE | IE | IE |
| 1 A 4 c ii | Agriculture/Forestry/Fishing: Off-road Vehicles and Other Machinery | 2738.92 | 425.19 | 270.14 | 2.98 |
| 1A 4 c iii | Agriculture/Forestry/Fishing: National Fishing | IE | IE | IE | IE |
| 1 A 5 a | Other, Stationary (including Military) | IE | IE | IE | IE |
| 1 A 5 b | Other, Mobile (including Military, Land-Based and Recreational Boats) | IE | IE | IE | IE |
| 1 B 1 a | Fugitive Emission from Solid Fuels: Coal Mining and Handling | 0.06 | 0.28 | 0.07 | 0.03 |
| 1 B 1 b | Fugitive Emission from Solid Fuels:Solid Fuel Transformation | 0.81 | 1.39 | 9.88 | 13.74 |
| 1 B 1 c | Other Fugitive Emissions from Solid Fuels | 0.67 | 0.79 | 9.34 | 0.73 |
| 1 B 2 a i | Exploration, Production, Transport | NA | NA | 0.03 | 0.00 |
| 1 B 2 a iv | Refining / Storage | 4.16 | 5.41 | 40.47 | 17.49 |
| 1 B 2 a v | Distribution of Oil Products | NA | NA | 51.13 | 0.00 |
| 1 B 2 b | Natural Gas | NA | NA | 371.47 | 0.00 |
| 1 B 2 c | Venting and Flaring | 29.49 | 29.49 | 1.71 | 32.03 |
| 1 B 3 | Other fugitive emissions from geothermal energy production, peat and other energy extraction not included in 1 B 2 | IE | IE | IE | IE |
| 2 A 1 | Cement Production | 8.00 | 23.37 | 0.20 | 16.11 |
| 2 A 2 | Lime Production | 1.43 | 2.91 | 0.00 | 1.27 |
| 2 A 3 | Limestone and Dolomite Use | NA | NA | NA | NA |
| 2 A 4 | Soda Ash Production and Use | NA | NA | NA | NA |
| 2 A 5 | Asphalt Roofing | 0.00 | NA | 0.00 | 0.00 |
| 2 A 6 | Road Paving with Asphalt | 3.54 | 1.11 | 4.49 | 0.50 |
| 2 A 7 a | Quarrying and Mining of Minerals Other Than Coal | 0.64 | 0.83 | 0.09 | 0.19 |
| 2 A 7 b | Construction and Demolition | NA | NA | NA | NA |
| 2 A 7 c | Storage, Handling and Transport of Mineral Products | NA | NA | NA | NA |
| 2 A 7 d | Other Mineral Products | 3.36 | 0.26 | 0.22 | 0.93 |
| 2 B 1 | Ammonia Production | 3.20 | 4.13 | 0.37 | 1.92 |
| 2 B 2 | Nitric Acid Production | NA | IE | NA | NA |
| 2 B 3 | Adipic Acid Production | IE | IE | NA | NA |
| 2 B 4 | Carbide Production | IE | IE | IE | IE |
| 2 B 5 a | Other Chemical Industry | 8.61 | 9.46 | 6.48 | 5.71 |
| 2 B 5 b | Storage, Handling and Transport of Chemical Products | IE | IE | IE | IE |
| 2 C 1 | Iron and Steel Production | 17.93 | 3.09 | 0.63 | 14.32 |
| 2 C 2 | Ferroalloys Production | 51.24 | 0.15 | 6.81 | 0.05 |

Notes:
1. Nomenclature for Reporting (NFR) sectors reported to the Convention on Long-range Transboundary Air Pollution (LRTAP).
2. Includes NH3 from Enteric Fermentation and emissions from Cultivation of Rice.
3. Includes PM sources.
4. Excludes waste incineration for energy (this is included in 1 A 1) and in industry (if used as fuel).
5. Includes accidental fires.
6. "National Total" refers to the territory declared upon ratification of the relevant Protocol of the Convention.
NA = Not applicable; NE = Not estimated; NO = Not occurring; IE = Included elsewhere; LTO = Landing and takeoff; POPs = Persistent organic pollutants..

Table A10-1   Carbon Monoxide, Nitrogen Oxides, Non-Methane Volatile Organic Compounds and Sulphur Oxides 2009    Emissions Summary for Canada   (cont'd)

| NFR Sectors Reported to LRTAP[1] | | CO | NOx | NMVOC | SOx |
|---|---|---|---|---|---|
| | | | | kt | |
| 2 C 3 | Aluminum Production | 371.46 | 0.77 | 0.80 | 60.44 |
| 2 C 5 a | Copper Production | 0.03 | 0.48 | 0.00 | 47.36 |
| 2 C 5 b | Lead Production | 0.11 | 0.06 | 0.00 | 8.25 |
| 2 C 5 c | Nickel Production | 0.00 | 0.06 | 0.00 | 145.73 |
| 2 C 5 d | Zinc Production | IE | IE | IE | IE |
| 2 C 5 e | Other Metal Production | 0.04 | 1.28 | 1.34 | 198.49 |
| 2 C 5 f | Storage, Handling and Transport of Metal Products | IE | IE | IE | IE |
| 2 D 1 | Pulp and Paper | 30.89 | 13.17 | 13.65 | 7.06 |
| 2 D 2 | Food and Drink | NA | NA | 2.60 | NA |
| 2 D 3 | Wood Processing | 19.40 | 2.95 | 33.45 | 0.18 |
| 2 E | Production of POPs | NO | NO | NO | NO |
| 2 F | Consumption of POPs and Heavy Metals (e.g. electrical and scientific equipment) | NA | NA | NA | NA |
| 2 G | Other Production, Consumption, Storage, Transportation or Handling of Bulk Products | 6.04 | 1.79 | 42.55 | 1.40 |
| 3 A 1 | Decorative Coating Application | NA | NA | IE | NA |
| 3 A 2 | Industrial Coating Application | NA | NA | IE | NA |
| 3 A 3 | Other Coating Application | NA | NA | 77.40 | NA |
| 3 B 1 | Degreasing | NA | NA | 253.54 | NA |
| 3 B 2 | Dry cleaning | NA | NA | 0.30 | NA |
| 3 C | Chemical products | 0.00 | 0.00 | 0.89 | 0.00 |
| 3 D 1 | Printing | NA | NA | 43.06 | NA |
| 3 D 2 | Domestic Solvent Use Including Fungicides | NA | NA | IE | NA |
| 3 D 3 | Other Product Use | NA | NA | NA | NA |
| 4 B 1 a | Cattle Dairy | 0.00 | NA | 26.32 | NA |
| 4 B 1 b | Cattle Non-Dairy | 0.00 | NA | 224.88 | NA |
| 4 B 2 | Buffalo | NE | NA | NE | NA |
| 4 B 3 | Sheep | 0.00 | NA | 1.49 | NA |
| 4 B 4 | Goats | IE | NA | IE | NA |
| 4 B 6 | Horses | NA | NA | 1.86 | NA |
| 4 B 7 | Mules and Asses | NA | NA | 0.00 | NA |
| 4 B 8 | Swine | NA | NA | 2.40 | NA |
| 4 B 9 a | Laying Hens | NA | NA | 0.06 | NA |
| 4 B 9 b | Broilers | NA | NA | 0.14 | NA |
| 4 B 9 c | Turkeys | NA | 0.00 | 0.02 | NA |
| 4 B 9 d | Other Poultry | NA | 0.00 | 0.22 | NA |
| 4 B 13 | Other | NA | 0.00 | 0.00 | NA |
| 4 D 1 a | Synthetic N-fertilizers[2] | NA | 0.00 | 0.00 | NA |
| 4 D 2 a | Farm-level Agricultural Operations Including Storage, Handling and Transport of Agricultural Products | NA | 0.00 | 0.00 | NA |
| 4 D 2 b | Off-farm Storage, Handling and Transport of Bulk Agricultural Products | 0.12 | 0.24 | 2.81 | 0.11 |
| 4 D 2 c | N-excretion on Pasture Range and Paddock Unspecified | NA | 0.00 | NA | NA |
| 4 F | Field Burning of Agricultural Wastes | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 G | Agriculture Other[3] | IE | IE | IE | IE |
| 6 A | Solid Waste Disposal on Land | NA | NA | 11.71 | NA |
| 6 B | Waste-water Handling | NA | NA | IE | NA |
| 6 C a | Clinical Waste Incineration[4] | IE | IE | IE | IE |
| 6 C b | Industrial Waste Incineration[4] | 1.90 | 0.64 | 0.64 | 0.52 |
| 6 C c | Municipal Waste Incineration[4] | 5.43 | 3.39 | 1.87 | 2.32 |
| 6 C d | Cremation | 0.02 | 0.02 | 0.00 | 0.01 |
| 6 C e | Small-scale Waste Burning | 11.18 | 0.80 | 3.99 | 0.13 |
| 6 D | Other Waste[5] | 0.58 | 0.65 | 0.34 | 0.08 |
| 7 A | Other (included in National Total for Entire Territory) | 13.56 | 0.29 | 2.74 | 0.00 |
| National Total for Entire Territory[6] | | 8789.93 | 1963.54 | 2007.66 | 1476.11 |

# Annex 11

## Supplementary Information Required under Article 7.1 of the Kyoto Protocol

This annex serves the purpose of reporting supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol (KP). At its first meeting, the Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol, agreed to guidelines for the preparation of the information required under Article 7 of the Kyoto Protocol (Decision 15/CMP.1 in FCCC/KP/CMP/2005/8/Add.2). The required supplementary information is to be provided in different documents: a party's Initial Report[1] (as per Annex to Decision 13/CMP.1), and a dedicated annex to the National Inventory Report.

This annex provides supplementary information on
- Land Use, Land-use Change and Forestry (LULUCF) activities under articles 3.3 and 3.4;
- accounting units;
- changes to the national system;
- changes to the national registry; and
- minimization of adverse impacts in accordance with article 3.14.

## A11.1. Supplementary Information Required under Articles 3.3 and 3.4

To facilitate the review of the required information, Table A11–1 lists all reporting requirements from paragraphs 5 to 9 in the annex to Decision 15/CMP.1, and indicates the location of this information in the present inventory report.

### A11.1.1. General Information

Canada's Monitoring Accounting and Reporting System (MARS) for Land Use, Land-use Change and Forestry has been designed and is flexible enough to meet the monitoring, accounting and reporting requirements of both the United Nations Framework Convention on Climate Change (UNFCCC – LULUCF Sector) and the Kyoto Protocol (LULUCF activities under articles 3.3 and 3.4). To achieve this objective while minimizing duplication and inconsistencies, Canada has sought to implement, to the extent possible, the same definitions, approaches and methodologies for the development of Convention and Kyoto Protocol estimates.

Hence, the definition of "forest" as described in Canada's initial report for use in accounting for its activities under Article 3, paragraphs 3 and 4, is equally applied to Convention estimates. The definition is based on the following single minimum values:

Minimum tree crown cover = 25%
Minimum land area = 1 ha
Minimum tree height = 5 m

In addition, as recommended in Chapter 4 of *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003), Canada has identified a minimum width of 20 metres (distance between trunks) as a definitional criterion to specify the shape of the forests. These parameters have been implemented in the procedures for mapping forest conversion under the Convention, and deforestation under the Kyoto Protocol.

Tables NIR-1 and NIR-3 of the KP module show which KP-LULUCF estimates are reported by Canada. All estimates relative to Article 3, paragraph 3 activities and to Cropland Management under Article 3, paragraph 4 are provided, with two exceptions: there is no liming occurring on afforested land, and emissions from liming on deforested land are included in the estimates provided for Cropland Management activities.

None of the LULUCF estimates reported by Canada explicitly factor in, or out, the putative effects of elevated atmospheric concentrations of $CO_2$ compared to pre-industrial levels, or of nitrogen deposition. The current knowledge on these indirect effects remains too limited to allow any

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**A11**

Table A11–1   Location of Additional Information Reported on LULUCF Activities Under the Kyoto Protocol

| INFORMATION ELEMENT | LOCATION |
|---|---|
| Emissions by sources and removals by sinks are clearly distinguished from emissions from Annex A sources. | 1. Annex A sources: CRF tables for categories 1, 2, 3, 4 and 6<br>2. LULUCF estimates under the Convention: CRF category 5<br>3. LULUCF estimates under the KP: CRF KP module " |
| Information on how inventory methodologies have been applied taking into account IPCC Good Practice Guidance for LULUCF and Decision 16/CMP.1. | Annex 11, Section 1, and references therein to Chapter 7 and Annex 3, Section 4 |
| Information on geographical location of the boundaries of areas that encompass: | |
| Units of land subject to activities under Article 3.3 | Annex 11, Section 1 and references therein to Chapter 7 and methodological Annex 3, Section 4 |
| Units of land subject to activities under Article 3.3, which would otherwise be included in land subject to elected activities under Article 3.4 | Actual estimates are provided by reporting zone in CRF KP module. |
| Land subject to elected activities under Article 3.4 | |
| Information on the spatial assessment unit for determining the area of accounting for afforestation, reforestation and deforestation. | Annex 11, Section 1 and references therein to Chapter 7 and methodological Annex 3, Section 4 |
| Information on GHGs resulting from activities under Article 3, paragraphs 3 and 4, for all geographical locations reported in the current and previous years since the beginning of the commitment period or the onset of the activity, whichever comes later. | 1. CRF KP module<br>2. Annex 11, Section 1 and references therein to Chapter 7 and methodological Annex 3, Section 4 |
| Information on which pools (above-ground / below-ground biomass, litter, dead wood and soil organic carbon) were not accounted for. | Annex 11, Section 1 and references therein to Chapter 7 and methodological Annex 3, Section 4 |
| Information should also be provided which indicates whether anthropogenic GHGs from LULUCF activities under KP3.3 + 3.4 factor out removals from: | |
| Elevated carbon dioxide concentrations above pre-industrial levels | Annex 11, Section 1 |
| Indirect nitrogen deposition | |
| The dynamic effects of age structure resulting from activities prior to 1 January 1990. | Not applicable |
| Specific information to be reported for Article 3.3 activities: | |
| Information that activities under Article 3.3 began on or after 1 January 1990 and before 31 December of the last year of the commitment period | Annex 11, Section 1 and references therein to Chapter 7 and methodological Annex 3, Section 4 |
| Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from deforestation | Annex 11, Section 1 |
| Information on emissions/removals from lands harvested during the first commitment period following afforestation and reforestation on these units of land since 1990. | Annex 11, Section 1 |
| Specific information to be reported for Article 3.4 activities: | |
| Information that activities under Article 3.4 occurred since 1 January 1990 and are human induced | Annex 11, Section 1 and references therein to Chapter 7 and methodological Annex 3, Section 4 |
| Cropland management, grazing land management, revegetation: emissions/removals reported for each year of the commitment period and for the base year for each of the elected activities on the geographical locations reported | CRF KP module |
| Information that emissions/removals from Article 3.4 activities are not accounted for under activities under Article 3.3 | Annex 11, Section 1 and references therein to Chapter 7 and methodological Annex 3, Section 4 |
| Forest management: information on the extent that GHG removal by sinks offsets the debit incurred under Article 3.3 | Not applicable |

reliable quantification at the scale of the Canadian land-scape.

## A11.1.2. Land Information

Canada's MARS for LULUCF uses a consistent spatial framework for the geographical referencing of all LULUCF estimates to "reporting zones". This framework, described in Chapter 7, Section 2 and Annex 3, Section 3.4.1 of the current report, is used to report all LULUCF estimates, including cropland management, afforestation, reforestation and deforestation under the Kyoto Protocol (see CRF KP module). The framework is compliant with the method used to identify the lands in the IPCC Method 1 (IPCC 2003, page 4.24, Section 4.2.2.2) by which multiple land units subject to afforestation, reforestation, deforestation or cropland management are encompassed within established geo-referenced boundaries (the reporting zones described in Chapter 7).

Canada's LULUCF system is integrated in such a way that different modelling frameworks for forest, cropland or wetlands can nevertheless exchange information on land that is converted from one category to another, using consistent spatial referencing. This ensures that neither land nor associated GHG estimates are double counted.

The land transition matrix (Table NIR-2) is very different from the LULUC matrix of Chapter 7. Under the Convention, the national territory is divided into six categories, while under the KP it is divided among the following four KP categories: Afforestation/Reforestation, Deforestation, Cropland Management, and Other. Since Canada has not chosen Forest Management, deforestation activities that occurred in 2009 are entirely captured in the land transition from Other to Deforestation; all Afforestation activities that occurred in 2009 are represented as a transition from Cropland Management. The 0.21 kha of land gained by Cropland Management in 2009 originated from grassland (in the Convention), but in the KP matrix are reported as a land transition from the category Other.

Inconsistencies between Convention and KP LULUCF area estimates for 2009 resulted solely from the differences in the temporal frameworks of otherwise comparable events such as "Forest Conversion" under the Convention and "Deforestation" under the KP. For example, the area of "Forest Conversion" (1019 kha) for inventory year 2009 equals the total forest area converted to other land categories from January 1, 1990, (from January 1, 2000, in the case of con-

version to reservoirs) to December 31, 2009; the "Deforestation" area [1023 kha in Table 5(KP-1)A.2] is the total area converted from January 1, 1990, to December 31, 2009. The difference amounts to -3.9 kha and corresponds to forests converted to reservoirs before 2000. These Convention and KP estimates will increasingly diverge after inventory year 2009, since areas deforested after December 31, 1989, will remain in the Deforestation category under KP, whereas the 20-year transition rule (10 years in the case of conversion to reservoirs) will continue to apply to the category "Forest Conversion" under the Convention.

Table 5(KP-1)A.2.1 illustrates the artefact of the Deforestation definition, which leads to ever-increasing area estimates, while in reality the annual rate of forest conversion in Canada has significantly decreased, from 76 kha in 1990 to 45 kha in 2009, as reflected in the Convention estimates.

## A11.1.3. Information Specific to Activities under Article 3, Paragraph 3

The general approach to estimate deforestation is the same as that used for forest conversion, and is described in Annex 3.4 of the present report, Section A3.4.2.2, including quality control procedures and uncertainty estimates. The core method involves identifying and interpreting the changes observed on Landsat imagery between two dates. Each deforestation event identified and larger than 1 ha is manually delineated. The 1975, 1990, 2000 and 2008 imagery, and abundant ancillary information, ensure that events are accurately assigned to the proper time period. A standard interpolation procedure is used to calculate annual deforestation rates, by cause, for each spatial unit, allowing a query and compilation of all events for each individual inventory year. The procedures are fully documented in Leckie et al. (2006).

Canada distinguishes a temporary loss of forest (due to harvesting or forest disturbance) from deforestation through the same system of visual interpretation of satellite imagery supported by ancillary data (as described above and in Annex 3.4 of this report). Potential causes of deforestation are captured explicitly and are subject to regular quality control procedures. The main potential causes of deforestation due to harvesting are forest roads and landings, which are explicitly captured, and insufficient regeneration, which is an exception and is not explicitly captured. Harvested areas are assumed to regenerate to forests that meet the definition stated above. A back-

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ground study (Canadian Forest Service 2008) determined that the small potential for such deforestation (0–0.5% of the harvested area) was well within the error bounds of the estimate of the total forest area converted annually in Canada.

Emission estimates from deforestation and afforestation/reforestation are developed in the same modelling framework as for all forest-related land-use change under the Convention, which is summarized in Annex 3, Section A3.4.2.1. The modelling framework notably includes all carbon pools.

Note that none of the afforestation land has been harvested since 1990; due to the slow tree growth rates under the Canadian climate, newly planted stands require several decades before reaching merchantable levels.

### A11.1.4. Information Specific to Activities under Article 3, Paragraph 4

Cropland management estimates for the years 2008 and 2009 (net removals of 11.7 and 12.4 Mt $CO_2$, respectively) reflect the combined effects of various changes in agricultural land management practices, and also include the residual emissions from pre-1990 forest conversion; both are described in more detail in Chapter 7 and Annex 3.4 of this report. KP estimates are constructed in essentially the same way as Convention estimates, the difference being that emissions and removals on forest land converted to cropland since January 1, 1990 (net emissions of 5.46 Mt $CO_2$ in 2008 and 5.51 in 2009) are reported under the Deforestation KP category. The ability to quantify emissions and removals on forest land converted to cropland, and report them under the category Deforestation, ensures that there is no double counting between the two activities. Likewise, cropland converted to forest is removed from the cropland modelling framework, thereby eliminating possible double counting of activities on these lands.

The management practices that drive emissions and removals on cropland soils are documented in the *Census of Agriculture*, which is published every five years. Changes in these practices are determined from a consistent time series of census data since 1981, allowing the best possible temporal allocation. Annex 3.4 of the present report provides more information.

Burning of perennial, woody biomass is not occurring on

Canadian cropland. A full time series of non-$CO_2$ emissions from controlled burning of crop residues is reported in the Agriculture Sector (see Chapter 6,).

## A11.2. Information on Accounting of Kyoto Units

### A11.2.1. Canada's Assigned Amount

Canada's assigned amount has been established as 2 791 792 771 tonnes $CO_2$ eq (UNFCCC Report of the review of Canada's Initial Report Under the Kyoto Protocol [2008]).[2]

### A11.2.2. Canada's Commitment Period Reserve

In accordance with Decision 11/CMP.1, the commitment period reserve is either 90% of a Party's assigned amount **or** 100% of five times its most recently reviewed inventory, whichever is lowest. Therefore Canada's commitment period reserve is calculated as either:

    a)  90% of Canada's assigned amount
        = 0.9 × 2 791 792 771 tonnes $CO_2$ eq
        = 2 512 613 494 tonnes $CO_2$ eq

or

    b)  100% of 5 × Canada's most recently reviewed inventory (2006)
        = 5 × 720 631 734 tonnes $CO_2$ eq
        = 3 603 158 670 tonnes $CO_2$ eq

The lower of the two numbers in a) and b) above is then calculated as 90% of Canada's assigned amount in a).

Therefore, Canada's commitment period reserve is 2 512 613 494 tonnes of $CO_2$ eq.

### A11.2.3. Reported Information in Standard Electronic Format Tables

In accordance with Decision 15/CMP.1 and reporting requirements under Article 7, paragraph 1 of the Kyoto Protocol, Parties included in Annex I must report in their

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2 UNFCCC's review of Canada's Initial Report Under the Kyoto Protocol is available online at http://unfccc.int/national_reports/initial_reports_under_the_kyoto_protocol/items/3765.php

Table A11–2    Total Quantities of Kyoto Protocol Units by Account Type at Beginning of 2010.[1]

| Account type | Unit type | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | AAUs | ERUs | RMUs | CERs | tCERs | ICERs |
| Party holding accounts | NO | NO | NO | NO | NO | NO |
| Entity holding accounts | NO | NO | NO | NO | NO | NO |
| Article 3.3/3.4 net source cancellation accounts | NO | NO | NO | NO | | |
| Non-compliance cancellation accounts | NO | NO | NO | NO | | |
| Other cancellation accounts | NO | NO | NO | NO | NO | NO |
| Retirement account | NO | NO | NO | NO | NO | NO |
| tCER replacement account for expiry | NO | NO | NO | NO | NO | |
| ICER replacement account for expiry | NO | NO | NO | NO | | |
| ICER replacement account for reversal of storage | NO | NO | NO | NO | | NO |
| ICER replacement account for non-submission of certification report | NO | NO | NO | NO | | NO |
| Total | NO | NO | NO | NO | NO | NO |

Notes:

1. Unit types (AAUs, ERUs, etc.) are fully defined in the Annex to Decision 9/CMP.1

Table A11–3    Annual Internal Transactions and Retirements

| Transaction Type | Additions | | | | | | Subtractions | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Unit type | | | | | | Unit type | | | | | |
| | AAUs | ERUs | RMUs | CERs | tCERs | ICERs | AAUs | ERUs | RMUs | CERs | tCERs | ICERs |
| **Article 6 issuance and conversion** | | | | | | | | | | | | |
| Party-verified projects | | NO | | | | | NO | | NO | | | |
| Independently verifed projects | | NO | | | | | NO | | NO | | | |
| **Article 3.3 and 3.4 issuance or cancellation** | | | | | | | | | | | | |
| 3.3 Afforestation and reforestation | | | NO | | | | NO | NO | NO | NO | | |
| 3.3 Deforestation | | | NO | | | | NO | NO | NO | NO | | |
| 3.4 Forest management | | | NO | | | | NO | NO | NO | NO | | |
| 3.4 Cropland management | | | NO | | | | NO | NO | NO | NO | | |
| 3.4 Grazing land management | | | NO | | | | NO | NO | NO | NO | | |
| 3.4 Revegetation | | | NO | | | | NO | NO | NO | NO | | |
| **Article 12 afforestation and reforestation** | | | | | | | | | | | | |
| Replacement of expired tCERs | | | | | | | NO | NO | NO | NO | NO | |
| Replacement of expired ICERs | | | | | | | NO | NO | NO | NO | | |
| Replacement for reversal of storage | | | | | | | NO | NO | NO | NO | | NO |
| Replacement for non-submission of certification report | | | | | | | NO | NO | NO | NO | | NO |
| **Other cancellation** | | | | | | | NO | NO | NO | NO | NO | NO |
| Sub-total | | NO | NO | | | | NO | NO | NO | NO | NO | NO |

| Transaction Type | Retirement | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | Unit type | | | | | |
| | AAUs | ERUs | RMUs | CERs | tCERs | ICERs |
| **Retirement** | NO | NO | NO | NO | NO | NO |

Table A11–4    Annual External Transactions and Additional Information

| | Additions | | | | | | Subtractions | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Unit type | | | | | | Unit type | | | | | |
| | AAUs | ERUs | RMUs | CERs | tCERs | ICERs | AAUs | ERUs | RMUs | CERs | tCERs | ICERs |
| **Transfers and acquisitions** | | | | | | | | | | | | |
| CDM | NO | NO | NO | 216750 | NO | NO | NO | NO | NO | NO | NO | NO |
| Sub-total | NO | NO | NO | 216750 | NO | NO | NO | NO | NO | NO | NO | NO |
| Independently verified ERUs | | | | | | | | NO | | | | |

Table A11–5    Total Annual Transactions

| | Additions | | | | | | Subtractions | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Unit type | | | | | | Unit type | | | | | |
| | AAUs | ERUs | RMUs | CERs | tCERs | ICERs | AAUs | ERUs | RMUs | CERs | tCERs | ICERs |
| **Total** (Sum of tables 2a and 2b) | NO | NO | NO | 216750 | NO | NO | NO | NO | NO | NO | NO | NO |

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Table A11–6    Expiry, Cancellation and Replacement

| Transaction or event type | Expiry, cancellation and requirement to replace | | Replacement | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Unit type | | Unit type | | | | | |
| | tCERs | ICERs | AAUs | ERUs | RMUs | CERs | tCERs | ICERs |
| **Temporary CERs (tCERS)** | | | | | | | | |
| Expired in retirement and replacement accounts | NO | | | | | | | |
| Replacement of expired tCERs | | | NO | NO | NO | NO | NO | |
| Expired in holding accounts | NO | | | | | | | |
| Cancellation of tCERs expired in holding accounts | NO | | | | | | | |
| **Long-term CERs (lCERs)** | | | | | | | | |
| Expired in retirement and replacement accounts | | NO | | | | | | |
| Replacement of expired lCERs | | | NO | NO | NO | NO | | |
| Expired in holding accounts | | NO | | | | | | |
| Cancellation of lCERs expired in holding accounts | | NO | | | | | | |
| Subject to replacement for reversal of storage | | NO | | | | | | |
| Replacement for reversal of storage | | | NO | NO | NO | NO | | NO |
| Subject to replacement for non-submission of certification report | | NO | | | | | | |
| Replacement for non-submission of certification report | | | NO | NO | NO | NO | | NO |
| **Total** | | | NO | NO | NO | NO | NO | NO |

Table A11–7    Total Quantities of Kyoto Protocol Units by Account Type at End of 2010

| Account type | Unit type | | | | | |
|---|---|---|---|---|---|---|
| | AAUs | ERUs | RMUs | CERs | tCERs | ICERs |
| Party holding accounts | 2.79E+09 | NO | NO | 216750 | NO | NO |
| Entity holding accounts | NO | NO | NO | NO | NO | NO |
| Article 3.3/3.4 net source cancellation accounts | NO | NO | NO | NO | | |
| Non-compliance cancellation accounts | NO | NO | NO | NO | | |
| Other cancellation accounts | NO | NO | NO | NO | NO | NO |
| Retirement account | NO | NO | NO | NO | NO | NO |
| tCER replacement account for expiry | NO | NO | NO | NO | NO | |
| lCER replacement account for expiry | NO | NO | NO | NO | | |
| lCER replacement account for reversal of storage | NO | NO | NO | NO | | NO |
| lCER replacement account for non-submission of certification report | NO | NO | NO | NO | | NO |
| **Total** | 2.79E+09 | NO | NO | 216750 | NO | NO |

Table A11–8    Summary Information on Additions and Subtractions

| Starting values | Additions | | | | | | Subtractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Unit type | | | | | | Unit type | | | | | |
| | AAUs | ERUs | RMUs | CERs | tCERs | ICERs | AAUs | ERUs | RMUs | CERs | tCERs | ICERs |
| Issuance pursuant to Article 3.7 and 3.8 | 2.79E+09 | | | | | | | | | | | |
| Non-compliance cancellation | | | | | | | NO | NO | NO | NO | | |
| Carry-over | NO | NO | | NO | | | | | | | | |
| Sub-total | 2.79E+09 | NO | | NO | | | NO | NO | NO | NO | | |
| **Annual transactions** | | | | | | | | | | | | |
| Year 0 (2007) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 1 (2008) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 2 (2009) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 3 (2010) | NO | NO | NO | 216750 | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 4 (2011) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 5 (2012) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 6 (2013) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 7 (2014) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 8 (2015) | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| Sub-total | NO | NO | NO | 216750 | NO | NO | NO | NO | NO | NO | NO | NO |
| **Total** | 2.79E+09 | NO | NO | 216750 | NO | NO | NO | NO | NO | NO | NO | NO |

Table A11–9     Summary Information on Replacement

| | Requirement for replacement | | Replacement | | | | | |
| | Unit type | | Unit type | | | | | |
| | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
|---|---|---|---|---|---|---|---|---|
| Previous CPs | | | NO | NO | NO | NO | NO | NO |
| Year 1 (2008) | | NO | NO | NO | NO | NO | NO | NO |
| Year 2 (2009) | | NO | NO | NO | NO | NO | NO | NO |
| Year 3 (2010) | | NO | NO | NO | NO | NO | NO | NO |
| Year 4 (2011) | | NO | NO | NO | NO | NO | NO | NO |
| Year 5 (2012) | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 6 (2013) | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 7 (2014) | NO | NO | NO | NO | NO | NO | NO | NO |
| Year 8 (2015) | NO | NO | NO | NO | NO | NO | NO | NO |
| Total | NO | NO | NO | NO | NO | NO | NO | NO |

Table A11–10    Summary Information on Retirement

| | Retirement | | | | | |
| | Unit type | | | | | |
| Year | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
|---|---|---|---|---|---|---|
| Year 1 (2008) | NO | NO | NO | NO | NO | NO |
| Year 2 (2009) | NO | NO | NO | NO | NO | NO |
| Year 3 (2010) | NO | NO | NO | NO | NO | NO |
| Year 4 (2011) | NO | NO | NO | NO | NO | NO |
| Year 5 (2012) | NO | NO | NO | NO | NO | NO |
| Year 6 (2013) | NO | NO | NO | NO | NO | NO |
| Year 7 (2014) | NO | NO | NO | NO | NO | NO |
| Year 8 (2015) | NO | NO | NO | NO | NO | NO |
| Total | NO | NO | NO | NO | NO | NO |

Table A11–11    Memo Item: Corrective Transactions Relating to Additions and Subtractions

| | Additions | | | | | | Subtractions | | | | | |
| | Unit type | | | | | | Unit type | | | | | |
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | |

Table A11–12    Memo Item: Corrective Transactions Relating to to Replacement

| | Requirement for replacement | | Replacement | | | | | |
| | Unit type | | Unit type | | | | | |
| | tCERs | lCERs | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |

Table A11–13    Memo Item: Corrective Transactions Relating to Retirement

| | Retirement | | | | | |
| | Unit type | | | | | |
| | AAUs | ERUs | RMUs | CERs | tCERs | lCERs |
|---|---|---|---|---|---|---|
| | | | | | | |

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Table A11–14    Information Elements to be Reported on Kyoto Protocol Accounting Units

| INFORMATION ELEMENT | Report |
|---|---|
| 15/CMP.1 Annex I.E, paragraph 11: Standard electronic format (SEF) | See Section A11.2.3. The SEF tables have been submitted to the UNFCCC. |
| 15/CMP.1 Annex I.E, paragraph 12: List of discrepant transactions | Canada had no discrepant transactions for the reporting year. |
| 15/CMP.1 Annex I.E, paragraphs 13 & 14: List of CDM notifications | Canada did not receive any CDM notifications in the reporting year. |
| 15/CMP.1 Annex I.E, paragraph 15: List of non-replacements | Canada had no non-replacements for the reporting year. |
| 15/CMP.1 Annex I.E paragraph 16: List of invalid units | Canada had no invalid units for the reporting year. |
| 15/CMP.1 Annex I.E, paragraph 17: Actions and changes to address discrepancies | Canada did not require any actions or changes to address discrepancies for the reporting year. |

inventory submissions information on their holdings and transactions of KP units. Table A11–2 to Table A11–13 provide, for Canada, the information specified in 15/CMP.1 Annex 1E, paragraph 11, in standard electronic formats.

In accordance with Decision 15/CMP.1 and reporting requirements under Article 7, paragraph 1 of the Kyoto Protocol, Parties included in Annex I must further report in their inventory submission, information on notifications received, records of non-replacement and additional information of a similar nature. Table A11–14 indicates where such information is provided, when applicable.

## A11.3.    Information on Changes to Canada's National System

Canada has not made any changes to its national system as compared to information reported since the 2009 submission. A description of how the national system is performing the general and specific functions, as defined in the guidelines for national systems under Article 5, paragraph 1, is provided in the National Inventory Report (NIR). To facilitate the review of the information, Table A11–15 indicates the location of this information in the present inventory report.

Table A11–15    Location of Supplementary Information Reported on the National System under the Kyoto Protocol

| | INFORMATION ELEMENT | Change from 2009 Submission | LOCATION |
|---|---|---|---|
| 30 (a) | The name and the contact information for the national entity and its designated representative with overall responsibility for the national inventory of the Party. | No | Chapter 1.2 |
| 30 (b) | The roles and responsibilities of various agencies and entities in relation to the inventory development process, as well as the institutional, legal and procedural arrangements made to prepare the inventory | No | Chapter 1.2.3 |
| 30 (c) | A description of the process for collecting activity data, for selecting emission factors and methods, and for the development of emission estimates | No | Chapter 1, Section 4 and throughout text |
| 30 (d) | A description of the process and the results of key source identification and, where relevant, archiving of test data | No | Annex 1 |
| 30 (e) | A description of the process for the recalculation of previously submitted inventory data | No | Chapter 9 |
| 30 (f) | A description of the quality assurance and quality control plan, its implementation and the quality objectives established, and information on internal and external evaluation and review processes and their results in accordance with the guidelines for national systems | No | Annex 6 and relevant sections within Chapters 3-8 Chapter 1.3 |
| 30 (g) | A description of the procedures for the official consideration and approval of the inventory. | No | Chapter 1.3 |

Table A11–16   Changes to Information Reported on the National Registry under the Kyoto Protoco

| Information Element | Change from last submission | Updated Information |
|---|---|---|
| The name and the contact information of the registry administrator designated by the Party to maintain the national registry | Yes | "Environment Canada, Legislative and Regulatory Affairs Division Primary Contact: Lynda Danquah Environment Canada, Legislative and Regulatory Affairs Directorate Trading Regimes Division lynda.danquah@ec.gc.ca 819-956-4448 351 St. Joseph Blvd. Gatineau, Quebec  K1A 0H3" Secondary contact: No change has been made to the secondary contact. |
| The names of the other Parties with which the Party cooperates by maintaining their national registries in a consolidated system | No | In accordance with Decision 15/CMP.1 and Article 7 of the Kyoto Protocol, Canada's Kyoto Protocol National Registry maintains its national registry as a stand-alone system, and does not maintain a system that is consolidated with other national registries. |
| A description of the database structure and capacity of the national registry | No | No changes have been made to the database or the capacity of Canada's Kyoto Protocol National Registry. |
| A description of how the national registry conforms to the technical standards for data exchange between registry systems for the purpose of ensuring the accurate, transparent and efficient exchange of data between national registries, the clean development registry and the transaction log (Decision 19/CP.7, paragraph 1)12 | Yes | In February 2010, Canada's Kyoto Protocol National Registry successfully connected with the International Transaction Log. |
| A description of the procedures employed in the national registry to minimize discrepancies in the issuance, transfer, acquisition, cancellation and retirement of Emission Reduction Units (ERUs), Certified Emission Reduction (CERs), temporary CERs (tCERs), long-term CERs (lCERs), Assigned Amount Units (AAUs) and/or Removal Units (RMUs), and replacement of tCERS and lCERs, and of the steps taken to terminate transactions where a discrepancy is notified and to correct problems in the event of a failure to terminate the transactions | No | No changes have been made to the procedures of Canada's Kyoto Protocol National Registry. |
| An overview of security measures employed in the national registry to prevent unauthorized manipulations and to prevent operator error, and an overview of how these measures are kept up to date | Yes | As Canada's Kyoto Protocol National Registry was not open to entity accounts, there was no need to make any changes to the security of the Registry. A threat and risk assessment and a risk mitigation plan were prepared and Canada will implement additional authentication measures before the Registry is open to entity accounts. |
| A list of the information publicly accessible by means of the user interface to the national registry | Yes | Publicly available information related to Canada's Kyoto Protocol National Registry was made available on the Registry website located at: http://www.ec.gc.ca/rncpk-ckpnr/default.asp?lang=En&n=1F96522D-1 |
| The Internet address of the interface to its national registry | No | No changes have been made to the Internet address of the national registry. |
| A description of measures taken to safeguard, maintain and recover data in order to ensure the integrity of data storage and the recovery of registry services in the event of a disaster | No | No changes were made to the data integrity measures of Canada's Kyoto Protocol National Registry during the reporting period. |
| The results of any test procedures that might be available or developed with the aim of testing the performance, procedures and security measures of the national registry undertaken pursuant to the provisions of Decision 19/CP.7 relating to the technical standards for data exchange between registry systems. | Yes | Testing and assessment of unit block fragmentation was performed to address the issues of fragmentation in Canada's Kyoto Protocol National Registry. The outcome of this testing identified that Canada's national registry could not process sufficient number of unit blocks. In addition to this, Canada's Kyoto Protocol National Registry was found to not be able to gracefully terminate transactions above the variable limit of 3000 unit blocks. To address this issue, Canada's Kyoto Protocol National Registry is scheduled to be enhanced in order to gracefully terminate transactions that exceed the 1000 character limit. |

## A11.4. Changes in Canada's National Registry

As per 15/CMP.1 Annex I, G, each Party included in Annex I with a commitment inscribed in Annex B shall include in its national inventory report, information on any changes that have occurred in its national registry, compared with information reported in its last submission, including information submitted in accordance with paragraph 32 of the guidelines.

To facilitate the review, Table A11–16 lists all changes to reporting requirements from paragraph 32 in Annex II to Decision 15/CMP.1, and provides the updated information (where applicable).

## A11.5. Minimization of Adverse Impacts in Accordance with Article 3.14

Canada's efforts to implement its commitments under Article 3, paragraph 1, of the Kyoto Protocol are undertaken in such a way as to minimize potentially adverse social, environmental and economic impacts on developing country Parties. The processes to establish and implement climate change response measures include consultations with federal departments with international responsibilities, including the Department of Foreign Affairs and International Trade and the Canadian International Development Agency, which provide advice on international aspects of proposed measures. Canada also consults with provinces and territories and other key stakeholders on issues related to the impacts of proposed policies and measures.

Canada maintains an open trading environment, consistent with the principles of free trade and investment, ensuring that both developed and developing countries can maximize opportunities in Canada's market regardless of the climate change response measures Canada undertakes. Canada also works with partner developing countries to strengthen their governance and enabling environments, improving their ability to respond to changing circumstances.

Domestically, Canada's *Federal Sustainable Development Act* received Royal Assent on June 26, 2008. The Act responds to a number of international commitments Canada has made to produce such a strategy, including at the Earth

Summit in Rio de Janeiro, Brazil, in 1992 and at the 2002 World Summit on Sustainable Development in Johannesburg, South Africa. The development of a federal sustainable development strategy (FSDS), is mandated by the Act.

The first FSDS was tabled on October 6, 2010. The FSDS clearly identifies Canada's environmental sustainability priorities and reports on progress in achieving them. The FSDS presents a detailed description of federal government activities to achieve environmental sustainability. The FSDS also commits to strengthening the guidelines for strategic environmental assessments by federal departments which help integrate environmental considerations related to economic and social decision making. The Office of Greening Government Operations provides a series of guidelines to help departments and agencies implement and report progress on the FSDS. FSDSs must be updated every three years through a regular cycle of progress reports.

In terms of the progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse-gas-emitting sectors, taking into account the need for energy price reforms to reflect market prices and externalities, Canada has undertaken a number of fiscal and tax measures, the details of which can be found in *Canada's Fifth National Communication on Climate Change*[3], Section 4.5 (pages 43–58).

Information on Canada's adaptation assistance provided to developing countries can also be found in *Canada's Fifth National Communication on Climate Change*, Section 4.5 (pages 86–90).

In terms of activities related to the transfer of technologies, a detailed description of selected projects or programs that have promoted practicable steps to facilitate and/or finance the transfer of, or access to, environmentally sound technologies is provided in *Canada's Fifth National Communication on Climate Change*, Section 4.5 (pages 166–181).

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3    Canada's Fifth National Communication on Climate Change is available online at http://unfccc.int/resource/docs/natc/can_nc5.pdf

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