NATIONAL INVENTORY REPORT 1990–2019: GREENHOUSE GAS SOURCES AND SINKS IN CANADA

CANADA'S SUBMISSION TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

PART 2

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Canada

Cat. No.: En81-4E-PDF
ISSN: 1910-7064
EC8369

The Executive Summary of this report is available at: canada.ca/ghg-inventory

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Meteorological Service of Canada's 150th anniversary
150e anniversaire du Service météorologique du Canada

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LIST OF COMMON ABBREVIATIONS AND UNITS

Abbreviations

CAC ..... criteria air contaminant

CANSIM ..... Statistics Canada's key socioeconomic database

CEPA 1999 ..... *Canadian Environmental Protection Act, 1999*

CESI ..... Canadian Environmental Sustainability Indicators

CFC..... chlorofluorocarbon

CFS..... Canadian Forest Service

ECCC..... Environment and Climate Change Canada

EF ..... emission factor

GDP ..... gross domestic product

GHG..... greenhouse gas

GHGRP ..... Greenhouse Gas Reporting Program

HFC..... hydrofluorocarbon

HWP..... harvested wood products

IPCC ..... Intergovernmental Panel on Climate Change

IPPU ..... Industrial Proccesses and Product Use

LTO ..... landing and takeoff

LULUCF ..... Land Use, Land-Use Change and Forestry

MSW ..... municipal solid waste

N/A..... not available

NIR..... National Inventory Report

NMVOC..... non-methane volatile organic compound

NPRI ..... National Pollutant Release Inventory

ODS ..... ozone-depleting substance

OECD..... Organisation for Economic Co-operation and Development

PFC..... perfluorocarbon

POP ..... persistent organic pollutant

QA..... quality assurance

QC ..... quality control

RESD ..... *Report on Energy Supply and Demand in Canada*

UNECE..... United Nations Economic Commission for Europe

UNFCCC ..... United Nations Framework Convention on Climate Change

Chemical Formulas

Al ..... aluminium

Al_2O_3 ..... alumina

CaC_2 ..... calcium carbide

$CaCO_3$..... calcium carbonate; limestone

$CaMg(CO_3)_2$ ..... dolomite (also $CaCO_3 \cdot MgCO_3$)

CaO ..... lime; quicklime; calcined limestone

CF_4..... carbon tetrafluoride

C_2F_6..... carbon hexafluoride

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

$CHCl_3$ ..... chloroform

CO ..... carbon monoxide

CO_2 ..... carbon dioxide

CO_2 eq ..... carbon dioxide equivalent

H_2..... hydrogen

H_2O ..... water

H_2S..... hydrogen sulphide

HCFC ..... hydrochlorofluorocarbon

HCl..... hydrochloric acid

HF ..... hydrogen fluoride

HNO_3..... nitric acid

K_2CO_3..... potassium carbonate

Mg..... magnesium

$MgCO_3$ ..... magnesite; magnesium carbonate

MgO ..... magnesia; dolomitic lime

N ..... nitrogen

N_2 ..... nitrogen gas

Na_2CO_3 ..... sodium carbonate; soda ash

Na_3AlF_6 ..... cryolite

NF_3 ..... nitrogen trifluoride

NH_3 ..... ammonia

NH_4+ ..... ammonium

NH_4NO_3 ..... ammonium nitrate

N_2O ..... nitrous oxide

N_2O-N ..... nitrous oxide emissions represented in terms of nitrogen

NO ..... nitric oxide

NO_2 ..... nitrogen dioxide

NO_3- ..... nitrate

NO_x ..... nitrogen oxides

O_2 ..... oxygen

SF_6 ..... sulphur hexafluoride

SiC ..... silicon carbide

SO_2 ..... sulphur dioxide

SO_x ..... sulphur oxides

Notation Keys

IE ..... included elsewhere

NA ..... not applicable

NE ..... not estimated

NO ..... not occurring

Units

g ..... gram

Gg ..... gigagram

Gt ..... gigatonne

ha ..... hectare

kg ..... kilogram

kha ..... kilohectare

km ..... kilometre

kt ..... kilotonne

kWh ..... kilowatt-hour

m ..... metre

Mg ..... megagram

Mha ..... million hectares

mm ..... millimetre

ML ..... megalitre

Mt ..... megatonne

MW ..... megawatt

PJ ..... petajoule

t ..... tonne

TWh ..... terrawatt-hour

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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. The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) 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 greenhouse gases in terms of the absolute level of emissions and removals, the trend in emissions and removals, or uncertainty in emissions and removals" (IPCC, 2006); this term is used in reference to both source and sink categories.

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 their contribution 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 weight to the categories whose relative trend departs from the overall trend (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, 2006). This threshold has therefore been used in this analysis to define an upper boundary for key category identification. Hence, when source and 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 Assessment

Level contribution of each source or sink is calculated according to Equation A1–1, which follows IPCC (2006):

Equation A1–1 **for source/sink category level assessment**

$$L_{x,t} = \frac{|E_{x,t}|}{\sum_y |E_{y,t}|}$$

$L_{x,t}$ = level assessment for source or sink x in latest inventory year (year t)

$|E_{x,t}|$ = the absolute value of emission or removal estimate of source or sink category x in year t

$\sum_y |E_{y,t}|$ = total contribution, which is the sum of the absolute values of emissions and removals in year t calculated using the aggregation level chosen by the country for key category analysis; because both emissions and removals are entered with positive sign, the total contribution/level can be larger than a country's total emissions less removals

Trend Assessment

The trend contribution of each source and sink is calculated according to Equation A1–2 and Equation A1–3 following IPCC (2006). Note that the use of Equation A1–3 only applies to source and sink categories where there are zero emissions in the base year.

Equation A1–2 **for source/sink category trend assessment**

$$T_{x,t} = L_{x,0} \bullet \left| \left[\frac{(E_{x,t} - E_{x,0})}{|E_{x,0}|} \right] - \left[\frac{(\sum_y E_{y,t} - \sum_y E_{y,0})}{|\sum_y E_{y,0}|} \right] \right|$$

$T_{x,t}$ = trend assessment of source or sink category x in year t as compared to the base year (year 0)

$L_{x,0}$ = the level assessment for source or sink category x in year 0 (derived in Equation A1–1)

$E_{x,t}$ and $E_{x,0}$ = real values of estimates of source or sink category x in years t and 0, respectively

$\sum_y E_{y,t}$ and $\sum_y E_{y,0}$ = total inventory estimates in years t and 0, respectively

Equation A1–3 **for source and sink category trend assessment with zero base year emissions**

$$T_{x,t} = \left| \frac{E_{x,t}}{\sum_y |E_{y,0}|} \right|$$

$T_{x,t}$ = trend assessment of source or sink category x in year t as compared to the base year (year 0)

$E_{x,t}$ = real values of estimates of source or sink category x in year t

$\sum_y |E_{y,0}|$ = total inventory estimates in year 0

The overall purpose of identifying key categories is the institution of best practices in greenhouse gas inventory development. The appropriate aggregation of categories is crucial to reflect not only actual sources and sinks but also identical estimation procedures. In this analysis, sectors and major categories such as Fuel Combustion, Fugitive Emissions, Industrial Processes and Product Use (IPPU), Agriculture and Waste are in keeping with the common reporting format (CRF). Thus, while the UNFCCC CRF categories provide a basis for identifying sources and sinks, some aggregation of these sources and sinks has been made for the purpose of key category analysis. In general, the aggregation of categories has been performed when estimates are based on common emission factors and activity data. An exhaustive list of the aggregated categories as well as explanations regarding the rationale for category aggregation is presented in Table A1–1.

Summary Assessment

Key categories were assessed for the 2019 inventory year using level and trend criteria and for the base year using the level criterion only. There were 34 level key categories in 1990, while in 2019there were 30 with all combined criteria. Combined assessment results are presented in Table A1–2.

Table A1–1 **Aggregation of IPCC Categories**

Source Table	Aggregated IPCC Category	Categories Included in the Aggregated IPCC Categories	Rationale for Aggregation
1-A-1	Stationary Fuel Combustion – Energy Industries	Public Electricity and Heat Production	Table 4.1, Volume 1: General Guidance and Reporting of the 2006 IPCC Guidelines suggest aggregation to the 1-A-1 level for a Tier 1 approach (IPCC, 2006).
		Petroleum Refining	
		Manufacture of solid fuels and other energy industries	
1-A-2	Stationary Fuel Combustion – Manufacturing industries and construction	Iron and Steel	Table 4.1, Volume 1: General Guidance and Reporting of the 2006 IPCC Guidelines suggest aggregation to the 1-A-2 level for a Tier 1 approach (IPCC, 2006).
		Non-ferrous metals	
		Chemicals	
		Pulp, paper and print	
		Non-metallic minerals	
		Other	
1-A-3-b	Fuel Combustion – Road Transportation	Heavy-Duty Diesel Vehicles	Table 4.1 in Volume 1 : General Guidance and Reporting of the 2006 IPCC Guidelines suggest that road transportation be aggregated to the 1-A-3-b level for a Tier 1 approach (IPCC, 2006).
		Heavy-Duty Gasoline Vehicles	
		Light-Duty Diesel Trucks	
		Light-Duty Diesel Vehicles	
		Light-Duty Gasoline Trucks	
		Light-Duty Gasoline Vehicles	
		Motorcycles	
		Natural Gas Vehicles	
		Propane Vehicles	
		Urban Bus	
1-A-4	Stationary Fuel Combustion – Other Sectors	Commercial/institutional	Table 4.1, Volume 1: General Guidance and Reporting of the 2006 IPCC Guidelines suggest aggregation to the 1-A-4 level for a Tier 1 approach (IPCC, 2006).
		Residential	
		Agriculture/forestry/fisheries	
1-B-2-(a+c)	Fugitive Emissions – Oil	Oil	Table 4.1, Volume 1: General Guidance and Reporting of the 2006 IPCC Guidelines suggest aggregation to the 1-B-2-a level for a Tier 1 approach (IPCC, 2006).
		Venting – Oil	
		Flaring – Oil	
		Venting – Combined (split with 1-B-2-(b+c))	
		Flaring – Combined (split with 1-B-2-(b+c))	
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	Natural Gas	Table 4.1, Volume 1: General Guidance and Reporting of the 2006 IPCC Guidelines suggest aggregation to the 1-B-2-b level for a Tier 1 approach (IPCC, 2006).
		Venting – Natural Gas	
		Flaring – Natural Gas	
		Venting – Combined (split with 1-B-2-(a+c))	
		Flaring – Combined (split with 1-B-2-(a+c))	
2-B-8	Petrochemical and Carbon Black Production	Carbide Production (reported in $2B_5$ in the CRF, but with $2B_8$ for the purpose of key category analysis)	For simplicity and data confidentiality reasons, these categories are included in "Petrochemical and Carbon Black Production" for the purpose of key category analysis. Efforts will be made to disaggregate these categories in future inventories. See below for comments related to CO_2 emissions from certain petrochemical categories.
		Methanol Production	
		Ethylene Production	
		Ethylene Dichloride Production	
		Carbon Black Production	
		Styrene Production	
		Ethylene Oxide Production	
		Other (Other Uses of Urea) (reported in $2B_{10}$ in the CRF, but with $2B_8$ for the purpose of key category analysis)	

Table A1–1 **Aggregation of IPCC Categories** (cont'd)

Source Table	Aggregated IPCC Category	Categories Included in the Aggregated IPCC Categories	Rationale for Aggregation
2-C-1	Iron and Steel Production	Steel Production	Disaggregation of the reductant portion of steel production (i.e. metallurgical coke) is not available and therefore emissions have to be reported under category 2.C.1.b Pig Iron production.
		Pig Iron Production	
		Metal Industry – Ferroalloys Production	CO_2 emissions from Ferroalloys Production (CRF category 2.C.2) are included in CRF category 2.C.1.a Steel Production. Production of ferroalloys is a direct production of specialty steels from iron ore via the electric arc furnace prcess using reductants.
2-D-3	Non-energy Products from Fuels and Solvent Use Other – Other (Other and Undifferentiated)	CO_2 emissions from Carbide Production, Carbon Black Production, Styrene Production, and Ethylene Dichloride and Vinyl Chloride Monomer Production	Disaggregation of national statistics to broader categories is currently not possible.
		Iron and Steel – Sinter production	
		Iron and Steel – Pellet production	
		Metal Industry – Lead Production	
		Metal Industry – Zinc Production	
		Non-energy Products from Fuels and Solvent Use – Other (Solvent use)	
		Non-energy Products from Fuels and Solvent Use – natural gas, solid fuels and liquid fuels (including lubricant and paraffin wax use)	
2-F	Product Uses as Substitutes for Ozone Depleting Substances	Refrigeration and Air conditioning	For simplicity reasons, these categories are included in "Product Uses as Substitutes for Ozone Depleting Substances" for the purpose of key category analysis. Efforts will be made to disaggregate these categories in future inventories.
		Foam Blowing Agents	
		Fire Protection	
		Aerosols	
		Solvents	
		Other Applications	
3-A	Agriculture – Enteric Fermentation	Cattle	For simplicity, the estimates were input by category rather than subcategory. Efforts will be made to disaggregate these categories in future inventories.
		Sheep	
		Swine	
		Other Livestock	
3-B	Agiculture – Manure Management	N_2O and NMVOC Emissions – Cattle	For simplicity, the estimates were input by category rather than subcategory. Efforts will be made to disaggregate these categories in future inventories.
		N_2O and NMVOC Emissions – Sheep	
		N_2O and NMVOC Emissions – Swine	
		N_2O and NMVOC Emissions – Other Livestock	
		N_2O and NMVOC Emissions – Indirect N_2O Emissions	
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	Inorganic N Fertilizers	For simplicity, the estimates were input by category rather than subcategory. Efforts will be made to disaggregate these categories in future inventories.
		Organic N Fertilizers	
		Urine and Dung Deposited by Grazing Animals	
		Crop Residues	
		Mineralization/Immobilization Associated with Loss/ Gain of Soil Organic Matter	
		Cultivation of Organic Soils	
3-D-2	Agriculture – Indirect N_2O Emissions from Managed Soils	Atmospheric Deposition	For simplicity, the estimates were input by category rather than subcategory. Efforts will be made to disaggregate these categories in future inventories.
		Nitrogen Leaching and Run-Off	
4-A-1	LULUCF – Forest Land remaining Forest Land	Forest Land remaining Forest Land	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied. To facilitate the identification, planning and prioritization of efforts needed to improve land category estimates.
		Biomass Burning, Forest Land remaining Forest Land	
		Emissions and removals from drainage and rewetting and other management of organic and mineral soils, Forest Land	
4-B-2	LULUCF – Land converted to Cropland	Land converted to Cropland	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied.
		Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization resulting from change of land use or management of mineral soils	
		Biomass Burning, Land Converted to Cropland	
4-C-1	LULUCF – Grassland Remaining Grassland	Grassland Remaining Grassland	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied.
		Biomass Burning, Grassland Remaining Grassland	
4-D-1	LULUCF – Wetlands remaining Wetlands	Emissions and removals from drainage and rewetting and other management of organic and mineral soils for Peat extraction lands (*only emissions associated to peat extraction remaining peat extraction)	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied. To facilitate the identification, planning and prioritization of efforts needed to improve land category estimates.
		Flooded land remaining Flooded land	
4-D-2	LULUCF – Land converted to Wetlands	Land converted to Flooded land	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied. To facilitate the identification, planning and prioritization of efforts needed to improve land category estimates.
		Emissions and removals from drainage and rewetting and other management of organic and mineral soils, Peat extraction lands (*only emissions associated to Land converted to peat extraction)	
		Biomass Burning, Land converted to Wetlands	
4-E-2	LULUCF – Land converted to Settlements	Land converted to Settlements	To be consistent with the level of land categories at which emission factors, parameters and estimation models are applied.
		Biomass Burning, Settlements	
5-A-1	Waste – Solid Waste Disposal	Municipal Solid Waste Landfills	To organize the two landfill sectors together which use similar methodologies
		Wood Waste Landfills	

Table A1–2 **Key Category Analysis Summary, 2019 Inventory Year**

Source Table	IPCC Category	Direct Greenhouse Gas	Key Category (1990 / 2019)	Criteria 1990 / 2019 L: Level, T: Trend
1.A.1	Stationary Fuel Combustion – Energy Industries	CO_2	Yes / Yes	L / L, T
1.A.1	Stationary Fuel Combustion – Energy Industries	CH_4	No / Yes	T
1.A.1	Stationary Fuel Combustion – Energy Industries	N_2O	No / No	
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CO_2	Yes / Yes	L / L, T
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CH_4	No / No	
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	N_2O	No / No	
1.A.4	Stationary Fuel Combustion – Other sectors	CO_2	Yes / Yes	L / L, T
1.A.4	Stationary Fuel Combustion – Other sectors	CH_4	No / Yes	T
1.A.4	Stationary Fuel Combustion – Other sectors	N_2O	No / No	
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	Yes / Yes	L / L, T
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-A-3-a	Fuel Combustion – Domestic Aviation	CO_2	Yes / Yes	L / L, T
1-A-3-a	Fuel Combustion – Domestic Aviation	CH_4	No / No	
1-A-3-a	Fuel Combustion – 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 / Yes	L / T
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 – Domestic Navigation	CO_2	No / Yes	L, T
1-A-3-d	Fuel Combustion – Domestic Navigation	CH_4	No / No	
1-A-3-d	Fuel Combustion – Domestic Navigation	N_2O	No / No	
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CO_2	Yes / Yes	L / L, T
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CH_4	No / Yes	T
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	N_2O	No / No	
1-A-3-e-i	Fuel Combustion – Pipeline Transport	CO_2	Yes / Yes	L / L
1-A-3-e-i	Fuel Combustion – Pipeline Transport	CH_4	No / No	
1-A-3-e-i	Fuel Combustion – Pipeline Transport	N_2O	No / No	
1-A-4-a	Fuel Combustion – Commercial Institutional/Off-Road Vehicles and Other Machinery	CO_2	No / Yes	T
1-A-4-a	Fuel Combustion – Commercial Institutional/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-4-a	Fuel Combustion – Commercial Institutional/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-A-4-b	Fuel Combustion – Residential/Off-Road Vehicles and Other Machinery	CO_2	No / Yes	T
1-A-4-b	Fuel Combustion – Residential/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-4-b	Fuel Combustion – Residential/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CO_2	Yes / Yes	L / L, T
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CH_4	No / No	
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	N_2O	No / No	
1-B-1-a	Fugitive Emissions – Coal Mining and Handling	N_2O	Yes / Yes	L / T
1-A-5-b	Fuel Combustion – Other Mobile (Military Aviation and Navigation)	CO_2	No / No	
1-A-5-b	Fuel Combustion – Other Mobile (Military Aviation and Navigation)	CH_4	No / No	
1-A-5-b	Fuel Combustion – Other Mobile (Military Aviation and Navigation)	N_2O	No / No	
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, T
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	
1-C-1	CO_2 Transport and Storage – Pipelines	CO_2	No / No	
2-A-1	IPPU – Cement Production	CO_2	Yes / Yes	L / L
2-A-2	IPPU – Lime Production	CO_2	No / Yes	T
2-A-3	IPPU – Glass Production	CO_2	No / No	
2-A-4-b	IPPU – Other Uses of Soda Ash	CO_2	No / No	
2-A-4-c	IPPU – Other (Magnesite Use)	CO_2	No / No	
2-A-4-d	IPPU – Other (Limestone and Dolomite Use Other)	CO_2	No / Yes	T
2-B-1	IPPU – Ammonia Production	CO_2	Yes / Yes	L / T
2-B-2	IPPU – Nitric Acid Production	N_2O	No / Yes	T
2-B-3	IPPU – Adipic Acid Production	N_2O	Yes / Yes	L / T
2-B-7	IPPU – Soda Ash Production	CO_2	No / No	
2-B-8	IPPU – Petrochemical and Carbon Black Production	CO_2	Yes / No	L
2-B-8	IPPU – Petrochemical and Carbon Black Production (including carbide production)	CH_4	No / No	

Table A1–2 **Key Category Analysis Summary, 2019 Inventory Year** (cont'd)

Source Table	IPCC Category	Direct Greenhouse Gas	Key Category (1990 / 2019)	Criteria 1990 / 2019 L: Level, T: Trend
2-B-8	IPPU – Petrochemical and Carbon Black Production	N_2O	No / No	
2-B-9-a	IPPU – Fluorochemical Production	HFCs	No / Yes	T
2-C-1	IPPU – Iron and Steel Production	CO_2	Yes / Yes	L / L, T
2-C-1	IPPU – Iron and Steel Production	CH_4	No / No	
2-C-3	IPPU – Aluminium Production	CO_2	No / Yes	L, T
2-C-3	IPPU – Aluminium Production	PFCs	Yes / Yes	L / T
2-C-3	IPPU – Aluminium Production	SF_6	No / No	
2-C-4	IPPU – Magnesium Production	SF_6	No / Yes	T
2-C-7	IPPU – Other (Magnesium Casting)	SF_6	No / No	
2-D-3-a	IPPU – Non-Energy Products from Fuels and Solvent Use – Other (Other and Undifferentiated)	CO_2	Yes / Yes	L / L, T
2-D-3-b	IPPU – Non-Energy Products from Fuels and Solvent Use Other – Other (Use of Urea in SCR Vehicles)	CO_2	No / No	
2-E-1	IPPU – Integrated Circuit or Semiconductor	PFCs	No / No	
2-E-1	IPPU – Integrated Circuit or Semiconductor	SF_6	No / No	
2-E-1	IPPU – Integrated Circuit or Semiconductor	NF_3	No / No	
2-E-5	IPPU – Other Emissives Applications	PFCs	No / No	
2-F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	No / Yes	L, T
2-F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	PFCs	No / No	
2-G-1	IPPU – Electrical Equipment	SF_6	No / No	
2-G-3-a	IPPU – Other (Medical Applications of N_2O)	N_2O	No / No	
2-G-3-b	IPPU – Other (Use of N_2O for Propellant)	N_2O	No / No	
2-G-4	IPPU – Other Contained Product Uses	PFCs	No / No	
3-A	Agriculture – Enteric Fermentation	CH_4	Yes / Yes	L / L, T
3-B	Agriculture – Manure Management	CH_4	No / Yes	L, T
3-B	Agriculture – Manure Management	N_2O	Yes / No	L
3-B-5	Agriculture – Indirect N_2O Emissions	N_2O	No / No	
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	N_2O	Yes / Yes	L / L, T
3-D-2	Agriculture – Indirect N_2O Emissions from Managed Soils	N_2O	No / Yes	L, T
3-F	Agriculture – Field Burning of Agricultural Residues	CH_4	No / No	
3-F	Agriculture – Field Burning of Agricultural Residues	N_2O	No / No	
3-G-1	Agriculture – Limestone $CaCO_3$	CO_2	No / No	
3-H	Agriculture – Urea Application	CO_2	No / Yes	T
3-I	Agriculture – Other Carbon-Containing Fertilizers	CO_2	No / No	
4-A-1	LULUCF – Forest Land remaining Forest Land	CO_2	Yes / Yes	L / L, T
4-A-1	LULUCF – Forest Land remaining Forest Land	CH_4	No / No	
4-A-1	LULUCF – Forest Land remaining Forest Land	N_2O	No / No	
4-A-2	LULUCF – Land converted to Forest Land	CO_2	No / No	
4-B-1	LULUCF – Cropland remaining Cropland	CO_2	No / Yes	L, T
4-B-2	LULUCF – Land converted to Cropland	CO_2	Yes / Yes	L / T
4-B-2	LULUCF – Land converted to Cropland	CH_4	No / No	
4-B-2	LULUCF – Land converted to Cropland	N_2O	No / No	
4-D-1	LULUCF – Wetlands remaining Wetlands	CO_2	No / No	
4-D-1	LULUCF – Wetlands remaining Wetlands	CH_4	No / No	
4-D-1	LULUCF – Wetlands remaining Wetlands	N_2O	No / No	
4-D-2	LULUCF – Land converted to Wetlands	CO_2	Yes / Yes	L / T
4-D-2	LULUCF – Land converted to Wetlands	CH_4	No / No	
4-D-2	LULUCF – Land converted to Wetlands	N_2O	No / No	
4-E-2	LULUCF – Settlements remaining Settlements	CO_2	Yes / Yes	L / L, T
4-E-2	LULUCF – Land converted to Settlements	CO_2	Yes / Yes	L / L, T
4-E-2	LULUCF – Land converted to Settlements	CH_4	No / No	
4-E-2	LULUCF – Land converted to Settlements	N_2O	No / No	
4-C	LULUCF – Grassland	CH_4	No / No	
4-C	LULUCF – Grassland	N_2O	No / No	
4-G	LULUCF – Harvested Wood Products (HWP)	CO_2	Yes / Yes	L / L, T
5-A-1	Waste – Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	Yes / Yes	L / L, T
5-A-2	Waste – Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	Yes / Yes	L / T
5-B	Waste – Biological Treatment of Solid Waste	N_2O	No / No	
5-B	Waste – Biological Treatment of Solid Waste	CO_2	No / No	
5-C-1	Waste – Incineration and Open Burning of Waste	N_2O	No / No	
5-C-1	Waste – Incineration and Open Burning of Waste	CH_4	No / No	
5-C-1	Waste – Incineration and Open Burning of Waste	CH_4	No / No	
5-D-1	Waste – Wastewater Treatment and Discharge	CH_4	No / No	
5-D-1	Waste – Wastewater Treatment and Discharge	N_2O	No / No	

Notes: L = key category by level (for an individual year), T = key category by trend (between the base year and the current year)

A1.2. Key Category Tables

A1.2.1. Level Assessment With and Without LULUCF

Table A1–3 shows the 1990 key categories identified from level assessment with and without LULUCF.

Table A1–4 shows the 2019 key categories identified from level assessment with and without LULUCF.

Table A1–3 **1990 Key Categories by Level Assessment With and Without LULUCF**

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Level Assessment		Cumulative Total	
			Base Year 1990	Current Year 2019	without LULUCF	with LULUCF	without LULUCF	with LULUCF
4-A-1	LULUCF – Forest Land remaining Forest Land	CO_2	-201 589	-133 575	NA	0.209	NA	0.209
1.A.1	Stationary Fuel Combustion – Energy Industries	CO_2	140 866	184 978	0.234	0.146	0.234	0.356
4-G	LULUCF – Harvested Wood Products (HWP)	CO_2	130 432	142 584	NA	0.136	NA	0.491
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	0.134	0.084	0.368	0.575
1.A.4	Stationary Fuel Combustion – Other sectors	CO_2	69 546	78 070	0.116	0.072	0.484	0.647
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CO_2	61 664	49 022	0.103	0.064	0.586	0.711
3-A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	0.037	0.023	0.623	0.735
5-A-1	Waste – Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	20 984	22 989	0.035	0.022	0.658	0.757
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CH_4	17 586	19 195	0.029	0.018	0.687	0.775
1-B-2-(a+c)	Fugitive Emissions – Oil	CH_4	16 804	17 201	0.028	0.017	0.715	0.792
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CO_2	15 451	4 725	0.026	0.016	0.741	0.808
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	N_2O	14 261	20 249	0.024	0.015	0.765	0.823
2-C-1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.017	0.011	0.782	0.834
2-B-3	IPPU – Adipic Acid Production	N_2O	10 303	0	0.017	0.011	0.799	0.845
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CO_2	9 880	11 278	0.016	0.010	0.816	0.855
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	9 103	14 005	0.015	0.009	0.831	0.864
4-B-2	LULUCF – Land converted to Cropland	CO_2	8 980	3 414	NA	0.009	NA	0.874
2-C-3	IPPU – Aluminium Production	PFCs	7 558	556	0.013	0.008	0.843	0.882
1-A-3-a	Fuel Combustion – Domestic Aviation	CO_2	7 203	8 223	0.012	0.007	0.855	0.889
1-A-3-e-i	Fuel Combustion – Pipeline Transport	CO_2	6 685	8 032	0.011	0.007	0.867	0.896
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CO_2	6 203	5 297	0.010	0.006	0.877	0.903
1-A-3-c	Fuel Combustion – Railways	CO_2	6 200	6 887	0.010	0.006	0.887	0.909
4-E-2	LULUCF – Land converted to Settlements	CO_2	5 885	6 422	NA	0.006	NA	0.915
2-A-1	IPPU – Cement Production	CO_2	5 823	7 177	0.010	0.006	0.897	0.921
2-D-3-a	IPPU – Non-Energy Products from Fuels and Solvent Use – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.010	0.006	0.907	0.927
1-B-2-(a+c)	Fugitive Emissions – Oil	CO_2	5 507	10 651	0.009	0.006	0.916	0.933
4-E-2	LULUCF – Settlements remaining Settlements	CO_2	-4 223	-4 422	NA	0.004	NA	0.937
5-A-2	Waste – Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	3 847	3 003	0.006	0.004	0.922	0.941
4-D-2	LULUCF – Land converted to Wetlands	CO_2	3 830	185	NA	0.004	NA	0.945
2-B-8	IPPU – Petrochemical and Carbon Black Production	CO_2	3 367	3 856	0.006	0.003	0.928	0.949
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	2 923	2 613	0.005	0.003	0.938	NA
1-B-1-a	Fugitive Emissions – Coal Mining and Handling	CH_4	2 824	1 391	0.005	0.003	0.942	NA
2-B-1	IPPU – Ammonia Production	CO_2	2 796	2 551	0.005	0.003	0.947	NA
3-B	Agriculture – Manure Management	N_2O	3 062	3 348	0.005	0.003	0.933	NA

Note: NA = Not Applicable

Table A1–4 **2019 Key Categories by Level Assessment With and Without LULUCF**

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Level Assessment		Cumulative Total	
			Base Year 1990	Current Year 2019	without LULUCF	with LULUCF	without LULUCF	with LULUCF
1.A.1	Stationary Fuel Combustion – Energy Industries	CO_2	140 866	184 978	0.253	0.179	0.25	0.18
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	0.206	0.146	0.46	0.32
4-G	LULUCF – Harvested Wood Products (HWP)	CO_2	130 432	142 584	NA	0.138	NA	0.46
4-A-1	LULUCF – Forest Land remaining Forest Land	CO_2	-201 589	-133 575	NA	0.129	NA	0.59
1.A.4	Stationary Fuel Combustion – Other sectors	CO_2	69 546	78 070	0.107	0.076	0.57	0.67
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CO_2	61 664	49 022	0.067	0.047	0.63	0.72
3-A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	0.033	0.023	0.67	0.74
5-A-1	Waste – Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	20 984	22 989	0.031	0.022	0.70	0.76
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	N_2O	14 261	20 249	0.028	0.020	0.73	0.78
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CH_4	17 586	19 195	0.026	0.019	0.75	0.80
1-B-2-(a+c)	Fugitive Emissions – Oil	CH_4	16 804	17 201	0.024	0.017	0.78	0.82
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	9 103	14 005	0.019	0.014	0.79	0.83
2-F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	12 414	0.017	0.012	0.81	0.84
2-D-3-a	IPPU – Non-Energy Products from Fuels and Solvent Use – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.016	0.011	0.83	0.85
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/ Off-Road Vehicles and Other Machinery	CO_2	9 880	11 278	0.015	0.011	0.84	0.86
1-B-2-(a+c)	Fugitive Emissions – Oil	CO_2	5 507	10 651	0.015	0.010	0.86	0.87
2-C-1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.011	0.008	0.87	0.88
1-A-3-a	Fuel Combustion – Domestic Aviation	CO_2	7 203	8 223	0.011	0.008	0.88	0.89
1-A-3-e-i	Fuel Combustion – Pipeline Transport	CO_2	6 685	8 032	0.011	0.008	0.89	0.90
4-B-1	LULUCF – Cropland remaining Cropland	CO_2	-1 902	-7 827	NA	0.008	NA	0.91
2-A-1	IPPU – Cement Production	CO_2	5 823	7 177	0.010	0.007	0.90	0.91
1-A-3-c	Fuel Combustion – Railways	CO_2	6 200	6 887	0.009	0.007	0.91	0.92
4-E-2	LULUCF – Land converted to Settlements	CO_2	5 885	6 422	NA	0.006	NA	0.93
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CO_2	6 203	5 297	0.007	0.005	0.92	0.93
2-C-3	IPPU – Aluminium Production	CO_2	2 715	4 737	0.006	0.005	0.92	0.93
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CO_2	15 451	4 725	0.006	0.005	0.93	0.94
4-E-2	LULUCF – Settlements remaining Settlements	CO_2	-4 223	-4 422	NA	0.004	NA	0.94
3-D-2	Agriculture – Indirect N_2O Emissions from Managed Soils	N_2O	2 790	4 197	0.006	0.004	0.94	0.95
1-A-3-d	Fuel Combustion – Domestic Navigation	CO_2	2 149	4 027	0.006	0.004	0.94	NA
3-B	Agriculture – Manure Management	CH_4	2 453	3 876	0.005	0.004	0.95	NA

Note: NA = Not Applicable

A1.2.2. Trend Assessment With and Without LULUCF

Table A1–5 and Table A1–6 show the key categories indicated from the trend assessment without and with LULUCF, respectively. These tables also show the contribution of the key categories to the trend assessment.

The integration of the LULUCF sector introduces additional key categories and alters the categories' relative contributions and overall trends, which causes a rearrangement in the ranking of key categories. For example, a single LULUCF category, Forest Land Remaining Forest Land (CO_2), is ranked as the second highest contributor in the trend assessments.

The trend assessment without LULUCF identifies 40 key categories, while the same analysis with LULUCF results in 44 key categories, including seven categories from the LULUCF sector.

Table A1–5 **Key Categories by Trend Assessment without LULUCF**

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Trend Assessment	Contribution to Trend	Cumulative Total
			Base Year 1990	Current Year 2019			
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	0.087	0.243	0.24
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CO_2	61 664	49 022	0.043	0.120	0.36
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CO_2	15 451	4 725	0.023	0.065	0.43
1.A.1	Stationary Fuel Combustion – Energy Industries	CO_2	140 866	184 978	0.023	0.065	0.49
2-B-3	IPPU – Adipic Acid Production	N_2O	10 303	0	0.021	0.058	0.55
2-F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	12 414	0.021	0.058	0.61
2-C-3	IPPU – Aluminium Production	PFCs	7 558	556	0.014	0.040	0.65
1.A.4	Stationary Fuel Combustion – Other sectors	CO_2	69 546	78 070	0.011	0.029	0.68
2-D-3-a	IPPU – Non-Energy Products from Fuels and Solvent Use – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.008	0.021	0.70
2-C-1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.007	0.021	0.72
1-B-2-(a+c)	Fugitive Emissions – Oil	CO_2	5 507	10 651	0.007	0.018	0.74
2-C-4	IPPU – Magnesium Production	SF_6	2 738	0	0.006	0.015	0.75
1-B-2-(a+c)	Fugitive Emissions – Oil	CH_4	16 804	17 201	0.005	0.015	0.77
3-A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	0.005	0.014	0.78
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/ Other/Off-Road Vehicles and Other Machinery	CO_2	9 103	14 005	0.005	0.014	0.80
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	N_2O	14 261	20 249	0.005	0.014	0.81
5-A-1	Waste – Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	20 984	22 989	0.004	0.012	0.82
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CO_2	6 203	5 297	0.004	0.010	0.83
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CH_4	17 586	19 195	0.004	0.010	0.84
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CO_2	2 824	1 391	0.003	0.010	0.85
1-B-1-a	Fugitive Emissions – Coal Mining and Handling	CH_4	2 824	1 391	0.003	0.009	0.86
5-A-2	Waste – Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	3 847	3 003	0.003	0.008	0.87
2-C-3	IPPU – Aluminium Production	CO_2	2 715	4 737	0.002	0.007	0.88
1-A-3-d	Fuel Combustion – Domestic Navigation	CO_2	2 149	4 027	0.002	0.007	0.88
1-A-4-b	Fuel Combustion – Residential/Off-Road Vehicles and Other Machinery	CO_2	9 880	11 278	0.002	0.006	0.89
3-H	Agriculture – Urea Application	CO_2	754	2 191	0.002	0.006	0.89
1.A.4	Stationary Fuel Combustion – Other sectors	CH_4	2 202	1 456	0.002	0.006	0.90
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CH_4	1 235	285	0.002	0.006	0.91
2-B-9-a	IPPU – Fluorochemical Production	HFCs	971	0	0.002	0.005	0.91
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	2 923	2 613	0.002	0.004	0.92
2-B-2	IPPU – Nitric Acid Production	N_2O	973	258	0.002	0.004	0.92
3-B	Agriculture – Manure Management	CH_4	2 453	3 876	0.001	0.004	0.92
2-A-2	IPPU – Lime Production	CO_2	1 813	1 339	0.001	0.004	0.93
1.A.1	Stationary Fuel Combustion – Energy Industries	CH_4	1 520	2 701	0.001	0.004	0.93
2-B-1	IPPU – Ammonia Production	CO_2	2 796	2 551	0.001	0.004	0.94
3-D-2	Agriculture – Indirect N_2O Emissions from Managed Soils	N_2O	2 790	4 197	0.001	0.004	0.94
1-A-3-c	Fuel Combustion – Railways	CO_2	6 200	6 887	0.001	0.003	0.94
1-A-4-a	Fuel Combustion – Commercial Institutional/Off-Road Vehicles and Other Machinery	CO_2	236	1 168	0.001	0.003	0.95
1-A-3-a	Fuel Combustion – Domestic Aviation	CO_2	7 203	8 223	0.001	0.002	0.95
2-A-4-d	IPPU – Other (Limestone and Dolomite Use Other)	CO_2	449	101	0.001	0.002	0.95

Table A1–6 **Key Categories by Trend Assessment with LULUCF**

Source Table	IPCC Category	Direct Greenhouse Gas	GHG Emission Estimates (kt CO_2 eq)		Trend Assessment	Contribution to Trend	Cumulative Total
			Base Year 1990	Current Year 2019			
1-A-3-b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	0.055	0.192	0.19
4-A-1	LULUCF – Forest Land remaining Forest Land	CO_2	-201 589	-133 575	0.028	0.097	0.29
1.A.2	Stationary Fuel Combustion – Manufacturing industries and construction	CO_2	61 664	49 022	0.026	0.090	0.38
1.A.1	Stationary Fuel Combustion – Energy Industries	CO_2	140 866	184 978	0.016	0.056	0.44
4-G	LULUCF – Harvested Wood Products (HWP)	CO_2	130 432	142 584	0.015	0.052	0.49
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CO_2	15 451	4 725	0.014	0.050	0.54
2-F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	0	12 414	0.013	0.045	0.58
2-B-3	IPPU – Adipic Acid Production	N_2O	10 303	0	0.013	0.045	0.63
2-C-3	IPPU – Aluminium Production	PFCs	7 558	556	0.009	0.031	0.66
4-B-2	LULUCF – Land converted to Cropland	CO_2	8 980	3 414	0.008	0.027	0.68
4-B-1	LULUCF – Cropland remaining Cropland	CO_2	-1 902	-7 827	0.007	0.023	0.71
1.A.4	Stationary Fuel Combustion – Other sectors	CO_2	69 546	78 070	0.006	0.020	0.73
2-D-3-a	IPPU – Non-Energy Products from Fuels and Solvent Use – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.005	0.017	0.74
4-D-2	LULUCF – Land converted to Wetlands	CO_2	3 830	185	0.005	0.016	0.76
2-C-1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.005	0.016	0.77
1-B-2-(a+c)	Fugitive Emissions – Oil	CO_2	5 507	10 651	0.004	0.014	0.79
2-C-4	IPPU – Magnesium Production	SF_6	2 738	0	0.003	0.012	0.80
3-D-1	Agriculture – Direct N_2O Emissions from Managed Soils	N_2O	14 261	20 249	0.003	0.011	0.81
1-A-2-g	Fuel Combustion – Manufacturing Industries and Construction/Other/Off-Road Vehicles and Other Machinery	CO_2	9 103	14 005	0.003	0.011	0.82
1-B-2-(a+c)	Fugitive Emissions – Oil	CH_4	16 804	17 201	0.003	0.011	0.83
3-A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	0.003	0.010	0.84
5-A-1	Waste – Solid Waste Disposal-Managed Waste Disposal Sites	CH_4	20 984	22 989	0.002	0.008	0.85
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CO_2	6 203	5 297	0.002	0.008	0.86
1-B-1-a	Fugitive Emissions – Coal Mining and Handling	CH_4	2 824	1 391	0.002	0.007	0.87
1-B-2-(b+c)	Fugitive Emissions – Natural Gas	CH_4	17 586	19 195	0.002	0.007	0.87
1-A-4-c	Fuel Combustion – Agriculture Forestry Fishing/Off-Road Vehicles and Other Machinery	CO_2	2 824	1 391	0.002	0.007	0.88
5-A-2	Waste – Solid Waste Disposal-Unmanaged Waste Disposal Sites	CH_4	3 847	3 003	0.002	0.006	0.89
2-C-3	IPPU – Aluminium Production	CO_2	2 715	4 737	0.002	0.005	0.89
1-A-3-d	Fuel Combustion – Domestic Navigation	CO_2	2 149	4 027	0.001	0.005	0.90
1-A-4-b	Fuel Combustion – Residential/Off-Road Vehicles and Other Machinery	CO_2	9 880	11 278	0.001	0.005	0.90
3-H	Agriculture – Urea Application	CO_2	754	2 191	0.001	0.005	0.91
1-A-3-e-ii	Fuel Combustion – Other Transport (Off Road)	CH_4	1 235	285	0.001	0.004	0.91
1.A.4	Stationary Fuel Combustion – Other sectors	CH_4	2 202	1 456	0.001	0.004	0.92
2-B-9-a	IPPU – Fluorochemical Production	HFCs	971	0	0.001	0.004	0.92
4-E-2	LULUCF – Settlements remaining Settlements	CO_2	-4 223	-4 422	0.001	0.004	0.92
3-B	Agriculture – Manure Management	CH_4	2 453	3 876	0.001	0.003	0.93
2-B-2	IPPU – Nitric Acid Production	N_2O	973	258	0.001	0.003	0.93
1-A-3-b	Fuel Combustion – Road Transportation	N_2O	2 923	2 613	0.001	0.003	0.93
1.A.1	Stationary Fuel Combustion – Energy Industries	CH_4	1 520	2 701	0.001	0.003	0.94
2-A-2	IPPU – Lime Production	CO_2	1 813	1 339	0.001	0.003	0.94
3-D-2	Agriculture – Indirect N_2O Emissions from Managed Soils	N_2O	2 790	4 197	0.001	0.003	0.94
2-B-1	IPPU – Ammonia Production	CO_2	2 796	2 551	0.001	0.003	0.94
4-E-2	LULUCF – Land converted to Settlements	CO_2	5 885	6 422	0.001	0.002	0.95
1-A-4-a	Fuel Combustion – Commercial Institutional/Off-Road Vehicles and Other Machinery	CO_2	236	1 168	0.001	0.002	0.95

UNCERTAINTY

A2.1. Introduction

All Annex I Parties to the United Nations Framework Convention on Climate Change are required to report estimated uncertainties associated with both annual estimates of emissions and emission trends over time in their respective national inventory reports. Uncertainty analysis helps to prioritize improvements of future inventories and to guide decisions on methodological choice (IPCC, 2006).

In this submission, Canada used the error propagation method (Approach 1) for combining uncertainties, as outlined in Volume 1 (Chapter 3) of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), to assess the uncertainty in emission estimates for the latest year. Uncertainty estimates were combined by completing Table 3.3 at the source category level. Uncertainty estimates for each source/sink category were either retained from previous studies (e.g. a comprehensive Monte Carlo analysis (Approach 2) conducted in 2003/2004), improved upon on the basis of these studies, or derived independently as in the Agriculture (methane and nitrous oxide), Energy (some fuel combustion categories and fugitive emissions), Industrial Processes and Product Use (IPPU) and Land Use, Land-Use Change and Forestry (LULUCF) sectors. For details on uncertainty related to specific sectors, refer to the uncertainty sections throughout Chapters 3 to 7.

A2.2. Interpretation of Uncertainty about Inventory Estimates

Often uncertainty about GHG estimates is incorrectly interpreted as a measure of accuracy or reliability. In fact, accuracy (or its inverse, bias) can only be quantified by measuring departure from the truth. Uncertainty estimation for inventories is not designed as a measure of accuracy, rather in the context of national inventories, the process of uncertainty estimation mostly aims to quantify precision. High uncertainty about a category estimate suggests it would be difficult to obtain agreement among repeated measurements. This can arise from many factors, including true heterogeneity over time and space: variability is an inherent property of many systems, including nature.

In IPCC good practice guidance, uncertainty information is primarily a "means to help prioritise efforts to improve the accuracy of inventories in the future and guide decisions on methodological choice, …" (IPCC, 2006 vol 1, chapter 3). Minimizing bias and obtaining reliable estimates are better achieved by implementing good practice in estimate development.

A2.3. Uncertainty Assessment on 2019 Greenhouse Gas Emissions and Removals

Separate analyses were conducted for the inventory as a whole with and without LULUCF. The 2019 national emission estimate (not including the LULUCF sector) of 730 Mt CO_2 eq lies within an uncertainty range of 708 Mt CO_2 eq to 753 Mt CO_2 eq (±3%) (Table A2–1). The Energy sector has the lowest uncertainty, at ±2%, while the Waste sector has the highest uncertainty, at ±66%. The IPPU sector and the Agriculture sector have uncertainties of ±5, and ±47%, respectively. The five emission source categories that made the largest contributions to uncertainty at the national level when LULUCF is not included were:

1. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
2. Agriculture – Direct Agriculture Soils, N_2O
3. Waste – Solid Waste Disposal – Unmanaged Waste Disposal Sites –Wood Waste Landfills, CH_4
4. Agriculture – Enteric Fermentation, CH_4
5. Energy – Fuel Combustion – Manufacturing Industries and Construction, CO_2

The 2019 national emission estimate, including LULUCF emissions and removals, of 740 Mt CO_2 eq, lies within an uncertainty range of 675 Mt CO_2 eq to 806 Mt CO_2 eq (±9%) (Table A2–2). The top five contributors influencing the national uncertainty when LULUCF is included were:

1. LULUCF – Forest Land Remaining Forest Land, CO_2
2. LULUCF – Harvested Wood Products (HWP), CO_2
3. Waste – Solid Waste Disposal – Managed Waste Disposal Sites, CH_4
4. Agriculture – Direct Agriculture Soils, N_2O
5. Waste – Solid Waste Disposal – Unmanaged Waste Disposal Sites – Wood Waste Landfills, CH_4

The calculation of trend uncertainty was performed with and without the LULUCF sector. The trend uncertainty, excluding LULUCF, was found to be 1%. Therefore, the total increase in emissions since 1990 of 129 Mt CO_2 eq (+21%) falls within an uncertainty range of a minimum of +128 Mt CO_2 eq to a maximum of +129 Mt CO_2 eq. The trend uncertainty, including LULUCF, was found to be 1%.

A2.4. Planned Improvements

Continuous improvement is one of the principles upon which Canada develops its annual GHG inventory. Planned improvements associated with uncertainty assessment will likely build on previous methods and databases, including making use of the Monte Carlo simulation data and methods performed in 2003–2004. New methodological changes and refinements consider the impact on uncertainty prior to implementation and therefore provide a basis for regular incremental improvement to the uncertainty analysis.

Uncertainty estimation of national emissions is the topic of a working paper to be released in 2020 (Laferrière et al. 2020). This study compares actual Tier 1 uncertainty estimates with a more general approach, namely Monte Carlo simulations (MCS). The comparison highlights:

- the impact on emissions uncertainty related with asymmetrical probability distribution function (PDF) and PDF other than normal;
- the effect of incorporating emission correlation across IPCC source category—often, it is difficult to justify the Tier 1 assumption that emission factors are uncorrelated across categories—the paper shows the importance of its recognition and compares trend uncertainty and category contribution to uncertainty; and
- the possibility to factor in dual uncertainty levels for the activity variables (for example, categories comprised of multiple activity datasets may individually have high uncertainty values but when aggregated the final result may have a lower uncertainty value).

Results of the recent uncertainty analysis were used for the category of Product Uses as Substitutes for Ozone Depleting Substance – HFCs. Improvements with respect to uncertainty estimates will continue for other categories in future inventories. Chapter 8 provides a summary of planned improvements.

Table A2–1 **Uncertainty Assessment Level and Trend without LULUCF**

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	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		**601 524**	**730 245**	**1.90**	**2.00**	**3.1**	**3.1**	**Assumption: Emission factors are fully correlated between years**	**Assumption: Activity data is fully correlated between years**	**0.59**
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	CO_2	93 982	68 043	0.48	4.60	4.60	0.00	0.35	0.00	0.00
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	CH_4	44	158	0.65	26.00	26.00	0.00	0.00	0.00	0.00
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	N_2O	492	432	0.47	160.00	160.00	0.00	0.04	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	CO_2	17 300	14 662	1.00	9.60	9.70	0.00	0.10	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	CH_4	11	8	0.87	190.00	190.00	0.00	0.00	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	N_2O	49	32	0.63	280.00	280.00	0.00	0.01	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	26 967	47 356	1.00	4.90	5.00	0.00	0.12	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 463	2 509	1.20	140.00	140.00	0.00	0.17	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	N_2O	184	291	1.20	550.00	550.00	0.00	0.06	0.00	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	64 281	103 940	2.70	4.00	4.30	0.00	0.17	0.02	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	CH_4	65	94	2.70	25.00	25.00	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	N_2O	496	856	2.70	41.00	41.00	0.00	0.02	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	CO_2	35 295	33 790	1.10	0.11	1.10	0.00	0.00	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	CH_4	1 288	509	1.10	11.00	11.00	0.00	0.02	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	N_2O	118	467	1.80	69.00	69.00	0.00	0.04	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	CO_2	7 203	8 223	0.77	0.40	0.87	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	CH_4	11	5	0.73	240.00	240.00	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	N_2O	67	71	0.74	670.00	670.00	0.00	0.01	0.00	0.00
1.A.3.b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	1.20	0.13	1.20	0.00	0.01	0.02	0.00
1.A.3.b	Fuel Combustion – Road Transportation	CH_4	308	245	1.00	110.00	110.00	0.00	0.02	0.00	0.00
1.A.3.b	Fuel Combustion – Road Transportation	N_2O	2 923	2 613	1.30	38.00	38.00	0.00	0.06	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	CO_2	6 200	6 887	3.00	0.28	3.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	CH_4	9	10	3.20	150.00	150.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	N_2O	709	806	3.20	200.00	200.00	0.00	0.02	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	CO_2	2 149	4 027	2.70	0.40	2.70	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	CH_4	5	10	2.80	45.00	45.00	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	N_2O	17	33	2.80	130.00	130.00	0.00	0.00	0.00	0.00

Table A2–1 **Uncertainty Assessment Level and Trend without LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	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.A.3.e	Fuel Combustion – Pipeline Transport	CO_2	6 685	8 032	0.99	1.40	1.70	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion – Pipeline Transport	CH_4	167	199	1.00	15.00	15.00	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion – Pipeline Transport	N_2O	53	63	1.00	490.00	490.00	0.00	0.00	0.00	0.00
1.A.4	Fuel Combustion – Other Sectors	CO_2	69 546	78 070	2.00	1.60	2.20	0.00	0.02	0.00	0.00
1.A.4	Fuel Combustion – Other Sectors	CH_4	2 202	1 456	5.70	15.00	15.00	0.00	0.03	0.00	0.00
1.A.4	Fuel Combustion – Other Sectors	N_2O	639	765	4.40	31.00	31.00	0.00	0.00	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	CO_2	866	213	2.70	0.25	2.70	0.00	0.00	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	CH_4	2	1	16.00	260.00	260.00	0.00	0.00	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	N_2O	7	2	2.60	120.00	120.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	CO_2	231	239	0.64	0.32	0.72	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	CH_4	0	0	0.50	350.00	350.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	N_2O	2	2	0.63	570.00	570.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	CO_2	28	74	0.92	0.09	0.92	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	CH_4	0	0	5.80	89.00	90.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	N_2O	0	1	0.95	41.00	41.00	0.00	0.00	0.00	0.00
1.B.1.a	Fugitive Sources – Coal Mining and Handling	CH_4	2 824	1 391	0.00	0.00	57.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	CO_2	121	665	0.00	0.00	25.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	CH_4	17 984	16 892	0.00	0.00	22.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	N_2O	30	104	0.00	0.00	310.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting	CO_2	6 995	9 513	0.00	0.00	26.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Flaring	CO_2	4 594	5 769	0.00	0.00	7.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting & Flaring	CH_4	16 406	19 505	0.00	0.00	6.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting & Flaring	N_2O	2	8	0.00	0.00	120.00	0.00	0.00	0.00	0.00
1.C	CO_2 Transport and Storage	CO_2	-	0	2.00	100.00	100.00	0.00	0.00	0.00	0.00
2.A.1	IPPU – Cement Production	CO_2	5 823	7 177	0.00	0.00	8.50	0.00	0.00	0.00	0.00
2.A.2	IPPU – Lime Production	CO_2	1 813	1 339	8.00	2.00	6.60	0.00	0.00	0.00	0.00
2.A.3	IPPU – Glass Production	CO_2	71	0	0.00	0.00	10.00	0.00	0.00	0.00	0.00
2.A.4.b	IPPU – Other Uses of Soda Ash	CO_2	194	98	0.00	0.00	6.20	0.00	0.00	0.00	0.00
2.A.4.c	IPPU – Other (Magnesite Use)	CO_2	147	116	7.80	2.10	8.10	0.00	0.00	0.00	0.00
2.A.4.d	IPPU – Other (Limestone and Dolomite Use)	CO_2	449	101	0.00	0.00	36.00	0.00	0.00	0.00	0.00
2.B.1	IPPU – Ammonia Production	CO_2	2 796	2 551	2.00	5.00	9.20	0.00	0.01	0.00	0.00
2.B.2	IPPU – Nitric Acid Production	N_2O	973	258	2.00	10.00	0.96	0.00	0.02	0.00	0.00
2.B.3	IPPU – Adipic Acid Production	N_2O	10 303	0	0.10	10.00	11.00	0.00	0.21	0.00	0.00
2.B.7	IPPU – Soda Ash Production	CO_2	-	0	0.00	0.00	14.00	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production	CO_2	3 367	3 856	0.00	0.00	3.10	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production (including carbide production)	CH_4	143	135	0.00	0.00	16.00	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production	N_2O	15	13	0.00	0.00	9.60	0.00	0.00	0.00	0.00

Table A2–1 **Uncertainty Assessment Level and Trend without LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	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.B.9.a	IPPU – Fluorochemical Production	HFCs	971	0	0.00	0.00	50.00	0.00	0.00	0.00	0.00
2.C.1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.00	0.00	5.60	0.00	0.00	0.00	0.00
2.C.1	IPPU – Iron and Steel Production	CH_4	2	2	1.00	410.00	410.00	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	CO_2	2 715	4 737	0.00	0.00	7.10	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	PFCs	7 558	556	0.00	0.00	9.10	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	SF_6	56	1	0.00	0.00	5.00	0.00	0.00	0.00	0.00
2.C.4	IPPU – Magnesium Production	SF_6	2 738	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.C.7	IPPU – Other (Magnesium Casting)	SF_6	225	290	0.00	0.00	9.20	0.00	0.00	0.00	0.00
2.D.3.a	IPPU – Non-Energy Products from Fuels and Solvent Use Other – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.00	20.00	20.00	0.00	0.15	0.00	0.00
2.D.3.b	IPPU – Non-Energy Products from Fuels and Solvent Use Other – Other (Use of Urea in SCR Vehicles)	CO_2	-	32	0.00	0.00	50.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	PFCs	0	8	2.00	19.00	19.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	SF_6	4	20	15.00	30.00	45.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	Ok	0	1	0.00	0.00	300.00	0.00	0.00	0.00	0.00
2.E.5	IPPU – Other Emissive Applications	PFCs	-	0	2.00	50.00	50.00	0.00	0.00	0.00	0.00
2.F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	12 414	0.00	0.00	11.00	0.00	0.00	0.00	0.00
2.F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	PFCs	-	2	0.00	0.00	23.00	0.00	0.00	0.00	0.00
2.G.1	IPPU – Electrical Equipment	SF_6	202	170	11.00	30.00	32.00	0.00	0.00	0.00	0.00
2.G.3.a	IPPU – Other (Medical Applications of N_2O)	N_2O	146	438	20.00	5.00	20.00	0.00	0.00	0.00	0.00
2.G.3.b	IPPU – Other (Uses of N_2O for Propellant)	N_2O	26	80	20.00	5.00	20.00	0.00	0.00	0.00	0.00
2.G.4	IPPU – Other Contained Product Uses	PFCs	-	30	2.00	50.00	51.00	0.00	0.00	0.00	0.00
	Agriculture – Total CH_4	CH_4	24 970	27 922	1.20	19.00	18.00	0.00	0.07	0.00	0.00
3.A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	1.20	18.00	22.00	0.01	0.09	0.00	0.00
3.B.1	Agriculture – Manure Management	CH_4	2 453	3 876	0.19	4.50	32.00	0.00	0.01	0.00	0.00
	Agriculture – Total N_2O	N_2O	20 779	28 505	0.00	0.02	24.00	0.01	0.00	0.00	0.00
3.B.2	Agriculture – Manure Management Direct Emissions	N_2O	3 062	3 348	0.00	0.00	51.00	0.00	0.00	0.00	0.00
3.B.2	Agriculture – Manure Management Indirect Emissions	N_2O	613	700	0.00	0.00	100.00	0.00	0.00	0.00	0.00
3.D.1	Agriculture – Direct Agriculture Soils	N_2O	14 261	20 249	0.00	0.00	34.00	0.01	0.00	0.00	0.00
3.D.2	Agriculture – Indirect Agrictulure Soils	N_2O	2 790	4 197	0.00	0.00	100.00	0.00	0.00	0.00	0.00
3.F	Agriculture – Field Burning of Agricultural Residues	CH_4	170	37	50.00	40.00	64.00	0.00	0.01	0.00	0.00
3.F	Agriculture – Field Burning of Agricultural Residues	N_2O	53	12	50.00	48.00	69.00	0.00	0.00	0.00	0.00
	Agriculture – Total CO_2	CO_2	1 191	2 631	13.00	42.00	44.00	0.00	0.08	0.00	0.00
3.G.1	Agriculture – Limestone $CaCO_3$	CO_2	385	171	30.00	50.00	58.00	0.00	0.02	0.00	0.00

Table A2–1 **Uncertainty Assessment Level and Trend without LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	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	%	%	%	%	%	%	%
3.H	Agriculture – Urea Application	CO_2	754	2 191	15.00	50.00	52.00	0.00	0.11	0.00	0.00
3.I	Agriculture – Other Carbon-Containing Fertilizers	CO_2	52	268	15.00	50.00	52.00	0.00	0.02	0.00	0.00
5.A.1	Solid Waste Disposal – Managed Waste Disposal Sites	CH_4	20 984	22 989	59.00	46.00	76.00	0.06	0.19	0.01	0.00
5.A.2	Solid Waste Disposal – Unmanaged Waste Disposal Sites – Wood Waste Landfills	CH_4	3 847	3 003	0.00	0.00	190.00	0.01	0.00	0.00	0.00
5.B.1	Biological Treatment of Solid Waste – Composting	CH_4	34	168	0.00	87.00	87.00	0.00	0.02	0.00	0.00
5.B.1	Biological Treatment of Solid Waste – Composting	N_2O	39	194	0.00	61.00	61.00	0.00	0.01	0.00	0.00
5.B.2	Biological Treatment of Solid Waste – Anerobic Digestion – Industrial & Municipal Facilities	CH_4	-	19	0.00	79.00	79.00	0.00	0.00	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	CO_2	178	105	4.50	36.00	37.00	0.00	0.01	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	CH_4	2	1	4.90	98.00	59.00	0.00	0.00	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	N_2O	92	80	4.40	88.00	88.00	0.00	0.00	0.00	0.00
5.D	Wastewater Treatment and Discharge	CH_4	486	532	43.00	36.00	55.00	0.00	0.00	0.00	0.00
5.D	Wastewater Treatment and Discharge	N_2O	342	490	10.00	50.00	51.00	0.00	0.01	0.00	0.00

Notes:

a. For categories where individual values are not given for emission factor and activity data uncertainty, combined uncertainty estimates are based on sectoral Monte Carlo analyses. For further information on sources of uncertainty data and calculation methods—as related to categories in the Energy, IPPU, and Waste sectors—the reader is referred to uncertainty sections in respective NIR chapters. In the case of Agriculture, emission factor uncertainty was back calculated from combined uncertainty from monte carlo analysis carried out for N_2O and CH_4 seperately and total contribution to uncertainty is the summation of uncertainty from monte carlo analysis of N_2O and CH_4, combined with error propagation calculations for CO_2. For IPPU categories where the uncertainty values for activity data and emission factor are not provided, the combined uncertainty value is calculated using many subcategory inputs which have varying activity data and emission factor uncertainty values.

b. 1.A.2.g.vii, 1.A.3.e.ii, 1.A.4.a.ii., 1.A.4.b.ii, 1.A.4.c.ii

Table A2–2 **Uncertainty Assessment Level and Trend with LULUCF**

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	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		**544 707**	**740 123**	**1.90**	**1.90**	**8.9**	**8.8**	**Assumption: Emission factors are fully correlated between years**	**Assumption: Activity data is fully correlated between years**	**0.84**
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	CO_2	93 982	68 043	0.48	4.60	4.60	0.00	0.50	0.00	0.00
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	CH_4	44	158	0.65	26.00	26.00	0.00	0.00	0.00	0.00
1.A.1.a	Fuel Combustion – Public Electricity and Heat Production	N_2O	492	432	0.47	160.00	160.00	0.00	0.07	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	CO_2	17 300	14 662	1.00	9.60	9.70	0.00	0.16	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	CH_4	11	8	0.87	190.00	190.00	0.00	0.00	0.00	0.00
1.A.1.b	Fuel Combustion – Petroleum Refining	N_2O	49	32	0.63	280.00	280.00	0.00	0.02	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CO_2	26 967	47 356	1.00	4.90	5.00	0.00	0.10	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 463	2 509	1.20	140.00	140.00	0.00	0.13	0.00	0.00
1.A.1.c	Fuel Combustion – Manufacture of Solid Fuels and Other Energy Industries	N_2O	184	291	1.20	550.00	550.00	0.00	0.04	0.00	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	CO_2	64 281	103 940	2.70	4.00	4.30	0.00	0.12	0.01	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	CH_4	65	94	2.70	25.00	25.00	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion – Manufacturing Industries and Construction	N_2O	496	856	2.70	41.00	41.00	0.00	0.01	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	CO_2	35 295	33 790	1.10	0.11	1.10	0.00	0.00	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	CH_4	1 288	509	1.10	11.00	11.00	0.00	0.03	0.00	0.00
1.A.2-3-4[b]	Fuel Combustion – Off-Road[b]	N_2O	118	467	1.80	69.00	69.00	0.00	0.04	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	CO_2	7 203	8 223	0.77	0.40	0.87	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	CH_4	11	5	0.73	240.00	240.00	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion – Civil Aviation	N_2O	67	71	0.74	670.00	670.00	0.00	0.02	0.00	0.00
1.A.3.b	Fuel Combustion – Road Transportation	CO_2	80 538	150 252	1.20	0.13	1.20	0.00	0.01	0.02	0.00
1.A.3.b	Fuel Combustion – Road Transportation	CH_4	308	245	1.00	110.00	110.00	0.00	0.03	0.00	0.00
1.A.3.b	Fuel Combustion – Road Transportation	N_2O	2 923	2 613	1.30	38.00	38.00	0.00	0.10	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	CO_2	6 200	6 887	3.00	0.28	3.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	CH_4	9	10	3.20	150.00	150.00	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion – Railways	N_2O	709	806	3.20	200.00	200.00	0.00	0.06	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	CO_2	2 149	4 027	2.70	0.40	2.70	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	CH_4	5	10	2.80	45.00	45.00	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion – Navigation	N_2O	17	33	2.80	130.00	130.00	0.00	0.00	0.00	0.00

Table A2–2 **Uncertainty Assessment Level and Trend with LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	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.A.3.e	Fuel Combustion – Pipeline Transport	CO_2	6 685	8 032	0.99	1.40	1.70	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion – Pipeline Transport	CH_4	167	199	1.00	15.00	15.00	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion – Pipeline Transport	N_2O	53	63	1.00	490.00	490.00	0.00	0.01	0.00	0.00
1.A.4	Fuel Combustion – Other Sectors	CO_2	69 546	78 070	2.00	1.60	2.20	0.00	0.05	0.01	0.00
1.A.4	Fuel Combustion – Other Sectors	CH_4	2 202	1 456	5.70	15.00	15.00	0.00	0.04	0.00	0.00
1.A.4	Fuel Combustion – Other Sectors	N_2O	639	765	4.40	31.00	31.00	0.00	0.01	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	CO_2	866	213	2.70	0.25	2.70	0.00	0.00	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	CH_4	2	1	16.00	260.00	260.00	0.00	0.00	0.00	0.00
1.A.4.c.iii	Fuel Combustion – Fishing	N_2O	7	2	2.60	120.00	120.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	CO_2	231	239	0.64	0.32	0.72	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	CH_4	0	0	0.50	350.00	350.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Aviation)	N_2O	2	2	0.63	570.00	570.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	CO_2	28	74	0.92	0.09	0.92	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	CH_4	0	0	5.80	89.00	90.00	0.00	0.00	0.00	0.00
1.A.5.b.	Fuel Combustion – Other (Military Navigation)	N_2O	0	1	0.95	41.00	41.00	0.00	0.00	0.00	0.00
1.B.1.a	Fugitive Sources – Coal Mining and Handling	CH_4	2 824	1 391	0.00	0.00	57.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	CO_2	121	665	0.00	0.00	25.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	CH_4	17 984	16 892	0.00	0.00	22.00	0.00	0.00	0.00	0.00
1.B.2.(a+b)	Fugitive Sources – Oil & Gas	N_2O	30	104	0.00	0.00	310.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting	CO_2	6 995	9 513	0.00	0.00	26.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Flaring	CO_2	4 594	5 769	0.00	0.00	7.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting & Flaring	CH_4	16 406	19 505	0.00	0.00	6.00	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources – Venting & Flaring	N_2O	2	8	0.00	0.00	120.00	0.00	0.00	0.00	0.00
1.C	CO_2 Transport and Storage	CO_2	-	0	2.00	100.00	100.00	0.00	0.00	0.00	0.00
2.A.1	IPPU – Cement Production	CO_2	5 823	7 177	0.00	0.00	8.50	0.00	0.00	0.00	0.00
2.A.2	IPPU – Lime Production	CO_2	1 813	1 339	8.00	2.00	6.60	0.00	0.00	0.00	0.00
2.A.3	IPPU – Glass Production	CO_2	71	0	0.00	0.00	10.00	0.00	0.00	0.00	0.00
2.A.4.b	IPPU – Other Uses of Soda Ash	CO_2	194	98	0.00	0.00	6.20	0.00	0.00	0.00	0.00
2.A.4.c	IPPU – Other (Magnesite Use)	CO_2	147	116	7.80	2.10	8.10	0.00	0.00	0.00	0.00
2.A.4.d	IPPU – Other (Limestone and Dolomite Use)	CO_2	449	101	0.00	0.00	36.00	0.00	0.00	0.00	0.00
2.B.1	IPPU – Ammonia Production	CO_2	2 796	2 551	2.00	5.00	9.20	0.00	0.01	0.00	0.00
2.B.2	IPPU – Nitric Acid Production	N_2O	973	258	2.00	10.00	0.96	0.00	0.02	0.00	0.00
2.B.3	IPPU – Adipic Acid Production	N_2O	10 303	0	0.10	10.00	11.00	0.00	0.26	0.00	0.00
2.B.7	IPPU – Soda Ash Production	CO_2	-	0	0.00	0.00	14.00	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production	CO_2	3 367	3 856	0.00	0.00	3.10	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production (including carbide production)	CH_4	143	135	0.00	0.00	16.00	0.00	0.00	0.00	0.00
2.B.8	IPPU – Petrochemical and Carbon Black Production	N_2O	15	13	0.00	0.00	9.60	0.00	0.00	0.00	0.00

Table A2–2 **Uncertainty Assessment Level and Trend with LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	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.B.9.a	IPPU – Fluorochemical Production	HFCs	971	0	0.00	0.00	50.00	0.00	0.00	0.00	0.00
2.C.1	IPPU – Iron and Steel Production	CO_2	10 478	8 261	0.00	0.00	5.60	0.00	0.00	0.00	0.00
2.C.1	IPPU – Iron and Steel Production	CH_4	2	2	1.00	410.00	410.00	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	CO_2	2 715	4 737	0.00	0.00	7.10	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	PFCs	7 558	556	0.00	0.00	9.10	0.00	0.00	0.00	0.00
2.C.3	IPPU – Aluminium Production	SF_6	56	1	0.00	0.00	5.00	0.00	0.00	0.00	0.00
2.C.4	IPPU – Magnesium Production	SF_6	2 738	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.C.7	IPPU – Other (Magnesium Casting)	SF_6	225	290	0.00	0.00	9.20	0.00	0.00	0.00	0.00
2.D.3.a	IPPU – Non-Energy Products from Fuels and Solvent Use Other – Other (Other and Undifferentiated)	CO_2	5 804	11 633	0.00	20.00	20.00	0.00	0.14	0.00	0.00
2.D.3.b	IPPU – Non-Energy Products from Fuels and Solvent Use Other – Other (Use of Urea in SCR Vehicles)	CO_2	-	32	0.00	0.00	50.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	PFCs	0	8	2.00	19.00	19.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	SF_6	4	20	15.00	30.00	45.00	0.00	0.00	0.00	0.00
2.E.1	IPPU – Integrated Circuit or Semiconductor	NF_3	0	1	0.00	0.00	300.00	0.00	0.00	0.00	0.00
2.E.5	IPPU – Other Emissive Applications	PFCs	-	0	2.00	50.00	50.00	0.00	0.00	0.00	0.00
2.F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	12 414	0.00	0.00	11.00	0.00	0.00	0.00	0.00
2.F	IPPU – Product Uses as Substitutes for Ozone Depleting Substances	PFCs	-	2	0.00	0.00	23.00	0.00	0.00	0.00	0.00
2.G.1	IPPU – Electrical Equipment	SF_6	202	170	11.00	30.00	32.00	0.00	0.01	0.00	0.00
2.G.3.a	IPPU – Other (Medical Applications of N_2O)	N_2O	146	438	20.00	5.00	20.00	0.00	0.00	0.00	0.00
2.G.3.b	IPPU – Other (Uses of N_2O for Propellant)	N_2O	26	80	20.00	5.00	20.00	0.00	0.00	0.00	0.00
2.G.4	IPPU – Other Contained Product Uses	PFCs	-	30	2.00	50.00	51.00	0.00	0.00	0.00	0.00
	Agriculture – Total CH_4	CH_4	24 970	27 922	1.20	19.00	18.00	0.00	0.21	0.00	0.00
3.A	Agriculture – Enteric Fermentation	CH_4	22 347	24 009	1.20	18.00	22.00	0.01	0.21	0.00	0.00
3.B.1	Agriculture – Manure Management	CH_4	2 453	3 876	0.19	4.50	32.00	0.00	0.00	0.00	0.00
	Agriculture – Total N_2O	N_2O	20 779	28 505	0.00	0.02	24.00	0.01	0.00	0.00	0.00
3.B.2	Agriculture – Manure Management Direct Emissions	N_2O	3 062	3 348	0.00	0.00	51.00	0.00	0.00	0.00	0.00
3.B.2	Agriculture – Manure Management Indirect Emissions	N_2O	613	700	0.00	0.00	100.00	0.00	0.00	0.00	0.00
3.D.1	Agriculture – Direct Agriculture Soils	N_2O	14 261	20 249	0.00	0.00	34.00	0.01	0.00	0.00	0.00
3.D.2	Agriculture – Indirect Agrictulure Soils	N_2O	2 790	4 197	0.00	0.00	100.00	0.00	0.00	0.00	0.00
3.F	Agriculture – Field Burning of Agricultural Residues	CH_4	170	37	50.00	40.00	64.00	0.00	0.01	0.00	0.00
3.F	Agriculture – Field Burning of Agricultural Residues	N_2O	53	12	50.00	48.00	69.00	0.00	0.01	0.00	0.00
	Agriculture – Total CO_2	CO_2	1 191	2 631	13.00	42.00	44.00	0.00	0.08	0.00	0.00
3.G.1	Agriculture – Limestone $CaCO_3$	CO_2	385	171	30.00	50.00	58.00	0.00	0.03	0.00	0.00
3.H	Agriculture – Urea Application	CO_2	754	2 191	15.00	50.00	52.00	0.00	0.11	0.00	0.00
3.I	Agriculture – Other Carbon-Containing Fertilizers	CO_2	52	268	15.00	50.00	52.00	0.00	0.02	0.00	0.00

Table A2–2 **Uncertainty Assessment Level and Trend with LULUCF** (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2019 Year Emissions	Activity Data Uncertainty[a]	Emission Factor Uncertainty[a]	Combined Uncertainty	Combined uncertainty as % of 2019 TOTAL	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	%	%	%	%	%	%	%
4.A.1	LULUCF – Forest Land Remaining Forest Land	CO_2	(201 589)	(133 575)	0.00	0.00	38.00	0.48	0.00	0.00	0.00
4.A.1	LULUCF – Forest Land Remaining Forest Land	CH_4	439	375	0.00	0.00	110.00	0.00	0.00	0.00	0.00
4.A.1	LULUCF – Forest Land Remaining Forest Land	N_2O	222	228	0.00	0.00	110.00	0.00	0.00	0.00	0.00
4.A.2	LULUCF – Land Converted to Forest Land	CO_2	(1 069)	(302)	0.00	0.00	110.00	0.00	0.00	0.00	0.00
4.B	LULUCF – Cropland	CO_2	(1 798)	(9 224)	0.00	0.00	23.00	0.00	0.00	0.00	0.00
4.B	LULUCF – Cropland	N_2O	14	13	0.00	0.00	40.00	0.00	0.00	0.00	0.00
4.C	LULUCF – Grassland	CH_4	0	1	0.00	0.00	64.00	0.00	0.00	0.00	0.00
4.C	LULUCF – Grassland	N_2O	0	0	0.00	0.00	69.00	0.00	0.00	0.00	0.00
4.D	LULUCF – Wetlands	CO_2	2 498	1 605	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.D	LULUCF – Wetlands	CH_4	6	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.D	LULUCF – Wetlands	N_2O	2	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.E	LULUCF – Settlements	CO_2	(4 175)	(4 403)	0.00	0.00	39.00	0.00	0.00	0.00	0.00
4.F	LULUCF – Conversion of Forest Land	CO_2	17 532	12 205	0.00	0.00	17.00	0.00	0.00	0.00	0.00
4.F	LULUCF – Conversion of Forest Land	CH_4	446	232	0.00	0.00	31.00	0.00	0.00	0.00	0.00
4.F	LULUCF – Conversion of Forest Land	N_2O	222	121	0.00	0.00	29.00	0.00	0.00	0.00	0.00
4.G.	LULUCF – Harvested Wood Products (HWP)	CO_2	130 432	142 584	0.00	0.00	24.00	0.21	0.00	0.00	0.00
5.A.1	Solid Waste Disposal – Managed Waste Disposal Sites	CH_4	20 984	22 989	59.00	46.00	76.00	0.05	0.47	0.02	0.00
5.A.2	Solid Waste Disposal – Unmanaged Waste Disposal Sites – Wood Waste Landfills	CH_4	3 847	3 003	0.00	0.00	190.00	0.01	0.00	0.00	0.00
5.B.1	Biological Treatment of Solid Waste – Composting	CH_4	34	168	0.00	87.00	87.00	0.00	0.02	0.00	0.00
5.B.1	Biological Treatment of Solid Waste – Composting	N_2O	39	194	0.00	61.00	61.00	0.00	0.02	0.00	0.00
5.B.2	Biological Treatment of Solid Waste – Anerobic Digestion – Industrial & Municipal Facilities	CH_4	-	19	0.00	79.00	79.00	0.00	0.00	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	CO_2	178	105	4.50	36.00	37.00	0.00	0.01	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	CH_4	2	1	4.90	98.00	59.00	0.00	0.00	0.00	0.00
5.C.1	Incineration and Open Burning of Waste – Waste Incineration	N_2O	92	80	4.40	88.00	88.00	0.00	0.01	0.00	0.00
5.D	Wastewater Treatment and Discharge	CH_4	486	532	43.00	36.00	55.00	0.00	0.01	0.00	0.00
5.D	Wastewater Treatment and Discharge	N_2O	342	490	10.00	50.00	51.00	0.00	0.00	0.00	0.00

Notes:

a. For categories where individual values are not given for emission factor and activity data uncertainty, combined uncertainty estimates are based on sectoral Monte Carlo analyses. For further information on sources of uncertainty data and calculation methods—as related to categories in the Energy, IPPU, and Waste sectors—the reader is referred to uncertainty sections in respective NIR chapters. In the case of Agriculture, emission factor uncertainty was back calculated from combined uncertainty from monte carlo analysis carried out for N_2O and CH_4 seperately and total contribution to uncertainty is the summation of uncertainty from monte carlo analysis of N_2O and CH_4, combined with error propagation calculations for CO_2. For IPPU categories where the uncertainty values for activity data and emission factor are not provided, the combined uncertainty value is calculated using many subcategory inputs which have varying activity data and emission factor uncertainty values.

b. 1.A.2.g.vii, 1.A.3.e.ii, 1.A.4.a.ii., 1.A.4.b.ii, 1.A.4.c.ii

ANNEX 3

METHODOLOGIES

A3.1. 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.

A3.1.1. Methodology

In general, estimating greenhouse gas (GHG) emissions from fuel combustion activities uses a top-down method, following the Tier 3 and Tier 2 sectoral approach from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). As illustrated by Equation A3.1–1, to calculate the emission for each source category, the quantity of fuel at the national and/or provincial level is multiplied by the corresponding fuel-specific emission factor. Sections A3.1.4.1 and A3.1.4.2 discuss refinements and deviations from the general approach to estimating combustion emissions for the stationary combustion and transport sections, 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. The Energy chapter (Chapter 3) of this report discusses specific methodological issues.

Equation A3.1–1 **for general fuel combustion**

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

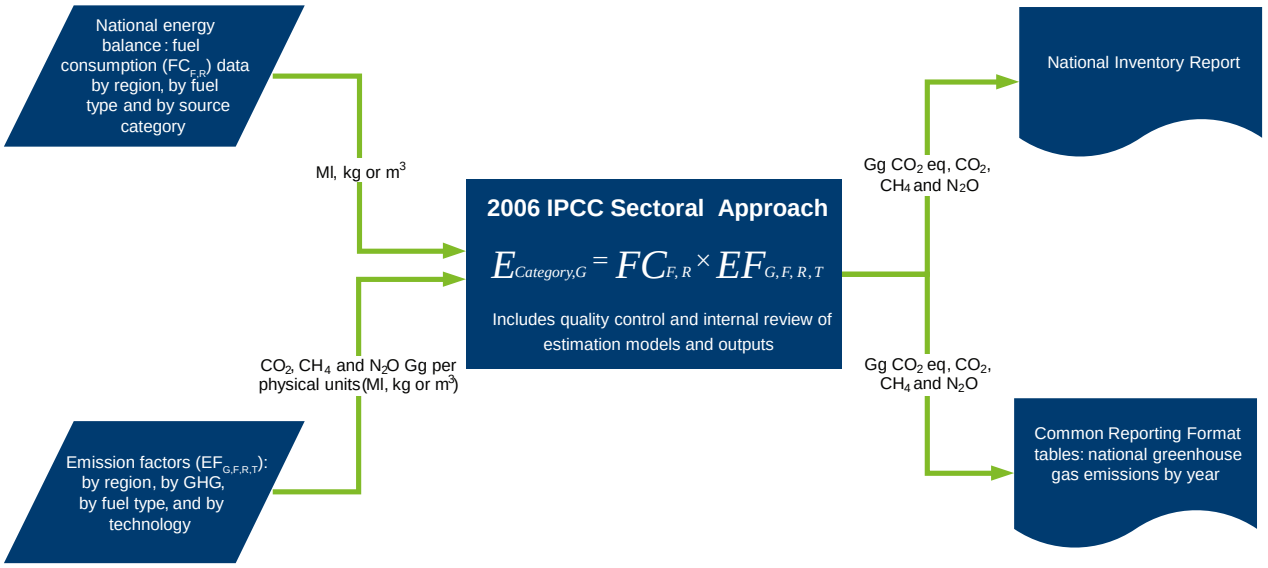
$E_{Category,G}$	=	GHG emissions by source category and by GHG (CO_2, CH_4 or N_2O)
$FC_{F,R}$	=	quantity of fuel consumed (in physical units, such as kg, L, or m^3) by fuel type (i.e. natural gas, sub-bituminous coal, kerosene, etc.) and by region
$EF_{G,F,R,T}$	=	country-specific emission factor (in physical units) by GHG, by fuel type, by region (where available) and by technology (for non-CO_2 factors)

The stationary combustion and transport models primarily use relational databases to process the national and provincial activity data and emission factors used to estimate GHG emissions (Figure A3.1–1). Statistics Canada prepares the national energy balance using data reported in physical units by the producing and consuming sectors. For this reason, the physical units were judged the most accurate for generating emission estimates. Country-specific emission factors, as applied, are in physical units to minimize the number of additional conversion factors and thus limit the uncertainty associated with estimates. The uncertainty of estimates are further reduced by applying available higher-resolution emission factors at the provincial/regional level rather than the national level (e.g. regional coal and natural gas emission factors are used to account for the variation in carbon content). Non-CO_2 emission factors address any existing combustion technology differences.

A3.1.2. Activity Data from Statistics Canada

The principal source of fuel and energy data used to estimate combustion emissions is the annual *Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada 1990–), also referred to as the national energy balance. The RESD uses both top-down and bottom-up approaches 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-use data is allocated using the North American Industrial Classification System (NAICS). Currently, the RESD reports energy used to generate electricity or steam by industry (auto producers) in two separate lines (one for electricity and one for steam), without any further disaggregation by industrial subcategories. Prior to 1998, the Industrial Consumption of Energy Survey (ICE) (Statistics Canada 2013) provided these summary line quantities. From 1998 on, the electricity line (from auto producers) is based on the quantities reported in the Electric Power Thermal Generating Station Fuel Consumption Survey (EPTGS) (Statistics Canada 2013). Statistics Canada implemented this improvement to

Figure A3.1–1 **GHG Estimation Process Flow**



increase the transparency and accuracy of subsector information, since the fuel used to generate electricity is more complete and of higher quality. The steam line continues to be populated using the ICE data.

While the RESD provides fuel use data at a provincial level, the accuracy of these data is generally not as high as that of the national data. Statistics Canada typically allocates final fuel demand by subcategories for the RESD through a number of surveys directed at producers and suppliers of energy, provincial energy ministries and some users of energy. The accuracy following these allocations is less than that of the total available energy supply at the national level. As a result, the total emission estimates for Canada are more certain than the emissions from specific subcategories. Since 1995, Statistics Canada has been collecting energy statistics directly from end users through the annual ICE survey. Estimating fuel use by industry using a bottom-up approach provides more accurate subcategory information. Refer to Annex 4, National Energy Balance, for additional discussion on the development of the RESD and the ICE data set, including a discussion of Statistics Canada's quality assurance / quality control activities. Sector-specific surveys provide verification of sector trends and emissions 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 Statistics Canada collects data from reporting facilities under the *Statistics Act.* The quantities of fossil fuel consumed are also available in gross calorific units; however, as discussed, this is assumed to be less accurate. When converting to energy values, with the exception of natural gas, Statistics Canada applies constant energy conversion factors (a factor for 1990 to 1997 and another factor for 1998 onward) to each fuel type without taking into account year-to-year variability in fuels such as coal, petroleum coke and refinery fuel gas (still gas). These energy conversion factors are applied for the reporting of fuel quantities in the CRF tables, and nationally weighted values were determined for reference approach calculations (refer to Table A4–2 for details). One exception involves waste fuels, for which the data are only available in energy units from the Cement Association of Canada. Statistics Canada and Environment and Climate Change Canada (ECCC) have initiated a multi-year work program to better track and update energy conversion factors. Refer to the Planned Improvement section of Chapter 3 for further details.

Additional non-Statistics Canada 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 A3.1.4.1 and A3.1.4.2).

A3.1.3. Fuel Combustion Emission and Oxidation Factors

The following is a brief summary of the emission factors for fuels that are the largest contributors to Canadian GHG emissions. A detailed description of emission factors used in the current fossil fuel combustion models can be found in Annex 6.

Natural Gas: The emission factors for CO_2 vary depending on the source of natural gas and whether the product is marketable or non-marketable (raw natural

gas for on-site consumption by natural gas producers). Therefore, provinces have varying emission factors based on 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): Refined petroleum products include, but are not limited to, fuels such as diesel, gasoline, light fuel oil and heavy fuel oil. The emission factors vary with fuel type and/or combustion technology (for CH_4 and N_2O).

Coal: The CO_2 emission factors vary by the coal properties, province of use and coal origin, whether domestic or foreign. The emission factors for CH_4 and N_2O vary by the combustion technology.

The IPCC default oxidation value applies to all fuels except coal, where country-specific oxidation factors applied at the provincial level reflect regional variations in combustion efficiencies. Refer to the Recalculation section of Chapter 3 and Annex 6 for more detail on coal oxidation factors.

A3.1.3.1. CO_2 Emission Factors

CO_2 emissions from fuel combustion activities depend on the amount of fuel consumed, the carbon content of the fuel and the applied oxidation factor. The applied emission factors vary by fuel type and by region, where applicable. There is discussion of CO_2 emission factor derivation in Annex 6, in *Fossil Fuel and Derivative Factors* (McCann 2000), in *Updated CO_2 Emission Factors for Gasoline and Diesel Fuel* (ECCC 2017b) and in *Updated Carbon Dioxide Emission Factors for Coal Combustion* (ECCC 2019). Fuel properties, such as carbon content, density and heating value, were determined using accepted industrial testing standards from the American Society for Testing and Materials (ASTM) and the Canadian General Standards Board (CGSB).

The waste fuel emission factor is based on energy content since activity data reported by the Cement Association of Canada (CAC) are in energy units.

A3.1.3.2. Non-CO_2 Emission Factors

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

- fuel type
- technology
- operating conditions
- 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 needed to better establish CH_4 emission factors for many combustion processes. Overall factors were developed for sectors based on typical technologies and available emission factors.

During combustion, some of the nitrogen in the fuel and air is converted to N_2O. The production of N_2O is dependent on the combustion temperature and the emission control technology employed. Additional research is needed to better establish N_2O emission factors for many combustion processes. Overall factors were developed for sectors based on typical technologies and available emission factors. Annex 6 lists non-CO_2 emission factors used in this inventory.

A3.1.4. Methodology for Stationary Combustion and Transport

This section discusses methods used to calculate and report emissions associated with the Energy sector, and specifically stationary combustion and transport.

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. The Land Use, Land-Use Change and Forestry (LULUCF) sector accounts for CO_2 emissions from biomass fuel combustion as a loss of biomass (forest) stocks. CO_2 emissions from biomass combustion for energy use is a memo item in the UNFCCC's Common Reporting Format (CRF) tables and is provided for information purposes. The Energy sector reports CH_4 and N_2O emissions from biomass fuel combustion in the appropriate subcategories and includes it in the inventory totals.

A3.1.4.1. 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 *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). The Industrial Processes and Product Use sector (Annex 3.3) presents the methodology for calculating SF_6 emissions from electrical transmission systems.

Emission calculations use nationally reported activity data, except when emission factors are available at the provincial/territorial level. In these instances, the national total is the aggregated sum of the provincial/territorial emissions.

Emission estimates are calculated using Equation A3.1–1 exclusively.

Table A3.1–1 presents activity data sources used in the stationary combustion model methodology. The data provided to ECCC is in electronic format and may differ slightly when compared with Statistics Canada's published values, which are rounded.

Much of the stationary combustion model's complexity lies in the reallocation of data presented in the RESD in order to comply with the requirements of IPCC categories and UNFCCC CRF reporting tables. In addition, in keeping with the 2006 IPCC Guidelines, the allocation of all fuel types uses the CRF fuel grouping (solid, liquid, gaseous, biomass and other) (see Table A4–2 in Annex 4).

Combined Heat and Power Allocation

Activity data, in the form of fuel used by utilities, are currently aggregated to two summary lines in the RESD (Electricity by Utilities and Steam Generation), representing, electricity generation, and combined heat and power facilities. In addition, solid wood waste and spent pulping liquor used by utilities are allocated to Table 10 – Solid Wood Waste and Spent Pulping Liquor.

Since the Electricity by Utilities line (RESD Line 10) is populated with EPTGS survey data, the reallocation was completed using fractions developed using the quantities reported by the Electricity Generation subcategory in the EPTGS survey. For each fuel and each province, the fuel use data reported in the EPTGS, along with a listing of facilities that are combined heat and power facilities (generated by ECCC), are used to develop the combined heat and power fraction of the total fuel use. The fractions are then used with RESD Line 10 to determine what portion of that line should be reallocated to combined heat and power. The remainder is allocated to electricity generation.

The solid wood waste and spent pulping liquor allocation are discussed below.

Electricity by Industry Allocation

Activity data, in the form of fuel used by industry (including Petroleum Refining) to generate electricity or steam, are currently aggregated to two summary lines in the RESD (Electricity by Industry and Steam Generation). In addition, solid wood waste and spent pulping liquor used by industry are allocated to Table 10 – Solid Wood Waste and Spent Pulping Liquor.

The Electricity by Industry line (RESD Line 11) is populated with EPTGS survey data. The reallocation of RESD Line 11 values from 1998 to present was completed using fractions developed based on the quantities reported by the Electricity Generation subcategory in the EPTGS survey, as follows:

- For each fuel and each province, the fuel use data reported by industry in the EPTGS for electricity generation are used to develop each industry's fraction of the total fuel use.
- The fractions are then used with Line 11 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 reallocation of RESD Line 11 values between 1990 and 1997 was completed using fractions developed using the quantities reported by the Electricity Generation subcategory in the ICE survey, since EPTGS data are not available prior to 1998.

- For each fuel and each province, the fuel use data reported by industry in the ICE survey for electricity generation are used to develop each industry's fraction of the total fuel use.
- The fractions are then used with Line 11 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.
- Since ICE data did not exist prior to 1995, for years between 1990 and 1995, the 1995 fractions were used.

Since the Steam Generation line (RESD Line 14) is populated with ICE data, the procedure used to reallocate the RESD Line 11 values between 1990 and 1997 is also applied to the RESD Line 14 values (for all years) using corresponding ICE data representing steam generation by facilities falling under the Electricity Generation subcategory.

The solid wood waste and spent pulping liquor allocation is discussed below.

Solid Wood Waste and Spent Pulping Liquor Allocation

Activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor).

The Solid Wood Waste and Spent Pulping Liquor table (RESD Table 10) is populated with ICE data. The procedure used to reallocate the RESD Line 11 values between 1990 and 1997 is also applied to the Table 10 values (for all years) using corresponding ICE data representing solid wood waste and spent pulping liquor consumption by facilities falling under the Electricity Generation subcategory.

Table A3.1–1 **Activity Data Model References**

Statistics Canada. 1990. *Report on Energy Supply and Demand in Canada*. Annual Report, Statistics Canada Catalogue no. 57-003-X.
Waste fuel data – Based on CEEDC. CEEDC Database on Energy, Production and Intensity Indicators for Canadian Industry. NAICS 327310 Cement Manufacturing. Canadian Energy and Emissions Data Centre.
Residential fuelwood consumption – Environment Canada. 2020. *Residential Fuelwood Consumption in Canada*. Unpublished report. Prepared by J. Kay, Pollutant Inventories and Reporting Division, Environment Canada.
Landfill Gas Utilization and Waste Incineration – Environment and Climate Change Canada. 2020. National Inventory Report (NIR). Section A3.6: Methodology for Waste Sector.

A3.1.4.1.1. Public Electricity and Heat Production (CRF Category 1.A.1.a)

The Public Electricity and Heat Production subcategory includes 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. This subcategory should include all emissions from main activity producers (previously known as public utilities) of electricity generation, combined heat and power generation, and heat plants. Emissions from auto producers are allocated to their respective industrial subcategories.

Two lines in the RESD (one for electricity and one for steam) report activity data from this subcategory; however, they are summary lines and are not divided into electricity generation, combined heat and power, and heat plants. In addition, activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated data need to be reallocated to the appropriate subcategory where the fuel is used. Section A3.1.4.1 provides a detailed discussion of the method used.

CO_2, CH_4 and N_2O emissions are estimated by applying Equation A3.1–1 to activity data and emission factors for each specific fuel. As previously discussed, in order to obtain higher accuracy in GHG emissions, regional emission factors are applied to provincial/territorial data where available. For this sector, there are regional emission factors for coal and natural gas. For the remaining fuels, the emission factors are applied to the nationally reported data.

Table A3.1–2 provides a summary of the methodology for the Public Electricity and Heat Production category.

A3.1.4.1.2. Petroleum Refining (CRF Category 1.A.1.b) and Manufacture of Solid Fuels and Other Energy Industries (CRF Category 1.A.1.c)

To meet the UNFCCC reporting requirements, activity data from the Manufacture of Solid Fuels and Other Energy Industries category were reallocated to two separate IPCC subcategories, both of which comprise the emissions associated with the combustion of fuels produced at the facilities (e.g. combustion of coal at a coal mine or natural gas at an oil and gas facility) as well as the combustion of purchased fuels. Combustion emissions that support coal production are allocated to 1.A.1.c.i – Manufacture of Solid Fuels, while combustion emissions that support crude oil and natural gas production and upgrading of oil sands bitumen are allocated to 1.A.1.c.ii – Oil and Gas Extraction.

The methodology for estimating emissions from these subcategories involves applying Equation A3.1–1 on a national basis and subtracting emissions associated with flaring from the total GHG emissions for Petroleum Refining and Oil and Gas Extraction. 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. To avoid double counting, the model subtracts fuel use, energy content and emission data associated with flaring. See Annex 3.2.2.7 for more details.

Determining the activity data associated with the Petroleum Refining subcategory requires the reallocation of some of the data reported as Producer Consumption in the RESD. The Petroleum Refining subcategory includes all refined petroleum products reported as Producer

Table A3.1–2 Emission Estimation Methodology for Public Electricity and Heat Production

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.1.a.i Electricity Generation	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Utilities[d] Steam Generation[d]
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.1.a.ii Combined Heat and Power Generation	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Utilities[d] Steam Generation[d]
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.1.a.iii Heat Plants	NO			

Notes:

NO = Not occurring

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC 2006, Volume 2, Table 1.1.
c. Publication references are provided in Table A3.1–1.
d. A portion of this data source is allocated to this CRF source category prior to calculating emissions.

Consumption, except in provinces where no refinery exists; these producer-consumed RPPs are assigned to Oil and Gas Extraction. Physical quantities of liquefied petroleum gases (LPGs) reported in the RESD as producer consumption are divided between propane and butane using energy data reported in the RESD.

Calculating the emissions associated with the fuels listed below involves summing the activity data reported under the RESD's Petroleum Refining and Producer Consumption lines and applying Equation A3.1–1 to:

- petroleum coke
- still gas
- kerosene
- light fuel oil
- heavy fuel oil
- butane
- propane

In addition, activity data in the form of fuel used by industry to generate electricity or steam are currently aggregated to two summary lines in the RESD (Line 11 – Electricity by Industry and Line 14 – Steam Generation). The aggregated data need to be reallocated to the appropriate industry where the fuel is used. Reallocation involves one of the two methods discussed in detail in section A3.1.4.1. Because of a lack of resolution in the RESD Producer Consumption line by specific industry, the Manufacture of Solid Fuels and Other Energy Industries subcategory does not include emissions associated with the transportation fuels listed below; these emissions are reported in the Petroleum Refining subcategory. In general, the combustion emissions calculations from the following transportation fuels, for the Petroleum Refining subcategory, use activity data reported in the RESD under Producer Consumption, together with Equation A3.1–1:

- aviation gasoline
- aviation turbo fuel
- diesel
- motor gasoline

The estimated N_2O emissions for petroleum coke and motor gasoline use IPCC default emission factors, which are based on the calorific value of the fuel. The RESD reports the gross calorific value for petroleum coke, and this can change annually. As a result, the petroleum coke emission factors for both crude bitumen upgrading and crude oil refining change on an annual basis. The conversion between the gross calorific value and the net calorific value, a necessary step in generating annual emission factors, uses data reported to, and published by, the Canadian Industrial Energy End-use Data Analysis Centre (CIEEDAC 2012).

To calculate GHG emissions from the Manufacture of Solid Fuels and Oil and Gas Extraction subcategories, activity data associated with the fuels listed below and reported under the producer consumption line and applicable portion of the total mining and oil and gas extraction line of the RESD are used in Equation A3.1–1:

- natural gas
- coal
- diesel
- propane
- butane
- petroleum coke
- still gas
- heavy fuel oil

The producer consumption line of the RESD includes petroleum coke, still gas and diesel used by refineries and by the crude bitumen upgrading industry. Information on the proportion of fuel consumed by the crude bitumen upgrading industry is provided in Table 11, Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil, of the RESD. This information is used to reallocate the relevant quantities of petroleum coke and still gas to the Oil and Gas Extraction subcategory (CRF category 1.A.1.c.ii). Diesel reported as producer consumption is used in oil sands mining trucks and is reallocated to Other Transportation (Off-Road) (see section A3.1.4.2.1).

The total mining and oil and gas extraction line of the RESD includes fuel consumption that occurs at coal mines, non-energy mines (including metal mining, sand, gravel and other aggregate mining, potash mining, diamond mining, etc.) and at facilities involved in the production of crude oil and natural gas. The RESD does not contain a sufficient level of detail to separate the fuel consumed at coal mines, non-energy mines and oil and gas extraction operations to allocate into the following CRF categories; Manufacture of Solid Fuels (1.A.1.c.i), Mining (1.A.2.g.iii), and Oil and Gas Extraction (1.A.1.c.ii). Other data sources therefore are used to allocate the fuel consumption to the proper categories. Fuel consumption at coal mining operations is estimated based on data from the study of the Canadian coal mining industry (Cheminfo/Clearstone 2014), while fuel consumption for the non-energy mining industry is based on data from the Canadian Energy and Emissions Data Centre (CEEDC no date; NAICS 2122 and 2123). As the oil and gas industry in Canada is the largest of these three industries, the remainder of fuel consumed in the total mining and oil and gas extraction line after subtracting coal mining and non-energy mining fuel consumption is allocated to Oil and Gas Extraction. For a more detailed explanation of the allocation procedure, please see Annex 10 – Reallocation of Emissions from IPCC Sector to Canadian Economic Sector.

Table A3.1–3 **Estimation Methodology for Petroleum Refining, Manufacture of Solid Fuels and Oil and Gas Extraction**

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.1.b Petroleum Refining	Solid Fuels	NA		
	Liquid Fuels	RESD	3 – Refined Petroleum Products	Electricity by Industry[d] Steam Generation[d]
			11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	Electricity by Industry[d] Steam Generation[d] Refined Petroleum Products Manufacturing
	Biomass	NA		
1.A.1.c.i Manufacture of Solid Fuels	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Producer Consumption Total Mining and Oil and Gas Extraction[e]
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	NA		
1.A.1.c.ii Oil and Gas Extraction	Solid Fuels	NA		
	Liquid Fuels	RESD	3 – Refined Petroleum Products 6 – Details of Natural Gas Liquids	Electricity by Industry[d] Producer Consumption Total Mining and Oil and Gas Extraction[f]
			11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	NA
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	Electricity by Industry[d] Producer Consumption Total Mining and Oil and Gas Extraction[f]
	Biomass	NA		

Notes:

NA = Not applicable (national aggregation only)

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC (2006) Volume 2, Table 1.1.
c. Publication references are provided in Table A3.1–1.
d. A portion of this data source is allocated to this CRF source category prior to calculating emissions.
e. The portion of fuel consumed at coal mining operations is allocated to this CRF category.
f. The portion of fuel consumed at oil and gas extraction facilities is allocated to this CRF category.

As previously mentioned in section A3.1.4.1.1, national level coal emissions from combusted coal use aggregated provincial/territorial level estimates.

Table A3.1–3 provides a summary of the methodology for this CRF category.

A3.1.4.1.3. Manufacturing Industries and Construction (CRF Category 1.A.2)

The Manufacturing Industries and Construction category includes 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 summary lines (one for electricity and one for steam), which are not broken down by industrial categories. In addition, activity data, in the form of solid wood waste and spent pulping liquor, are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated data need to be reallocated to the appropriate industry where the fuel is used. Section A3.1.4.1 describes this reallocation method in detail.

Emissions are calculated for the following categories:

- Mining
- Iron and Steel
- Non-Ferrous Metals
- Chemicals
- Pulp, Paper and Print
- Non-Metallic Minerals
- Construction
- Other Manufacturing (includes Food Processing, Beverages and Tobacco)

GHG emissions associated with the Manufacturing Industries and Construction category are calculated by applying Equation A3.1–1 to activity data reported in the RESD and corresponding emission factors for each fuel type (as presented in A6.1). Section A3.1.4.1.1 describes the handling of coal emissions. The Industrial Processes and Product Use sector reports emissions from fuels used as feedstocks, while the Transport category reports emissions generated from the use of transportation fuels (e.g. diesel and gasoline).

The Industrial Processes and Product Use sector reports all emissions associated with the manufacture and use of metallurgical coke in the iron and steel industry for the reduction of iron ore in blast furnaces.

Industrial consumption of biomass and spent pulping liquor is reported in the RESD; however, some of the data are limited. The RESD data for Newfoundland and Nova Scotia are combined. Facility-level data are used to reallocate this consumption to Nova Scotia.

As previously described in section A3.1.4.1.2 the total mining and oil and gas extraction line in the RESD includes fuel consumption that occurs at coal mines, non-energy mines (including metal mining, sand, gravel and other aggregate mining, potash mining, diamond mining, etc.) and at facilities involved in the production of crude oil and natural gas. The RESD does not contain a sufficient level of detail to separate the fuel consumed at coal mines, non-energy mines and oil and gas extraction operations for allocation to the Manufacture of Solid Fuels (1.A.1.c.i), Mining (1.A.2.g.iii), and Oil and Gas Extraction (1.A.1.c.ii) categories, respectively. Other data sources are therefore used to allocate the fuel consumption to the proper categories. Fuel consumption for the non-energy mining industry is based on data from CEEDC (no date; NAICS 2122 and 2123). For a more detailed explanation of the allocation procedure, please see Annex 10 – Reallocation of Emissions from IPCC Sector to Canadian Economic Sector.

The Other Manufacturing category also includes GHG emissions associated with the combustion of waste for energy purposes. A portion of the waste is considered biogenic, so CO_2 emissions associated with combustion of this portion are reported but not included in the national total. The CO_2 emissions associated with the combustion of the non-biogenic portion, along with the total CH_4 and N_2O emissions, are included in the national total.

CO_2 emissions from the combustion of waste fuels in the cement industry are calculated using data provided by the Cement Association of Canada and reported by CIEEDAC (2013) on an energy basis. Table A3.1–4 provides a summary of the methodology for the Non-Metallic Minerals category.

A3.1.4.1.4. Other Sectors (CRF Category 1.A.4)

The Other Sectors category consists of three subcategories: Commercial/Institutional, Residential, and Agriculture/Forestry/Fishing. GHG emissions associated with the Other Sectors category (with the exception of emissions from the combustion of residential firewood) are calculated by applying Equation A3.1–1 to activity data reported in the RESD and corresponding emission factors for specific fuels (refer to Annex 6.1).

The activity data used in the calculation of GHG emissions from the combustion of residential firewood are based on estimated fuel use, as determined from the *Residential Fuelwood Consumption in Canada* study (ECCC 2020). Firewood consumption data were collected through a survey of residential wood use for the years 1997, 2003, 2007, 2015 and 2017 (Statistics Canada 1997, 2003, 2007, 2015, 2017). Pellet and manufactured log consumption data were collected for the years 1996, 2006, 2012, and 2017 (Canadian Facts 1997; TNS 2006; TNS 2012; Statistics Canada 2017). These data were collected by province and grouped into eight major appliance-type categories:

- Fireplaces
- Fireplace Inserts
- Wood Stoves
- Wood Furnaces
- Pellet Stoves
- Hydronic Heater
- Water Heater
- Other Equipment

Some of these appliance types were further broken down into either advanced technology (catalytic or non-catalytic) or conventional technology (air-tight or not-air tight).

The 2017 survey also collected data on the type of wood used, by reconciliation unit, and the moisture content of the wood. Section A3.5.1 describes the boundaries of reconciliation units in detail. Since the firewood consumption data were collected on a volume basis, an average density value was determined by reconciliation unit, based on the proportion of the different types of wood used, the corresponding wood densities and the moisture content of the wood. The wood densities were taken from various Canadian wood density studies (Alemdag 1984; Gonzalez 1990; Jessome 2000). The ratio of wood used, by reconciliation unit, and the moisture content of the wood compared to the total firewood consumption in the province was applied to all surveys. The pellet and manufactured log consumption data were collected on a mass basis.

Table A3.1–4 **Estimation Methodology for Manufacturing Industries and Construction**

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.2.a. Iron and Steel	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Iron and Steel Manufacturing
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.2.b. Non-Ferrous Metals	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Aluminum and Non-ferrous Metal Manufacturing
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.2.c. Chemicals	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Chemicals and Fertilizer Manufacturing
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.2.d. Pulp, Paper and Print	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Pulp and Paper Manufacturing
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.2.e. Food Processing, Beverages and Tobacco	Emissions for this subcategory are included in 1.A.2.g.viii.1 Other Manufacturing			
1.A.2.f. Non-Metallic Minerals	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Cement
		Waste fuel data from the Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC)		
	Liquid Fuels	RESD	3 – Refined Petroleum Products	Electricity by Industry[d] Steam Generation[d] Cement
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
1.A.2.g.iii Mining	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Total Mining and Oil and Gas Extraction[f]
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	NA	
1.A.2.g.v Construction	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Construction
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	NA	
1.A.2.g.viii.1 Other Manufacturing	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Other Manufacturing
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Other Fossil Fuels	NIR	Table A3.6–13[e]	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
		NIR	Table A3.6–13[e]	

Notes:

NA = Not applicable (national aggregation only)

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC (2006) Volume 2, Table 1.1.
c. Publication references are provided in Table A3.1–1.
d. A portion of this data source is allocated to this CRF source category prior to calculating emissions.
e. The non-biogenic portion of MSW incineration is included under Other Fossil Fuels, the biogenic portion is under biomass.
f. The portion of fuel consumed at non-energy mining operations is allocated to this CRF category.

The mass of biomass consumed for the other years was interpolated and extrapolated using the number of heating degree days in each province in relation to the survey years. GHG emissions were calculated by multiplying the amount of biomass burned in each appliance by the emission factors.

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

The Commercial/Institutional category includes GHG emissions associated with the combustion of landfill gas. As landfill gas is considered a biofuel, CO_2 emissions associated with combustion are reported but not included in the national total. CH_4 and N_2O emissions are, however, included.

The Commercial/Institutional category also includes GHG emissions associated with the combustion of waste for energy purposes. A portion of the waste is biogenic, and CO_2 emissions associated with combustion of this portion are reported but not included in the national total. The CO_2 emissions associated with the combustion of the non-biogenic portion, along with the total CH_4 and N_2O emissions, are included.

In addition, activity data in the form of fuel used by industry (including the Commercial/Institutional category) to generate electricity are currently aggregated to a summary line in the RESD (Line 11 – electricity by industry). Activity data in the form of solid wood waste and spent pulping liquor are currently aggregated to a summary table in the RESD (Table 10 – Solid Wood Waste and Spent Pulping Liquor). The aggregated fuel use data need to be reallocated to the appropriate subcategory. Section A3.1.4.1 discusses the disaggregation method used.

The Agriculture/Forestry/Fishing 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 space heating and are estimated using fuel use data for agriculture and forestry as reported in the RESD. Fishery emissions are reported under either the Transport or Other Manufacturing (i.e. food processing) category. Mobile emissions associated with this category are not disaggregated and are all included as off-road or marine emissions reported under the Transport category.

Table A3.1–5 provides a summary of the methodology for this CRF category.

Table A3.1–5 **Estimation Methodology for the Other Sectors Category**

CRF Source Category[a]	Fuel Type[b]	Data Source		
		Publication[c]	Table	Line
1.A.4.a.i Commercial/Institutional – Stationary Combustion	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Commercial and Other Institutional Public Administration
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Other Fossil Fuels	NIR	Table A3.6–13[e]	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	
		NIR	Table A3.6–13[e]	
		NIR	Table A3.6–6	
1.A.4.b.i Residential – Stationary Combustion	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Residential
	Liquid Fuels	RESD	3 – Refined Petroleum Products	Residential
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	Residential
	Biomass	Estimated using Environment Canada residential fuelwood consumption model.		
1.A.4.c.i Agriculture/Forestry/Fishing – Stationary Combustion	Solid Fuels	RESD	1 – Primary and Secondary Energy Coal Details (unpublished)	Electricity by Industry[d] Steam Generation[d] Forestry and Logging and Support Activities for Forestry Agriculture
	Liquid Fuels	RESD	3 – Refined Petroleum Products	
	Gaseous Fuels	RESD	1 – Primary and Secondary Energy 6 – Details of Natural Gas Liquids	
	Biomass	RESD	10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption[d]	

Notes:

a. The CRF categories listed are the lowest-level subcategories for which emissions are estimated.
b. As outlined in IPCC (2006) Volume 2, Table 1.1.
c. Publication references are provided in Table A3.1–1.
d. A portion of this data source is allocated to this CRF source category prior to calculating emissions.
e. The non-biogenic portion of MSW incineration is included under Other Fossil Fuels and the biogenic portion under Biomass.

A3.1.4.2. Transport (CRF Category 1.A.3)

GHG emissions from the Transport category are divided into six subcategories:

- Domestic Aviation
- Road Transportation
- Railways
- Domestic Navigation
- Other Transportation (Pipeline Transport)
- Other Transportation (Off-Road)

Emission estimates are developed at the provincial/territorial level and aggregated to the national level. Fuel combustion emissions associated with the Transport category are calculated using various adaptations of Equation A3.1–1.

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 6 provides a complete listing of transportation-related emission factors and their specific references.

For the Road Transportation and Other Transportation (Off-Road) categories, Canada uses the Motor Vehicle Emissions Simulator (MOVES) model, MOVES2014 version, developed by the U.S. EPA, and a modified version of the U.S. EPA's NONROAD model (NONROAD2012c). The primary reasons for these updates are to remain current with regulatory changes in the Canadian vehicle fleet, which are harmonized with those of the United States, to align GHG estimates with those published in *Canada's Air Pollutant Emissions Inventory Report 1990–2019* and *Canada's Black Carbon Inventory Report 2013–2019* and to create a bottom-up inventory for off-road emissions by making use of equipment and operational data. Use of the NONROAD model also has the added benefit of allocation to additional economic subsectors on an equipment basis. Therefore, under the CRF classification system, some emissions that were previously reported in the 1.A.3 categories are allocated to the 1.A.2 and 1.A.4 categories. The Aviation Greenhouse Gas Emission Model (AGEM) is used to calculate aviation emissions. The Marine Emissions Inventory Tool (MEIT) is used to calculate navigation emissions. Railway emissions are derived from fuel reported in the RESD. Combustion emissions associated with pipeline transport are estimated separately.

A3.1.4.2.1. Road Transportation (CRF Category 1.A.3.b.i-v) and Other Transportation (Off-Road) (CRF Categories 1.A.2.g.vii, 1.A.3.e.ii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii)

The methodology used to estimate Road Transportation and Other Transportation (Off-Road) GHG emissions follows a detailed IPCC Tier 3 approach. Since these two categories are collectively normalized to fuel available as reported in the RESD, a combined methodology for the two categories is outlined below.

Step 1: On-Road Activity Data—Vehicle Populations, Technology Penetration, Catalyst Survival Rate, Kilometre Accumulation Rates, Fuel Consumption Rates and Biofuels

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 and 2005–2015 were obtained from the Canadian Vehicles in Operation Census, which is maintained by DesRosiers Automotive Consultants Inc. Light-duty vehicle and truck populations for 2003–2004 were derived from Statistics Canada's Canadian Vehicle Survey. Heavy-duty vehicle populations were obtained from R.L. Polk & Co. for 1994–2002 and 2005–2015. Heavy-duty vehicle populations for 2003–2004 were derived from Statistics Canada's Canadian Vehicle Survey, while populations for 1990–1993 were estimated based on historical population trends. The 2016–2019 populations were estimated based on scrappage and growth rates.[1] 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.[2]

1 Scrappage rates for all vehicle classes (including motorcycles) were developed based on historical population trends. The growth rates for light-duty vehicles and motorcycles are from the U.S. EPA Motor Vehicle Emission Simulator (MOVES2014, 2014). For all other classes, Power Systems Research Inc. provided growth rates.

2 The 2005–2015 light- and heavy-duty populations received from DesRosiers and Polk were in a new format when compared with previously received data sets and were derived using updated vehicle identification algorithms. As a result, when the 1990–2004 data set was merged with the 2005–2015 data set, there were step changes in some classes between 2004 and 2005. The classes affected were light-duty trucks (GVWR less than or equal to 3900 kg) and heavy-duty vehicle 2b and 3 classes (GVWR between 3901 kg and 6351 kg). Since the newer data set with updated algorithms is believed to be more representative, the class ratios between light-duty trucks and heavy-duty vehicle 2b and 3 classes from the newer data were applied to the older data set while maintaining the overall population of the older data set.

Motorcycle populations for 1990–2013 were based on road motor vehicle annual registrations from Statistics Canada (CANSIM Table 405-0001 and Table 405-0004). The annual motorcycle counts were then stratified into model year bins with the aid of published age distributions found in the Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. EPA 2015). The 2014–2019 population was estimated based on a scrappage and growth rate.

Technology penetration

To account for the effects of emission control technologies on emission rates 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. The vast majority of on-road vehicles in use in 2019 are subject to Tier 1 and Tier 2 regulatory tiers, approximately representing model years 1996 and onwards. However, since the National Inventory estimates a time series starting at 1990, as well as considering a small number of pre-1996 model year vehicle still in active fleet, additional technology emission rates for CH_4 and N_2O emission factors are also used. These include emission controls ranging from completely uncontrolled vehicles to those using Tier 1 regulatory standards. Similarly, heavy-duty gasoline vehicles (HDGVs), heavy-duty diesel vehicles (HDDVs) and motorcycles (MCs) have advanced emissions controls starting with the 1996 model year. Emission factors for uncontrolled and/or moderate controls are used for 1995 and older model years. CH_4 and N_2O emission factors for the full range of emissions controls are listed in Annex 6.

Catalyst survival rate

With use, catalytic converters deteriorate, affecting tailpipe 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 programs (Ontario and British Columbia), the catalyst survival rate is not applied to Tier 0, Tier 1 or Tier 2 technologies, as these emission control technologies are inspected and replaced or repaired as necessary.

Fuel consumption rates (FCR)

With the adoption of MOVES2014, fuel consumption rates are now embedded within the model in the form of energy rates in kilojoules per second (kJ/s). The rates vary, taking into account a range of default parameters or user inputs, such as vehicle type, model year, speed, road type and operating mode. As the Canadian and U.S. vehicle markets are made virtually identical through regulation, it is believed that the MOVES energy rates are representative of fuel consumption for Canadian vehicles. MOVES also factors in more current fuel efficiency regulations, such as the *On-Road Vehicle and Engine Emission Regulations* for light-duty vehicles and the *Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations* for heavy-duty vehicles. Further documentation on MOVES energy rates for both light- and heavy-duty vehicles can be found on the U.S. EPA website at https://www.epa.gov/moves/moves-technical-reports.

For this submission, Canada only uses MOVES' energy allocation capability. MOVES output is on an energy basis and Canada's current emission factors are developed on a fuel-volume basis. The energy output from MOVES is therefore converted to fuel volumes using energy conversion factors, as reported in *Updated CO_2 Emission Factors for Gasoline and Diesel Fuel* (ECCC 2017b), taking into consideration the use of biofuels (see below). MOVES reports energy output on a lower heating value basis. Canada plans to review the GHG emission factors within MOVES for their potential use in a future submission.

Kilometre accumulation rates

Kilometre accumulation rates (KARs) are a measure of the average annual kilometres travelled by a single vehicle of a given age in a specific vehicle class. Light-duty car and truck KARs are estimated from the results reported in a study that examined observed differences in a vehicle odometer reading recorded between successive inspection and maintenance tests from Ontario and British Columbia (Stewart Brown Associates 2013). Given the absence of inspection and maintenance 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.

Biofuels

MOVES requires biofuel content on a relative content basis (i.e., percent) as an input, as well as a range of other fuel characteristics, such as vapour pressure, sulphur content, and benzene content. These parameters are derived by ECCC using information collected under the *Renewable Fuels Regulations, Sulphur in Liquid Fuels* reports and related sources. However, volumes of biofuels are recalculated as outputs such that emissions can be estimated by selecting appropriate emission factors in Annex 6 and applying Equation A3.1–1.

Step 2: On-Road Fuel Calculation

Using the inputs from Step 1, on-road fuel consumption is estimated by converting MOVES2014 energy outputs into litres of fuel volume. This calculation represents the initial "bottom-up" fuel calculation for consideration in the fuel normalization process described below. On-road vehicles are grouped into eight major vehicle classes:

- Light-duty gasoline vehicles (LDGV)
- Light-duty gasoline trucks (LDGT)
- Heavy-duty gasoline vehicles (HDGV)
- Motorcycles (MC)
- Light-duty diesel vehicles (LDDV)
- Light-duty diesel trucks (LDDT)
- Heavy-duty diesel trucks (HDDV)
- Propane and natural gas vehicles

Step 3: Other Transportation (Off-Road) (CRF Category 1.A.3.e.ii)

GHG emissions for off-road transportation are calculated using NONROAD2012c, a Canadianized update to NONROAD2008 developed by the U.S. EPA. Key inputs to the model are equipment population, average rated power, load factor and activity (in hours/year). Further, the Canadian modifications to NONROAD include a user-defined age distribution of equipment that is not part of the U.S. model, as well as a unique coding for oil sands equipment and additional renewable fuels capabilities. NONROAD outputs are expressed on a fuel volume basis, to which Equation A3.1–1 is applied using the emission factors in Annex 6.

Activity data used in the model are largely derived from Power Systems Research (PSR) data. PSR is an independent supplier of data which maintains PartsLink, a comprehensive database that includes off-road equipment used in Canada. A significant study conducted by PSR in 2011 forms the basis of activity input, which includes parameters such as engine populations, age distribution, engine size, load factor and hours of use for the years 1990 to 2019. Construction equipment populations used in oil sands mining operations were identified with a mining equipment database provided by The Parker Bay Company (ECCC 2018b). Where possible, the hours-of-use parameter provided by PSR was replaced using Canada-specific information collected from resale markets. As an example, activity data from nearly 2000 used snowmobile advertisements were used to derive hours-of-use data, by engine stroke (ECCC 2018a). NONROAD default parameters used include deterioration and other factors. Updates to the 2011 data set were performed in 2012 and 2013. Unlike MOVES, which outputs on an energy basis, NONROAD calculates fuel use on a volume basis, which is later scaled upwards or downwards in the fuel normalization step (Step 4) once biofuels are taken into account.

A great advantage of NONROAD is its capability to allocate emissions to distinct sectors on an equipment basis. Primary sectors from NONROAD include agriculture, airport (equipment), commercial, construction and mining, industrial, residential, forestry, railway (equipment) and recreational equipment. Where applicable, emissions from these sectors are reported under the appropriate CRF sector.

Step 4: Normalization

In an effort to mitigate some of the uncertainties associated with separate bottom-up calculations for on- and off-road estimates, the fuel consumption estimates from these two subsectors are combined and balanced against top-down fuel availability information. The source of top-down fuel availability data to be considered against the bottom-up fuel consumption estimate is the RESD (Statistics Canada 1990–).

Statistics Canada has stated that the volumes of gasoline reported in the RESD include ethanol. Therefore, the estimated volume of ethanol fuel is removed from the volume of gasoline reported. As a result, when comparing total volumes of gasoline in the RESD with that of the CRF, one should be cognizant that the CRF gasoline volume must be added to the CRF ethanol volume in order to equate to the RESD gasoline volume. For diesel fuel, the opposite is true: given that the RESD does not report biodiesel, diesel fuel volumes in the CRF will equate to the diesel fuel volumes in the RESD.

In Step 4, bottom-up estimates of fuel consumption from on- and off-road sources are pooled together on a fuel basis at the provincial/territorial level, and the total volume of fuel is scaled to match the fuel available as reported in the RESD. At a provincial level, top-down and bottom-up gasoline consumption estimates differ slightly; however, at a national level, the degree of correlation between the two estimates is higher. Please refer to Table A3.1–6 and Table A3.1–7 for the normalization factors calculated on a national basis for gasoline and diesel fuel, respectively.

Step 5: Emission Calculation

Once a final allocation of fuel is complete for all vehicle and equipment types, emissions are calculated using Equation A3.1–1 with the emission factors in Annex 6.

Table A3.1–6 **Gasoline Normalization Values, Selected Years**

Category	Statistic	1990	2005	2013	2014	2015	2016	2017	2018	2019
Raw	Bottom-Up On-Road Fuel Consumption Estimate (ML)	37 113	40 653	48 301	49 418	50 529	50 340	50 203	51 356	52 251
	Bottom-Up Off-Road Fuel Consumption Estimate (ML)	7 463	3 189	3 158	3 463	3 531	3 335	3 458	3 581	3 518
	Total Bottom-Up Fuel Consumption Estimate (ML)	44 576	43 842	51 459	52 881	54 060	53 675	53 661	54 937	55 770
	Bottom-Up On-Road Portion (%)	83	93	94	93	93	94	94	93	94
	Bottom-Up Off-Road Portion (%)	17	7	6	7	7	6	6	7	6
Target	Total Top-Down Fuel Available (ML)	33 943	40 850	44 263	43 437	44 423	46 046	46 390	47 037	47 633
	National Scaling Factor (%)	76	93	86	82	82	86	86	86	85
Scaled	Final On-Road Fuel Estimate (ML)	28 298	37 868	41 528	40 567	41 493	43 160	43 385	43 961	44 621
	Final Off-Road Fuel Estimate (ML)	5 645	2 981	2 735	2 870	2 930	2 886	3 005	3 076	3 012
	Sum of Final On- and Off-Road Fuel (ML)	33 943	40 850	44 263	43 437	44 423	46 046	46 390	47 037	47 633

Table A3.1–7 **Diesel Fuel Normalization Values, Selected Years**

Category	Statistic	1990	2005	2013	2014	2015	2016	2017	2018	2019
Raw	Bottom-Up On-Road Fuel Consumption Estimate (ML)	5 324	14 638	18 974	19 489	19 344	20 196	21 105	21 899	22 202
	Bottom-Up Off-Road Fuel Consumption Estimate (ML)	9 404	10 322	9 278	9 254	9 851	9 892	10 594	11 281	11 367
	Total Bottom-Up Fuel Consumption Estimate (ML)	14 728	24 960	28 252	28 743	29 195	30 089	31 699	33 180	33 569
	Bottom-Up On-Road Portion (%)	36	59	67	68	66	67	67	66	66
	Bottom-Up Off-Road Portion (%)	64	41	33	32	34	33	33	34	34
Target	Total Top-Down Fuel Available (ML)	13 188	22 766	27 613	27 475	27 462	26 186	27 927	29 629	29 506
	National Scaling Factor (%)	90	91	98	96	94	87	88	89	88
Scaled	Final On-Road Fuel Estimate (ML)	5 266	13 872	18 797	18 771	18 393	17 805	18 760	19 737	19 696
	Final Off-Road Fuel Estimate (ML)	7 922	8 894	8 816	8 704	9 070	8 381	9 167	9 891	9 810
	Sum of Final On- and Off-Road Fuel (ML)	13 188	22 766	27 613	27 475	27 462	26 186	27 927	29 629	29 506

A3.1.4.2.2. Domestic Aviation (CRF Category 1.A.3.a)

The methodology used to estimate GHG emissions from the Domestic Aviation category employs a modified IPCC Tier 3 approach. The Aviation model has been named AGEM as an acronym for Aviation Greenhouse Gas Emission Model.

This category includes all emissions from domestic air transport (commercial, private, agricultural, etc.). In accordance with the 2006 IPCC Guidelines, and because of the Tier 3 approach, military air transportation emissions are reported in the Other – Mobile category (CRFcategory 1.A.5.b). Excluded are emissions from fuel used at airports for ground transport, which are reported under Other Transportation (Off-Road), and emissions from 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.

Careful consideration should be paid when comparing emission estimates in this category against those reported to other institutions, such as the International Energy Agency (IEA). The IEA estimates are, in particular, quite different from those reported in the CRF when comparing domestic and international (bunker) emissions from aviation turbo fuel. The Tier 3 method employed by AGEM in the NIR allows detailed flight-by-flight distinction between domestic and international movements based on a flight's origin and destination. The fuel consumption values (disaggregated into domestic and international sectors) reported to the IEA by Canada assume that all fuel sold to Canadian carriers is domestic and that all fuel sold to foreign carriers is international, which greatly underestimates the amount of emissions identified as aviation bunkers, given that many movements by Canadian carriers are international in nature. Because the reporting requirements for these two separate reports (UNFCCC, IEA) do not align, the reported values will not align either.

Step 1: Activity Data: Aircraft Movements, Flight Path Length, Airport Coordinates, Aircraft Fuel Use Characteristics, Representative Aircraft Mapping, Aircraft Emission Performance

Aircraft movements

The aircraft movement data (AMS 2020) used in AGEM are flight-by-flight tower data collected by NAV Canada (Canada's civil air navigation services provider) starting in November 1996 and by Transport Canada before November 1996. Both data streams are processed by Statistics Canada and redistributed to NAV Canada and Transport Canada. ECCC 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 identify, among other things, the origin, destination and aircraft type for any given movement occurring in Canada. Statistics Canada's processing of the data includes adding information based on other raw data fields provided to it as well as validation of airports, aircraft types and various data fields that are not crucial to modelling fuel use.

Military emissions are estimated on the basis of 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 called the Aviation Environmental Design Tool (AEDT) (formerly System for Assessing Aviation's Global Emissions [SAGE]) that is based on true radar data. The FAA provided Environment Canada with an extract from its 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 aircraft 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[3]) 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/aircraft 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, and elevation, were compiled from various sources, including the 2009 and 2019 Canada Flight Supplement (NAV Canada 2009, 2019a), 2018 and 2019 Canada Water Aerodrome Supplement (NAV Canada 2018b, 2019b), Airport International Air Transport Association (IATA) and International Civil Aviation Organization (ICAO) codes (NAV Canada 2018a), the FAA (FAA 2020), Airline and Location Code Search database (IATA 2020), SAGE (Fleming 2008b), the Modeling and Database Task Force (MODTF) (Fleming 2008c) and World Airport Codes (2020). The main data required to calculate a GCD for use in determining the flight path length are the geographical coordinates.

Aircraft fuel use characteristics

Once the flight path length is determined, the fuel consumed by the aircraft for that movement can be calculated using the fuel characteristics of that aircraft. The fuel characteristics of various representative aircraft are drawn from the Base of Aircraft Data (BADA) (BADA 2019), the ICAO via their engine emissions databank (ICAO 2019), the Swedish Defence Research Agency (FOI) via their turbo prop engine emissions databank (Hagstrom 2010), and the Federal Office of Civil Aviation (FOCA) in Switzerland (FOCA 2007).

Information from ICAO, FOI and FOCA is used to estimate fuel use for the taxi-out, taxi-in and takeoff phases of each flight. Information from BADA is used to estimate fuel use for the climb-out, climb, cruise, descent and landing phases of each flight.

3 Great circle distance is the shortest distance between two points on a sphere; with respect to aviation, it is the shortest possible flight path length between the origin and destination of a flight movement.

Representative aircraft mapping

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 2019, FAA 2018, IPCC 2006, ICAO 2016, ICAO 2020) and by matching aircraft characteristics (MTOW,[4] 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 from aviation turbo fuel, aircraft-specific emission factors are used within AGEM, when applicable, for the LTO cycle. When there is no aircraft-specific CH_4 emission factor, the 2006 IPCC default factor is used. The factors are taken from Table 3.6.9 in the 2006 IPCC Guidelines and converted into grams per litre of fuel consumed. 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 will be based on total fuel consumed (LTO and cruise).

Table 3.6.9 in the 2006 IPCC Guidelines also has N_2O aircraft-specific aviation turbo fuel emission factors on a total LTO cycle basis; however, they are calculated using a Tier 1 fuel-based emission factor. Therefore, the Tier 1 factor is used directly since the amount of fuel consumed during the LTO cycle is calculated by AGEM.

Country-specific emission factors on a g/L basis are used for CO_2 emissions from aviation turbo fuel aircraft and for CO_2, CH_4 and N_2O emissions from aviation gasoline aircraft.

Step 2: Aircraft Fuel Calculation

Fuel consumed by each individual movement is estimated using the following equation.

Equation A3.1–2

$$FC_{FlightTotal} = FC_{Taxi\text{-}out} + FC_{Takeoff} + FC_{Climb\text{-}out} + FC_{Climb} + FC_{Cruise} + FC_{Descent} + FC_{Landing} + FC_{Taxi\text{-}in}$$

$FC_{FlightTotal}$	=	total fuel consumed on a per-flight basis
$FC_{Taxi\text{-}out}$	=	fuel consumption during the taxi-out phase
$FC_{Takeoff}$	=	fuel consumption during the takeoff phase
$FC_{Climb\ out}$	=	fuel consumption during the climb-out phase
FC_{Climb}	=	fuel consumption during the climb phase
FC_{Cruise}	=	fuel consumption during the cruise phase
$FC_{Descent}$	=	fuel consumption during the descent phase
$FC_{Landing}$	=	fuel consumption during the landing phase
$FC_{Taxi\text{-}in}$	=	fuel consumption during the taxi-in phase

4 Maximum takeoff weight.

The landing and takeoff (LTO) phase of flight (3000 ft and below) consists of takeoff (accelerating down the runway until liftoff), climb out (from liftoff to 3000 ft), landing (3000 ft to touchdown) and taxi in/out (manoeuvring from the airport runway to/from the gate). The various LTO phases of flight are quantified by using either standard time-in-modes for that phase multiplied by the fuel consumption rate for that phase (drawn from ICAO, FOI or FOCA) or BADA fuel use characteristics for the aircraft as applicable (only available for the climb-out and approach phases).

The cruise phase of flight (above 3000 ft) is calculated using the BADA fuel use characteristics of the aircraft 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 movement 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 aircraft, the time-in-mode and flight path length, the LTO and cruise fuel estimates can be computed.

Step 3: Normalization

All aviation turbo fuel and aviation gasoline consumed in Canada is reported in the RESD (Statistics Canada 1990–). 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 A3.1–1. The individual emission estimates are then summed to generate the national emission estimate.

A3.1.4.2.3. Domestic Navigation (CRF Category 1.A.3.d)

The methodology used to estimate GHG emissions from the domestic navigation category is considered an IPCC Tier 2 method for CO_2 emissions and an IPCC Tier 1 for CH_4, and N_2O emissions.

This category includes emissions from vessels navigating between Canadian ports. In accordance with the 2006 IPCC Guidelines, military marine transportation emissions are reported in the Other Mobile category (CRF category 1.A.5.b). Likewise, emissions from fishing vessels are reported in the Fishing category (CRF category 1.A.4.c.iii). Excluded are emissions from smaller recreational vessels (reported under Other Transportation [Off-Road]). Emissions from international voyages are designated as “bunker” emissions and are not included in national totals but are estimated and reported separately under International Bunkers as a Memo Item.

Marine emissions are developed using the Marine Emissions Inventory Tool (MEIT), a model developed using vessel tracking information. Unlike the RESD, where fuel values are based on fuel sales data and organized by flag of vessel, MEIT is based on vessel movements and domestic or international emissions are assigned according to port origin destination information. Therefore, and similar to the Aviation subcategory, careful consideration should be paid when comparing fuel consumption (in terms of energy) in this subcategory against the national energy balance reported in the RESD and IEA data. Due to design and operating procedures of marine vessels, it is not uncommon for vessel to store significant amounts of fuel onboard. This means that it is possible for vessels to navigate in Canadian waters without purchasing fuel from a Canadian supplier. Since the RESD is based on fuel transactions in Canada, it is possible to have more fuel consumed in the marine sector than what is reported in the national energy balance. When using the reference approach, excess fuel is accounted for as a “temporary import”.

Step 1: Activity Data: Marine Emission Inventory Tool

The Marine Emission Inventory Tool uses vessel traffic data and vessel characteristics to estimate the quantity of fuel required for each vessel manoeuvre within Canadian waters. Vessel traffic data are used for the 2010, 2015, 2016, 2017 and 2018 calendar years. However, MEIT developed backcasts/forecasts for 1990 to 2050 in 5-year increments. Fuel quantities between those years were linearly interpolated. Since the 2015, 2016, 2017 and 2018 calendar years are the only years for which estimates are available at a detailed level, the proportions of fuel use for those years are applied to the other calendar years to further break down the fuel quantity.

For the 2010, 2015, 2016, 2017 and 2018 calendar years, the MEIT data are based on vessel traffic data from the Canadian Coast Guard Information System on Marine Navigation (INNAV) and Automatic Identification System (AIS) and the Department of Fisheries and Oceans' fishing license data. The vessel movements are grouped into 1-km segments, which provide the distance and time between each point. To estimate the fuel use, the vessel characteristics/classifications are taken into consideration. Three sources of fuel consumption are considered: main engines, auxiliary engines and boilers. MEIT uses general assumptions for the auxiliary engines and boilers, however, more parameters are used to determine the fuel consumed by the main engine. The load factor has a significant influence on the fuel estimate from the main engine and is therefore calculated for each data point based on the propeller law.

From 1990 to 2010 the data was backcasted using multiple factors including Transport Canada commodity data for 1990 to 2005, port dry bulk and containerized (TEU) data, Northwest and Canada Cruise Association (NWCCA) passenger data, and Statistics Canada population data.

From 2018 to 2050 the data was forecasted by scaling the ship movements per vessel class on the basis of estimated sector growth/contraction, and adjusting the emission factors on the basis of regulations and policies in place for that future year.

Step 2: Fuel allocation and time series consistency

The amount of fuel from the RESD is compared against the values estimated by the MEIT in order to determine how much of the fuel burned is likely to have been obtained from Canadian fuel suppliers. The comparison is performed systematically at a regional and category level.

In the event that the RESD values are greater than the fuel consumption values estimated by MEIT (Scenario 1), it is assumed that fuel values from MEIT for military, fishing, domestic and international navigation are all purchased from Canadian suppliers. Any fuel difference between the RESD and MEIT is attributed to the International Navigation (Bunkers) category. It is assumed in this scenario that the MEIT model underestimated the amount of fuel used for international navigation, which is likely due to the MEIT only covering movement within Canadian waters.

In the event that the RESD values are less than the fuel consumption values estimated by MEIT (Scenario 2), the following procedure is followed:

Case 1 – Military. If the amount of fuel available in the RESD is greater than the amount of fuel estimated by MEIT to be used by military vessels, then it is assumed that all fuel used for military operations was obtained from Canadian suppliers. If the amount of fuel available in the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers, while the remainder of fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 2 – Fishing. If the amount of fuel available in the RESD (minus that used for military operations) is greater than the amount of fuel estimated by MEIT to be used by fishing vessels, then it is assumed that all fuel used for commercial fishing was obtained from Canadian suppliers. If the amount of fuel available in the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers, while the rest of fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 3 – Domestic Navigation. If the amount of fuel available in the RESD (minus that used for military and fishing operations) is greater than the amount of fuel estimated by MEIT used by vessels involved in domestic voyages, then it is assumed that all fuel used for domestic navigation was obtained from Canadian suppliers. If the amount of fuel available in the RESD is less than the amount from MEIT, the portion of fuel equal to that of the RESD is assumed to be purchased from Canadian fuel suppliers, while the rest of fuel used in that region is assumed to be purchased from a foreign fuel supplier.

Case 4 – International Navigation (Bunkers). The portion of fuel equal to the amount of fuel available in the RESD (minus that used for military, fishing and domestic navigation) is assumed to be purchased from a Canadian supplier to be used for international navigation (bunkers). Then the difference between the MEIT fuel and the RESD fuel is assumed to be purchased from foreign fuel suppliers.

Step 3: Emission Calculation

Emissions are calculated by multiplying the fuel quantity by the fuel-specific emission factors (see Annex 6).

A3.1.4.2.4. Railways (CRF Category 1.A.3.c)

The methodology is considered to be an IPCC Tier 2 method for CO_2 emissions and an IPCC Tier 1 for CH_4, and N_2O emissions. Railway fuel consumption reported in the RESD (Statistics Canada 1990–) is multiplied by fuel-specific emission factors (see Annex 6).

In Canada, locomotives are powered primarily by diesel fuel. A review of emissions attributable to steam train operations in Canada has determined that emissions associated with steam trains are insignificant. Electrically driven locomotives are accounted for under electricity production.

A3.1.4.2.5. Biomass (CRF Category 1.D.3)

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 fuel on-road transportation and an IPCC Tier 1 method for off-road transportation, railways and domestic marine. The volume of biofuels consumed

for transportation is proportionally reallocated back into the respective diesel fuel and gasoline emission technology classes based on those classes' initial consumption volumes.

The volumes of biofuels used for on- and off-road transportation are described in section A3.1.4.2.1. The volumes of biofuels used for the rail and marine categories are based on information collected from *Canada's Renewable Fuels Regulations*. Currently, it is assumed that no biofuels are used in the aviation sector.

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

A3.1.4.2.6. Pipeline Transport (CRF Category 1.A.3.e.i)

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 A3.1–1 to activity data and emission factors, at the provincial level for natural gas, and national level for other fuels.

A3.2. Methodology for Fugitive Emissions from Fossil Fuel Production, Processing, Transmission and Distribution

Detailed methodologies for estimating fugitive emissions from solid fuel production and the oil and gas industry are 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 crude oil production. For a description of all sources of fugitive emissions, refer to Chapter 3.

All greenhouse gas (GHG) emissions from fuel combustion activities associated with fossil fuel exploration, production, processing, transmission and distribution are reported under the Energy Industries (section 3.2.4) and Transport (section 3.2.6) sections of Chapter 3, and their respective methodologies can be found in Annex 3.1 (sections A3.1.4.1 and A3.1.4.2).

A3.2.1. Solid Fuels

A3.2.1.1. Coal Mining

Canada Specific Coal Mining Studies

Canada's fugitive emission estimates are largely based on three studies: *Methane Emissions from Canadian Coal Operations: A Quantitative Estimate*, prepared by B. Hollingshead (1990) for the Transalta Utilities Corp.; *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options*, prepared by B. King (1994) for Neill and Gunter Ltd; and *Compilation of a National Inventory of Greenhouse Gas and Fugitive VOC Emissions by the Canadian Coal Mining Industry*, prepared by Cheminfo Services Inc. and Clearstone Engineering Ltd (Cheminfo and Clearstone, 2014) for Environment and Climate Change Canada (ECCC). These three studies contain mine-specific information upon which Canada has based its country-specific data, parameters and information regarding surface and underground mines, and they are confidential.

The Hollingshead study was commissioned by Transalta Utilities Corp., with the goal of estimating methane (CH_4) emissions from coal mines and coal combustion in Canada. The study developed, for the year 1989, estimates of fugitive emissions from underground and surface mines and combustion emissions from all coal use in Canada. As such, the emphasis of this study was not on developing emission factors (EFs) that would be usable on a yearly basis, but rather on providing a snapshot of

all emissions from coal for a particular year. However, in the process of estimating these total emissions, a large amount of useful data was collected pertaining to the CH_4 composition of coal mined in Canada.

Canada has had, in most years, both underground and surface coal mines, and the method developed by King (1994) produced CH_4 emission factors for all coal types and all individual coal mines. Where possible, King employed the Canada-specific data included in the Hollingshead study, while clearly identifying and explaining this data source. King's method for surface and underground mines is a modified version of a process developed for the International Energy Agency by the Coal Industry Advisory Board (CIAB). Further discussion of some of these modifications can be found in the section below on surface mines. Prior to the 2016 submission, the EFs for CH_4 determined in the King (1994) study were used to estimate the CH_4 fugitive emissions from all 23 operational mines and from all mines abandoned after 1990 in Canada.

In 2014, ECCC awarded a contract to Cheminfo Canada and Clearstone Engineering to update the EFs for coal mines in western Canada. The study produced new EFs for seven of the then 21 active surface mines using field tests from two sub-bituminous coal mines in central Alberta, one bituminous coal mine in northeast British Columbia and one bituminous coal mine in northwest Alberta. Results from the four tested mines were applied to three nearby mines that exploited the same coal seams and had similar geography. The mobile plume transect system (MPTS) that was employed develops a two-dimensional y-z plot of the pollutant concentration and wind profile downwind of the target source(s). The measurement system comprised: (1) a cavity ring-down spectrometer; (2) an 8-channel multiplexer sampling system; (3) an ultrasonic 3-D wind anemometer; (4) a GPS and inertial system; (5) a vehicle equipped with a vertical sampling mast; and (6) a computer and software.

The emissions model is a hybrid of IPCC Tier 2 and Tier 3 methodologies that depends on the availability of mine-specific data. Gross production values provided by Statistics Canada, before any cleaning and prep work, is used to calculate fugitive emissions for all mine types. The associated post-mining activity emissions are accounted for in the underground and surface mining EFs. Additional details of the methodologies used to estimate the emissions from underground and surface mines are provided in their respective sections.

The EFs vary for each coal field, region and mine type, whether above or below ground.

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. In the absence of measured data, emissions from the mine shaft ventilation system were estimated using Equation A3.2–1.

Equation A3.2–1

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

Y = emissions of CH_4 per gross 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 CH_4 content of the mined coal was unknown, then 1.5 m^3/t, the global average for coals (King, 1994) was assumed. All underground mines in Canada are drift mines and have an effective depth of zero metres. Emissions from post-mining activities are included in the coal production EFs, after all quantities are converted to mass units, using a standard conversion of 0.67 kg/m^3 CH_4.

Between 1992 and 1999, all underground mining ceased in eastern Canada. The remaining underground mines were located in Alberta and British Columbia and were less gassy than mines in eastern Canada. Between 2015 and 2017 there were no active underground coal mines in Canada, however, the Donkin mine in Nova Scotia resumed operation in 2018.

Surface Mines

The CIAB methodology was modified to incorporate confidential Canadian and U.S. site-specific data (from King, Hollingshead and Cheminfo and Clearstone) for the three coal types mined in Canada, rather than using a generalized international data set to represent country-specific circumstances. King developed EFs by region, by mine and by coal types; the average CH_4 content of bituminous or sub-bituminous coal was 0.4 m^3/t (based on tests at 50 mines in the United States, obtained by King) and the Canada-specific CH_4 content for lignite was 0.05 m^3/t (Hollingshead, 1990), with the assumption that 60% of the gas is released before combustion. A field testing campaign to measure fugitive emissions of CH_4, Carbon dioxide (CO_2) and Volatile Organic Compounds (VOCs) was performed on four coal mines in late February 2014:

- Sites 1 and 2: two sub-bituminous coal mines in central Alberta
- Site 3: one bituminous coal mine in northeast British Columbia
- Site 4: one bituminous coal mine in northwest Alberta

CH_4 emissions were measured remotely using a ground-based mobile plume transect system (MPTS) for area sources and tracer tests for volume and point sources (Cheminfo and Clearstone, 2014). Data from this field testing was used to modify the CH_4 emission factors of 7 of the 23 producing mines in Canada. The EFs in Table A3.2–1 incorporate these data and assumptions.

In addition, the overall CH_4 emission factor uncertainty is reported in Table A3.2–1 category 1.B.1.a Fugitive Sources – Coal mining and Handling.

Surrounding unmined strata are a significant source of emissions from surface mines. Using Canadian mine-specific data from the Hollingshead study, King applied a high-wall adjustment to the surrounding unmined strata, to a depth of 50 m below the mining surface. Base EFs for surface mining were increased by 50% (King 1994) to account for this out-gassing adjustment and are reflected in the EFs in Table A3.2–1.

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

Equation A3.2–2

$$Provincial\ Emissions = \sum(EF_{i,j,k,l} \times Coal_{i,j,k,l})$$

$EF_{i,j,k,l}$ = the emission factor from the King (1994) or Cheminfo and Clearstone (2014) studies for province i, coal type j, mine k and coal field l

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

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

Despite the closing of east coast underground mines, production increases at less gassy surface mines in Alberta and British Columbia have sustained Canada's total annual coal production. The net effect is that, while production has stayed steady, total fugitive emissions associated with coal mining have declined significantly since 1990.

Activity Data

The model requires the gross mine output data for each type of coal mined in each province. Until 2002, the data was obtained from Statistics Canada's *Coal and Coke Statistics* publication (Cat. No. 45-002-X, Table 2). In 2002, the publication was discontinued, and Statistics Canada now provides this data directly to Environment and Climate Change Canada via a memorandum of understanding.

Emission Factors

EFs were developed by coal type, coal mine type and coal field. Because of confidentiality requirements, factors can only be reported at the provincial level. Therefore, weighted EFs were developed at the provincial level.

These weighted EFs, by mine and coal type, were developed using the King (1994), and Cheminfo and Clearstone (2014) studies and are listed in Table A3.2–1.

A3.2.1.2. Abandoned Underground Coal Mines

Coal mine methane (CMM) and other gases naturally exist within coal seams and are released to the atmosphere under suitable conditions. Of these gases, CH_4 is of greatest concern, while others releases, such as CO_2, are considered small and are not reported since the IPCC provides no method for estimating these emissions (IPCC, 2006).

As noted in A3.2.1.1, structural disturbance exposes the coal to lower atmospheric pressures, allowing the release of fugitive emissions during mining and post-mining operations, including handling, crushing and transportation. Once an underground mine closes and active venting stops, emissions may continue for decades. After production ceases, all subsequent emissions are estimated using the model described in this section.

Methodology

CMM is influenced by many factors, including geological seam structure, coal rank and characteristics, mining activities, pressure gradients, mine flooding and post-mining venting and capping. Though no Canadian data is available on post-mining venting and capping, provincial regulations require all recently abandoned mines to be capped for safety.

The IPCC Tier 2 equation for abandoned mines takes the general form in Equation A3.2–3.

Table A3.2–1 **Fugitive Emission Factors for Coal Mining**

Area	Coal Type	Mine Type	Emission Factor	Units
Nova Scotia	Bituminous	Surface	0.07	t CH_4 / kt coal mined
Nova Scotia	Bituminous	Underground	14.49	t CH_4 / kt coal mined
New Brunswick	Bituminous	Surface	0.07	t CH_4 / kt coal mined
Saskatchewan	Lignite	Surface	0.07	t CH_4 / kt coal mined
Alberta	Bituminous	Surface	0.53	t CH_4 / kt coal mined
Alberta	Bituminous	Underground	1.69	t CH_4 / kt coal mined
Alberta	Sub-bituminous	Surface	0.24	t CH_4 / kt coal mined
British Columbia	Bituminous	Surface	0.93	t CH_4 / kt coal mined
British Columbia	Bituminous	Underground	2.78	t CH_4 / kt coal mined

Note: Adapted from King (1994) and Cheminfo et al. (2014).

Equation A3.2–3 **IPCC Tier 2**

$$CH_4 \text{ Emissions} = \text{Unflooded Mines} \times \text{Fraction Gassy} \times \text{Average Emission Rate} \times EF \times \text{Conversion Factor}$$

CH_4 Emissions	=	yearly emissions (Gg/year)
Unflooded Mines	=	number of unflooded mines
Fraction Gassy	=	% of mines defined as gassy
Average Emission Rate	=	(m^3/year)
EF	=	emission factor, dimensionless, of the form (1+aT)b
Conversion Factor	=	converts CH_4 volume to mass (0.67 kg/m^3, at 20°C and 1 atmosphere pressure)

The IPCC Tier 3 equation for abandoned mines takes the general form in Equation A3.2–4.

Equation A3.2–4 **IPCC Tier 3**

$$CH_4 \text{ Emissions} = (\text{Emission rate at closure} \times EF \times \text{Conversion Factor})$$

CH_4 Emissions	=	yearly emissions (Gg/year)
Emission rate at closure	=	known emission rate for specific mine (m^3/year)
EF	=	emission factor, dimensionless, of the form (1+aT)b
Conversion Factor	=	converts CH_4 volume to mass (0.67 kg/m^3, at 20°C and 1 atmosphere pressure)

Detailed data on mine CH_4 emission rates during production years was only available for five mines in Nova Scotia (King 1994). This data allowed the use of Equation A3.2–4, following the IPCC Tier 3 approach, to estimate abandoned mine emissions in this region. For all other regions of Canada, known production data for abandoned mines was averaged over the life of the mines, and the EFs in Table A3.2–1 were used to estimate emissions in the final year of production. On the basis of this estimate, Equation A3.2–3 was used to calculate emissions. Calculations were done using five time intervals, which can be seen in Table A3.2–4 following the Tier 2 approach for the determination of percent gassy mines per time interval. Mines abandoned before 1900 are assumed to be non-emitting (IPCC, 2006).

Following the end of mining activities, CH_4 emissions have been shown empirically to drop off following a hyperbolic decline curve. This is modelled using the IPCC Tier 2/3 emission factor equation (1+aT)b, where a and b are mine- or basin-specific constants and T is the time since abandonment (IPCC, 2006). See Table A3.2–2 for a list of constants applied to Canadian data. This IPCC EF formula was used for all provincial estimates.

CH_4 emissions from flooding mines decrease dramatically once active pumping ceases. Water pressure inhibits CH_4 from being emitted due to reduced relative permeability. U.S. EPA empirical studies (U.S. EPA, 2004) based on U.S. mines indicate that mine flooding occurs within eight years. The 2006 IPCC Guidelines (IPCC, 2006) indicate that fully flooded mines be assigned zero emissions but be explicitly listed.

For the purposes of calculating emissions, mines are assumed unflooded unless specific data exists. Provincial experts in Alberta indicated that most mines are flooded, but had knowledge of flooding at only the Bellevue Mine Museum. Therefore, only the 12 abandoned mines in the near vicinity of the Bellevue Mine Museum—that closed over 20 years ago—were assumed flooded. For Nova Scotia, provincial experts at Nova Scotia Environment confirmed that underground mines started flooding immediately after pumps were turned off and that all mines were flooded by end of summer 2013.[5] Table A3.2–3 characterizes the condition of abandoned mines by flooded and non-flooded, for all regions of

5 Nova Scotia Environment. 2015. Personal communication (email from Miller M, Policy Analyst, Nova Scotia Environment to Baker W, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada, dated November 16, 2015).

Table A3.2–2 **IPCC Tier 2/3 – Emission Factor Coefficients**

Coal Rank	a	b
Anthracite	1.72	-0.58
Bituminous	3.72	-0.42
Sub-bituminous	0.27	-1.00

Table A3.2–3 **IPCC Tier 2/3 – Abandoned Underground Coal Mines, 2019**

Region	Number of Abandoned Coal Mines[a]	Number of Abandoned Mines Flooded[b]
Nova Scotia[c]	281	281
Saskatchewan[d]	245	0
Alberta	855	13
British Columbia	51	0
CANADA	**1 432**	**294**

Notes:

a. Only mines that produced more than 0.5 kilotonnes are included.
b. When no data is available, mines are assumed to be non-flooded.
c. Tier 2 and 3 estimates used for Nova Scotia.
d. Saskatchewan lignite mine estimate uses IPCC Tier 2 sub-bituminous emissions factor calculated for each time band (see IPCC 2006 4.27, Equation 4.1.12).

Table A3.2–4 **IPCC Tier 2, % Gassy Mines per Time Interval**

Time Interval	Low	High
1900–1925	0%	10%
1926–1950	3%	50%
1951–1975	5%	75%
1976–2000	8%	100%
2001–present	9%	100%

Canada that have underground coal mines. In 2018 the Donkin mine in Nova Scotia returned to production and is no longer included in the data for abandoned mines.

The IPCC defaults in Table A3.2–4 were used to estimate the percentage of gassy mines in each region and time interval. For all regions of Canada, with the exception of Saskatchewan, the default high values for gassiness were assumed.

The lower IPCC default percentage of gassy mines was chosen for Saskatchewan mines based on time since abandonment, lignite rank, small mine size and shallow depth—often dug from a riverbed into a slight hill. Additionally, during a public safety review, all mine entrances were either capped or sealed. The non-gassy nature of these mines was previously reported in Hollingshead (1990).

Activity Data

This model uses data obtained from industry and from provincial and federal government sources. The general lack of detailed data sources affected the choice of estimation methods, preventing the incorporation of likely but unconfirmed flooding and mine-specific emissions measurements. Conservative assumptions were made when accurate data was unavailable for mine gassiness, flooded status and EFs. As previousely noted, in 2018 the Donkin mine in Nova Scotia returned to production and is no longer included in the data for abandoned mines.

Emissions

The results of emission calculations, for select years, are shown in Chapter 3.3.1 of the NIR. Abandoned mines in Nova Scotia have historically contributed the largest proportion of emissions; the two emission peaks in 1993 and 2000 correspond to closures of large mines in that province. There were two recent mine abandonments in western Canada and the effect of these closures on the model's decline curves are visible in the latest reporting years.

A3.2.2. Oil and Natural Gas

A3.2.2.1. Upstream Oil and Natural Gas Production

Fugitive emissions from the upstream oil and gas (UOG) industry are estimated using two different methods:

- 2010–2019 reported venting and flaring emissions in Alberta (see section A3.2.2.1.2)
- All other fugitive emission sources in all other provinces and territories (see section A3.2.2.1.1)

Table A3.2–5 lists the emission sector categories and fugitive sources estimated and the allocation of these emissions according to the Common Reporting Format (CRF) categories.

A3.2.2.1.1. UOG and CAPP Study

Except where otherwise noted, fugitive emissions from the UOG industry are based on two separate studies: a study titled *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), prepared by Clearstone Engineering Ltd. for the Canadian Association of Petroleum Producers (CAPP) and referred to hereafter as the CAPP study, and an update to the inventory that was completed in 2014 for Environment Canada by Clearstone Engineering Ltd. and referred to hereafter as the UOG study (EC, 2014). Both inventories used an IPCC Tier 3 bottom-up assessment to estimate all GHG emissions from the UOG sector, with the exclusion of oil sands mining, extraction and upgrading. The CAPP study provided a detailed emission inventory for the year 2000, while the UOG study produced inventories for the years 2005 and 2011.

In general, the emission inventories for the years 2000, 2005 and 2011 were used directly, except for a few special cases. If a specific source did not exist in one of the inventory years (e.g. the 2000 inventory) due to insufficient data, but did exist in another inventory year (e.g. the 2005 inventory), then emissions for that particular source were extrapolated from the known year and included in the inventory that was missing data to ensure completeness. A brief description of the methodology used in the CAPP and UOG studies follows, along with the methodology used to estimate the emissions for 1990–1999, 2001–2004, 2006–2010 and from 2012 onwards.

Methodology for the 2000, 2005 and 2011 Estimates

The emission estimates contained in the CAPP and UOG studies were developed using a bottom-up approach, beginning at the individual facility and process unit level and aggregating the results to provide emission estimates by facility and geographic area. The Canadian UOG sector's assets and operations are vast: the 2011 inventory included over 300 000 capable oil and gas wells, 14 100 batteries producing gas into more than 5000 gathering systems delivering to almost 750 gas plants, and 24 000 oil batteries delivering to 150 tank terminals, all of which are interconnected by tens of thousands of kilometres of pipeline carrying hydrocarbons from wells to batteries to plants and finally to markets.

Emissions from flaring, venting, equipment leaks, formation CO_2 venting, storage losses, loading/unloading losses and accidental releases were estimated. The basic methods used to estimate GHG emissions were:

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

Table A3.2–5 **Allocation of Upstream Oil and Gas Inventory Emissions to CRF Fugitive Categories**

	Emission Sector Categories	Emission Source Categories
1.B.2.a.2 Oil – Production	Light/Medium Crude Oil Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Heavy Crude Oil Cold Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Well Servicing	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Heavy Crude Oil Thermal Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Well Testing	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
	Disposal and Waste Treatment	Fugitive Equipment Leaks
1.B.2.a.3 Oil – Transport	Petroleum Liquids Transportation	Fugitive Equipment Leaks; Storage Losses
1.B.2.b.2 Natural Gas – Production	Natural Gas Production	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
1.B.2.b.3 Natural Gas – Processing	Natural Gas Processing	Fugitive Equipment Leaks; Loading/Unloading; Storage Losses
1.B.2.b.4 Natural Gas – Transmission and Storage	Gas Transmission; Gas Storage	Fugitive Equipment Leaks; Spills/Pipeline Ruptures
1.B.2.b.5 Natural Gas – Distribution	Gas Distribution	Fugitive Equipment Leaks; Spills/Pipeline Ruptures
1.B.2.b.6 Natural Gas – Other – Accidents and Equipment Failures	Accidents and Equipment Failures	Surface Casing Vent Flow/Gas Migration; Spills/Pipeline Ruptures
1.B.2.c.1.i Venting – Oil	Light/Medium Crude Oil Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Heavy Crude Oil Cold Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Heavy Crude Oil Thermal Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Petroleum Liquids Transportation	Reported Venting; Unreported Venting
1.B.2.c.1.ii Venting – Natural Gas	Natural Gas Production	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Natural Gas Processing	Glycol Dehydrator Off-Gas; Formation CO_2; Reported Venting; Unreported Venting
	Gas Transmission	Reported Venting
	Gas Distribution	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Gas Storage	Reported Venting; Unreported Venting
1.B.2.c.1.iii Venting – Combined	Well Drilling; Well Servicing	Reported Venting
	Well Testing	Glycol Dehydrator Off-Gas; Reported Venting; Unreported Venting
	Disposal and Waste Treatment	Unreported Venting
1.B.2.c.2.i Flaring – Oil	Light/Medium Crude Oil Production; Heavy Crude Oil Production; Heavy Crude Oil Thermal Production; Petroleum Liquids Transportation	Flaring
1.B.2.c.2.ii Flaring – Natural Gas	Natural Gas Production; Natural Gas Processing; Gas Transmission; Gas Storage; Gas Distribution	Flaring
1.B.2.c.2.iii Flaring – Combined	Well Drilling; Well Servicing; Well Testing; Disposal and Waste Treatment	Flaring

In order to estimate emissions, large amounts of data were collected including:

- 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.)
- 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
- composition of the inlet and outlet streams

Refer to the CAPP study (CAPP, 2005a) and UOG study (EC, 2014) for further details.

Methodology for Extrapolating Emission Estimates

The method for extrapolating emissions from a known inventoried year to other non-inventoried years was developed by Clearstone Engineering Ltd. (CAPP, 2005b). This method was used to backcast the 2000 emission estimates for the 1990–1999 time period, to extrapolate the 2011 inventory for 2012 onwards and, in conjunction with other curve fitting methods, to interpolate the 2001–2004 and 2006–2010 time periods.

Equation A3.2–5 is used to estimate emissions for non-inventoried years by multiplying base year emissions data for a given source and sector by the ratio of activity data for the non-inventoried year to that of the base year. Various types of activity data for each province/territory and year were used, such as natural gas and crude oil production volumes, fuel, flare and vent volumes, number of wells drilled, number of spills, ruptures and blowouts, total capable oil and gas wells, and shrinkage. Not all activity data is available for all years or all regions. Emission sources for specific sectors and regions were extrapolated using the most appropriate activity data. Where activity data was not available for the entire time series, the methodology to interpolate intermediate years, which is described later in this section, was used to provide one consistent time series.

Table A3.2–6 lists the publicly available activity data used to extrapolate emissions along with the corresponding data source. Table A3.2–7 contains a list of the activity data used to estimate flaring emissions for each region, sector category and time period while Table A3.2–8 contains the same information for reported venting. Table A3.2–9 displays the activity data that is used to extrapolate emissions for all other UOG fugitive sources such as fugitive equipment leaks, unreported venting,[6] storage losses, etc.

Equation A3.2–5

$$ER_{i,j}^{k} = ER_{i,j}^{baseYr} \times \left(\frac{AF_{j}^{k}}{AF_{j}^{baseYr}} \right)$$

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k, t/year
$ER_{i,j}^{baseYr}$	=	base year (e.g. 2011) emission rate for compound i and source j, t/year
AF_{j}^{k}	=	activity factor for source j and year k
AF_{j}^{baseYr}	=	base year (e.g. 2011) activity factor for source j

6 Unreported venting includes venting from processes or equipment that is not typically included in reported venting volumes. This includes pneumatic devices (e.g. chemical injection pumps, natural gas operated instrumentation), compressor start gas, purge gas and blanket gas that is discharged directly to the atmosphere and gas vented from drill-stem tests.

The emissions for 1990–1999 were backcast by sector and source at the provincial level based on the year 2000 emission estimates from the CAPP study (CAPP, 2005a). The only exception to this was the province of Nova Scotia, which from 1992 to 1999 was an oil-only producing province. In 2000, it switched to a gas-only producing province. As such, the year 2000 data could not be used to estimate emissions for the 1990–1999 time period, and 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.

The emissions from 2012 onwards were extrapolated using emissions by sector and source at the provincial/territorial level based on the year 2011 emission estimates from the UOG study (EC, 2014).

Methodology for 2001–2004 and 2006–2010

In order to estimate emissions for the 2001–2004 and 2006–2010 time periods, all three base year inventories (2000, 2005 and 2011) were extrapolated for the 2000–2011 time period using the method described previously. This resulted in three curves which were used to interpolate the intermediate years by using either a "wedging" or "proportional adjustment" method, depending on the circumstance. The "wedging" method was used unless it resulted in negative emission estimates for any year in the time period. Less than 0.3% of cases required the use of the "proportional adjustment" method.

Wedging

The "wedging" method evenly distributes the difference in emissions for a given source and sector in a given province between an inventoried year and an extrapolated year to maintain the emissions trend using Equation A3.2–6.

Equation A3.2–6

$$ER_{i,j}^{k} = ER_{i,j}^{k,k1\_exp} + \frac{\left(ER_{i,j}^{k2\_inv} - ER_{i,j}^{k2,k1\_exp} \right)}{(k2 - k1)} \times (k - k1)$$

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k
$ER_{i,j}^{k,k1\_exp}$	=	emission rate of compound i and source j from extrapolated year k1 data
$ER_{i,j}^{k2\_inv}$	=	emission rate of compound i and source j from inventoried year k2 data
$ER_{i,j}^{k2,k1\_exp}$	=	emission rate of compound i, source j and year k2 from extrapolated year k1 data
k	=	year between k1 and k2
$k1$	=	base year 1 (e.g. 2000 or 2005)
$k2$	=	base year 2 (e.g. 2005 or 2011)

If k1 is equal to 2005, k2 is equal to 2011, and k is equal to k1, then the result of Equation A3.2–6 is the emission rate from the 2005 inventoried year. This occurs since the 2005 extrapolated data uses the 2005 inventoried year as is for the year 2005. If k is equal to k2, then the result is the emission rate from the 2011 inventoried year. This shows that this method will maintain the emission estimates for the inventoried years, while interpolating the intermediate years and maintaining the emissions trend.

Table A3.2–6 **Required Activity Data and Their Sources**

Publisher	Publication	Activity Data
Alberta Energy Regulator (AER)	ST60B: Upstream Petroleum Industry Flaring and Venting Report (AER, 2020a)	Reported venting and flaring volumes
	ST3: AER Industries Monthly Statistics, Gas Supply and Disposition (AER, 2020b)	Shrinkage
	Alberta's Energy Reserves and Supply/Demand Outlook (AER, 2020c)	In-situ bitumen production
	AER Compliance Dashboard (AER, 2020d)	Number of incidents
British Columbia Government	Production and distribution of natural gas (BC, 2019)	Reported venting volumes Shrinkage
	B.C. Gas Plant/Dehydrator Report (BC, 2020)	Shrinkage
British Columbia Oil and Gas Commission	Drilling Kicks and Blowouts by Area (BCOGC, 2020a)	Sum of kicks and blowouts
	Air Summary Report (BCOGC, 2019)	Reported flaring volumes
	2019 Fuel, Flare and Vent Volumes (BCOGC, 2020b)	Reported venting and flaring volumes
Canada Energy Regulator (CER)	Canada's Energy Future (CER, 2020)	Non-associated gas production
Canada – Newfoundland and Labrador Offshore Petroleum Board (CNLOPB)	Development Wells – Hibernia (CNLOPB, 2020a)	Number of capable wells
	Development Wells – Terra Nova (CNLOPB, 2020b)	Number of capable wells
	Development Wells – White Rose (CNLOPB, 2020c)	Number of capable wells
	Development Wells – North Amethyst (CNLOPB, 2020d)	Number of capable wells
	Development Wells – Hebron (CNLOPB, 2020e)	Number of capable wells
	Environment Statistics – Spill Frequency and Volume Annual Summary (CNLOPB, 2020f)	Number of spills
	Monthly Gas Flaring (CNLOPB, 2020g)	Reported flaring volumes
Canadian Association of Petroleum Producers (CAPP)	Statistical Handbook for Canada's Upstream Petroleum Industry (CAPP, 2020)	Total wells drilled (including dry and service) (Tables 1.2b–1.2f)
		Sum of Operated Oil Wells (Table 3.17a) and Operated Gas Wells (Table 3.18a)
Manitoba Government	Petroleum Industry Spill Statistics (MB, 2020)	Number of spills
New Brunswick Natural Resources and Energy Development	Monthly Production Statistics (NB NRED, 2020a)	Light/medium crude oil production Natural gas production
Saskatchewan Ministry of Energy and Resources	2018 Crude Oil Volume and Value Summary (SK MER, 2020a)	Light/medium crude oil production Heavy crude oil production
	2018 Natural Gas Volume and Value Summary (SK MER, 2020b)	Non-associated gas production
	Saskatchewan Fuel, Flare and Vent (SK MER, 2020c)	Reported flaring and venting volumes
	Saskatchewan Upstream Oil and Gas IRIS Incident Report (SK MER, 2020d)	Number of spills
	Saskatchewan Annual Petroleum Statistics (SK MER, 2009–2011)	Reported flaring and venting volumes Shrinkage
	Saskatchewan Mineral Statistics Yearbook, Petroleum and Natural Gas. (SK MER, 1990–2008)	Reported flaring and venting volumes Shrinkage
Statistics Canada	Table 25-10-0047-01 (formerly CANSIM 131-0001) Natural gas, monthly supply and disposition (Statistics Canada, n.d.[a])	Gross production Field flared and waste Field disposition and usage Gathering system disposal and use Plant uses Shrinkage
	Table 25-10-0055-01 (formerly CANSIM 131-0004) Supply and disposition of natural gas, monthly (Statistics Canada, n.d.[b])	Gross withdrawals
	Table 25-10-0014-01 (formerly CANSIM 126-0001) Crude oil and equivalent, monthly supply and disposition (Statistics Canada, n.d.[c])	Heavy crude oil production Light/medium crude oil production Synthetic crude oil production Crude bitumen production
	Table 25-10-0063-01 (formerly CANSIM 126-0003) Supply and disposition of crude oil and equivalent (Statistics Canada, n.d.[d])	Heavy crude oil production Light/medium crude oil production Synthetic crude oil production Non-upgraded production of crude bitumen
	Report on Energy Supply and Demand in Canada (Statistics Canada, 2003)	Total RPP Retail Pump Sales

Table A3.2–7 **Activity Data Used to Extrapolate Flaring Emissions by Region and Year**

Region	Emission Sector Category	Time Period	Activity Data	Time Period	Activity Data
AB	Light/Medium Crude Oil Production	1990–2000	Field flared and waste	2000–2009	Flaring – Oil batteries
	Heavy Crude Oil Cold Production				Flaring – Oil batteries + Bitumen batteries
	Heavy Crude Oil Thermal Production				Flaring – Bitumen batteries
	Natural Gas Production				Flaring – Gas batteries + Gas gathering systems
	Natural Gas Processing				Flaring – Gas plants
	Well Testing				Flaring – Well testing
	Petroleum Liquids Transportation				Flaring – Total
	Disposal and Waste Treatment				Flaring – Total
BC	Light/Medium Crude Oil Production	1990–1995	Field flared and waste	1996–2019	Flaring – Solution Gas
	Natural Gas Production				Flaring – Production Facilities
	Natural Gas Processing				Flaring – Gas Processing Plants
	Well Testing		Wells Drilled		Flaring – Well Cleanup and Testing
	Well Drilling				Flaring – Underbalanced Drilling
SK	Light/Medium Crude Oil Production	1990–2000	Field flared and waste	2000–2019[a]	Flaring – Non-heavy oil
	Heavy Crude Oil Cold Production				Flaring – Heavy oil
	Heavy Crude Oil Thermal Production				Flaring – Heavy oil
	Natural Gas Production				Flaring – Gas batteries + Gas gathering systems
	Natural Gas Processing				Flaring – Gas plants
NL	Light/Medium Crude Oil Production	1997–2019	Total flaring		
MB, NB, NT	Light/Medium Crude Oil Production	1990–2019	Light/medium crude production		
NB, NS, ON, YT	Natural gas production	1990–2019	Natural gas production		
NT	Natural gas processing	1990–2019	Field flared and waste		
NS, ON	Natural gas processing	1990–2019	Natural gas production		
BC, ON, SK	Petroleum Liquids Transportation	1990–2019	Total crude production		
AB	Well Servicing	1990–2019	Wells Drilled		
SK	Well Testing	1990–2019	Wells Drilled		

Note:

a. Delineation of flaring volumes by oil type (e.g. non-heavy oil, heavy oil) only available from 2012 onwards. Prior to this, flaring volumes from crude oil facilities in Saskatchewan were available as Associated flaring. Associated flare volumes were used to extrapolate cold heavy, thermal heavy and light/medium crude flaring.

Table A3.2–8 **Activity Data Used to Extrapolate Reported Venting Emissions by Region and Year**

Region	Emission Sector Category	Time Period	Activity Data	Time Period	Activity Data
AB	Light/Medium Crude Oil Production	1990–2000	Light/medium crude production	2000–2009	Venting – Oil batteries
	Heavy Crude Oil Cold Production		Heavy crude production		Venting – Oil batteries + Bitumen batteries
	Heavy Crude Oil Thermal Production		In-situ thermal production		Venting – Bitumen batteries
	Natural Gas Production		Natural gas production		Venting – Gas batteries + Gas gathering systems
	Natural Gas Processing		Natural gas production		Venting – Gas plants
	Well Testing		Wells drilled		Venting – Well testing
	Petroleum Liquids Transportation		Total crude production		Venting – Total
BC	Light/Medium Crude Oil Production	1990–2011	Light/medium crude production	2011–2019	Field vented
	Natural Gas Production		Natural gas production		Field vented
	Natural Gas Processing		Natural gas production		Natural gas production
SK	Light/Medium Crude Oil Production	1990–2005	Light/medium crude production	2005–2019[a]	Venting – Non-heavy oil
	Heavy Crude Oil Cold Production		Heavy crude production		Venting – Heavy oil
	Heavy Crude Oil Thermal Production		Heavy crude production		Venting – Heavy oil
	Natural Gas Production	1990–2011	Natural gas production	2011–2019	Venting – Gas batteries + Gas gathering systems
MB	Light/Medium Crude Oil Production	1990–2019	Light/medium crude production		
NT	Natural gas processing	1990–2019	Natural gas production		
AB, SK, BC	Well Servicing, Well Drilling	1990–2019	Wells Drilled		

Note:

a. Delineation of venting volumes by crude oil type (e.g. non-heavy oil, heavy oil) only available from 2012 onwards. Prior to this, venting volumes in Saskatchewan were available as non-associated and associated venting. Non-associated vent volumes were used to extrapolate reported venting from Natural gas production, while associated vent volumes were used to extrapolate cold heavy, thermal heavy and light/medium crude reported venting.

Table A3.2–9 **Activity Data Used to Extrapolate Other Fugitive Emissions by Region for All Years**

Emission Sector Category	Emission Source Category	Region	Activity Data
Accidents and Equipment Failures	Spills/Pipeline Ruptures	All	Total number of spills, ruptures and blowouts
Accidents and Equipment Failures	Surface Casing Vent Flow/Gas Migration	All	Total number of capable oil and gas wells
Light/Medium Crude Oil Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	All	Light/medium crude oil production
Heavy Crude Oil Cold Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	AB, SK	Heavy crude oil production
Heavy Crude Oil Thermal Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	AB	In-situ bitumen production
		SK	Heavy crude oil production
Natural Gas Production	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	AB, BC, SK	Non-associated gas production
		All other provinces	Natural gas production
Natural Gas Processing	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Loading/Unloading Storage Losses Unreported Venting	All	Natural gas production
Natural Gas Processing	Formation CO_2	All	Shrinkage
Disposal and Waste Treatment	Fugitive Equipment Leaks Storage Losses Unreported Venting	AB	Total crude production
Petroleum Liquids Transportation	Fugitive Equipment Leaks Storage Losses Unreported Venting	PE and QC	Total RPP Retail Pump Sales
		All other provinces	Total crude production
Well Servicing Well Testing	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Storage Losses Loading/Unloading Unreported Venting	All	Wells drilled
Gas Storage	Fugitive Equipment Leaks Unreported Venting	All	Natural gas delivered to and received from storage
Gas Transmission Gas Distribution	Fugitive Equipment Leaks Glycol Dehydrator Off-gas Spills/Pipeline Ruptures Unreported Venting	All	Kilometres of pipeline

Figure A3.2–1 shows the results of the "wedging" method in graphical form. In general, the 2000 and 2005 inventory years are used to interpolate emissions by sector, source and province/territory for the 2001–2004 time period, while the 2005 and 2011 inventory years are used to interpolate emissions for the 2006–2010 time period. However, there are a few special cases where the 2000 and 2011 inventory years are used to interpolate emissions for the 2001–2010 time period. This occurs when data was missing or incomplete for the 2005 data year and, as a result, specific sector, source and province/territory combinations were not able to be estimated for the 2005 inventory. In addition, on the basis of conversations with the contractor and the province of Saskatchewan, the Saskatchewan venting emissions for the cold production heavy crude oil sector in the 2005 inventory were determined to be unreliable. As a result, emissions for this source and sector were interpolated using the 2000 and 2011 data as end points with the 2005 data point being omitted.

Finally, if any specific source and sector in a given province/territory only existed in one of the inventoried years, then the inventoried data was extrapolated for the entire time series. All of this was done to ensure time-series consistency.

Proportional Adjustment

As stated previously, if the "wedging" method resulted in negative emissions in any year of the interpolation time period, then the method was abandoned for that given sector, source and province/territory and the "proportional adjustment" method was used, as shown in Equation A3.2–7.

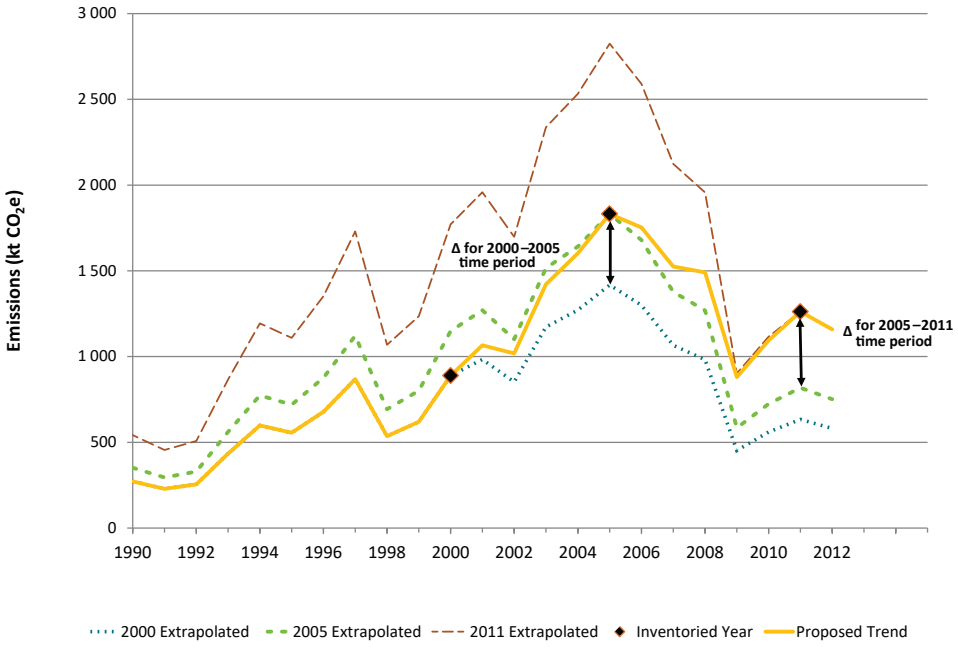
Equation A3.2–7

$$ER_{i,j}^{k} = ER_{i,j}^{k,k1\_exp} \times \frac{\left(ER_{i,j}^{k2\_inv}\right)}{\left(ER_{i,j}^{k2,k1\_exp}\right)}$$

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k
$ER_{i,j}^{k,k1\_exp}$	=	emission rate of compound i and source j from extrapolated year k1 data
$ER_{i,j}^{k2\_inv}$	=	emission rate of compound i and source j from inventoried year k2 data
$ER_{i,j}^{k2,k1\_exp}$	=	emission rate of compound i, source j and year k2 from extrapolated year k1 data
k	=	year between k1+1 and k2
$k1$	=	base year 1 (e.g. 2000 or 2005)
$k2$	=	base year 2 (e.g. 2005 or 2011)

If k1 is equal to 2005, k2 is equal to 2011 and k is equal to k2, then the result of Equation A3.2–7 is the emission rate of the inventoried year for 2011. Otherwise, the emission rate of the extrapolated data is modified by the same percentage for each year in the interpolated time period. This method was required in less than 0.3% of all cases and was generally only required for sources with very low emissions.

Figure A3.2–1 **Graphical Representation of the "Wedging" Method**



A3.2.2.1.2. Alberta Reported Venting and Flaring

Methodology

Reported venting and flaring emissions from 2010–2019 for the province of Alberta are estimated directly instead of extrapolated from the CAPP and UOG studies (CAPP, 2005a; EC, 2014). Reported volumes of gas flared and vented by operator and facility from the Petrinex reporting system (Petrinex, 2020) are used in conjunction with gas composition data by Alberta township (Tyner and Johnson, 2020) to estimate emissions.

Activity Data

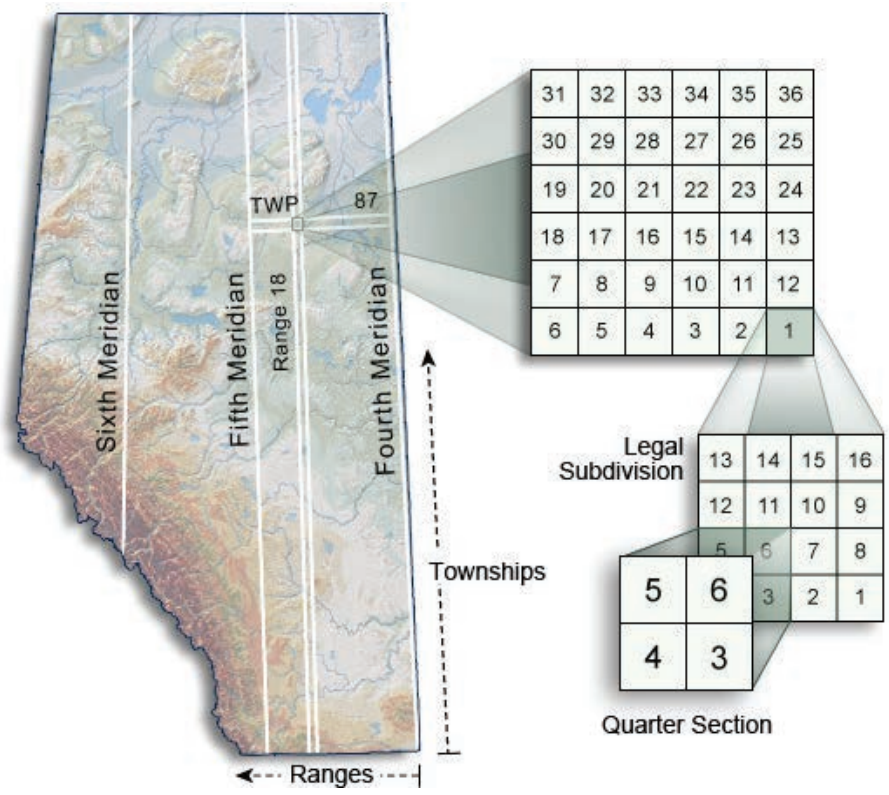
The Petrinex reporting system collects various volumetric production accounting data for the primary purpose of collecting royalties. Oil and gas facilities in Alberta must report various data to Petrinex on a monthly basis. This data includes tombstone data for each facility such as FacilityID, subtype classification, facility name, operator, geographic location, etc. as well as volumetric data corresponding to a specific ProductID (e.g. crude oil, crude bitumen, water, gas, etc.) and ActivityID (e.g. flare, vent, fuel, production, receipts, disposition). Petrinex reported gas flaring and gas venting volumes are summarized by Alberta township.

The Alberta Township Survey (ATS) system follows the Dominion Land Survey (DLS) method, whereby any parcel of land in Western Canada can be located by its legal land description. In the ATS, land is designated as being west of the 4th, 5th, or 6th Meridians (110°, 114°, 118° west longitude, respectively). Six-mile-wide columns between meridians are called ranges and are numbered consecutively from east to west. Townships are six-mile-wide rows that intersect ranges and are numbered consecutively from south to north. The term township also describes the six-by-six mile square formed by the intersection of ranges and townships. Townships are further sub-divided into 36 sections, and sections are then divided into quarters (NE, NW, SE, SW), or into 16 legal subdivisions (LSD), as indicated in Figure A3.2–2.

Emission Factors

In order to reflect the regional variability in gas composition, emissions for flaring and reported venting are estimated using recently developed natural gas composition data for the UOG industry in Alberta by the Energy and Emissions Research Laboratory (EERL) of Carleton University (Tyner and Johnson, 2020) (hereafter referred to as EERL study). The EERL study uses measured gas composition data from approximately 400 000 wells in Alberta taken over a

Figure A3.2–2 **Alberta Township System (ATS)**



Note: Source – Government of Alberta (2021)

span of several decades across the province's many oil and gas producing regions to generate gas compositions by Alberta township (see Figure A3.2–3).

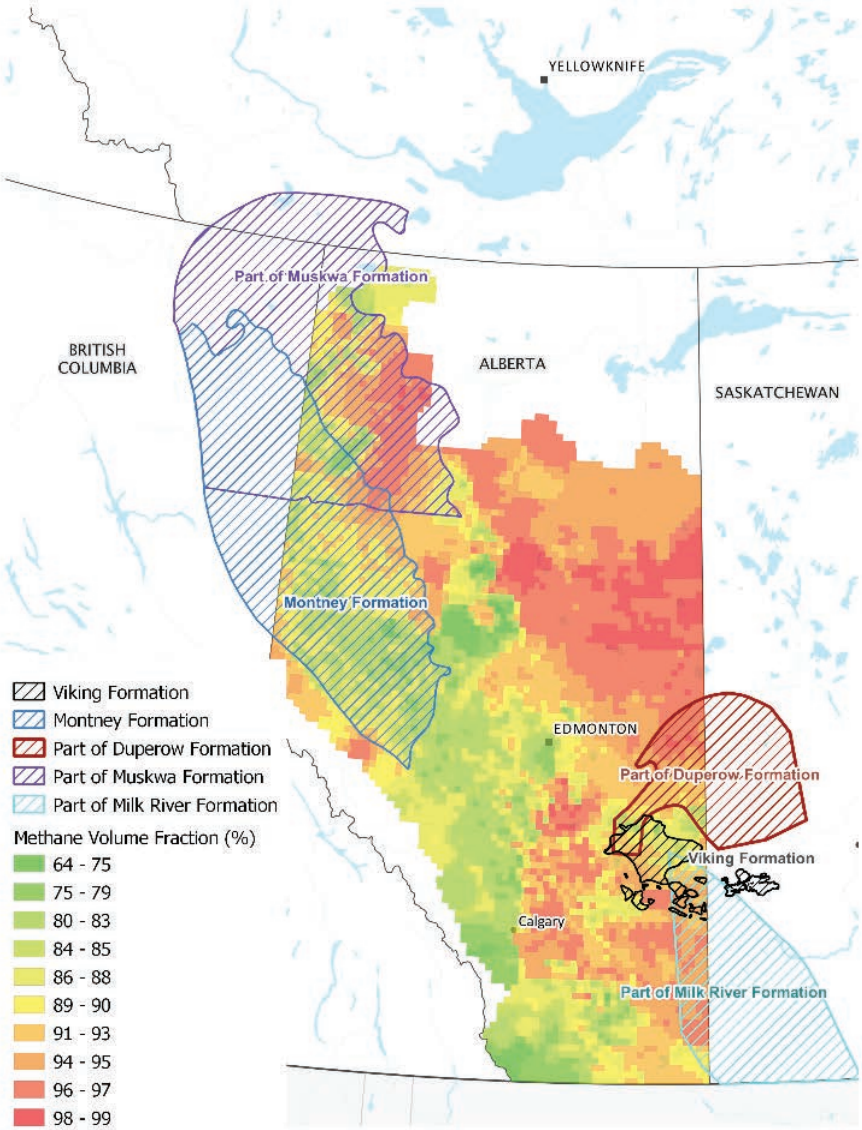
CO_2, CH_4 and N_2O emission factors for flaring are calculated using the EERL study data as shown in Equation A3.2–8, Equation A3.2–9, and Equation A3.2–10, respectively. The calculated EFs by township are then multiplied by the volumetric data from Petrinex (2020) to estimate emissions. Similarly, CO_2 and CH_4 emissions from reported venting are estimated using Equation A3.2–11. Township level emissions are summed to calculate flaring and reported venting emission estimates for the province of Alberta.

Equation A3.2–8

$$EF_{CO2,i} = \sum_j \frac{y_{i,j} \cdot n_{c,j} \cdot MW_{CO2}}{V_{STP}} \cdot g_c$$

$EF_{CO2,i}$	=	CO_2 emission factor for flaring in township i (g/m³)
$y_{i,j}$	=	mole fraction of component *j* in township *i*
$n_{c,j}$	=	number of carbon atoms per molecule of component *j*
MW_{CO2}	=	molecular weight of CO_2 (g/mol) = 44.010 g/mol
V_{STP}	=	volume of gas at standard conditions (101.325 kPa and 15°C) = 23.6444813 m³/kmol
g_c	=	constant of proportionality = 1000 mol/kmol

Figure A3.2–3 **Methane Content by Alberta Township with Select Oil and Gas Producing Formations**



Equation A3.2–9

$$EF_{CH4\,i} = \sum \frac{y_{CH4\,i} \cdot MW_{CH4} \cdot (1 - CE)}{V_{STP}} \cdot g_c$$

$EF_{CH4,i}$ = CH_4 emission factor for flaring in township *i* (g/m^3)

$y_{CH4,i}$ = mole fraction of CH_4 in township *i*

MW_{CH4} = molecular weight of CH_4 (g/mol) = 16.04206 g/mol

CE = combustion efficiency = 0.98 (EC 2014)

V_{STP} = volume of gas at standard conditions (101.325 kPa and 15°C) = 23.6444813 m^3/kmol

g_c = constant of proportionality = 1000 mol/kmol

Equation A3.2–10

$$EF_{N2O,i} = ER_{N2O} \cdot HHV_i$$

$EF_{N2O,i}$ = N_2O emission factor for flaring in township *i* (g/m^3)

ER_{N2O} = flaring emission rate for N_2O (g/MJ) = 0.0000952 g/MJ (WCI.363(k) 2012)

HHV_i = higher heating value for township i (MJ/m^3)

Equation A3.2–11

$$Emis_{i,j} = y_{i,j} \cdot Vol_i \cdot \rho_j$$

$Emis_{i,j}$ = vented emissions of component *j* in township i (kilotonnes)

$y_{i,j}$ = mole fraction of component *j* in township *i*

Vol_i = volume of gas vented in township *i* (10^3 m^3)

ρ_j = density of component *j* at standard conditions (101.325 kPa and 15°C) (kg/m^3)

A3.2.2.2. Natural Gas Transmission and Storage

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 several documents. The first, *CH_4 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 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 CH_4 emissions for 1997–1999 were estimated based on province/territory natural gas transmission pipeline length and leakage rates, which were developed based on the 1996 emissions from CAPP (1999) and pipeline lengths from Statistics Canada.

For the years 2005 and 2011, emissions are taken from the UOG study (EC, 2014), which followed an IPCC Tier 3 approach that rolled-up the reported GHG emissions from individual natural gas companies. Input data for the natural gas transmission and storage industry was compiled by ORTECH Consulting Inc. (2013) for the Canadian Energy Partnership for Environmental Innovation (CEPEI). Data for the years 2000–2004, 2006–2010 and 2012–2014 was provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2015–2019 were extrapolated from 2014 data using the same extrapolation method as described for the UOG sector (see Equation A3.2–5), with the length of natural gas transmission pipeline used as the activity factor.

The emissions are calculated per province/territory and then summed to obtain 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 fugitive emissions from those lines are accounted for in the 1.B.2.b.2 – Natural Gas – Production category of the CRF table.

No natural gas transmission pipelines were operating in Nova Scotia, New Brunswick or the Northwest Territories until 1999.

Similar to natural gas transmission, fugitive emissions from natural gas storage are taken from the UOG study (EC, 2014) for the years 2005 and 2011. Data for the years 2000–2004, 2006–2010 and 2012–2014 was provided directly by CEPEI. Emission estimates for 1990–1999 and 2015–2019 were extrapolated using the previously described extrapolation methods, with the volume of gas delivered to and withdrawn from storage as the activity factor.

Activity Data

The activity data required to estimate the fugitive emissions from natural gas transmission for 1997–1999 and 2015–2019 is the annual length of the natural gas transmission pipeline by region. Transmission pipeline lengths were published annually by Statistics Canada in *Natural Gas Transportation and Distribution.* Statistics Canada has discontinued this publication but still collects the data and releases it to Environment and Climate Change Canada (ECCC) (Statistics Canada, 2020). However, pipeline length data was only available up to and including 2018; pipeline lengths for 2019 were therefore estimated. For Quebec, Ontario, Manitoba, Saskatchewan, Alberta, British Columbia and the Northwest Territories, the 2019 pipeline lengths were estimated based on the average annual change in length between 2000 and 2018. The 2019 values were assumed to be the same as 2018 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.

For natural gas storage, annual volumes of natural gas delivered to storage and withdrawn from storage are taken from *Canadian natural gas storage, Canada and provinces* (Statistics Canada, n.d.[f]) for the 2015–2019 time period and *Natural gas utilities, monthly receipts and disposition* (Statistics Canada, n.d.[g]) for data prior to 2015.

A3.2.2.3. 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 this 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 (unintentional releases), process venting and flaring. The combustion methodology for petroleum refining is discussed in Annex 3.1 of the National Inventory Report.

Methodology

Fugitive Emissions

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

The fugitive emissions are generated using Equation A3.2–12.

Equation A3.2–12

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

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 and Demand in Canada* (Statistics Canada 2003 – #57-003-XIB), including fuels listed under producer consumption from the refined petroleum products 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 EFs are 2.78 t CO_2/GJ for CO_2 and 11.89 t CH_4/GJ for CH_4.

The refinery study has listed fugitive N_2O emissions for 1990 and 1994–2002 as a constant 100 t N_2O/year; however, there were not enough data to develop an emission factor for them. The N_2O emissions were kept constant at 100 t N_2O/year for the years 1991–1993 and 2003 onwards. 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 onwards.

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 onwards were estimated based on this correlation and known RPP production data.

Activity Data

The activity data required to estimate the fugitive emissions from refineries is listed in Table A3.2–10.

Table A3.2–10 **Required Refinery Activity Data and Their Sources**

Publisher	Publication	Activity Data
Statistics Canada	*Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada, 2003–)	Refinery and producer consumption (by refineries) annual energy consumption. Refinery RPP production
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

A3.2.2.4. Natural Gas Distribution

Methodology

Fugitive emissions for the 1990–1999 time period from natural gas distribution are based on the Canadian Gas Association (CGA) report titled *1995 Air Inventory of the Canadian Natural Gas Industry* (CGA, 1997) and the Gas Research Institute (GRI) report titled *Vented Emissions from Maintenance at Natural Gas Distribution Stations in Canada* (GRI, 2000). The CGA study estimated emissions from the Canadian gas pipeline industry for the years 1990 and 1995 using an IPCC Tier 3 approach. Emissions were calculated based on EFs from the U.S. EPA, other published sources and engineering estimates. The activity data was obtained from published sources and specialized surveys of gas distribution system companies. The surveys contained information on equipment schedules, operating parameters of equipment, pipeline lengths used in the Canadian distribution system, etc. The GRI (2000) report is an update to the CGA (1997) study with more accurate and better substantiated data for station vents. An emission factor was developed for the distribution system based on the study data (CGA, 1997; GRI, 2000) and on gas distribution pipeline distances by province provided by Statistics Canada, which were then used to estimate emissions for the 1990–1999 time period.

For 2000 and onwards, emissions are based on data from the UOG study (EC, 2014), following an IPCC Tier 3 approach that rolled up the reported GHG emissions from individual natural gas companies for 2005 and 2011. Input data for the natural gas distribution industry was compiled by ORTECH Consulting Inc. (2013) for CEPEI. Data for the years 2000–2004, 2006–2010 and 2012–2014 was provided directly by CEPEI, again following an IPCC Tier 3 approach. Emission estimates for 2015–2019 were estimated using the length of natural gas distribution pipeline, taking the approach governed by Equation A3.2–5.

The fugitive emissions for natural gas distribution are estimated for each province and then summed to obtain the overall emissions for Canada. At present, no natural gas distribution pipelines exist in the following provinces and territories: Newfoundland and Labrador, Prince Edward Island, Nunavut, Yukon, and Nunavut.

Activity Data

The required activity data is the length of natural gas distribution pipeline per province, which was historically published in Statistics Canada's *Natural Gas Transportation and Distribution* report. Statistics Canada discontinued this publication in 2003 but still collects the data and releases it to ECCC (Statistics Canada, 2019). However, pipeline length data was only available up to and including 2018; pipeline lengths for 2019 were therefore estimated for all provinces based on the change in length between 2017 and 2018.

For New Brunswick and Nova Scotia, pipeline lengths for 2000–2006 were provided by Enbridge Gas New Brunswick[7] and Heritage Gas,[8] respectively. In the Northwest Territories, the Ikhil Pipeline began providing Inuvik with natural gas in 1999. Distribution lengths for 1999–2006 were backcast based on the change in distribution length between 2007 and 2008.

The 2007 pipeline length for British Columbia provided by Statistics Canada was twice the 2006 value. Statistics Canada confirmed that the data for 2006 and previous years was incorrect but was unable to provide corrected distribution lengths. It was assumed that the 1999 value was correct, and a linear trend was used to fill in the 2000–2006 data.

A3.2.2.5. 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); in its natural state, it 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). Fugitive emissions from the mining, processing and upgrading of bitumen and heavy oil are taken from two separate reports: *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 (referred to hereafter as the bitumen study), and an update to the study that was completed in 2017 by Clearstone for Environment and Climate Change Canada titled *An Inventory of GHGs, CACs, and Other Priority Emissions by the Canadian Oil Sands Industry: 2003 to 2015* (ECCC, 2017) (referred to hereafter as the oil sands study).

In general, the bitumen study (CAPP, 2006) is the basis for the 1990–2003 fugitive emissions estimates, and the oil sands study (ECCC, 2017) is the basis for

7 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 December 7, 2010).

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

the 2004–2019 fugitive emission estimates for the OS/HOU industry. 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 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
- 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

Bitumen Study: 1990–2003 Emission Estimates

The bitumen study (CAPP, 2006) is a compilation of the individual Tier 3 inventories of facilities involved in the OS/HOU industry from 1990–2003. Table A3.2–11 lists the OS/HOU facilities included in the study.

The facility boundaries were determined to ensure that all target emissions, including those from cogeneration facilities, were included.

The bitumen study (CAPP, 2006) used emissions from individual facility reports, where available. These emissions were verified against inventories and data reported to Alberta Environment. When this was not possible, emissions were estimated on the basis of 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 EFs. If no activity data were available, the emission factor ratio technique was applied. Refer directly to the bitumen study (CAPP, 2006) for a discussion of the specific methodologies.

Table A3.2–11 **List of Oil Sands and Heavy Oil Upgrading Facilities in the Bitumen Study (CAPP, 2006)**

Operator	Facility Name
Husky Energy Inc.	Lloydminster Upgrader
Consumer's Co-operative Refineries Ltd.	Regina Upgrader
Suncor Energy Inc.	Tar Island
Syncrude Canada Ltd.	Mildred Lake and Aurora

The following sources were used to estimate emissions:

- facility operator information
- energy statistics published by the Alberta Energy Regulator (AER)
- source emission monitoring results reported to Alberta Environment
- data from company submissions to the Voluntary Challenge Registry
- environmental impact assessment files as part of recent energy development applications in the OS/HOU industry
- open literature

Consult the bitumen study (CAPP, 2006) for more details.

Oil Sands Study: 2003–2019 Emission Estimates

The oil sands study (ECCC, 2017) is a facility-based Tier 3 emissions inventory for the OS/HOU industry completed for the 2015 reference year. It was used as the basis for extrapolating emissions both forwards and backwards in time. Where facility emission reports were available from operators, extrapolation was not required and actual emissions were used. These emission records were verified by Clearstone Engineering Ltd. Table A3.2–12 is a list of the OS/HOU facilities included in the study.

Table A3.2–12 **List of Oil Sands and Heavy Oil Upgrading Facilities in the ECCC Bitumen Study (ECCC, 2017)**

Operator	Facility Name	Oil Sands Operations
Suncor Energy Inc.	Millennium & Steepbank Mines and Upgrader	Integrated Mining and Upgrading
Syncrude Canada Ltd.	Mildred Lake & Aurora Mines and Upgrader	
Canadian Natural Resources Ltd.	Horizon Mine and Upgrader	
Husky Energy Inc.	Lloydminster Upgrader	Upgrading
Shell Canada Energy	Scotford Upgrader	
Nexen Energy ULC	Long Lake Upgrader	
Imperial Oil Resources	Kearl Mine	Mining and Ore Processing
Canadian Natural Upgrading Ltd.	Muskeg River and Jackpine Mines	
Aux Sable Canada Ltd.	Heartland Offgas Plant	Hydrocarbon Liquids Extraction
Inter Pipeline Offgas Ltd.	Suncor Liquids Extraction Plant	

The Regina Upgrader operated by Consumers' Co-operative Refineries Limited was excluded from the oil sands study because it is defined strictly as a refinery even though it does upgrade heavy crude oil. The refinery began operation in 1935 and added upgrading capabilities in 1988. It was included in the bitumen study (CAPP, 2006) due to its capabilities to upgrade heavy crude oil. Fugitive emissions for this facility are estimated using the refinery model (see section A3.2.2.3).

In 2016, the Horizon liquid extraction plant operated by Inter Pipeline Offgas Ltd. came online. Emissions from this facility were estimated using emissions data from the Suncor liquid extraction plant (ECCC, 2017) and facility-level activity data (AER, 2020e) for the two facilities. This method is justified due to the similar operations at the two facilities. In late 2017, both the Fort Hills mine and Sturgeon refinery started operations. Emission estimates for these facilities were developed using emissions data reported to the Greenhouse Gas Reporting Program (GHGRP) (ECCC, 2020).

Depending on when each facility commenced operation, emissions were estimated using data from either the bitumen study (CAPP, 2006), the oil sands study (ECCC, 2017), or both. Table A3.2–13 shows the study used to estimate emissions for each year of the time series for each facility.

Methodology for Extrapolating Emission Estimates

The oil sands model provides emission estimates for the OS/HOU industry for 2003–2019 by multiplying base year emissions data (i.e. 2015) by the ratio of the activity data for the non-inventoried year to that of the base year, as shown in Equation A3.2–13. The base year emissions data were taken from the oil sands study (ECCC, 2017).

Equation A3.2–13

$$ER_{i,j}^{k} = ER_{i,j}^{baseYr} \times \left(\frac{AF_{j}^{k}}{AF_{j}^{baseYr}} \right)$$

$ER_{i,j}^{k}$ = emission rate of compound i, source j, and year k, t/year

$ER_{i,j}^{baseYr}$ = base year (e.g. 2015) emission rate for compound i and source j, t/year

AF_{j}^{k} = activity values for source j and year k

AF_{j}^{baseYr} = base year (e.g. 2015) activity factor for source j

Activity Data

Table A3.2–14 lists the activity data used to estimate fugitive emissions for each oil sands operation and emission subcategory.

A3.2.2.6. Abandoned Oil and Gas Wells

When an oil or gas well reaches the end of its productive life, the well operator is required to properly abandon the well by removing all the equipment and plugging the well. This is done to prevent gas leakage from the well and to prevent the migration of oil and gas to the surrounding strata. However, CH_4 can be emitted into the atmosphere even when well abandonment best practices are followed. Additionally, abandoned wells that were not properly decommissioned exist. There are a number of reasons for this, including abandonment prior to the enactment of regulations and bankruptcy of the well owner.

There are two main categories of abandoned wells: plugged and unplugged wells. Unplugged wells are wells without recent production (i.e. inactive, temporarily abandoned/suspended or dormant) or without an operator (i.e. orphaned wells). Plugged wells are wells that have been plugged with cement or any mechanical plug to prevent migration of fluid. Emissions result

Table A3.2–13 **Basis of Emission Estimates for Each Facility in the Oil Sands and Heavy Oil Upgrading Industry**

Operator	Facility Name	Bitumen Study	Oil Sands Study
Suncor Energy Inc.	Millennium & Steepbank Mines and Upgrader	1990–2003	2004–2019
Syncrude Canada Ltd.	Mildred Lake & Aurora Mines and Upgrader	1990–2003	2004–2019
Husky Energy Inc.	Lloydminster Upgrader	1992–2003	2004–2019
Canadian Natural Upgrading Ltd.	Muskeg River and Jackpine Mines	-	2002–2019
Shell Canada Energy	Scotford Upgrader	-	2003–2019
Inter Pipeline Offgas Ltd.	Suncor Liquid Extraction Plant	-	2003–2019
Canadian Natural Resources Ltd.	Horizon Mine and Upgrader	-	2008–2019
Nexen Energy ULC	Long Lake Upgrader	-	2009–2019
Aux Sable Canada Ltd.	Heartland Offgas Plant	-	2011–2019
Imperial Oil Resources	Kearl Mine	-	2013–2019
Inter Pipeline Offgas Ltd.	Horizon Liquid Extraction Plant	Emission estimates for 2016–2019 were developed using emissions data for the Suncor Liquid Extraction Plant (ECCC, 2017) and facility level activity data (AER, 2020e).	
Fort Hills Energy Corporation	Fort Hills Mine	Emission estimates for 2017–2019 were developed from data reported to the Greenhouse Gas Reporting Program (ECCC, 2020).	

Table A3.2–14 **Activity Data Required for the Oil Sands Model**

Oil Sands Operation	Source Category	Subcategory	Activity Data for Extrapolation
Hydrocarbon Liquids Extraction	Flaring and Incineration	All	Process Gas Receipts (AER, 2020e)
	Fugitive	Equipment Leaks	
	Venting	All	
Mining and Ore Processing	Flaring and Incineration	All	Crude Bitumen Production (AER, 2020e)
	Fugitive	Equipment Leaks	
		Exposed Mine Face	
		Other	
		Storage Losses	
		Tailings Ponds	
	Process Emissions	Sulphur Recovery	
	Venting	All	
Upgrading	Flaring and Incineration	All	Synthetic Crude Oil Production (AER, 2020e; Husky Energy Inc., 2020)
	Fugitive	Equipment Leaks	
		Other	
		Spills and Pipeline Ruptures	
		Storage Losses	
	Venting	All	
	Process Emissions	Sulphur Recovery	
		H_2 Production	

from both plugged and unplugged wells, but emissions from unplugged wells are significantly higher than emissions from plugged wells. Emissions may also vary depending on the type of production. However, due to data limitations, the approach described here does not differentiate on the basis of the type of production.

Estimation Methodology

A Tier 1 approach was used to estimate emissions from abandoned oil and gas wells using Equation A3.2–14.

Equation A3.2–14

$$ER_{i,j}^{k} = \sum_{j=1}^{n} EF_{i,l} \times WellCount_{j,l}^{k}$$

$ER_{i,j}^{k}$ = emission rate of compound i, province j and year k, tonnes/year

$EF_{i,l}$ = emission rate per abandoned well for compound i and well type l, tonnes/year

$WellCount_{j,l}^{k}$ = well count for province j, well type l and year k

Emission Factors

The CH_4 emission factors were taken from a study titled *Emissions of Coalbed and Natural Gas Methane from Abandoned Oil and Gas Wells in the United States* (Townsend-Small et al., 2016) on abandoned oil and gas wells in the United States. There are currently no emissions data from abandoned oil and gas wells in Canada.

Table A3.2–15 shows the EFs used for estimating emissions for both abandoned oil and gas wells. The EFs are presented in terms of plugging status (i.e. plugged or unplugged) and location (i.e. onshore or offshore). For provinces where limited data is available on the well plugging status, the emission factor for all well types is used.

Table A3.2–15 **Emission Factors for Abandoned Oil and Gas Wells**

Abandoned Well Type	Value (kg CH_4/well/yr)	Uncertainty
Plugged wells[a] (onshore)	0.02	-87% to +130%
Unplugged wells[a] (onshore)	87.78	-99% to +150%
Plugged wells[a] (offshore)	0.0035	-87% to +130%
Unplugged wells[a] (offshore)	17.6	-99% to +150%
All well types (plugged and unplugged, onshore)[a,b]	12.09	-83% to +124%
All well types (plugged and unplugged, offshore)[a,b]	2.4	-83% to +124%

Notes:

a. Emission factors taken from Townsend-Small et al. 2016, based on abandoned well results in the United States.

b. Assumption for all well types EF: Based on 86% plugged wells and 14% unplugged wells.

Activity Data

Annual counts of abandoned wells by province were developed using the data sources shown in Table A3.2–16.

The count of abandoned wells for each year of the time series was further subcategorized into well type (gas or oil), well status (plugged, unplugged or unknown) and location (onshore or offshore). Several assumptions were made to assign the plugging status of a well.

- An unplugged well is a well with a well status of suspended or inactive.
- A plugged well is a well with a well status of abandoned, downhole abandoned, or junked and abandoned.
- Any offshore well that is abandoned or not producing for an extended period is considered plugged.
- Where the plugging status could not be determined, it was considered unknown and a default emission factor was used to estimate emissions.

For the Northwest Territories and Nova Scotia, this level of disaggregation of activity data was not possible. For the Northwest Territories, there is no publicly available data on abandoned wells for oil and gas operations, and it was therefore difficult to evaluate the number of abandoned wells. For this reason, data from CAPP (CAPP, 2020) was used to estimate the abandoned well count. It was assumed that the abandoned well count is the difference between the total number of wells drilled in the province and the number of oil and gas wells completed in the province. Following that, it is assumed that the average lifespan of completed wells is 20 years. For Nova Scotia, monthly production data by well was used to determine the abandonment date of the well. It was assumed that wells were abandoned 6 months after last production.

For the remaining provinces (i.e. Alberta, British Columbia, Saskatchewan, Yukon, Manitoba, New Brunswick, Newfoundland and Ontario), sufficient information was available in the provincial datasets to determine the number of abandoned wells by well type, well status and location.

Occasionally, the well type was not known. In this case, the emissions from these wells are allocated to oil or gas based on the known ratio of abandoned oil to gas wells in the same year.

A3.2.2.7. Flaring Special Case – Avoiding Double Counting

As defined in the *Report on Energy Supply and Demand in Canada* (Statistics Canada, 2003–), producer consumption "is the consumption by the producing industry of its own produced fuel—for example refined petroleum products consumed by the refined petroleum product industry, or natural gas used in the field, flared and waste, field uses, gathering uses, plant uses and metering adjustments."

Table A3.2–16 **Activity Data Required for Abandoned Oil and Gas Wells**

Region	Source	Publication
Alberta	Alberta Energy Regulator	ST37: List of Wells in Alberta (AER, 2020f)
British Columbia	British Columbia Oil and Gas Commission	Well Surface Hole Locations (BCOGC, 2020c)
Saskatchewan	Saskatchewan Ministry of Energy and Resources	Abandoned well counts were provided upon request[a]
Manitoba	Government of Manitoba: Oil & Gas	Petroleum Statistics, Unique Well Identifier Key List Report (MB, 2020b)
Ontario	Ontario Oil, Gas & Salt Resource Library	Petroleum Well Data (OGSRL, 2020)
Newfoundland & Labrador	Canada–Newfoundland & Labrador Offshore Petroleum Board	Schedule of Wells Summary (CNLOPB, 2020h)
Nova Scotia	Canada–Nova Scotia Offshore Petroleum Board	Cohasset Panuke production report (CNSOPB, 2019)
		Sable Offshore production report (CNSOPB, 2019)
		Deep Panuke production report (CNSOPB, 2019)
Yukon	Yukon Government: Energy Mines and Resources	Yukon Well Listing (YK, 2020)
Northwest Territories	CAPP Statistical Handbook	Land, Exploration, Drilling Categories (CAPP, 2020)
		• Oil wells completed
		• Gas wells completed
		• Wells drilled
New Brunswick	New Brunswick Borehole Database	New Brunswick Well Listing (NB NRED, 2020b)

Note:

a. Saskatchewan Ministry of Economy. 2020. Personal communication (email from Perras, A, to Barrigar, O, Pollutant Inventories and Reporting Division, Environment and Climate Change Canada, dated November 1, 2020).

Statistics Canada determines natural gas producer consumption volumes by summing the following fields from *Natural gas, monthly supply and disposition* (Statistics Canada, n.d.[a]) for each province:

- field flared and waste
- field disposition and use
- gathering system and processing plant
- plant use
- adjustment

Up until and including the 2015 data year, the data contained in *Natural gas, monthly supply and disposition* was collected by Statistics Canada through administrative agreements with most provinces. For example, the AER collects detailed production accounting data from all oil and gas production facilities in the province. This production accounting data includes the volumes of gas produced, flared, vented, etc. and is incorporated into the Statistics Canada data and subsequently the *Report on Energy Supply and Demand in Canada* (RESD). In 2015 Statistics Canada stopped publishing the detailed data contained in the *Natural gas, monthly supply and disposition report*. They now use publically available provincial data to determine the producer consumption volumes reported in the RESD. ECCC has access to this same provincial data and knows the method used by Statistics Canada to determine the producer consumption volumes. The correct amount of gas flared and vented is therefore able to be subtracted to avoid double counting for the years 2015 onwards.

Combustion emissions from the consumption of producer-consumed fuels are estimated using the fuel volumes reported in the RESD (See Annex 3.1). Since flaring and venting emissions are estimated separately using the various fugitive models and reported as fugitives, it is necessary to subtract the volume of flared and vented gas, and the associated emissions, from the combustion estimates in order to avoid double counting, as described in section A3.1.4.1.2.

Based on the previously discussed information, the volume of gas reported as field flared and waste is subtracted from producer consumption.

The provinces that have producer consumption of natural gas values in the RESD accounted for over 98% of total crude oil production in Canada in 2018 and 99.9% of gross natural gas production.

In situations where flaring or venting emissions are estimated for a particular province that has no producer consumption reported in the RESD, the flaring emissions and associated natural gas volumes are not subtracted to ensure there is no underestimation of emissions.

Estimates for flaring emissions from petroleum refining are calculated using the refinery model (see A3.2.2.3). The volume of fuel flared is back-calculated from the flaring emissions and then subtracted from the producer consumption of still gas (also known as refinery fuel gas) since the method used by Statistics Canada to determine producer consumption of still gas is currently not well understood.

A3.3. Methodology for Industrial Processes and Product Use

The Industrial Processes and Product Use (IPPU) sector covers greenhouse gas (GHG) emissions arising from non-energy-related industrial activities. Categories included in this sector are Mineral Industry, Chemical Industry, Metal Industry, Non-energy Products from Fuels and Solvent Use, Electronics Industry, Product Uses as Substitutes for Ozone Depleting Substances (ODS), and Other Product Manufacture and Use. Chapter 4 presents methodological issues for each of these categories. This section of Annex 3 provides additional details on the methodologies used to estimate emissions in the following IPPU categories:

- Chemical Industry – CO_2 emissions from Ammonia Production
- Metal Industry – CO_2 emissions from Iron and Steel Production
- CO_2 emissions from Non-energy Products from Fuels and Solvent Use
- HFC emissions from Product Uses as Substitutes for ODS
- Other Product Manufacture and Use – SF_6 emissions from Electrical Equipment

A3.3.1. CO_2 Emissions from Ammonia Production

Steam methane reforming (SMR), which generates hydrogen—an essential feedstock for the Haber-Bosch process in the production of ammonia—may use natural gas as the energy source to drive the process. Natural gas is also used as feedstock for the SMR process to provide a source of hydrogen. In both uses, the majority of carbon in natural gas ends up as CO_2 emissions. The source category 2.B.1, Ammonia Production, includes CO_2 emissions from the feedstock use of natural gas in the SMR process and emissions recovered for urea production. GHG emissions (CO_2, N_2O, and CH_4) from the energy use of natural gas in SMR process and GHG emissions from fuels used in non-SMR ammonia production processes are accounted for in the Energy sector.

Facility-level data on feedstock use of natural gas and annual ammonia production were obtained as part of Environment Canada's voluntary data collection for the years 2005 through 2009. These data were then used to develop the facility-level ammonia-to-feed fuel (conversion) factors. Of the nine plants in operation, seven (two of which have two SMR units each) provided ammonia-to-feed fuel factors. One of the two plants that did not provide information does not operate an SMR unit. These facility-level ammonia-to-feed fuel factors are considered confidential and are therefore not publicly available. However, based on the data collected, the average ammonia-to-feed fuel factor is 671 m^3 of natural gas/tonne of NH_3 produced, and this average was used to estimate emissions from facilities that did not participate in the voluntary data collection. Furthermore, at plant level, the variability of ammonia-to-feed fuel factor is very stable (it varied less than 0.001% from year to year over the 5 surveyed years). Similarly, the average ammonia-to-feed fuel factor varied less than 0.001% from year to year over the 5 surveyed years.

The facility-level annual ammonia production data are then multiplied by the facility-specific (or average) ammonia-to-feed fuel factors to determine the amount of natural gas used as feedstock for each facility. The feedstock uses of natural gas are then aggregated according to the province in which the facilities are located (Equation A3.3–1).

Equation A3.3–1

$$NG_p = \sum_{i=1}^{n} P_{ammonia,i} \times FF_{ammonia,i}$$

NG_p	=	natural gas consumed as feedstock in province *p*, m^3 natural gas
i	=	the SMR facility
n	=	the total number of SMR facilities in province *p*
p	=	a province of Canada containing one or more SMR ammonia-producing facilities
$P_{ammonia,i}$	=	the annual production of ammonia, in facility i, kt
$FF_{ammonia,i}$	=	the ammonia-to-feed fuel factor of facility i, m^3 natural gas/kt NH_3

The aggregated feedstock use (i.e., natural gas) for each province is then multiplied by the respective provincial natural gas carbon content found in Table A6.1–1 of Annex 6 (CO_2 emission factors for marketable natural gas) to determine the total carbon used. It is expected that all carbon present in the feedstock is transformed to CO_2 (IPCC, 2006). Based on these factors, the (gross) generated process CO_2 emissions from ammonia production are calculated using Equation A3.3–2.

Equation A3.3–2

$$Generated\ CO_2 = \sum_{p=1}^{m} NG_p \times CC_p \times COF$$

$Generated\ CO_2$	=	CO_2 emissions generated, kt
NG_p	=	natural gas consumed as feedstock in province *p*, m^3 natural gas
p	=	a province of Canada containing one or more SMR ammonia-producing facilities
m	=	the total number of provinces containing one or more SMR ammonia-producing facilities
CC_p	=	carbon content factor of the fuel in province *p*, t CO_2/m^3 natural gas
CO_F	=	carbon oxidation factor = 1 (unitless)

The portion of emissions recovered for use in urea production is estimated using Equation A3.3–3, based on the assumption that urea production consumes a stoichiometric quantity of CO_2 and that 0.005 tonnes of CO_2 are emitted per tonne of urea produced.

Equation A3.3–3

$$Recovered\ CO_2 = \sum_{p=1}^{m}\left\{\sum_{i=1}^{n} P_{urea,i} \times R\right\}$$

$Recovered\ CO_2$	=	CO_2 emissions from Urea Production for a SMR facility
p	=	a province of Canada containing one or more SMR ammonia-producing facilities
m	=	the total number of provinces containing one or more SMR ammonia-producing facilities
n	=	the total number of SMR facilities in province *p*
i	=	the SMR facility
$P_{urea,\ i}$	=	annual urea production of facility *i*, t urea
R	=	CO_2 emissions recovery factor per unit mass of urea production (where R = [M – L] = 0.728 t CO_2/t urea)
M	=	stoichiometric mass ratio of CO_2 required for urea production, 44/60 or 0.733 t CO_2/t urea
L	=	urea production process losses of CO_2, 0.005 t CO_2/t urea

The net national CO_2 emissions from ammonia production are then calculated by subtracting the recovered CO_2 for urea production in Equation A3.3–2 from the gross generated CO_2 emissions in Equation A3.3–3.

It should be noted that the quantity of natural gas feedstock used in the SMR process is subtracted from the overall non-energy use of natural gas, as reported by Statistics Canada, in order to estimate the residual (non-ammonia-related) process CO_2 emissions (refer to section A3.3.3, Non-energy Products from Fuels and Solvent Use).

The annual facility-level ammonia production data for the years 1990 to 2019 were obtained from the following sources: 1990 to 2004 from the Cheminfo Services (2006) study; 2005 to 2009 from EC's voluntary data collection; and 2008 to 2019 from Statistics Canada's annual survey titled *Industrial Chemicals and Synthetic Resins* (Statistics Canada, 46-002-X).

Facility-level urea production data for the years 2008 through 2019 were also obtained from Statistics Canada's *Industrial Chemicals and Synthetic Resins* survey. Facility-level urea production values for earlier years (1990 through 2007) were estimated using the six-year average ratio of urea-to-ammonia production for the data years 2008–2013.

A3.3.2. CO_2 Emissions from Iron and Steel Production

Canadian Iron and Steel Manufacturing Facilities

As of 2019, the Canadian steel sector consisted of 14 facilities, namely 4 integrated mills and 10 non-integrated mills (9 mini-mills and 1 ilmenite mill). Of the 14 facilities, 8 are located in Ontario (including 4 integrated mills), 3 in Quebec and 1 in each of Alberta, Saskatchewan, and Manitoba. Table A3.3–1 provides a list of these facilities along with the type of manufacturing processes used.

Canadian Iron and Steel Process Technologies

Steel is produced in Canada by two main steelmaking processes (see Figure A3.3–1): basic oxygen furnaces and electric arc furnaces. The basic oxygen furnace is used in integrated mills in conjunction with coke making, sintering, and blast furnace iron making operations. Integrated mills, which smelt iron ore and melt scrap, produce the greatest diversity of products, including bars, rods, structural shapes, plates, sheets, pipes and tubes, and wire rods. Although electric arc furnace technology is gaining importance, it is usually used in non-integrated mills (mini-mills or specialty steel mills) fed by scrap or direct reduced iron to produce a wide product range of carbon and alloy steels. ArcelorMittal Dofasco Inc. operates the only integrated steel plant in Canada that produces part of its steel by the electric arc furnace process. ArcelorMittal Contrecoeur operates the only Canadian steel mill that produces and uses direct reduced iron as part of its raw material feed. Ancillary or secondary steelmaking processes that are common to

Table A3.3–1 **Iron, Steel and Ilmenite Smelting Facilities (2019)**

Integrated Mills	
ArcelorMittal Dofasco	Hamilton, ON
Essar Steel Algoma	Sault Ste. Marie, ON
U.S. Steel Canada – Hamilton Works	Hamilton, ON
U.S. Steel Canada – Lake Erie Works	Nanticoke, ON
Mini-Mills [a, b]	
AltaSteel Ltd.	Edmonton, AB
ArcelorMittal Contrecoeur	Contrecoeur, QC
ArcelorMittal Contrecoeur – Ouest	Contrecoeur, QC
ASW Steel	Welland, ON
EVRAZ North America	Regina, SK
Gerdau Ameristeel – Cambridge	Cambridge, ON
Gerdau Ameristeel Manitoba	Selkirk, MB
Gerdau Ameristeel – Whitby	Whitby, ON
Ivaco Inc.	L'Orignal, ON
Ilmenite Smelting Facility	
Rio Tinto – Fer et Titane Inc.	Sorel-Tracy, QC

Notes:

Information adapted from ECCC 2017.

a. Removed Mini-mill: Hamilton Specialty Bar Corp., Hamilton, ON, which closed permanently in 2018.

b. Added ASW Steel, Welland, ON, which is a small mini-mill that was excluded from the Canada Gazette notice.

both integrated and non-integrated steelmaking include ladle metallurgy, continuous casting, hot forming, cold forming and finishing.

The following is a list of all process materials that are considered in the CO_2 emission estimates for CRF category 2.C.1, Iron and Steel Production.

- metallurgical coke (source: Statistics Canada, 1990–2019)
- pig iron production (source: Statistics Canada, 1990–2012; CSPA, 2013–2017; GHGRP, 2018–2019)
- pig iron charge to steel furnace (including direct reduced) (source: Statistics Canada, 1990–2012; CSPA, 2013–2017; GHGRP 2018–2019)
- scrap steel (own and purchased) (source: Statistics Canada, 1990–2012; CSPA, 2013–2017; GHGRP, 2018–2019)
- limestone and dolomite use (source: NRCan, 1990–2019)

Emission factors and carbon contents applied are included in Annex 6.

Note that due to the integrated nature of the iron and steel facilities that manufacture coal-based metallurgical coke in Canada, it is currently not possible to disaggregate the data submitted by this industry for energy use. All emissions related to the use of metallurgical coke as a reagent for reduction of iron ore in the production of pig iron are allocated in CRF category 2.C.1. As illustrated in Chapter 4 (Equation 4–8), emissions from pig iron production are estimated on the basis of various parameters, including the mass of metallurgical coke used as a reductant and its respective emission factor.

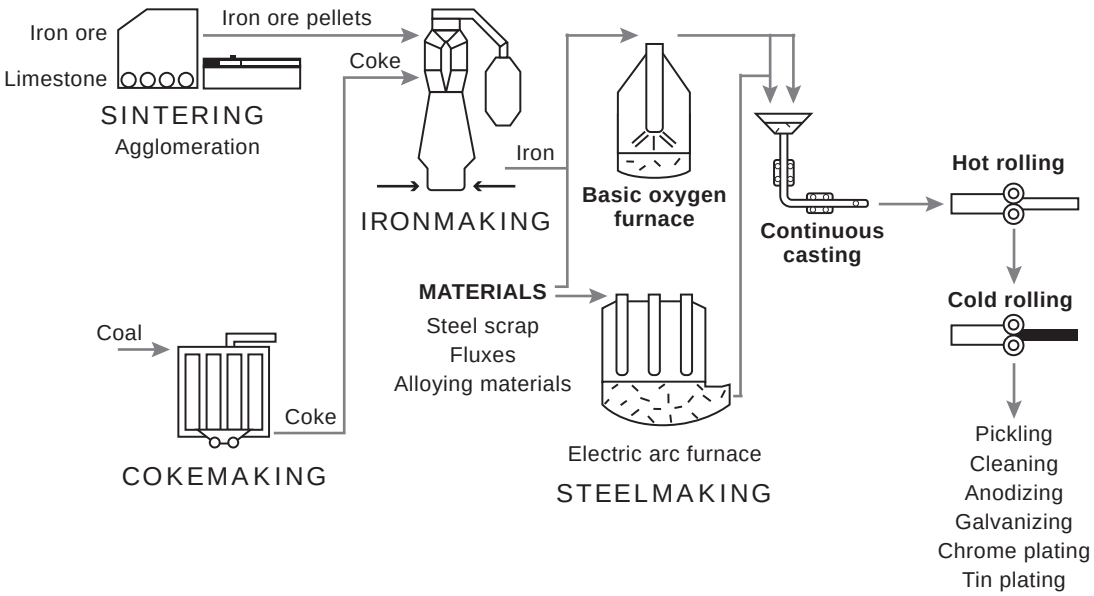
Also note that CO_2 emissions from CRF category 2.C.2, Ferroalloys Production, are included in CRF category 2.C.1.a, Steel Production, since production of ferroalloys is a direct production of specialty steels from iron ore via the electric arc furnace process using reductants. However, disaggregation of the reductant portion (i.e., metallurgical coke) is not available and therefore these emissions are included in CRF category 2.C.1.b, Pig Iron Production.

A3.3.3. CO_2 Emissions from Non-Energy Products from Fuels and Solvent Use

Industrial activities in Canada that use fuel for non-energy purposes (e.g., feedstock material) include ammonia production, petrochemical production, non-ferrous mining and processing, iron and steel production, and other chemical industries.

CO_2 emissions from non-energy use of hydrocarbons—which are not reported elsewhere in the inventory—are reported under the category of Non-energy Products from Fuels and Solvent Use. The emission estimates are based on non-energy fossil fuel use data collected by Statistics Canada (*Report on Energy Supply and Demand in Canada* [RESD] [Statistics Canada 1990–2019]) and aggregated by fuel type (e.g., natural gas, coke, butane, ethane, etc.) at the provincial/territorial level. Statistics Canada does not disaggregate this fuel data by industry

Figure A3.3–1 **Canadian Steelmaking Processes**



or industrial activity, which means that without other supporting information, it is not possible to allocate this fuel data to a specific industry.

In some cases, Canada has obtained supporting information (e.g., through studies, surveys, other data sources, etc.) such that all or part of the non-energy fuel use data can be disaggregated and allocated to the appropriate source category. Allocation of non-energy fuel use data to specific source categories is possible for the following industrial activities:

- natural gas used to produce hydrogen for ammonia production
- various fuels used as feedstock in the production of petrochemicals (methanol, ethylene and ethylene dichloride)
- carbon anodes used to electrically reduce alumina to aluminium in the aluminium production process
- coke used in iron and steel production

For these industrial activities, known or estimated non-energy fuel types and quantities are used in estimating emissions. The known or estimated fuel quantities are then subtracted from the RESD non-energy fuel use data, and the remaining (residual) fuel quantities represent the non-energy fuel used by other industries. This avoids double counting of emissions and improves transparency in the inventory.

To estimate emissions, average national level CO_2 emission factors are available for each fuel type and are applied to the total non-energy fuel quantities (or residual quantities, if applicable) at the provincial/territorial level. Provincial/territorial estimates are then aggregated to provide a national total for CRF source category 2.D, Non-energy Products from Fuels and Solvent Use.

The following describes the methods used to estimate emissions for each category of non-energy use of fossil fuels (gaseous, solid and liquid fuels) and, where possible/applicable, explains how emissions are disaggregated and allocated to specific source categories (previously mentioned) in order to avoid double counting of emissions.

Gaseous Fuels

The only gaseous fuel considered in this category is natural gas. Natural gas can be used for methanol and thermal carbon black production; however, a large portion is used in the SMR process to manufacture ammonia.

CO_2 emissions from ammonia production and methanol production are estimated and reported in CRF source categories 2.B.1 and 2.B.8.a, respectively. The quantities of natural gas used as feedstock in ammonia and methanol manufacturing are subtracted from the RESD's overall non-energy natural gas to determine the remaining (residual) quantity of non-energy natural gas.

Based on a study conducted in 2005 (Cheminfo Services, 2005a), a CO_2 emission factor for the residual non-energy use of natural gas was developed (38 g CO_2/m^3) and applied to the residual non-energy natural gas quantity to estimate emissions from this source.

Note that emissions arising from 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.

Solid Fuels

Solid fuels considered in the Non-energy Products from Fuels and Solvent Use category are:

- Canadian bituminous coal
- sub-bituminous coal
- foreign bituminous coal
- lignite
- anthracite
- metallurgical coke
- petroleum coke

CO_2 emissions from the non-energy use of these solid fuels are determined by applying the fuel-, province- and/or year-specific emission factors presented in tables A6.1–6, A6.1–9 and A6.1–10 of Annex 6 for petroleum coke, coal and metallurgical coke (coke from coal), respectively, to the RESD data.

The emission factors used for estimating releases of CO_2 from the non-energy use of coal are the same as those for combustion; it is assumed that 100% of the carbon in these products will eventually be oxidized and emitted as CO_2.

CO_2 emissions resulting from the consumption of electrodes in the aluminium industry are reported in CRF source category 2.C.3, Aluminium Production. A key fuel used to make electrodes for the aluminium industry is petroleum coke. Non-energy coke is also used to make electrodes used in electric arc furnaces in the iron and steel industry (CRF source category 2.C.1, Iron and Steel Production). The quantities of petroleum coke used in the aluminium industry and iron and steel industry are subtracted from the RESD's overall non-energy use of petroleum coke. The CO_2 emissions from the residual non-energy petroleum coke use are calculated by applying the emission factors provided in Table A6.1–6 of Annex 6.

Liquid Fuels

In addition to the emissions from gaseous and solid fuels, CO_2 emissions from the non-energy use of liquid fuels (natural gas liquids (NGLs), oil refinery petrochemical feedstocks and lubricants) are also reported in CRF category 2.D, Non-energy Products from Fuels and Solvent Use.

CO_2 emissions resulting from the use of liquid fuels (feedstock use) in the production of ethylene are estimated and reported in CRF source category 2.B.8.b. The quantities of liquid fuels (specifically propane, butane, ethane, petrochemical feedstocks) used as feedstock in the production of ethylene are subtracted from the RESD's overall non-energy liquid fuels. The remaining quantities of non-energy liquid fuels are multiplied by the corresponding emission factors, as shown in Table A6.2–9 in Annex 6 to estimate CO_2 emissions from this source.

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 the residual non-energy use of NGLs—i.e., residual of petrochemical production use—the emission factors provided in the McCann (2000) study assume that all the carbon is oxidized and are presented in Table A6.2–9 in Annex 6.

The residual and non-residual 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 Non-energy Products from Fuels and Solvent Use category. Derivations of the non-energy use emission factors are shown in Table A6.2–9 in Annex 6. To estimate emissions at national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

A3.3.4. HFC Emissions from Product Uses as Substitutes for Ozone Depleting Substances (ODS)

A3.3.4.1. Activity Data

HFC emission estimates for 1995 were based on data gathered from an initial HFC survey conducted by EC in 1996.[9] The Department revised subsequent surveys to obtain more detailed activity data for later years. The 1998, 1999, 2001 and 2005 HFC surveys were the source of activity data for emission estimates for the years 1996–2000 and 2004 (2004–2006 emails from Y. Bovet and Y. Guilbault).[10] In some cases, one survey was done to collect data for two years. HFC sales data for 2001–2003 were also collected in 2005 from major HFC importers in Canada (Cheminfo Services, 2005b). These data were provided by market segment, such that the total quantity used for each type of application could be determined. HFC import and sales data for 2005–2010[11] were collected by EC through a voluntary data submission process, whereby requests for data were sent to the main importers of bulk HFCs and to companies that import/export manufactured items containing HFCs. For 2009, the distribution list for data collection was expanded, as EC became aware of other importers/exporters in the market (either importers of bulk HFCs or importers/exporters of manufactured items containing HFCs) by looking at HFC import data collected by the Canada Border Services Agency (CBSA).[12] Information on HFC-245fa received in these surveys were incorporated for bulk HFCs from 2001 to 2007 and for manufactured items containing HFCs for 2010. Data sets from 1995 to 2000 were verified for use, import and export of HFC-245fa, and no instances were found. Where data were unavailable, the quantities were extrapolated to the current inventory year.

In 2014, EC performed a mandatory survey of bulk importers for the data years 2008 to 2012, and the results of the survey (ECCC 2015a) were incorporated into the inventory. Where duplicate reporting occurred between the mandatory and voluntary surveys, the mandatory survey was chosen for the inventory due to the legal reporting requirements.

In 2016, Environment and Climate Change Canada (ECCC) performed mandatory surveys of bulk importers (ECCC, 2016a, 2016b) for the data years 2013–2014 and 2015, which have been included in the inventory. No surveys were performed for the 2016 data year.

In 2018, 2019 and 2020, ECCC collected bulk import and export HFC data for the data years 2017, 2018 and 2019 respectively, under the mandatory reporting system set out under the *Ozone-depleting Substances and Halocarbon Alternatives Regulations* (ODS Regulations), which came into force December 29, 2016 (ECCC, 2018). Updates to the mandatory surveys of bulk importers for the data years 2008–2015 were also received and implemented in this submission.

Table A3.3–2 shows the years where there are activity data for bulk HFC imports and exports, the years when the activity data were collected, and the source of the data. Table A3.3–3 shows the years where there are activity data for imported and exported manufactured items containing HFCs, the years when the activity data were collected, and the source of the data.

9 Bovet Y, Guilbault Y. 2004–2006. Personal communications (emails received from Bovet Y and Guilbault Y to Au A, Greenhouse Gas Division, during the years 2004–2006). Use Patterns and Control Implementation Section.

10 Bovet Y, Guilbault Y. 2004–2006. Personal communications (emails received from Bovet Y and Guilbault Y to Au A, Greenhouse Gas Division, during the years 2004–2006). Use Patterns and Control Implementation Section.

11 Except for 2010, data collected by EC on bulk HFCs only covered sales. However, with no Canadian production existing for HFCs and an insignificant amount of exports, the import values should theoretically be close to the sales values.

12 It should be noted that HFC data from the CBSA cannot be used for GHG inventory purposes, as they are collected and categorized only under three types: HFC-134a, HFC-152a and others. Also, the data are not presented by use type. However, company-specific data from the CBSA are a useful tool for data verification and for expanding the distribution list for the HFC data collection.

Table A3.3–2 **Years of Activity Data for Bulk HFC Imports and Exports, Years of Collection, and Data Source**

Data Year	Data Collection Year	Data Source
1995	1996	Mandatory survey from UPCIS
1996	1998	Mandatory survey from UPCIS
1997	1998	Mandatory survey from UPCIS
1998	1999	Mandatory survey from UPCIS
1999	2001	Mandatory survey from UPCIS
2000	2001	Mandatory survey from UPCIS
2001	2005	Voluntary survey from Cheminfo Services
2002	2005	Voluntary survey from Cheminfo Services
2003	2005	Voluntary survey from Cheminfo Services
2004	2005	Mandatory survey from UPCIS
2008	2014	Mandatory survey from section 71 of CEPA 1999
2009	2014	Mandatory survey from section 71 of CEPA 1999
2010	2014	Mandatory survey from section 71 of CEPA 1999
2011	2014	Mandatory survey from section 71 of CEPA 1999
2012	2014	Mandatory survey from section 71 of CEPA 1999
2013	2016	Mandatory survey from section 71 of CEPA 1999
2014	2016	Mandatory survey from section 71 of CEPA 1999
2015	2016	Mandatory survey from section 71 of CEPA 1999
2017	2018	Mandatory survey from ODS Regulations of CEPA 1999
2018	2019	Mandatory survey from ODS Regulations of CEPA 1999
2019	2020	Mandatory survey from ODS Regulations of CEPA 1999

Table A3.3–3 **Years of Activity Data Imported and Exported Manufactured Items Containing HFCs, Years of Collection, and Data Source**

Data Year	Data Collection Year	Data Source
1996	1998	Mandatory survey from UPCIS
1997	1998	Mandatory survey from UPCIS
1998	1999	Mandatory survey from UPCIS
2004	2005	Mandatory survey from UPCIS
2005	2006	Voluntary survey from UPCIS
2006	2007	Voluntary survey from UPCIS
2007	2008	Voluntary survey from UPCIS
2008	2009	Voluntary survey from UPCIS and voluntary additional data from section 71 mandatory survey of CEPA 1999
2009	2010	Voluntary survey from UPCIS and voluntary additional data from section 71 mandatory survey of CEPA 1999
2010	2011	Voluntary survey from UPCIS and voluntary additional data from section 71 mandatory survey of CEPA 1999
2011	2014	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2012	2014	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2013	2016	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2014	2016	Voluntary additional data from section 71 mandatory survey of CEPA 1999
2015	2016	Voluntary additional data from section 71 mandatory survey of CEPA 1999

A3.3.4.2. Methodology

Canada uses a relatively detailed sector breakdown of HFC sub-applications (Table A3.3–4), requiring that the HFC use data be broken down at this level annually. To meet this requirement, missing data had to be filled in, and data collected at an application level had to be broken down to sub-application levels.

A variety of techniques were used to fill in the data gaps from reporters between voluntary surveys. For instance, when a company did not report in subsequent years, the data were held constant. Another technique employed for years in which no surveys were performed (e.g., imports/exports of manufactured items from 1999 to 2003) was the use of linear interpolation to estimate the missing data.

To meet the requirements of a Tier 2 methodology, ECCC used two approaches to break down the 1995 to 2004 application- level data to the sub-application level. In a given year, the HFCs reported at an application level were broken down based on the proportions of the corresponding sub-application levels if a large amount of HFCs were reported in those corresponding sub-application levels in the same year. If sufficient breakdown was not available for the year and application level, the breakdown from the closest historical year for the same HFC and application level was used.

For the 2008 to 2012 mandatory survey data, the HFCs reported at an application level were broken down based on the 2004 breakdown. The 2004 data were used because the breakdown for this year was the most complete and is currently the best information available. For the 2013 to 2015 data from the mandatory surveys, the HFCs reported at an application level were broken down to sub-application levels based on the 2012 breakdown and, when sufficient information was not available, on the 2004 breakdown. For some of the 2008–2015 data, when bulk importers had initially only reported HFCs (by HFC type) without specifying the associated applications or sub-applications, the surveyed bulk importers were asked to provide, to the best of their knowledge, a list of sub-application levels for the reported HFCs. This list of sub-applications was then used by ECCC to evenly distribute the reported HFC quantities.

For the 2017 to 2019 bulk import and export data collected under the ODS Regulations, all the reported data needed to be broken down to sub-application levels. The 2015 breakdown was determined to be the most appropriate because it was the most recent mandatory survey where breakdowns by sub-application were available.

Table A3.3–4 **Canadian HFC Applications and Sub-Applications**

Application/Sub-Application Description
Aerosols
Personal care products
Pharmaceutical products
Medical products
Household products
Mining application products
Commercial/industrial products
Blowing Agent in Foams
Cushioning – automobiles (seats, roof, etc.)
Cushioning – other (furniture, mattresses, etc.)
Thermal insulation – homes and buildings
Thermal insulation – pipes
Thermal insulation – refrigerators and freezers
Thermal insulation – other (specify)
Packaging – food (specify)
Packaging – non-food (specify)
Other foam uses (specify)
Air Conditioning (Original Equipment Manufacture)
Air conditioner units in motor vehicles
Chillers (specify centrifugal or reciprocating)
Residential (air conditioners, dehumidifiers, etc.)
Air Conditioning (Service/Maintenance)
Air conditioner units in motor vehicles
Chillers (specify centrifugal or reciprocating)
Residential (air conditioners, dehumidifiers, etc.)
Refrigeration (Original Equipment Manufacture)
Commercial transport
Commercial and institutional (retail foods, vending machines, etc.)
Industrial (warehouses, process equipment, etc.)
Residential (freezers, refrigerators)
Other equipment (specify)
Refrigeration (Service/Maintenance)
Commercial transport
Commercial and institutional (retail foods, vending machines, etc.)
Industrial (warehouses, processes, etc.)
Residential (refrigerators, freezers, etc.)
Other equipment (specify)
Solvent
Electronic industry
Metal cleaning/drying
Dry cleaning
Laboratory solvent
General cleaning (specify)
Fire Suppression/Extinguishing Systems (Original Equipment Manufacture)
Portable (mobile) systems
Total flooding (fixed) systems
Fire Suppression/Extinguishing Systems (Service/Maintenance)
Portable (mobile) systems
Total flooding (fixed) systems
Miscellaneous
Hospital/institutional sterilizing
Leak testing
Other (Specify)

For the information on new HFCs received under the ODS Regulations, existing breakdowns of an application to the sub-application level of other HFCs (generally HFC-134a) were used.

The bulk import and export data collected through voluntary submission for the 2005 to 2007 data years were considered incomplete and were therefore estimated using linear interpolation between the 2004 and 2008 data years.

The 1995 data on the quantities of HFCs contained in imported and exported manufactured items, except imported and exported vehicles, were not available. Therefore, the 1996 to 1998 results were used to linearly extrapolate back to 1995. For 1999–2003, these quantities were linearly interpolated from the data available in 1998 and 2004.

The data were reviewed with respect to time series consistency according to Volume 1, Chapter 5, Section 5.3.3.4 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) and some gaps were noted for data on bulk imports and exports and on imported and exported manufactured items containing HFCs. The 2016 data year is a year for which bulk import and export data do not exist, and the 2011 to 2019 data years are years for which a complete set of data on imported and exported manufactured items containing HFCs does not exist. Extrapolation using proxy variables were applied to fill in the data gaps as required. Table A3.3–5 lists the various proxy variables applied for the extrapolation process.

Table A3.3–5 **Proxy Variables Used for HFC Trend Extrapolation**

Proxy Variable Description
Commercial floor space
Residential floor space
Population
Gross domestic product
Gross output for the following categories:
Computer and Electronic Products Manufacturing
Fabricated Metal Products
Food
Furniture and Related Products
Health Care and Social Assistance
Mining (excluding Oil, Gas and Coal)
Other Manufacturing
Other Services (excluding Public Administration)
Professional, Scientific and Technical Services
Transportation Equipment

A3.3.4.3. Emission Factors and Lifetimes

In 2013, EC conducted a survey of the air-conditioning and refrigeration applications to obtain information for developing emission factors.

The information was reviewed ([EHS 2013; ECCC 2015b), in accordance with the quality control measures set out in Volume 1, Chapter 6, Section 6.7.1.2 of IPCC 2006. The emission factors developed using the collected information were also compared to default emission factors published in Table 7.9 of Volume 3, Chapter 7 of IPCC 2006 and most were found to be within the same range. Some emission factors (e.g. end-of-life decommissioning) did not meet the quality control checks from Volume 1, Chapter 6, Section 6.7.1.2 of IPCC 2006 for expert elicitation; values were therefore chosen within the range of emission factors published in Table 7.9 of Volume 3, Chapter 7 of IPCC 2006, guided by other information such as the regulatory environment in Canada. These emission factors have been applied to the whole time series from 1995 onwards.

The emission factors for the sub-application of "Other equipment" under Refrigeration—a mix of specialty applications—were derived through a weighted average of the emission factors from the other specific refrigeration sub-applications.

For the air conditioning and refrigeration applications, the expected lifetimes applied in the emission estimations were chosen based on the survey results and the information published in Table 7.9 of Volume 3, Chapter 7 of IPCC 2006.

For the remaining HFC applications, emission factors and lifetimes were chosen from Volume 3, Chapter 7 of IPCC 2006.

Table A6.2–11 in Annex 6 presents the emission factors used to estimate the HFC emissions.

A3.3.4.4. Emission Estimations

The net consumption of a HFC in a specific sub-application are calculated using Equation A3.3–4. This equation is a modified version of Equation 7.1 from Volume 3, Chapter 7 of IPCC 2006 that has been adapted to the Canadian context. The total quantity of each HFC that remains in products after assembly, in-service and end-of-life losses, also known as a HFC bank, is also calculated.

Equation A3.3–4

$$C_{net,i} = IM_{bulk,i} + IM_{manufacture,i} - EX_{manufacture,i}$$

$C_{net,i}$	=	net consumption of HFC i, kg
$IM_{bulk,i}$	=	imports of bulk of HFC i, kg
$IM_{manufacture,i}$	=	imports of manufactured items of HFC i, kg
$EX_{manufacture,i}$	=	exports of manufactured items of HFC i, kg

Annual emissions for each applicable lifecycle stage are estimated for each sub-application by multiplying the HFC quantity in that stage by its corresponding emission factor. It is assumed that once an item is manufactured, the technology and its inherent in-service emissions rate will remain constant throughout its lifetime. The in-service emission estimate takes into consideration the quantity of HFC that has already been emitted during the assembly stage. Likewise, the emission estimate from the end-of-life of the product is based on the quantity of HFC available after the assembly and in-service emissions have taken place and on the corresponding emission factor for the sub-application. The end-of-life emission factor used also considers regulations in place at the time of decommissioning.

The following sections explain the HFC emission estimation equations applied for each unique application/sub-application in more detail.

A3.3.4.4.1. HFC Emissions from Aerosols

HFC emissions from aerosols application are estimated using Equation A3.3–5, which is Equation 7.6 from Volume 3, Chapter 7 of IPCC 2006.

Equation A3.3–5

$$EA_t = (A_t \times EF_A) + (A_{t-1} \times (1 - EF_A))$$

EA_t	=	emissions from aerosols in year t, tonnes
A_t	=	quantity of HFC contained in aerosol products sold in year t, tonnes
A_{t-1}	=	quantity of HFC contained in aerosol products sold in year t-1, tonnes
EF_A	=	in-service emission factor for aerosols, fraction

A3.3.4.4.2. HFC Emissions from Blowing Agent in Open-cell Foams

HFC emissions from open-cell foam blowing are estimated using Equation A3.3–6, which is Equation 7.8 from Volume 3, Chapter 7 of IPCC 2006.

Equation A3.3–6

$$EOCF_t = M_t$$

$EOCF_t$	=	emissions from blowing agent in open-cell foams in year t, tonnes
M_t	=	quantity of HFC used in manufacturing new open-cell foams in year t, tonnes

A3.3.4.4.3. HFC Emissions from Blowing Agent in Closed-cell Foams

HFC emissions from closed-cell foam blowing are estimated using Equation A3.3–7, which is a modified version of Equation 7.7 from Volume 3, Chapter 7 of IPCC 2006. The reason for the modification is that no information on recovery and destruction of HFCs in closed-cell foams and their blowing agents is available.

Equation A3.3–7

$$ECCF_t = (CCF_t \times (EF_A + EF_{IS})) + (CCFBank_{t-n} \times EF_{IS}) + (DL_t \times EF_{EOL})$$

$ECCF_t$	=	emissions from blowing agent in closed-cell foams in year t, tonnes
CCF_t	=	quantity of HFC used in manufacturing new closed-cell foams in year t, tonnes
EF_A	=	assembly emission factor for closed-cell foams, fraction
$CCFBank_{t-n}$	=	quantity of HFC charged into closed-cell foam manufacturing between year t and year t-n, tonnes
EF_{IS}	=	in-service emission factor for closed-cell foams, fraction
DL_t	=	decommissioning losses in year t = remaining losses of HFC at the end of service life that occur when the product/equipment is scrapped, tonnes
EF_{EOL}	=	end-of-life emission factor for closed-cell foams, fraction
n	=	product lifetime of closed-cell foam
t	=	current year

A3.3.4.4.4. HFC Emissions from Air Conditioners and Refrigerators Manufactured in Canada

HFC emissions from air conditioning and refrigeration equipment manufactured in Canada are estimated using Equation A3.3–8, which is a modified version of Equation 7.10 from Volume 3, Chapter 7 of IPCC 2006.

Equation A3.3–8

$$EACROEM_t = (ACROEM_t \times (EF_A + EF_{IS})) + (ACROEMBank_{t-n} \times EF_{IS}) + (DL_t \times EF_{EOL})$$

$EACROEM_t$	=	emissions from air conditioners or refrigerators manufactured in Canada in year t, tonnes
$ACROEM_t$	=	quantity of HFC used in manufacturing new air conditioners or new refrigerators in year t, tonnes
EF_A	=	assembly emission factor for new air conditioners or new refrigerators, fraction
$ACROEMBank_{t-n}$	=	quantity of HFC charged into air conditioners or refrigerators between year t and year t-n, tonnes
EF_{IS}	=	in-service emission factor for air conditioners or refrigerators, fraction
DL_t	=	decommissioning losses in year t = remaining losses of HFC at the end of service life that occur when the air conditioner or refrigerator is scrapped, tonnes
EF_{EOL}	=	end-of-life emission factor for air conditioners or refrigerators, fraction
n	=	product lifetime of air conditioner or refrigerator
t	=	current year

A3.3.4.4.5. HFC Emissions from Air Conditioners and Refrigerators Manufactured Elsewhere

Equation A3.3–8 is applied for estimating HFC emissions from air conditioners and refrigerators manufactured elsewhere, except that the assembly emission factor in this case is zero.

A3.3.4.4.6. HFC Emissions from Solvents

HFC emissions from solvents are estimated using Equation A3.3–9, which is a modified version of Equation 7.5 from Volume 3, Chapter 7 of IPCC 2006. The reason for the modification is that no information on destruction of HFCs used as solvents is available.

Equation A3.3–9

$$ES_t = (S_t \times EF_S) + (S_{t-1} \times (1 - EF_S))$$

ES_t	=	emissions from solvents in year t, tonnes
S_t	=	quantity of HFC contained in solvents sold in year t, tonnes
S_{t-1}	=	quantity of HFC contained in solvents sold in year t-1, tonnes
EF_S	=	in-service emission factor for aerosols, fraction

A3.3.4.4.7. HFC Emissions from Fire Suppression and Extinguishing Systems

HFC emissions from fire suppression/extinguishing systems are estimated using Equation A3.3–10, which is a modified version of Equation 7.17 from Volume 3, Chapter 7 of IPCC 2006. The reason for the modification is that no information on the destruction of HFCs used in fire suppression and extinguishing systems is available.

Equation A3.3–10

$$EFSES_t = ((FSES_t + FSESBank_{t-n})) \times EF_{IS}) + (DL_t \times EF_{EOL})$$

$EFSESM_t$	=	emissions from fire suppression and extinguishing systems in year t, tonnes
$FSES_t$	=	quantity of HFC used in fire suppression and extinguishing systems in year t, tonnes
$FSESBank_{t-n}$	=	quantity of HFC charged into fire suppression and extinguishing systems between year t and year t-n, tonnes
EF_{IS}	=	in-service emission factor for fire suppression and extinguishing systems, fraction
DL_t	=	decommissioning losses in year t = remaining losses of HFC at the end of service life that occur when the fire suppression and extinguishing system is scrapped, tonnes
EF_{EOL}	=	end-of-life emission factor for fire suppression and extinguishing systems, fraction
n	=	product lifetime of fire suppression and extinguishing system
t	=	current year

A3.3.4.4.8. HFC Emissions from Miscellaneous and Other Applications

HFC emissions from miscellaneous and other application are estimated using Equation A3.3–11, which is Equation 7.18 from Volume 3, Chapter 7 of IPCC 2006.

Equation A3.3–11

$$EMOA_t = (MOA_t \times EF_{MOA}) + (MOA_{t-1} \times (1 - EF_{MOA}))$$

$EMOA_t$	=	emissions from miscellaneous and other applications in year t, tonnes
MOA_t	=	quantity of HFC contained in miscellaneous and other products sold in year t, tonnes
MOA_{t-1}	=	quantity of HFC contained in miscellaneous and other products sold in year t-1, tonnes
EF_{MOA}	=	in-service emission factor for miscellaneous and other products, fraction

A3.3.4.4.9. Total Annual HFC Emission Estimations

The total annual emission estimates for each HFC are derived by summing the emissions from all applicable applications. Once the total annual emission estimates at the national level are obtained, they are distributed by province/territory based on proxy variables, such as gross output of accommodation and food services for commercial refrigeration and number of households for residential refrigeration.

A3.3.5. SF_6 Emissions from Electrical Equipment

A3.3.5.1. Methodology – Derivation of the Country-Specific Quantification Method

To quantify SF_6 emissions (for 2006–2019), the Canadian electricity industry uses a method derived from the basic Tier 3 IPCC 2006 life-cycle Equation 8.10 (Volume 3), as explained in the following sections.

A3.3.5.1.1. Equipment Manufacturing Emissions

According to some utilities, electrical equipment purchased by the Canadian electricity sector is manufactured in the United States, Europe or Asia and hence emissions associated with manufacturing would have occurred mainly outside of Canada.

A3.3.5.1.2. Equipment Installation Emissions

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

A3.3.5.1.3. 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 it properly charged and operational. By topping up equipment with SF_6 gas, utilities are able to replace the amount of gas that has escaped.

A3.3.5.1.4. 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 as a result of 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 leaks out of the equipment. Equipment damage is therefore a potential source of emissions.

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

A3.3.5.1.5. 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 United States. 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 uses a modified, country-specific Tier 3 IPCC approach to estimate SF_6 releases. Only emissions from equipment use and equipment decommissioning and failure are calculated, as shown in Equation A3.3–12.

Equation A3.3–12

$$\textit{Total utility } SF_6 \textit{ emissions} = \sum \textit{Equipment use emissions} + \sum \textit{Equipment decommissioning and failure emissions}$$

A3.3.5.2. 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, the SF_6 gas is recovered from it and, once the 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. 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.

A3.3.5.2.1. Options for Tracking SF_6 Consumed for Top-ups

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. Canadian electric utilities may track the amount of SF_6 that is used annually for top-up purposes (i.e., the amount that has been emitted) by using mass flow meters or a mass balance, or by counting the number of cylinders consumed.

For all of these tracking options, it is assumed that the quantities of SF_6 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 pressurization are typically provided by the switchgear vendor at time of installation and hence do not come out of the utility inventory (see also A3.3.5.1.2, 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: Mass Balance

Utilities may choose to weigh their SF_6 cylinders to determine the quantity of SF_6 consumed for top-up operations. The difference in mass of the cylinders can be determined either every time there is an equipment top-up operation or on an inventory basis. Utilities must also account for any purchases or additions to the inventory, the weight of SF_6 cylinders returned to suppliers, and the quantity of SF_6 sent off-site for recycling or destruction during the year. When using a mass balance, 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, rather than ± 5 kg, to weigh a 50-kg cylinder.

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 be assumed to be equal to the amount of SF_6 purchased in a year or equal to the change in maintenance inventory.

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.

A3.3.5.3. 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 A3.3–13

$$\textit{Equipment decommissioning emissions} = \textit{Nameplate capacity of retired equipment} - \textit{SF}_6 \textit{ amount recovered from retired equipment}$$

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 failure or damage occurs to the point where it cannot be repaired, it is assumed that the nameplate capacity of the equipment is representative of the emissions that have taken place as a result of equipment failures.

The information provided in this section (5) is extracted from the *SF_6 Emission Estimation and Reporting Protocol for Electric Utilities* (ECCC and Canadian Electricity Association 2008), available at http://www.publications.gc.ca/site/eng/454401/publication.html. For further details on data uncertainty, data quality control, data verification by third party, transfer of information and data to ECCC, documentation and archiving, new information or data updates, and protocol reviews and amendments, please refer to the Protocol.

A3.3.5.4. Data Sources

The SF_6 emissions by province for 2006–2019 were provided by the Canadian Electricity Association and BC Hydro.

A3.4. Methodology for the Agriculture Sector

Overview of Agricultural Emission Methodologies

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

- methane (CH_4) emissions from enteric fermentation
- CH_4 and nitrous oxide (N_2O) emissions from manure management and field burning of agricultural residues
- N_2O emissions from agricultural soils (direct emissions, indirect emissions and animal manure emissions on pasture, range and paddock)
- carbon dioxide (CO_2) emissions from agricultural use of lime and urea

The sources of animal population data required to calculate agricultural emissions of CH_4 and N_2O are presented in section A3.4.1. The methods used to calculate agricultural GHG emissions are described in sections A3.4.2 to A3.4.8. 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 3.5).

Livestock and crop production are integrated systems that interact in the production of GHG emissions. The GHG estimation methodology described in Annex 3.4 begins with an estimation of emissions related to livestock production, followed by emissions related to crop production (Figure A3.4–1). All approaches prescribed by IPCC (2006) for calculating emissions follow the basic formula of "activity data" x "emission factor." In the case of agricultural emissions, "activity data" refers mainly to the number of animals or amount of nitrogen applied to soils. "Emission factor" is an average emission rate for a specific GHG from a given source, relative to a unit of activity data. The calculation of emissions is sequential because activity data in the form of nitrogen are passed from the livestock system to the cropping system and nitrogen is tracked as it moves from one source to another.

Livestock emissions are primarily driven by animal populations, but emission factors are dependent on other drivers. The quality and quantity of animal feed influences how quickly animals grow and how much they produce (milk production for example) but animal feed also affects the amount of methane that is produced by an individual animal and how much manure (and therefore both carbon and nitrogen) they excrete back into the environment. As a result, feed quality and animal productivity can be drivers that change livestock emission factors over time. Furthermore, changes in manure management infrastructure (for manure storage and spreading), or farming practices such as changes to the amount of time animals spend on pasture, may further alter the quantity or profile of emissions. Therefore, activity data changes from year to year, but so do emission factors in some cases.

Livestock estimation methodologies used in the NIR can generally be grouped into four categories: (1) dairy, (2) beef (non-dairy), (3) swine, and (4) all other animals (Figure A3.4–1). For the beef category, emission estimates from the process of enteric fermentation and management of animal manure are based on IPCC Tier 2 methodologies populated with country-specific parameters collected through an expert consultation (Boadi et al., 2004a; Marinier et al., 2004), and animal production data in the form of carcass weight increase (Agriculture and Agri-Food Canada, n.d.). For the dairy category, the expert consultation was improved by the introduction of better feed data and production data, and the introduction of information derived from Statistics Canada's farm environmental survey data. For the "swine" and "all other animals" categories, the default IPCC tier 1 methodology is used to estimate emissions from the process of enteric fermentation. Emissions from the management of swine manure are estimated using a Tier 2 methodology based on expert consultation data (Marinier et al., 2004), animal production data in the form of carcass weight increases, and information derived from farm environmental surveys. For most other livestock, emissions from the management of manure emissions are calculated based on expert consultations or IPCC Tier 1 methods.

N_2O emissions from crop production on agricultural soils are primarily driven by nitrogen fertilizer sales and annual crop yields, but where and how much nitrogen is applied to the land are also influenced by nitrogen from manure and human biosolids. A combination of activity data (animal populations) and drivers feed quality and quantity; animal productivity and manure management infrastructure influence the total quantity of nitrogen that is passed from the livestock system to agricultural soils and the amount of nitrogen lost to the environment during these transfers.

Spatially, nitrogen is distributed to agricultural ecodistricts, which represent one level within Canada's National Ecological Framework. The country is divided into 1027 ecodistricts, characterized by a distinctive assemblage of relief, landforms, geology, soil, vegetation, water bodies and fauna. Application rates are calculated as a function of the total manure N in the ecodistrict and crop requirements, which are then adjusted to provincial fertilizer sales as outlined in section A3.4.5. A country-specific emission factor for agricultural soils is calculated for each ecodistrict (section A3.4.5.1) that is adjusted based on the topography, soils and climate of the ecodistrict, as well as management practices such as tillage, summerfallow and irrigation. Emissions are then calculated from the amount of nitrogen applied to the soil, multiplied by the unique emission factor for the ecodistrict in which it was applied. The quantity of emissions that results from a given unit of nitrogen added to soils therefore varies by ecodistrict. Sources of nitrogen include

inorganic fertilizers, organic fertilizers and crop residue (nitrogen contained in plant matter remaining in fields after harvest).

Nitrogen is tracked throughout the process of crop production and ammonia losses after application of fertilizer and manure to croplands are calculated at a Tier 2 level for fertilizer and manure nitrogen from dairy and swine (Tier 1 IPCC default loss factors are used for all other animals). Indirect emissions of N_2O from nitrogen that is lost from the agriculture system are estimated using Tier 1 IPCC 2006 emission factors (section A3.4.5.2).

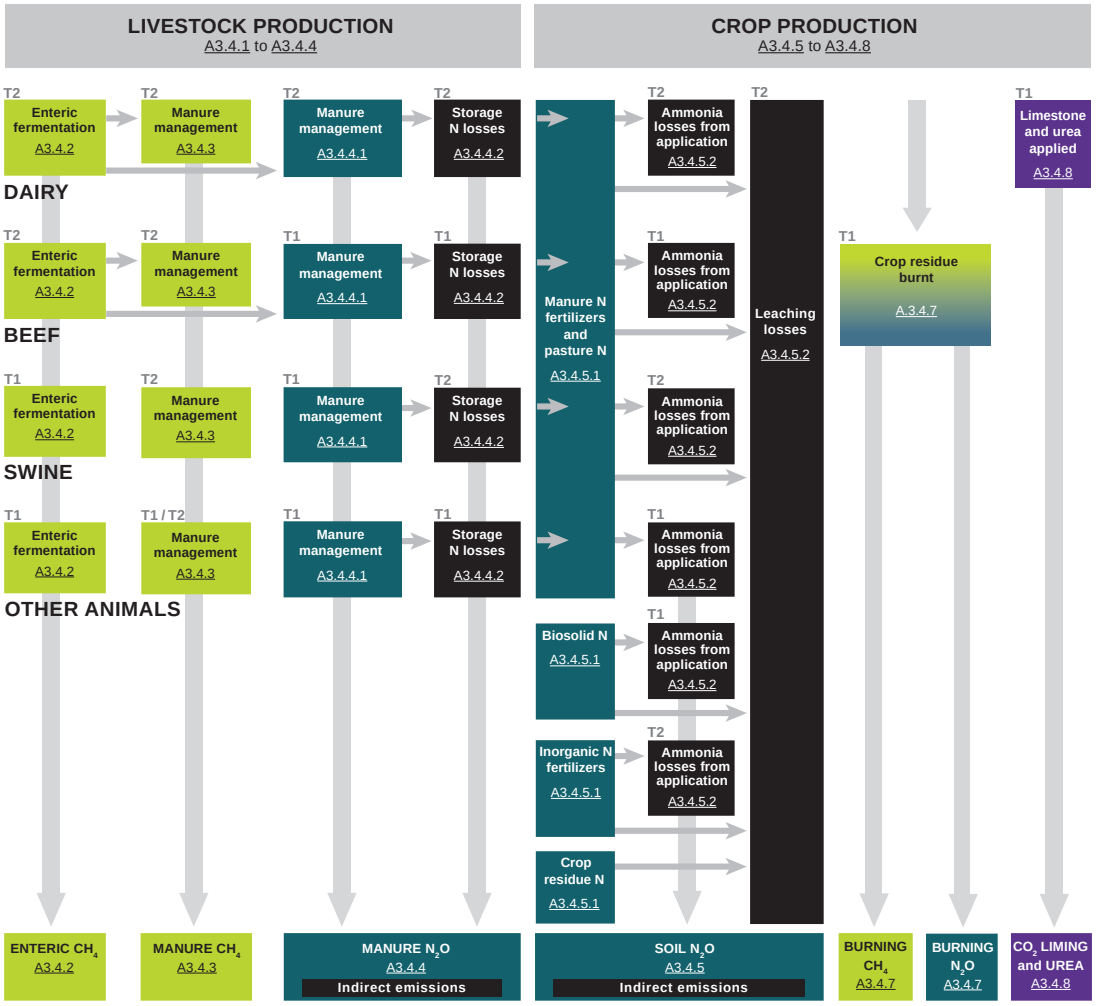
Minor emission sources, such as CO_2 emissions from agricultural use of lime and urea and CH_4 and N_2O emissions from field burning of agricultural residues, are described in sections A3.4.8 and A3.4.7, respectively.

A3.4.1. 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 and other sources, as described in Table A3.4–1.

Annual cattle, sheep and swine populations are presented as the simple mean of semi-annual or quarterly surveys. These smaller surveys are corrected by Statistics Canada to the *Census of Agriculture* (COA) population estimates, which are collected every five years, to assure the accuracy of the estimates.

Figure A3.4–1 **Overview of the Key Methodologies and IPCC Tier Levels Used in Livestock and Crop Production**



The population estimates for horses, goats, bison,[13] llamas and alpacas, deer and elk, wild boars, rabbits and poultry are taken from the COA exclusively, and annual populations are developed by linear interpolation in order to avoid large changes in census years. Populations of deer and elk, considered new to Canadian livestock production and only reported in the COA for census years beginning in the reporting period, were extrapolated back to zero for the census year previous to their first appearance in the COA. Mule and ass populations were received via personal communication[14] and originate from recently compiled responses to the COA for the years 2001, 2006 and 2011. Mule and ass populations were not compiled prior to the 2001 census year and were assumed to be constant at the 2001 level from 1990 to 2000. Wild boar populations for census years 1991, 1996 and 2016 were received via personal communication[15,16] and were compiled from responses to the COA. Wild boar and buffalo populations were not collected in 1986; thus, the populations were set constant for 1990 at the 1991 level.

13 In the CRF tables, the IPCC animal category Buffalo is used to report values for North American bison (*Bison bison*) raised for meat.

14 Laborde L. 2015. Personal communication (e-mail from Laborde L to Section Head, Agriculture, Forestry and Other Land Uses, dated September 2, 2015). Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

15 Laborde L. 2016. Personal communication (e-mail from Laborde L to Flemming C, Agriculture, Forestry and Other Land Uses, dated October 26, 2016). Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

16 Taylor, P. 2016. Personal communication (e-mail from Taylor P to Flemming C, Agriculture, Forestry and Other Land Use, dated September 21, 2018).

Table A3.4–1 **Animal Categories and Sources of Population Data**

Category	Sources/Notes
Cattle	Statistics Canada. Table: 32-10-0130-01 (formerly: CANSIM 003-0032)—Number of cattle, by class and farm type, annual (head). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210013001 (accessed September 29, 2020)
– Dairy Cattle	All cattle used in the production of milk and milk products
– Non-dairy Cattle	All other cattle
Bison, Goats, Horses, Llamas and Alpacas, Deer and Elk	Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue No. 23-502-X), 2011 and 2016 Census of Agriculture: Statistics Canada. Table: 32-10-0427-01 (formerly CANSIM 004-0224). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042701 – linear interpolation between census years, remains constant after last census
Wild Boars	Census year 2016[a]: Taylor, Patrick (Statistics Canada). Personal communication received September 21, 2018. Census years 2001 to 2011: Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001 and 2006 (Catalogue No. 23-502-X), 2011 Census: Statistics Canada. Table 95-640-XWE - 2011 Farm and farm operator data (database). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042701 – linear interpolation between census years, remains constant after last census Census years[a] 1991, 1996: Laborde, Leon (Statistics Canada). Personal communication received October 26, 2016. – linear interpolation between census years, 1990 kept constant from 1991
Mink and Foxes	Statistics Canada. Table 32-10-0116-01 (formerly CANSIM Table 003-0015)—Supply and disposition of mink and fox on fur farms, annual (Number). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210011601 (accessed November 6, 2019). Populations for year 2019 were not available as of November 20, 2020 and as a result the 2018 populations were held constant for 2019.
Mules and Asses[a]	Census year 2016: Laborde, Leon (Statistics Canada). Personal communication received May 16, 2018. Census years 2001 to 2011: Laborde, Leon (Statistics Canada). Personal communication received September 2, 2015. – population held constant prior to 2001 Ccensus, and after the last census
Rabbits	Agriculture and Agri-Food Canada, Red Meat Market Information, Alternative Livestock. https://www.agr.gc.ca/eng/animal-industry/red-meat-and-livestock-market-information/rabbit-industry-at-a-glance/?id=1415860000120 – linear interpolation between census years, remains constant after last census – correction factor applied to isolate the breeding population based on expert opinion from Brian Tapscott, Alternative Livestock Specialist, OMAFRA
Sheep and Lambs	Statistics Canada. Table 32-10-0129-01 (formerly CANSIM 003-0031)—Number of sheep and lambs on farms, annual (head). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210012901 (accessed September 30, 2020)
Swine	Statistics Canada. Table 32-10-0290-01 (formerly CANSIM 003-0004)—Number of hogs on farms at end of quarter, quarterly (head), CANSIM (database). Years 1990–2006. Statistics Canada. Table 32-10-0145-01 (formerly CANSIM 003-0100)—Hogs statistics, number of hogs on farms at end of semi-annual period, (Head). Years 2007–2018. https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210014501 (accessed September 30, 2020)
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 No. 95-632). (Statistics Canada [2007b]) 2011 and 2016 Census: Statistics Canada. Table: 32-10-0428-01 (formerly CANSIM 004-0225). Poultry inventory on census day. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042801 (accessed October 22, 2018) – linear interpolation between census years and remains constant after latest census

Note:

a. These data may be affected by errors due to coverage.

The estimates for breeding mink and fox populations are taken from an annual Statistics Canada survey titled *Supply and Disposition of Mink and Fox on Fur Farms*, which provides the number of foxes and mink on farms for January 1 of the survey year. Rabbit populations were taken from responses to the COA as provided on the AAFC Red Meat Market website (see Table A3.4–1), but were modified based on expert opinion[17] using a correction factor in order to estimate the number of does, as opposed to total rabbits.

To populate an IPCC Tier 2 enteric fermentation model for the Beef and Dairy sectors, the subcategories of provincial cattle populations collected by Statistics Canada were further disaggregated into subannual production stages (i.e., "production subcategory") to isolate and quantify the effect of specific production practices on gross energy intake and, as a consequence, CH_4 emissions. Data to describe the production environment and associated performance of classes of animals were collected from a combination of sources, including: (1) production and management practices published in scientific journals; (2) a survey of dairy and beef production practices conducted and administered to regional and provincial beef and dairy livestock specialists across the country; (3) consultation with scientists at universities and federal research institutions; and (4) provincial/national associations and provincial/regional performance-recording organizations (Boadi et al., 2004a).

These data were used to create an annual cattle production model that takes into account regional and seasonal variations in production practices. The eight cattle subcategories were broken down into 38 distinct cattle production stages—29 for the Beef sector and 9 for the Dairy sector—observed throughout the different provinces of Canada (Table A3.4–2). The model characterizes cattle by physiological status, diet, age, sex, weight, growth rate, activity level and production environment. Further work on the Dairy sector was implemented in the 2018 inventory analysis to refine estimates of certain Tier 2 parameters. This update created a time series datum that better captures changes in production practices in the Dairy sector and introduced an analysis of changes in dairy nutrition considering more recent Canadian and North American research (Ellis et al., 2007; Ellis et al., 2010; Sheppard et al., 2011a; Sheppard et al., 2011b; Vanderzaag et al., 2013; Appuhamy et al., 2016; Chai et al., 2016; Jayasundara et al., 2016).

The feeding practices for Beef and Dairy sector livestock are detailed in the next section.

17 Tapscott B. 2015. Personal communication (e-mail from Tapscott B, OMAFRA, to Section Head, Agriculture, Forestry and Other Land Uses, dated September 16, 2015). Pollutant Inventories and Reporting Division, Environment and Climate Change Canada.

Dairy Sector Production and Performance

Dairy production practices vary across the country because of differences in land prices, climate, forage availability and market access. They have also changed significantly between 1990 and the present. The predominant management practices for each province are reflected in the province-specific parameters entered into the IPCC Tier 2 equations for both enteric fermentation and manure management emissions.

Table A3.4–3 provides an example of production performance data collected for the Canadian Dairy sector, originally used as a quality assurance (QA) verification of the data incorporated in the Tier 2 model at the inception of the Boadi et al. (2004a) study. While the basic subcategory classes developed by Boadi et al. (2004a) were accurate for the mid-2000s when the Tier 2 model was populated, it was recognized that certain production parameters were not static over time and that these parameters could impact all aspects of emissions from the sector. Since 1990, with the increase in milk production in the dairy herd, there has also been a shift in the diet of an average dairy cow, both in the quantity and quality of feed consumed.

There are no consistent national data sources for complete dairy feed quality linked to dairy production and performance. However, certain regional and partial resources exist, specifically the feed quality database from Lactanet[18] for parts of Eastern Canada and Cost of Production[19] (COP) surveys for Quebec and Ontario. However, consistent milk production statistics do exist for the entire country. Production statistics identifying the relative proportions of the national dairy herd that fall into high, medium and low productivity classes and are linked to herd characteristics such as farm size are collected,managed and prepared for the inventory by Lactanet.

To develop parameters that link productivity with production practice, the feed quality database developed by Lactanet, consisting of feed data collected and analyzed for more than 2000 dairy herds in Quebec and Atlantic Canada, was used as a model to develop a matrix of animal diets that could be related to specific farm sizes and productivity classes. Feed composition, digestibility, crude protein content and some herd characteristics, such as lactation lengths and cattle weights, were grouped according to five categories of farm size and three categories of productivity class. The feed composition statistics required for Tier 2 calculations were attributed to provinces based on the proportions of their animal populations that fell into different farm size and productivity classes. As the data used in this analysis from Lactanet were collected between 2000 and 2010, further cost of production survey data were used as a

18 https://www.valacta.com/en-CA/library

19 cdc-ccl.gc.ca/CDC/index-eng.php?id=3941

Table A3.4–2 **Cattle Production Stage Model**

Subcategory	Production Environment	Period of Year [a]	Province
Beef cows	Pregnant, confined	Jan–Apr/Oct–Dec	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef cows	Lactating, pasture	May–Oct	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef cows	Pregnant, confined	Feb–Mar	MB
Beef cows	Lactating, pasture	Jan/Mar–Dec	MB
Breeding bulls	Mature, confined	Jan–Apr/Nov–Dec	PE/NS/QC/ON/MB/SK/AB/BC
Breeding bulls	Mature pasture	May–Oct	PE/NS/QC/ON/MB/SK/AB/BC
Breeding bulls	Young confined	Mar–Apr	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Breeding bulls	Young pasture	May–Oct	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Breeding bulls	Young confined	Nov–Dec/Jan–Feb	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Birth to pasture	Mar	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Pasture	Apr–Sep	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Beef calves	Heifer replacement	Oct–Dec/Jan–Mar	PE/NS/QC/ON/MB/SK/AB/BC
Beef calves	Background heifers	Oct–Dec/Jan–Mar	PE/NS/QC/ON/MB/SK/AB/BC
Beef calves	Background steers	Oct–Dec/Jan–Mar	NL/PE/NS/NB/ON/MB/SK/AB/BC
Beef calves	Finisher heifers	Oct–Dec/Jan–Mar	NL/PE/NS/NB/ON/MB/SK/AB/BC
Beef calves	Finisher steers	Oct–Dec/Jan–Mar	PE/NS/NB/ON/MB/SK/AB/BC
Heifer replacement	Young, not pregnant	Apr–May	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Heifer replacement	Early gestation	Jun–Sep	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Heifer replacement	Late gestation	Oct–Dec/Jan–Mar	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Finisher heifers	Feedlot, short-keeps	Apr–Jun	PE/NS/NB/ON/MB/SK/AB/BC
Finisher steers	Feedlot, short-keeps	Apr–Jun	PE/NS/NB/ON/MB/SK/AB/BC
Finisher heifers	Feedlot short-keep long-finish	April–Jul	NS/ON/MB
Finisher steers	Feedlot short-keep long-finish	April–Jul	NS/ON/MB
Background heifers	Confined	Mar–May	NL/NS/ON/MB/SK/AB/BC
Background steers	Confined	Mar–May	NL/NS/ON/MB/SK/AB/BC
Background heifers	Pasture	Jun–Sep	NL/NS/ON/MB/AB/BC
Background steers	Pasture	Jun–Sep	NL/NS/ON/MB/AB/BC
Finisher heifers	Feedlot, long-keeps	Oct–Dec	PE/NS/NB/QC/ON/MB/SK/AB/BC
Finisher steers	Feedlot, long-keeps	Oct–Dec	PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy cows	Lactating, confined	var [b]	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy cows	Lactating, pasture	var	NL/PE/NB
Dairy cows	Lactating, confined (after pasture)	var	PE
Dairy cows	Dry, low-quality feed	var	NL/PE/NS/NB/QC/ON/MB/SK/BC
Dairy cows	Dry, high-quality feed	var	MB/SK/AB/BC
Dairy cows	Dry, pasture	var	NL/ON
Dairy heifers	Confined (243 days year)	Jan–Apr/Oct–Dec	NL/PE/NS/NB/QC/ON/MB/SK/AB/BC
Dairy heifers	Pasture	May–Oct	NL/PE/NB/ON/SK
Dairy heifers	Confined (365 days year)	Jan–Dec	NB/ON/SK

Notes:

a. Actual period of the year could vary slightly from province to province.
b. Variable dependent on farm, province and animal cycles.

proxy to project changes in certain feed components, specifically the proportion of silage in diets relative to the proportion of hay for the period of 1990 to 1999.

A time series consisting of the annual weighted provincial averages for feed digestibility, lactation lengths and crude protein content in feed was transferred into the Boadi model structure. Furthermore, provincial cattle weights for dairy animals were modified based on average measurements included in the Lactanet database for each farm size and productivity class. The percentage change in cattle weight was used as an indicator of changes in body weight, mature weight and weight gain from the 2001 benchmark values established by Boadi et al. (2004a). The resulting dairy animal weight time series is also incorporated into the Tier 2 methodology.

Table A3.4–3 **Typical Characteristics of Dairy Production in 2001 in Canada**

Animal Category/Parameters	Production Characteristics [b]	Data Sources [c]
Dairy cows [a]		
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 [d] %	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:

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

Milk Yield and Fat Data

Milk productivity has increased in all Canadian provinces (Table A3.4–4), as documented by Lactanet,[20] which collects a sample of milk production representing more than two thirds of the Canadian dairy cow population for the 1999–2019 period and compiles and prepares the data for use in the inventory. These data represent the best estimate of actual milk production per average cow per province in Canada. However, from 1990 to 1998, this data set does not exist for all of Canada. The only data that are available from 1990 to 1998 for all of Canada are publishable data that were reported by Agriculture and Agri-Food Canada. The publishable data are collected for the most productive animals and the quantity of milk that is produced in the first 305 days of their lactation period. The time series of real milk production for the entire Canadian herd from 1990 to 1998 was calculated based on the average ratio between the publishable data and the management data from 1999 to 2007. The trend of increased milk production is reflected in the emission factor for dairy cows.

Duration of Time in a Production Environment

It was assumed that cows that were dry (not lactating) during the summer months were on pasture; cows that were dry during the remainder of the year were in confinement. Replacement heifers were assumed to calve at 24 months. Lactation cycles were on average 320 days; however, cycles vary regionally and are based on herd productivity.

Percentage of Cows Pregnant

An estimate of the percentage of cows pregnant in the herd at any given time was calculated in Boadi et al. (2004a) by dividing average gestation length by the regional average calving interval and subtracting the number of cows that are culled annually due to reproductive failure.

Ration Digestibility (DE%)

Digestibility of rations (DE%) was based on feed data in the Lactanet database and cost of production surveys. The values used in the Tier 2 calculations are weighted averages based on measured digestibility in the different diets associated with a specific farm size and productivity class from the data collected by Lactanet. For individual provinces not represented directly by Lactanet's data, DE% values were obtained by multiplying the DE% by the proportion of animals in each farm size and productivity class for

20 canwestdhi.com/publications.htm

Table A3.4–4 **Average Milk Production from 1990 to 2019 at a Provincial Level**

	Average Milk Production (kg/head/day)									
Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC
1990	21.0	20.9	21.0	20.8	20.3	21.7	22.1	22.2	23.2	24.3
1995	23.1	23.1	23.2	23.0	22.2	24.0	24.2	24.2	25.5	26.8
2000	27.4	26.1	26.8	26.4	25.5	26.5	27.9	27.7	29.0	30.0
2005	27.0	27.1	26.9	26.4	25.9	26.7	27.4	29.3	29.3	30.4
2010	27.4	27.8	27.7	26.8	27.3	27.8	28.8	31.1	30.6	31.1
2011	27.9	28.5	28.3	27.0	27.4	28.0	28.3	30.1	30.2	30.7
2012	27.9	28.5	27.9	27.1	27.4	28.4	28.4	30.6	30.9	30.4
2013	29.6	29.7	29.1	28.5	28.7	30.2	30.7	32.0	32.8	32.7
2014	30.0	29.3	28.4	27.6	28.8	29.5	29.8	32.9	33.0	32.6
2015	30.3	29.4	28.9	27.3	28.7	30.1	30.6	33.1	34.2	33.0
2016	30.9	30.0	29.7	27.6	29.3	31.0	31.5	35.6	35.5	34.0
2017	30.5	31.3	30.8	28.4	29.8	31.3	31.5	35.0	34.6	32.2
2018	31.8	31.6	31.1	29.8	30.3	31.3	32.0	37.0	35.5	33.9
2019	34.9	33.1	32.0	30.2	31.2	32.5	33.2	36.4	35.7	34.3

Note:

Data source – Lactanet (2020)

each province. The provincial DE% time series was then inserted into the existing Tier 2 approach, replacing the fixed values from Boadi et al. (2004a).

Since 1990, the proportion of hay in feed has decreased, while the proportion of silages has increased. Silages typically have a higher feed value as the digestible portion of the feed is better preserved and, as a result, more of the feed is available for digestion by the animal. Furthermore, there has been a small overall increase in the amount of concentrates and supplements used in diets. Overall, DE% ranges from 69% to 72% for lactating cows, and 63% to 65% for dry cows, while heifers were assumed to have a diet similar to dry cows.

A3.4.1.1. Non-Dairy Cattle

Production Practices and Performance

Production practices for livestock reported under 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. (2004a) characterized the predominant practices in 2001 for each province according to animal type, physiological status, age, gender, growth rate, activity level and production environment. The values presented in Table A3.4–5 provide examples of production performance data collected for Canadian beef cattle, originally used as a QA verification of the data incorporated in the Tier 2 model.

Trends in carcass weights are used as an indicator of changes in mature weight from the 2001 benchmark values established by Boadi et al. (2004a) for the specific animal subcategories presented in Table A3.4–6. Carcass weight data are collected by the Canadian Beef Grading Agency (CBGA) and published by Agriculture and Agri-Food Canada (AAFC 1990–2019). Carcass weights increased from 1990 to 2003 for beef cows, heifers for slaughter, steers and bulls (Figure A3.4–2). Since 2003, beef cow carcass weights have remained more or less stable, but slaughter animal weights have continued to increase until recently when weights stabilized. In 2003, the Canadian beef cattle industry was affected by bovine spongiform encephalopathy (BSE) disease, which shut down beef exports to the United States. After 2003, the slaughtered carcass weights 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 were retained at their 2002 value. From 2009 to 2018, the slaughter weights of bulls were used in the time series again. Bull weights were observed to decrease considerably in 2013. This observation was verified; in general, bull weights are prone to higher variability due to the low numbers being slaughtered on an annual basis.

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) is 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 are either in feedlots or backgrounded. Animals scheduled for slaughter may be identified as either short-keeps or long-keeps. Short-keeps go directly to the feedlot to be slaughtered after 3 to 4 months, whereas long-keeps are typically backgrounded for 6 months before being sent to feedlots, where they are finished after 2 to 4 months.

Table A3.4–5 **Typical Characteristics of Beef Production in Canada in 2001 from Various Sources**

Animal Category/Parameters	Production Characteristics [a]	Data Sources [b]
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	620 (51)	
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)	

Notes:

Values represent typical values observed in Canada but not population-weighted averages quantitatively representing Canadian beef production, as reported in the CRF.

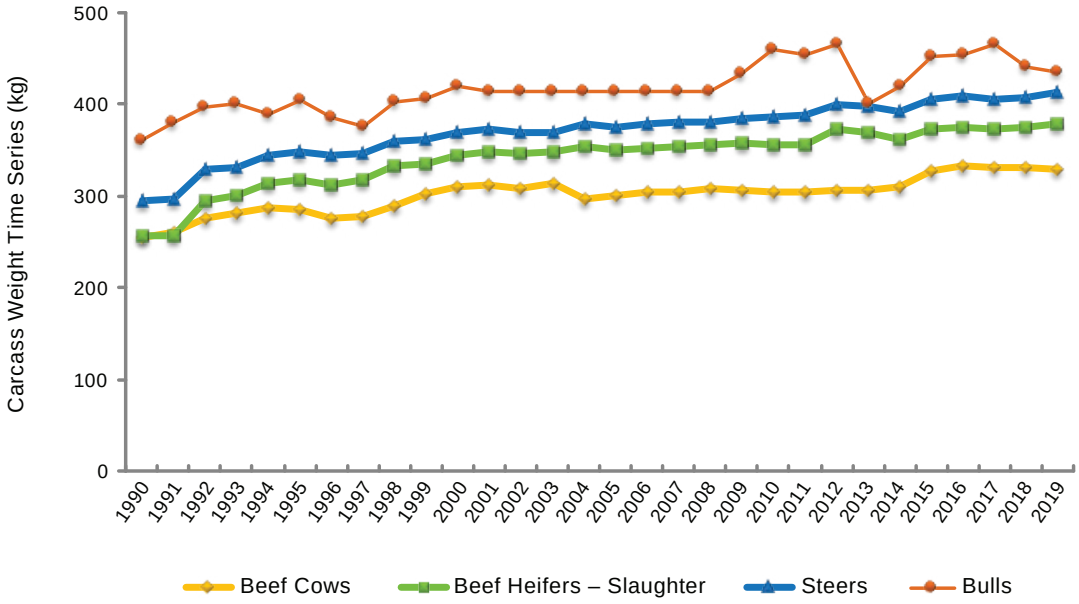
a. The numbers in parentheses are the standard deviations.

b. Values with no reference were obtained from expert consultations compiled in Boadi et al. (2004b).

Table A3.4–6 **Indicators of Live Body Weight Change Over Time for Cattle Subcategories**

Cattle Subcategory	Trend in Live Weight Applied
Beef cows	Trends in beef cow carcass weight used as an indicator of live weight.
Heifers for slaughter	Trends in heifer carcass weight used as an indicator of live weight.
Beef heifers	Trends in beef cow carcass weight used as an indicator of live weight.
Steers	Trends in steer carcass weight used as an indicator of live weight.
Bulls	Trends in bull carcass weight used as an indicator of live weight from 1990 to 2002; 2003 to 2008 live weights are set constant to the 2002 live weight; 2009–Present uses carcass weight trend again.
Calves	No change
Dairy cows	Provincial trends in dairy cow productivity are used along with average body weight by productivity class as an indicator of live weight.
Dairy heifers	Trends in dairy cow live weight used as an indicator of dairy heifer live weight.

Figure A3.4–2 **Non-Dairy Cattle Carcass Weight, Based on Data Collected by CBGA and Published by Agriculture and Agri-Food Canada**



Ration Digestibility (DE%)

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, Food and Rural Development and the University of Alberta (2003) were used for Alberta, whereas values from the U.S. National Research Council (2001) were used to estimate DE% for British Columbia and the Eastern provinces. Overall, DE% ranged from 60% to 84%, depending on rations and feeding regimes.

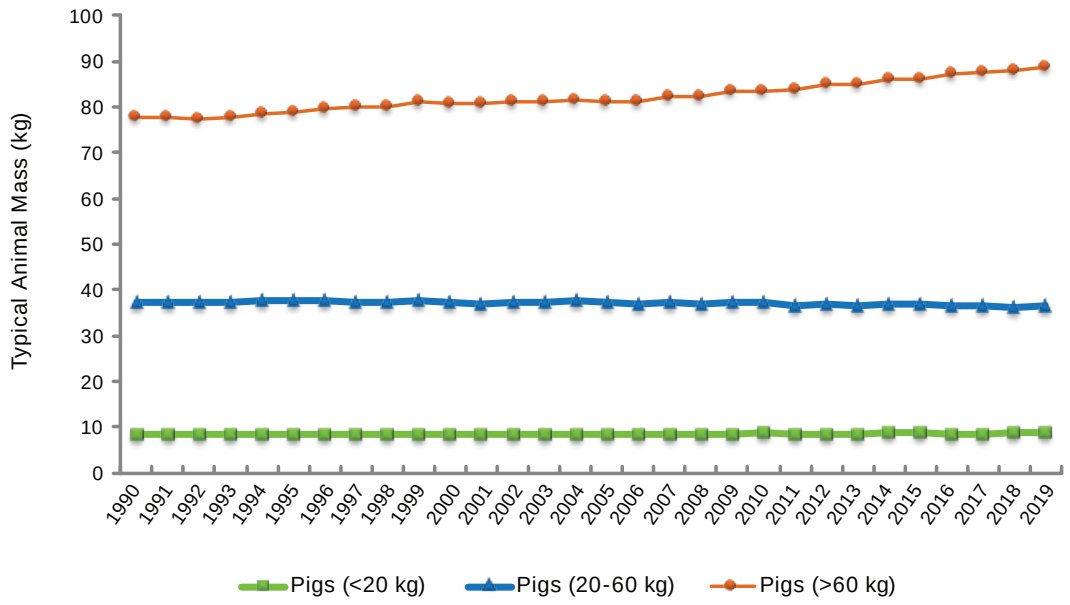
Calves were assumed to have a non-functional rumen or to consume very small amounts of dry feed from birth until two or three months of age. Therefore, enteric CH_4 emissions in these first few months are assumed to be zero.

A3.4.1.2. Swine

Production Performance

Trends in carcass weights are used as an indicator of changes in mature weight. Carcass weight data are collected and published by Statistics Canada as part of the quarterly Farm Cash Receipts (FCR) survey (Statistics Canada, n.d. [c]). Average cold-trimmed carcass weights are converted to live weights using the corresponding conversion factor (Agriculture and Agri-Food Canada, 2018). Since 1990, hog carcass weights have increased steadily from 77 kg to 100 kg (+30%), as a result of a change in production practices and genetics. Relationships between live weight and average daily weight gain, as well as changes in average daily weight gain over time by animal weight class, were developed based on data from the Prairie Swine Research Centre and combined with the time series of mature weights to develop a time series of typical animal mass for market swine. The typical animal mass for market swine varies by weight class (Figure A3.4–3) based on increased rates of growth and, in the case of the upper weight class, an increase in carcass weights since 1990. Animal mass for breeding animals was held constant using the default IPCC value.

Figure A3.4–3 **Typical Animal Mass for Swine, by Weight Class**



A3.4.2. CH_4 Emissions from Enteric Fermentation

The release of CH_4 from the process of enteric fermentation is calculated using Equation A3.4–1 for all categories of livestock in Canada. CH_4 emissions reported under Enteric Fermentation for cattle are estimated using the country-specific emission factors derived from IPCC (2006) Tier 2 equations (Table A3.4–8). For the other animal categories, the IPCC Tier 1 methodology and default emission factors are applied (see Annex 6).

Equation A3.4–1

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

CH_{4EF}	=	CH_4 emissions from the process of enteric fermentation for all animal categories
N_T	=	animal population for the T^{th} animal category or subcategory in each province
$EF_{(EF)T}$	=	emission factor for the T^{th} animal category or subcategory (Table A3.4–8 for cattle; for other animal categories, see Annex 6)

A3.4.2.1. Enteric CH_4 Emission Factors for Cattle

Emission factors were derived at the provincial level using IPCC (2006) 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 A3.4–2.

Equation A3.4–2

$$GE = \left[\left[\frac{\left(NE_m + NE_a + NE_l + NE_p \right)}{(REM)} \right] + \left[\frac{NE_g}{(REG)} \right] \right] / \left[\frac{DE\%}{100} \right]$$

GE	=	gross energy, MJ/day
NE_m	=	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_p	=	net energy required for pregnancy, MJ/day
REM	=	ratio of net energy available in a diet for maintenance to digestible energy consumed
NE_g	=	net energy required for growth, MJ/day
REG	=	ratio of net energy available in a diet for growth to digestible energy consumed
$DE\%$	=	digestibility of the ration, %

All net energy estimates are applied according to equations in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). Due to the Canadian climate, Equation 10.2 from the Guidelines (Equation A3.4–3) was implemented for Non-Dairy Cattle.

Equation A3.4–3

$$Cf_i\ (in\ cold) = Cf_i + 0.0048 \times (20 - {}^{o}C)$$

Cf_i = A coefficient that varies for each animal category relating weight to energy requirements for body maintenance, MJ/day/kg

${}^{o}C$ = Mean daily temperature during the winter season

The cold-adjusted Cf_i was derived by using the average temperature for the period October to April for each Canadian province, weighted based on the geographic location of non-dairy types of cattle (distributed at the ecodistrict scale) in the province. It was then corrected based on the percentage of animals kept in barns for different provinces, taken from Sheppard and Bittman (2012) and was applied to all production stages that occur during the winter months. Production stages that occur in both winter and summer, specifically finishing stages for steers and slaughter heifers, were averages of the default and the cold-adjusted Cf_i. As a result of this implementation, considering the different production stages of the animal, average annual Cf_i values varied between 0.43 for non-dairy cows in Manitoba, the coldest province, and 0.37 for non-dairy cows in Ontario and some of the Maritime provinces. Based on a weighting of production stages, the Cf_i would typically be 0.35, not considering the temperature effect. The lower Cf_i in Eastern Canada is due mainly to milder temperatures, but also to the practice of keeping animals in barns over winter, whereas in Western Canada, cattle are mainly kept outdoors. As a result, the impact of cold on the net energy of maintenance is largely observed in Western Canada.

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, emissions reported under Dairy Cattle 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, and a weighted average emission factor was therefore calculated. Criteria used in the weighting included duration of time spent in each production stage 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 each province, an emission factor ($EF_{(EF)}$) is calculated according to Equation A3.4–4. 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 A3.4–8). For emission factors reported under Non-Dairy Cattle, the IPCC default methane conversion rate (Y_m) of 6.5% was used to calculate non-feedlot cattle emission factors and 3% was used for animals in feedlots.

The dairy Y_m factor was derived directly from production data and empirical CH_4 prediction equations developed from North American research. Briefly, the farm size by productivity matrix used to derive ration digestibility was also used to provide more detailed feed characteristics such as neutral detergent fibre, fat content and non-fibre carbohydrate content. These feed, herd and production characteristics separated by farm size and productivity class were inserted into 12 predictive methane equations, compiled from three scientific publications (Ellis et al., 2007; Ellis et al., 2010; Appuhamy et al., 2016). Gross energy for each production and farm size class was calculated according to Equation A3.4–2 based on the herd specific characteristics. Finally, the methane conversion rates (Y_m) were back-calculated from predicted methane emissions and calculated gross energy intake.

An average Y_m per productivity and farm size class was calculated based on the results of the 12 predictive equations. This value was then weighted for each province based on the proportional breakdown of the population of animals in each productivity and farm size class in the same way as a provincial digestibility value was derived. The Y_m that was derived varied between 5.9% for the lowest productivity classes and 5.4% for the highest productivity class. Weighted provincial Y_m values varied between 5.5% and 5.7%.

Dry matter intake (DMI) is based on the cattle production model and calculated at the provincial level based on regional trends and seasonal stages of production. Weighted national DMI (Table A3.4–7) for dairy cows has increased by 24% since 1990 in response to increased milk production per cow (Table A3.4–4), while DMI for dairy heifers decreased by 3% over this period due to increased feed digestibility resulting from changes in ration composition. For beef cattle, DMI is driven by trends in carcass weights (Figure A3.4–2).

Equation A3.4–4

$$EF_{(EF)T} = \sum_{T} \left[\frac{GE_P \times Y_{mP} \times 365}{55.65} \times TP_P \right]$$

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

GE_P = gross energy for a given cattle stage of production P, MJ/day

Y_{mP} = methane conversion rate at which the fraction of gross energy is converted to methane by an animal within defined population T, m^3/kg

55.65 = energy content of methane, MJ/kg CH_4

TP_P = time within a stage of production P, days/year

Table A3.4–7 **Dry Matter Intake (DMI) by Cattle Subcategory, for Select Years from 1990 to 2019, estimated from Gross Energy (GE) Intake**

	DMI – (kg DM/head/day)							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[a]	Steers[a]	Calves
1990	17	10	14	13	10	10	9	6
1995	17	10	15	14	11	11	10	7
2000	18	10	15	15	11	11	10	7
2005	18	10	15	15	11	11	10	7
2010	19	10	16	15	11	11	10	7
2011	19	10	16	15	11	11	10	7
2012	19	10	17	15	11	12	11	7
2013	19	10	15	15	11	12	10	7
2014	19	10	15	15	11	11	10	7
2015	20	10	16	15	12	12	11	7
2016	20	10	16	15	12	12	11	7
2017	20	10	17	15	12	12	11	7
2018	20	10	16	15	12	12	11	7
2019	21	10	16	15	12	12	11	7

Note:

a. Reported as kg/head/day; however, emissions are calculated based on time to slaughter.

A3.4.2.2. Verification of Parameter Selection Against Canadian Research

In 2011, an internal Tier 2 quality assurance/quality control (QA/QC) was carried out on the Enteric Fermentation source category (MacDonald and Liang, 2011). In this analysis, a review and compilation of Canadian literature related to methane production from the process of enteric fermentation were carried out. The results were then evaluated in light of the implementation of the 2006 IPCC Guidelines.

The 2011 analysis research measuring enteric fermentation processes in Canada indicates that the average measured methane conversion rates (Y_m) are 6.6% (±2.4) of gross energy (GE) for non-dairy cattle animals outside of feedlots, 3.2% (±1.9) of GE for non-dairy types of cattle on feedlots and 5.7% (±0.9) for dairy livestock (McCaughey et al., 1997, 1999; Boadi and Wittenberg, 2002; Boadi et al., 2002, 2004b; 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; Ellis et al., 2010; Jayasundara et al., 2016). For the Non-Dairy Cattle category, these values agree broadly with the values published in the 2006 IPCC Guidelines. Recent work by Escobar-Bahamondes et al. (2016) suggests that further differentiation of Y_m factors by production subcategory is possible, which could aid in improving the accuracy of emission estimates. From the same compilation of research, the emission factor for the Non-Dairy Cattle category is observed to be 57 (±22) kg CH_4/head/year outside of feedlots and 56 (±24) kg CH_4/head/year in feedlots, and the average measured emission factor for the Dairy Cattle category is 130 (±34) kg CH_4/head/year.

Caution must be used in interpreting these values because this data set did not include animals in cold conditions and because the majority of studies focus on yearling heifers and steers. Also, the average value does not take into account the relative importance of different cattle subcategories to the average emission factor. Nonetheless, the emission factor values do agree, in general, with the emission factors used by Canada for the Non-Dairy Cattle category (i.e., 60 to 70 kg CH_4/head/year) and Dairy Cattle category (i.e., 115 to 137 kg CH_4/head/year). A recent publication by Jayasundara et al. (2016) compiled literature data from 11 studies and found that Y_m factors for Canadian dairy livestock were on average 5.7 (±0.9)%. In the current Canadian cattle model, Y_m for dairy cows is varied over time and by province, averaging 5.5%–5.7% of GE, while a fixed Y_m of 6.5% is used for dry dairy cows, dairy heifers.

As it currently stands, no evident bias could be identified from the review of Canadian literature results. It appears that a bias that is introduced through the use of the Y_m values from the 2006 IPCC Guidelines is compensated for by the estimate of GE for specific animal subcategories.

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).

Improvements to the dairy model in the 2018 national inventory report, in particular with the Y_m derived directly from empirical relationships from North American studies, assure that emission rates are consistent with recent measurements of CH_4 emissions, greatly improving the

Table A3.4–8 **CH_4 Emission Factors for Enteric Fermentation for Cattle in Select Years from 1990 to 2019**

	$EF_{(EF)T}$ (kg CH_4/head/year)[a]							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	115.4	79.4	108.0	105.9	82.5	44.7	41.4	43.8
1995	119.1	78.6	117.2	112.1	85.9	48.8	43.6	43.8
2000	125.4	78.0	121.0	117.5	89.4	53.0	47.8	43.8
2005	125.0	77.2	119.9	114.4	87.0	52.8	46.0	43.6
2010	128.6	76.8	128.5	115.2	87.8	52.8	47.0	43.7
2011	129.2	76.8	127.6	115.0	87.5	52.7	47.4	43.7
2012	129.6	76.8	129.8	115.6	87.6	53.8	48.0	43.7
2013	134.0	76.8	117.1	115.3	87.5	53.7	48.0	43.8
2014	134.1	76.7	121.1	116.3	88.1	53.2	48.1	43.8
2015	135.2	76.7	127.5	120.0	90.7	53.8	48.8	43.8
2016	137.5	76.7	128.0	121.3	91.6	53.9	48.8	43.8
2017	138.1	76.7	130.1	120.8	91.3	53.6	48.4	43.8
2018	139.6	76.7	125.3	120.5	91.2	53.7	48.5	43.8
2019	142.2	76.6	124.0	120.3	91.0	53.9	49.0	43.7

Notes:

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

accuracy of emission estimates. Similar approaches would significantly improve estimates for the Non-Dairy Cattle category, but data are still being compiled to carry out these studies. In general, it is difficult to improve Canadian estimates through updates of single parameters. Improving on the current model requires a comprehensive approach effectively linking regional animal production characteristics to animal productivity, as has been done for the Dairy Cattle category.

A3.4.2.3. 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 6). When default emission factors are not available for the minor livestock categories, logical proxies are used to estimate emissions; swine emission factors are used for wild boars, and sheep emission factors are used for llamas and alpacas. These proxies are based on species similarities as well as similarities in production practices.

A3.4.2.4. Uncertainty

A comprehensive uncertainty analysis was carried out on all methodologies used in the calculation of methane from livestock for 2010. Uncertainty ranges (percentages) of means were rerun for the 2014 NIR submission and have not been rerun since that submission. In the analysis, a stochastic reproduction of the livestock CH_4 emission model was built in Mathematica© and a Monte Carlo simulation (MCS) was run according to the methodology proposed in the IPCC Good Practice Guidance (IPCC, 2000). This analysis built on a recent study (Karimi-Zindashty et al., 2012). However, the Environment Canada stochastic model (ECSM) built in Mathematica© (1) applied the exact parameters and equations used in the Canadian inventory methodology based on the Good Practice Guidance (IPCC, 2000); (2) included uncertainty associated with populations and duration of production stages, which impact subcategory emission factors (Table A3.4–9); and (3) used the provincial distribution of manure management systems with improved estimates of probability distributions (Table A3.4–9). The ECSM was run for the years 1990, 2005, 2010 and 2012. A trend analysis was carried out to establish the uncertainty in the estimate of the differences in emissions from 1990 to 2012. The relative uncertainties from the previous analysis were applied to the current year's values. Uncertainty analysis on the revised dairy model, however, has not yet been carried out and reported uncertainty estimates are based on the Boadi et al. (2004a) methodology.

Currently, the data required to create probability distributions of the coefficients used in the agricultural IPCC Tier 2 models simply do not exist. Some of the default coefficients in Tier 2 equations are provided with an uncertainty range, often estimated by expert opinion; for other coefficients, ranges are taken from a few studies, often using methodologies that are not easily comparable. In general, the analysis of Rypdal and Winiwarter (2001) applies to the agricultural emission model as a whole, and it can be understood that large probability distributions are associated with default Tier 2 coefficients due to a lack of appropriate measurements and subsequent generalizations, uncertainties in measurements and an inadequate understanding of emission processes. This initial uncertainty analysis has applied a precautionary principle, and for coefficients with very little information, uncertainty bounds were conservative.

Uncertainties in populations of major animal categories, i.e., cattle, swine and sheep, were supplied directly by Statistics Canada based on biannual and quarterly survey statistics. For small provinces with few animals in certain categories, sample variance is large, as indicated by uncertain values of > ±50%. However, because the data were collected based on a sampling design proportional to population distributions, the overall uncertainty for major animal categories at the national level was low. National populations for non-dairy cattle types have the lowest uncertainty (±1.8% of the mean), with slightly higher uncertainty for swine (±2.6% of the mean), dairy cattle (±5.4% of the mean) and sheep (±6.0% of the mean).

All other animal population estimates are renewed only through the *Census of Agriculture*. To account for the increase in uncertainty due to the time that has elapsed since the census, a model was developed that estimated the increase in uncertainty as a function of time from the census. A linear regression was run through census year population estimates from 1991, 1996, 2001, 2006 and 2011. The uncertainties for populations in 2012 were estimated as the agricultural census uncertainty at the provincial level plus the 95% confidence interval for the linear regression multiplied by the number of years since the last census (one year). Due to the recent *Census of Agriculture*, the other animals tended to have lower population uncertainties in the 2012 analysis than the 2010–2011 uncertainties, similar to those animals for which population estimates are taken from biannual and quarterly surveys, though this had little impact on total uncertainty. The national population uncertainties for other animal categories ranged from ±2% of the mean for poultry to ±4% of the mean for bison; however, these animal categories contribute little to total emissions.

The parameters used in the calculation of Tier 2 emission factors for cattle can be divided into two categories: (1) those associated with cattle production and performance (see section A3.4.2 for detailed descriptions of parameters); and (2) those that are specific to the IPCC Tier 2 equations (see section A3.4.2 for details). For the most part, the uncertainty assigned to parameters associated with cattle production and performance is relatively low, as these estimates are collected on a provincial basis, from provincial experts, and are values that are generally known within the industry. The largest source of uncertainty in production practices is the duration and fraction of animal populations in specific production stages. This source of uncertainty is associated with the number of animals that are backgrounded and the duration of that backgrounding period. These are parameters that are highly dependent on prices and import/export markets, and therefore confidence in the values that are currently being used is low. A high level of uncertainty (30%) was applied to the number of animals backgrounded, and a non-symmetrical triangular distribution was applied to the duration of backgrounding as a precautionary approach to account for high levels of potential variability in these production practices. The uncertainty in production population fraction and the duration of production stages was not accounted for directly in Karimi-Zindashty et al. (2012).

The uncertainties for parameters used in IPCC Tier 2 equations were taken, for the most part, directly from Karimi-Zindashty et al. (2012), who used the probability distributions either from Monni et al. (2007) or from the 2006 IPCC Guidelines. Two differences are notable: (1) digestible energy probability distributions became available from data supplied by Lactanet after the Karimi-Zindashty et al. (2012) study was completed, allowing the calculation of typical distributions of different types of feed; and (2) Karimi-Zindashty et al. (2012) used the 2006 IPCC methodology and therefore did not include the effects of weight loss on gross energy. A uniform distribution was therefore used in the ECSM analysis to account for the impact of incorporating an estimate of net energy mobilized through weight loss during lactation (NE_{mob}) that varied according to duration of weight loss between 0% and 20% of the lactation period. As this parameter has been removed from the 2006 IPCC Guidelines, this approach was an effective way to evaluate the overall impact of this parameter.

A trend analysis was carried out using the ECSM in which the uncertainty in the magnitude of the change in emissions over time was calculated. For the long-term trend, emissions for 1990 and 2012 were calculated simultaneously, allowing only time-dependent parameters to vary independently in the estimates. These parameters represent the elements of the calculation model that change over time, and therefore an estimate is available for a value in 1990 and in 2012 (noted by a superscript g in Table A3.4–9). The parameters in 1990 and 2012 are considered entirely independent and, as a consequence, for each calculation in the Monte Carlo simulation, a value was selected from the probability distribution for 1990 and 2012 independently. In contrast, other parameters used a value selected once from their probability distribution for the calculation of emissions in both 1990 and 2012. The parameters that were allowed to vary independently for the enteric fermentation process analysis were animal populations, milk production and fat content for dairy cows, and body weights for cattle. The relative uncertainty values for the trend analysis were applied to the 2013 results.

The summary results of the uncertainty analysis for emissions from the process of enteric fermentation are reported in Chapter 5, section 6.2.3. Briefly, the fixed range used in calculating uncertainty ranges for emissions from enteric fermentation is 39% (-17% to +22% of the mean) (see Chapter 5). Most uncertainty in the estimate is associated with the Tier 2 emission factors for cattle; they lie within an uncertainty range of -19% to +22% of the mean emission factor for the Non-Dairy Cattle category and -16% and +21% of the mean emission factor for the Dairy Cattle category. In the case of other animals that use Tier 1 IPCC (2006) default emission factors, uncertainty ranges of ±50% were assigned, with the exception of swine, which was ±37% based on

Monni et al. (2007). Relative to cattle, the Tier 1 emission factors for other animals have little impact on the total uncertainty because of the small contribution of other animal categories to total enteric fermentation emissions. Mean emissions for both the Dairy Cattle and Non-Dairy Cattle categories estimated using the stochastic model are slightly higher than calculated in the inventory database (roughly 2%). This difference is likely due to the introduction of the non-symmetrical triangular distribution that increased the length of backgrounding for slaughter heifers and steers and to the uniform distribution of the factor that defines energy released from weight loss during lactation in dairy cows.

The overall uncertainty for each estimate of each individual year changes little over time. The uncertainty range for emissions in 1990 and 2012 is 39% to 40%. Based on the trend analysis, over the long term, CH_4 emissions increased between the 1990 base year and 2012 by 9% to 19%, with a most likely value (MLV) of 15% (trend uncertainty 10%). Most of the increase in emissions is associated with the Enteric Fermentation category, which increased by 11% to 22%, with an MLV of 16%. To estimate the trend uncertainty reported in Chapter 5, the relative trend uncertainties from the previous analysis were applied to the current year's mean change in emissions. In general, this uncertainty analysis was consistent with other agricultural estimates of uncertainty. The paper by Monni et al. (2007) is, to our knowledge, currently the only one detailing agricultural CH_4 emission uncertainty with the use of IPCC Tier 2 methodology. The use of comparable probability distributions for IPCC Tier 2 default parameters provides comparability between the two different national emission estimation methodologies. Monni et al. (2007) estimated the national-scale uncertainty for Enteric Fermentation emissions from Finnish agriculture for different cattle subcategories as ranging from -22% to +29% of the mean to -29% to +39% of the mean. Rypdal and Winiwarter (2001) reported uncertainties for some European countries ranging from ±20% of the mean in the United Kingdom to ±50% of the mean in Austria, but they used mainly Tier 1 estimation methodologies. We did not find comparable publications for trend uncertainty analysis in the field of agriculture.

The results of this uncertainty analysis were, of course, very similar to those produced by Karimi-Zindashty et al. (2012), who also observed an overall uncertainty range for enteric fermentation emissions of 39%, indicating that the uncertainty associated with the production stage duration and population fractions had little impact on the overall uncertainty. The incorporation of the uncertainty associated with weight loss during lactation did not increase overall uncertainty, but tended to skew the uncertainty distribution for Dairy Cattle category estimates towards higher emission estimates. The sensitivity analysis carried out by Karimi-Zindashty et al. (2012) indicated that the major drivers of uncertainty in emission estimates were associated with the default IPCC Tier 2 parameters, in particular the methane conversion rate (Y_m) and the factor associated with the net energy of maintenance (Cf_i), applied at the national scale. Uncertainty in the Tier 2 methodology may be reduced through the development of country-specific parameters at the regional scale for different animal categories. It is suspected that the recent revisions to the dairy model will have reduced the overall uncertainty of enteric emission estimates; however, further analysis is required to quantify the impact of improvements on the uncertainty estimates.

A3.4.3. CH_4 Emissions from Manure Management

The IPCC Tier 2 methodology is used to estimate CH_4 emission factors from manure management systems (IPCC, 2006), also referred to as animal waste management systems (AWMS). Equation A3.4–5 is used to calculate CH_4 emissions from the management of manure for all categories of livestock in Canada with the exception of deer and elk, rabbits, mules and asses, and fur-bearing animals, which were calculated using IPCC Tier 1 emission factors. Wild boar emission factors were calculated based on average swine Tier 2 parameters, but assuming only solid manure. Sources of animal population data are the same as those used in the reporting of Enteric Fermentation estimates and are listed in Table A3.4–1.

When default emission factors or country-specific information sources are not available for the minor livestock categories, logical proxies are used to estimate emissions. These proxies are based on species similarities as well as similarities in production practices. When proxies are used at a provincial level, weighted national values may not match between the native and proxy livestock categories due to differences in provincial populations used for weighting.

The following proxies and expert judgement are used for minor animal categories:

- Manure management system parameters from the Non-Dairy Cattle category are used to represent bison, including the maximum CH_4 producing potential (B_0) and provincial AWMS distributions.
- Provincial AWMS distributions for horses are used to represent mules and asses.
- Provincial AWMS distributions for the Non-Dairy Cattle category are used for the reporting of Deer and Elk, except that liquid systems are distributed to PRP based on expert judgement that deer and elk livestock manure is unlikely to be handled by liquid manure systems.
- Volatile solids for the Swine category are used to represent wild boars at a provincial level. The disaggregation of swine animal subcategories and scaling of VS with animal mass (section A3.4.3.6) are not used for this proxy relationship. Lastly, all manure from wild boar livestock is allocated to solid AWMS based on expert judgement.
- Sheep manure management system parameters are used to represent llamas and alpacas, including volatile solids (VS) and provincial AWMS distributions.

Total emissions from the minor animal categories Mules and Asses, Deer and Elk, Llamas and Alpacas, Mink, Foxes, Rabbits and Wild Boars represented less than 100 kt CO_2 eq in 2019 (<0.2% of total agricultural emissions), including direct and indirect emissions and emissions from application to agricultural soils. Changes to these proxies could not have a significant impact on emission estimates from the agricultural sector, and based on the insignificant impact of these animal categories on agricultural emissions, improvements to these animal categories are of the lowest priority in the agricultural inventory.

Equation A3.4–5

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

CH_{4MM}	=	emissions for all animal categories
N_T	=	animal population for the T[th] animal category or subcategory in each province
$EF_{(MM)}T$	=	emission factor for the T[th] animal category or subcategory calculated according to Equation A3.4–6

To develop Tier 2 CH_4 emission factors representing manure management systems, country-specific inputs were required that take into account climate, livestock rations and the type of manure storage system included in Equation A3.4–6. The following equation represents an IPCC Tier 2 estimate of CH_4 emission factors from manure management systems:

Equation A3.4–6

$$EF_{(MM)T} = VS_T \times 365 \times B_{0T} \times 0.67 kg/m^3 \times \sum_{ij} MCF_{ij} \times AWMS_{Tij}$$

$EF_{(MM)T}$	=	annual emission factor for defined animal population T, kg CH_4/head-year
VS_T	=	daily volatile solids excreted for an animal within the defined population T, kg/day
B_{0T}	=	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
$AWMS_{Tij}$	=	system distribution factor, defined as the fraction of animal category T's manure that is handled using manure system i in climate region j, often referred to in IPCC documents as management system (MS)
0.67	=	conversion factor of m^3 CH_4 to kilograms CH_4

The following sections outline the sources of input values for VS, DE%, ASH, B_0, MCF and AWMS.

A3.4.3.1. 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 digestibility (DE%) of dietary intake, manure ash content and gross energy (GE) consumed by a given animal subcategory, and the urinary energy (UE) fraction of the gross energy intake, according to the 2006 IPCC Guidelines.

For cattle subcategories, the GE depends on the cattle production model defined for estimating emissions from the enteric fermentation process (Boadi et al., 2004a), as shown in Equation A3.4–3. Estimates of VS were derived for each cattle subcategory at the provincial level based on regional and seasonal stages of production (Equation A3.4–7). Increases in milk production in dairy cows and carcass weight in beef cattle have increased VS with increased dry matter intake and, as a result, CH_4 emission factors over the time series; however, increases of DE% in dairy feed over time have moderated this effect for dairy cows.

Equation A3.4–7

$$VS = \left[GE \times \left(1 - \frac{DE\%}{100} \right) + (UE \times GE) \right] \times \left(\frac{1 - ASH}{18.45\ MJ} \right)$$

VS	=	volatile solids excretion, kg/head/day
GE	=	gross energy consumed by a given animal, MJ/head/day
$DE\%$	=	digestibility of the ration, %
UE	=	urinary energy (unitless)
ASH	=	ash fraction of the manure, %

Swine (VS)

Volatile solids reported for the Swine category (Table A3.4–11) were estimated by first calculating provincial VS excretion based on values in Marinier et al. (2004), using the IPCC 2006 Tier 2 approach and taking into account the variability in the values of DMI, DE% and ASH derived from expert surveys. Typical animal mass was used to convert the temporally fixed VS into units of VS per 1000 kg body weight (kg VS/1000 kg animal mass/day), which was then applied to the full animal mass time series.

All Other Animals (VS)

Volatile solids for animal categories other than Dairy Cattle, Non-Dairy Cattle and Swine were calculated based on values in Marinier et al. (2004), using the IPCC 2006 Tier 2 approach and taking into account the variability in the values of DMI, DE% and ASH derived from expert surveys. The values for DMI, DE% and ASH taken

Table A3.4–9 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Enteric Fermentation**

Parameter Category	Parameter	Coefficient/Parameter Source	Distribution Type	Uncertainty Range[a]	Uncertainty Distribution Source and Notes	Spatial Allocation/Animal Category Allocation
Population Data[g]						
Cattle Biannual Surveys						
	Dairy	Statistics Canada (Table 003-0032)	normal	±6% – ±42%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[d]	Provincial/subcategory
	Non-dairy			±5% – ±73%		
Other Survey-based Populations						
	Swine	Statistics Canada (Tables 003-0004 and 003-0031)		±8% – ±89%		
	Sheep			±14% – ±80%		
Census of Agriculture						
	Goats	*Census of Agriculture* (Statistics Canada, 2012a)		±9% – ±21%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	
	Poultry			±5% – ±12%		
	Bison			±18% – ±85%		
	Llamas and Alpacas			±16% – ±42%		
	Horses			±5% – ±16%		
Cattle Production Parameters and Performance						
	Milk production[g]	Valacta/Canwest DHI	normal	±8%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
	Fat content[g]	Valacta/Canwest DHI				
	Dairy herd efficiency[g]	Valacta/Canwest DHI				
	Pregnancy coefficient	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	
	Average daily gain (ADG)	Boadi et al. (2004b)				
	Pregnancy period	Boadi et al. (2004b)				
	Production stage duration	Boadi et al. (2004b)	normal except slaughter animals, triangular, non-symetric	±5%, Slaughter animals: MLV[e] from Boadi et al. (2004b) LB: 12% of MLV: UB: 25% of MLV	Expert opinion, Boadi et al. (2004b) – for feeder heifers and steers, a triangular distribution was assumed based on interpretation of potential market effects (Canfax Research Services, 2009)	Provincial/production stage subcategory, internal correlation[f]
	Production stage population fraction	Boadi et al. (2004b)	normal	±5% – ±30%		
Cattle Weight Estimates[g]						
	Live weight, 2001	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/production stage subcategory
	Mature weight, 2001	Boadi et al. (2004b)				
	Carcass weight	CBGA[b] and published AAFC[c] (1990–2010)				National/subcategory
Emissions Factors for Cattle (IPCC Tier 2 Equations)						
	Methane conversion rate (Y_m)		normal	Feedlot animals – ±30% Other animals – ±15%	Karimi-Zindashty et al. (2012) – IPCC (2006)	National/feedlot vs. non feedlot
Gross Energy for Cattle Calculation IPCC Tier 2 Equation A3-18						
	Digestible energy (DE)	Boadi et al. (2004b)	normal	Pasture ±9% Confined ±9% Background ±7.5% Prepared feed ±5.5%	Derived from raw data supplied by Valacta Dairy Services	Provincial/production stage subcategory
Net Energy for Cattle Tier 2 Equations 4.1 to 4.10, IPCC Good Practice Guidance (2000)						
	Animal activity coefficient (C_a)	IPCC (2000)	normal	±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
	Gender coefficient (C)		normal	±30%		
	Maintenance coefficient Cf_i			±30%		
	Lactation coefficient			±30%		
	Weight loss rate		normal	5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
	Weight loss duration		uniform	LB: 0 UB: 20% of lactation period.	Interpretation of differences between 2000 and 2006 IPCC Guidelines	
Non-cattle Emission Factors						
	Swine	IPCC (2000)	normal	±37%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/category
	Other animals			±50%		

Notes:

a. Where differences in uncertainty exist for different provinces or animal categories, maximum and minimum uncertainties are given.
b. Canadian Beef Grading Agency.
c. Agriculture and Agri-Food Canada.
d. Personal communication. Plourde R, Statistics Canada, Livestock and Food Section, Ottawa, ON. April 4, 2010.
e. MLV = most likely value; LB = lower bound; UB = upper bound.
f. Internal correlation indicates values that vary in terms of a fraction of the whole, i.e., a fraction of a total equalling 100%.
g. Values that were allowed to vary independently during trend analysis.

from that survey were used to calculate VS for non-cattle livestock categories for each individual province (Equation A3.4–8). Confidence intervals were developed using a Monte Carlo simulation performed with Crystal Ball® (Decisioneering 2000), resulting in a probability distribution based on the variance in expert opinion and scientific literature (Table A3.4–10).

Table A3.4–10 **Mean Volatile Solids in Manure of Non-Cattle Animal Categories in 2019 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 [a]	0.60	31
Mature Horses	3.6	16
Goats	0.72	41
Bison	3.1	16
Wild Boars [b]	0.23	50
Poultry	0.02	20

Notes:

a. Llamas and alpacas are given the same values as sheep at the provincial level, and weighted based on the population of llamas and alpacas in each province.
b. The value for wild boars is calculated on the basis of the value for swine.

Table A3.4–11 **Mean Volatile Solids in Swine Manure in 2019**

Animal Category	VS (kg / 1000 kg body mass / day)	Typical Animal Mass (kg)	VS (kg/day)
Sows	1.57	198	0.31
Boars	1.57	198	0.31
Pigs (<20 kg)	10.78	8.7	0.09
Pigs (20–60 kg)	5.13	37	0.19
Pigs (>60 kg)	4.56	89	0.40

Equation A3.4–8

$$VS = \left[DMI \times 18.45 \times \left(1 - \frac{DE\%}{100}\right) + (UE \times DMI \times 18.45)\right] \times \left(\frac{1 - ASH}{18.45\ MJ}\right)$$

VS	=	volatile solids excretion, kg/head/day
DMI	=	dry matter intake, kg/head/day
$DE\%$	=	digestibility of the ration, %
UE	=	urinary energy (unitless)
ASH	=	ash content of the manure, %

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

Digestibility (DE%) and Dry Matter Intake (DMI)

The sources of information used for DE% for both the Dairy Cattle and Non-Dairy Cattle categories are detailed in section A3.4.1.1.

Broad regional differences in ration composition were identified for sheep, horses and swine livestock. Regional differences were not considered for goats or poultry livestock, 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 A3.4–12). This method does not, however, account for additives that may increase or decrease digestibility. The DMI for non-cattle animal categories was determined through consultation with experts and published values (Table A3.4–13).

Table A3.4–12 **Approximate Ration Digestibility (DE%) for Selected Livestock Subcategories and Data Sources**

Animal Category	DE (%)	Data Sources [a]
Goats	65	W. Whitmore, Manitoba Agriculture and Food
Laying Hens	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Chickens	80	S. Leeson, University of Guelph; D. Korver, University of Alberta
Turkeys	78	S. Leeson, University of Guelph
Swine	87	C.F. deLange, University of Guelph
Feeding on Grain Diet		
Sheep	74	Weston (2002)
Horses	70	L. Warren, Colorado State University
Feeding on Roughage Diet		
Sheep	65	W. Whitmore, Manitoba Agriculture and Food
Horses	60	L. Warren, Colorado State University

Note:

a. Data source – Expert consultations (Marinier et al., 2004).

Table A3.4–13 **Dry Matter Intake for Selected Livestock**

Animal Category	DMI (kg/head/day)	Data Sources
Sheep and Lambs		
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 [a]	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)

Notes:
Data source – Expert consultations (Marinier et al., 2004).
a. Calculated as 3.5% of body weight.

Manure Ash Content (ASH)

The ash content in the manure is the inorganic portion of the manure. Table A3.4–14 contains the values used in this inventory for ash content in volatile solid calculations and their sources.

Table A3.4–14 **Manure Ash Content for Selected Livestock and Data Sources**

Animal Category	ASH (%)	Data Sources
Cattle	8	IPCC (2000)
Sheep	8	IPCC (2000)
Goats	8	IPCC (2000)
Horses	4	IPCC (2000)
Laying Hens	10	Marinier et al. (2004)
Chickens	7	Marinier et al. (2004)
Turkeys	5	Marinier et al. (2004)
Swine	5	Marinier et al. (2004)
Wild Boars	5	(Taken from Swine)

A3.4.3.2. 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 as m^3/kg VS loaded. The values published in the 2006 IPCC Guidelines were used for all animals. For bison, the values of the Non-Dairy Cattle category were used.

A3.4.3.3. Animal Waste Management System (AWMS) Distribution Factor

The AWMS factor is the proportional distribution of AWMS of a livestock category within a given area. There is little reliable published information on the distribution of manure management systems in Canada.

Anaerobic treatment lagoons and daily spread are not typically used for manure storage in Canada. Though some examples may exist, they cannot be quantified and, for this reason, are currently considered non-significant and are not estimated. The existence of these types of systems was not identified in the expert consultation carried out by Marinier et al. (2004) or across Farm Environmental Management Surveys, which are the sources of AWMS allocation data for Canada. Therefore,

the amount of manure treated by these systems is assumed to be negligible. Earthen storage systems exist in Canada, but in these storage systems, solids are removed regularly when the storage systems are emptied on an annual basis and there is no long-term accumulation and anaerobic treatment of solids in the lagoon, as is the case with "anaerobic treatment lagoons" as defined by the IPCC guidelines.

Dairy

For the Dairy Cattle category, a relationship between farm size and time spent on pasture, in exercise yards and in barns was developed from Sheppard et al. (2011) for each province. The proportion of manure excreted in each of these locations is assumed to be equal to the time spent in each area. Time spent on pasture was found to decrease with increasing farm size, and the fraction of manure deposited on pasture decreased on average from 19% in 1990 to 16% in 2016 due to a shift towards larger farm operations.

For manure deposited in barns, a manure storage time series was developed from a combination of data from the Farm Inputs Management Survey (1995), the Farm Environmental Management Surveys (2001, 2006, 2011) and the Livestock Farm Practices Survey (2005). The use of liquid systems was estimated based on a relationship to farm size, for Eastern and Western Canada respectively, derived from the survey data. Liquid system use increased from 17% in 1990 to 64% in 2011, the most recent survey year, while solid manure is assumed to be inversely related to liquid use. Survey data were used to disaggregate liquid systems into three AWMS sub-systems: earthen basin, tank and slatted floor. A portion of total solid manure is composted, while the remainder is disaggregated into two solid AWMS sub-systems based on survey data: pack and pile. For each liquid subsystem, manure was separated by the presence or absence of crust formation based on data collected from the Livestock Farm Practices Survey compiled in Sheppard et al. (2011a). Lastly, for each liquid and solid subsystem in a given province, manure was further divided based on the use of manure covers during storage.

Swine

For swine, a manure storage time series was developed from a combination of data from the Farm Inputs Management Survey (1995), the Farm Environmental Management Surveys (2001, 2006, 2011) and the Livestock Farm Practices Survey (2005). The use of liquid systems was estimated based on a relationship with farm size and was modelled based on provincial farm sizes from the *Census of Agriculture*. Liquid system use increased from 80% in 1990 to 97% in 2011, the most recent survey year included, while solid manure was assumed to be inversely related to liquid use. Survey data were used to disaggregate liquid systems into three AWMS sub-systems: earthen basin, tank and slatted floor. Solid manure was disaggregated into two solid AWMS sub-systems: Pack and Pile, based on survey data. For each liquid subsystem, manure was separated by the presence or absence of crust formation based on data collected from the Livestock Farm Practices Survey (Sheppard et al., 2010b). Lastly, for each liquid and solid subsystem in a given province, manure was further divided based on the use of manure covers during storage.

All Other Animals

A survey of experts on the topics of 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 A3.4–12. Briefly, among the dominant animal production categories across the country, poultry manure is stored as solid manure, and beef cattle manure is equally distributed between solid storage and deposition on pasture, with the exception of British Columbia and Manitoba, where the majority of manure is deposited on pasture.

For minor livestock categories where the default IPCC Tier 1 methodology is used to estimate manure management CH_4 emissions, AWMS distributions are reported in CRF tables for consistency with reporting of manure management N_2O emissions (see A3.4.4.1), but are not incorporated in the calculations.

A3.4.3.4. 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 were used for all animals, with the exception of poultry. Where a range of temperature dependent MCFs were available, the value for cool climate and average annual temperature of 12ºC was used.

For poultry animals on liquid manure management systems, an MCF that was consistent with all other livestock liquid manure management systems was used, as storage methods for liquid poultry manure in Canada do not differ significantly from storage systems used in dairy or swine production.

For the Dairy Cattle and Swine categories, MCF values from the 2006 IPCC Guidelines were assigned to each AWMS subsystem (section A3.4.3.3). In liquid subsystems, the Liquid/Slurry MCF value of 20% (without crust) or 13% (with crust) was used for Tank and Earthen Basin, while Pit Storage Below Animal Confinements was used for Slatted Floor systems (MCF=20%). For solid subsystems, the Drylot MCF was used for Pack, while the Solid Storage MCF was used for manure heaps. For Dairy Cattle, the Drylot MCF was also used for Exercise Yards. A full list of MCF values by livestock and manure system can be found in Annex 6.4.

Table A3.4–15 **Percentage of Manure Handled by Animal Waste Management Systems (AWMS) for Canada (per Animal Category, Based on the Distribution of Animal Populations in 2019)**

Animal Category	Liquid Systems	Solid Storage and Drylot	Pasture, Range and Paddock	Other Systems
Non-Dairy Cattle	5.3	45	45	4.2
Dairy Cattle	64	18	16	2.9
Poultry	7.0	92	0.6	0.6
Sheep and Lambs	0.1	34	66	0.02
Llamas and Alpacas [a]	0.03	28	72	0.02
Swine	97	3	0	0
Goats	0	42	58	0
Horses	0	31	68	0.7
Bison	0.2	46	50	4.0
Deer and Elk [b]	0	47	50	3.5
Fur-Bearing Animals [c]	0	100	0	0
Mules and Asses [d]	0	32	68	0.7
Wild Boars [c]	0	100	0	0

Notes:

Totals may not add up to 100% due to rounding.

a. Assumes that manure handled by AWMS is the same for llamas and alpacas as for sheep and lambs, at the provincial level.
b. Identical distributions to non-dairy cattle, except that liquid systems are distributed to pasture, range and paddock (PRP).
c. Assumed 100% solid manure.
d. Assumes that manure handled by AWMS is the same for mules and asses as for horses.

Table A3.4–16 **Emission Factors to Estimate CH_4 Emissions from Manure Management for Cattle Subcategories from 1990 to 2019**

	$EF_{(MM)T}$ (kg CH_4/head/year)							
Year	Dairy Cows	Dairy Heifers [a]	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter [b]	Steers [b]	Calves
1990	13	8	4.5	4.1	3.2	1.9	1.8	2.2
1995	15	9	4.7	4.3	3.2	2.0	1.9	2.1
2000	20	11	4.7	4.5	3.3	2.1	1.9	2.3
2005	26	12	4.6	4.3	3.1	2.1	1.9	2.4
2010	33	15	5.0	4.4	3.1	2.1	2.0	2.8
2011	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2012	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2013	36	16	4.5	4.3	3.1	2.1	2.0	2.8
2014	36	17	4.7	4.4	3.1	2.1	2.0	2.9
2015	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2016	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2017	38	17	5.0	4.5	3.2	2.1	2.0	2.9
2018	38	17	4.8	4.5	3.2	2.2	2.0	3.0
2019	39	17	4.8	4.5	3.2	2.2	2.0	3.0

Notes:

a. For dairy heifers, emission factors were estimated using B_0, MCF and manure management systems for dairy cows.
b. Reported as kg/head/year, but emissions are calculated based on time to slaughter.

A3.4.3.5. Cattle Manure Management CH_4 Emission Factors

Cattle emission factors that are developed to calculate CH_4 emissions from manure management systems vary by animal subcategory and over time (Table A3.4–16). 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 (1) the increase in milk productivity of dairy cows, (2) the variation in overall methane conversion rates as impacted by changes to manure storage practices, and (3) the change in live weight of beef cattle as explained in sections A3.4.1, A3.4.3.4 and A3.4.1.1, respectively. Emission factors are highest from dairy cattle, reflecting their high rates of confinement, use of liquid manure management systems and high dietary intake for sustained milk production. Dairy emission factors have

more than doubled since 1990 due to the increasing use of liquid manure management systems. 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.

A3.4.3.6. Swine Manure Management CH_4 Emission Factors

Swine emission factors are developed to calculate CH_4 emissions from manure management systems and vary by animal subcategory and over time (Table A3.4–17).

A provincial emission factor time series was derived for swine to reflect (1) the variation in overall methane conversion rates as impacted by changes to manure storage practices, and (2) changes in the growth rates and live weights of market swine by weight class, as explained in sections A3.4.3.4 and A3.4.1.2, respectively. The swine emission factor is first calculated using VS derived from Marinier et al. (2004), and incorporating the latest scientific information available on B_0 and MCF taken from the 2006 IPCC Guidelines (IPCC, 2006). The annual VS excretion rates are then recalculated using animal mass from the Marinier survey year, and expressed as VS per 1000 kg animal mass. Lastly, VS is scaled over time using the swine TAM time series.

Emission factors for pigs in the low-weight and middleweight classes decrease slightly over time due to increases in the rate of weight gain and increases in the methane conversion factor. In contrast, a steady increase in the upper-weight class emission factor reflects increases in live weight. A small decrease in the emission factor for sows over time is the result of proportional changes to provincial animal populations, leading to an overall decrease in VS.

A3.4.3.7. Manure Management CH_4 Emission Factors for All Other Livestock

Manure management system emission factors for animals other than swine and cattle vary by animal subcategory but are constant over time (Table A3.4–18). For the largest other animal categories—sheep and poultry—growth stages for animals are taken into account. Emission factors for sheep, lambs, goat, horses, bison, llamas and alpacas, and poultry are calculated using the 2006 IPCC Tier 2 methodology. Volatile solids are derived from Marinier et al. (2004); however, since this report was based on the 2000 IPCC Guidelines, the emission factors were recalculated to incorporate the latest scientific information available on B_0 and MCF taken from the 2006 IPCC Guidelines (IPCC, 2006). Proxies are used for very minor livestock categories that account for less than 0.2% of total agricultural emissions, as described in A3.4.3.

Emission factors for other minor categories tend to be low due to the large portion of manure that is deposited either on pasture, range or paddock or in solid form in pens and holding yards. Default Tier 1 IPCC emission factors from Table 10.15 of Chapter 10 of the 2006 IPCC guidelines are used for deer and elk, foxes, mink, rabbits, and mules and asses, and represent less than 0.1% of total agricultural emissions.

Table A3.4–17 **Emission Factors to Estimate CH_4 Emissions from Manure Management for Swine Subcategories from 1990 to 2019**

	$EF_{(MM)T}$ (kg CH_4/head/year)				
Year	Boars	Sows	Pigs (< 20 kg)	Pigs (20-60 kg)	Pigs (> 60 kg)
1990	7.0	7.3	2.1	4.5	8.2
1995	7.0	7.2	2.1	4.5	8.3
2000	7.0	7.2	2.1	4.4	8.5
2005	7.0	7.1	2.1	4.4	8.5
2010	7.0	7.0	2.1	4.3	8.6
2011	7.0	7.0	2.1	4.3	8.7
2012	7.0	7.0	2.1	4.3	8.8
2013	7.0	7.0	2.1	4.3	8.8
2014	7.0	7.0	2.1	4.3	8.9
2015	7.0	7.0	2.1	4.3	8.9
2016	7.0	7.0	2.1	4.3	9.0
2017	7.0	7.0	2.1	4.2	9.0
2018	7.0	7.0	2.1	4.2	9.0
2019	7.0	7.0	2.1	4.2	9.2

Table A3.4–18 **2019 CH_4 Emission Factors for Manure Management for All Other Livestock**

Non-Cattle Animal Categories	Manure Management Emission Factors $EF_{(MM)}$ (kg CH_4/head/year)
Other Livestock	
Sheep	0.33
Lambs	0.22
Goats	0.32
Horses	2.6
Bison	2.1
Elk and Deer	0.22
Wild Boars [a]	0.56
Foxes	0.68
Mink	0.68
Rabbits	0.08
Mules and Asses	0.76
Poultry	
Chickens	0.03
Hens	0.12
Turkeys	0.10

Note:

a. Emission factor based on swine VS, assuming 100% solid manure.

A3.4.3.8. Verification of Parameter Selection Against Canadian Research

The Manure Management source category was a part of a Tier 2 QA/QC for the Agriculture sector for the 2011 submission (MacDonald and Liang, 2011), including a review and compilation of Canadian literature related to methane production from manure storage.

Few studies have measured emissions from manure storage or quantified the characteristics of manure and manure storage strategies that influence emissions in Canada. Observed emission factors are highly variable, as are measurement techniques. The methodological variability makes comparison of specific parameters used in Tier 2 calculations extremely difficult. When the liquid storage MCF was estimated from *in-situ* measurements, it varied from greater than 100% (suggesting that B_0 is also underestimated) 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., 2005; Xu et al., 2007; Hao, 2007; Hao et al., 2001b, 2008, 2009, 2010a, 2010b). As was the case with liquid manure systems, variability in emissions and methodology makes comparisons to IPCC parameters difficult.

Godbout et al. (2010) carried out an analysis on a small sample set from Eastern Canadian farms and suggested that the B_0 values for Swine, Non-Dairy Cattle and Dairy Cattle category livestock were 0.47–0.42, 0.21–0.19 and 0.35–0.30 m^3 CH_4 kg^{-1} VS, respectively. The values for Non-Dairy Cattle and Swine are consistent with IPCC default values, though dairy manure is the exception, with observed B_0 being 50% higher than the default value. In VanderZaag et al. (2018) B_0 for raw manure from two dairy farms was found to be 0.248 (SD=2) and 0.247 (SD=6). Further analyses of B_0 are required for a wider range of regions and production practices.

Quantities of volatile solids stored in the manure management systems for different animal categories tend to be consistent with quantities estimated in inventory calculations. The variability observed in studies is therefore likely linked to a combination of differences in measurement methodology, variability in manure characteristics (B_0) and differences 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., 2005; 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 is required in order to understand the relative weight of factors that influence emissions from manure storage and to refine estimation methodology.

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

Desjardins et al. (2018) measured CH_4 flux for full farm systems, including emissions from both manure management and enteric fermentation processes using an aircraft-based platform and compared top-down estimates with a bottom-up footprint adjusted inventory estimate of emissions for an agricultural region in eastern Ontario, Canada. They concluded that when a wetland area in the flux footprint was less than 10%, the top-down and bottom-up estimates were within the measurement error. They noted, however, that top-down CH_4 fluxes significantly over-estimated methane emissions when contributions from wetlands were not considered in the potential sources. Fine-scale mapping of wetlands was required to effectively quantify natural methane emission sources. Where estimates from the two methods were inconsistent, the discrepancy was related to both increasing fractional area of wetlands in the flux footprint and increasing surface temperature.

A3.4.3.9. Uncertainty in Manure Management CH_4 Emissions

Methane emissions from manure management systems were included in the comprehensive uncertainty analysis discussed in section A3.4.2.4. As was the case with the enteric fermentation process, the analysis built on the recent study by Karimi-Zindashty et al. (2012) and applied a precautionary principle such that for parameters with very little information, probability distributions were intentionally conservative (Table A3.4–19). Data on the probability distributions of the coefficients used in the agricultural manure management IPCC Tier 2 models are scarce, and expert opinions were the main source of probability distributions, particularly those compiled in the Marinier et al. (2004) report. As was the case with the method for enteric fermentation, the relative uncertainty for the 2012 analysis was applied to the current year and no new uncertainty analysis was carried out for the changes to the model for dairy cattle livestock.

Population uncertainty for major animal categories was identical to that discussed in section A3.4.2.3, and the distributions used to define uncertainties can be found in Table A3.4–9.

The parameters used in the calculation of Tier 2 manure management system emission factors for all animals can be divided into two categories: those associated with volatile solid calculation and those specific to the calculation of IPCC Tier 2 emission factors. The confidence intervals assigned to coefficients used in the calculation of volatile solids were relatively small compared to parameters used in the calculation of emission factors. With the exception of the ash content of manure, parameters tend to be under 10%, largely because parameters such as DMI and DE% are values with which producers are very familiar and which can provide some degree of confidence. In the case of cattle, volatile solids vary according to the gross energy (GE) of consumption and are subsequently similar in variability to the enteric fermentation emission factor (±19%).

The probability distributions for coefficients used in IPCC Tier 2 equations used to calculate the emission factors were taken, for the most part, directly from Karimi-Zindashty et al. (2012), who derived the distributions either from expert opinion within the Marinier et al. (2004) report or directly from the 2006 IPCC Guidelines. The uncertainty for B_0 was taken from Marinier et al. (2004), but no reliable source was available for the estimate of

Table A3.4–19 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used in Estimating Methane Emissions from Manure Management**

Parameter Category	Parameter/Animal Category or Subcategory	Distribution Type	Uncertainty Range		Spatial Allocation/Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[a]		
Volatile Solid Calculations (Equation A3.4–6 and A3.4–7)						
Dry Matter Intake (DMI)						
- Swine		Triangular			National/Subcategory	Marinier et al. (2004)
	Boars		1.2–3.4	2.28		
	Sows		2.0–2.5	2.25		
	Pigs < 20 kg		0.55–0.72	0.68		
	Pigs 20–60 kg		0.63–2.1	1.75		
	Pigs > 60 kg		2.1–3.3	2.7		
- Poultry						
	Laying hens		7.4–9.9	9.85		
	Broilers		0.085–0.088	0.086		
	Turkeys		0.23–0.53	0.27		
- Other livestock						
	Sheep		1.2–3.0	2		
	Lambs		1.2–1.6	1.35		
	Goats		1.4–2.3	1.75		
	Horses		7.4–9.9	9.85		
	Buffalo		6.8–10.1	8.43		
Ash						
- Cattle		Triangular	3.9–11	8	National/Category[b]	Marinier et al. (2004)
- Swine			3.9–11	4.8–5.1		
- Poultry	Laying hens		3.9–11	10		
	Broilers		3.9–11	7		
	Turkeys		3.9–11	5		
- Other livestock						
	Sheep		3.9–11	8		
	Lambs		3.9–11	8		
	Goats		3.9–11	8		
	Horses		3.9–11	4		
	Buffalo		3.9–11	8		

Table A3.4–19 **Uncertainties in Inputs, Sources of Uncertainty and the Spatial Scale and Animal Category to Which Uncertainty is Assigned, for Parameters Used in Estimating Methane Emissions from Manure Management** (cont'd)

Parameter Category	Parameter/Animal Category or Subcategory	Distribution Type	Uncertainty Range		Spatial Allocation/Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[a]		
Digestible Energy (DE)						
-Cattle		Normal	Pasture ±9%/ Confined ±9% /Background ±7.5%/Prepared feed ±5.5%		Provincial/Production subcategory	Derived from raw data supplied by Valacta Dairy Services
-Swine			±9%		Provincial/Category	
-Poultry	Laying hens		±5.5%		National/Subcategory	
	Broilers					
	Turkeys					
-Other livestock						
	Sheep		±9%		Provincial/Category	
	Lambs				Provincial/Category	
	Goats				Provincial/Category	
	Horses				Provincial/Category	
	Buffalo				Provincial/Category	
Emission Factor Calculation (Equation A3.4–5)						
Methane Conversion Factor (MCF)						
	All Animals	Normal	±45%		National	Karimi-Zindashty et al. (2012) – expert opinion
Maximum Methane Producing Potential (B_0)						
	Dairy cattle	Triangular	0.1–0.24	0.24	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
	Non-dairy cattle		0.19–0.33	0.19		
	Swine		0.32–0.48	0.48		
	Poultry		0.24–0.39	0.32		
	Sheep and lambs		0.19–0.36	0.19		
	Goats		0.15–0.19	0.18		
	Horses		0.30–0.36	0.3		
	Buffalo		0.19–0.33	0.19		
Animal Waste Management Systems (MS)[d]						
	Dairy cattle	Triangular	LB: MLV-10% UB: MLV+25%	MLV from Marinier et al. (2005)	Provincial/Category	Expert opinion, bounds based on interpretation of multiple data sources
	Swine		LB: MLV-10% UB: 100%	MLV from Marinier et al. (2005)		Internally correlated variable[c] Liquid systems allowed to vary to non-symmetric triangular distributions
	Non-dairy cattle	Normal	±17%			Marinier et al. (2005). Internally correlated variable[c]
	Poultry					
	Sheep and lambs					
	Goats					
	Horses					
	Buffalo					

Notes:

MLV = most likely value; LB = lower bound; UB = upper bound

a. Most likely value when triangular distribution, normal distributions given as simple ±%.
b. Ash for swine varies among some provinces.
c. Internal correlation indicates values that vary in terms of a fraction of the whole, i.e., a fraction of a total equalling 100%.
d. Values that vary independently during trend analysis.

uncertainty around the MCF. In the current study, a large uncertainty range was used (±45% of the mean) based on expert opinions. However, the choice of this value simply indicates that our confidence in the MCF value is low. The actual value of the total uncertainty estimate for manure management systems must therefore be taken within the context that it is highly dependent on a value and a probability distribution function that is highly uncertain.

In contrast with the Karimi-Zindashty (2012) study, the current analysis was based on a provincial distribution of manure management systems, and uncertainty ranges were estimated from values observed in different provincial and national reports (Koroluk and Bourque, 2003; BPR-Infrastructure, 2008) and surveys (Sheppard et al., 2009, 2010, 2011; Sheppard and Bittman, 2011). In the case of dairy cattle livestock, the lower bound

for liquid manure management systems was based on a comparison between reports that suggested that manure treated by liquid systems could vary by as much as 10% above or below the Marinier et al. (2005) estimate. Furthermore, it was reported that there has been a continual movement towards liquid manure systems over time. Therefore, the upper bound was set as 25% based on the rate of adoption of liquid systems from BPR-Infrastructure (2008) and the number of years that have passed since the survey by Marinier et al. (2005). In the case of swine animals, liquid manure management systems' upper bounds were fixed at 100%. Other manure management systems' lower bounds for all animal types were 0, also tending to skew probability distributions. This approach resulted in non-symmetrical distributions for all manure management systems. While this approach increased the uncertainty of each individual manure management system, relative to the Karimi-Zindashty study, it likely reduced its impact on the national emission uncertainty because the manure systems were disaggregated to the provincial level, and the total manure management systems were held to 100% of total manure management systems.

The trend analysis carried out using the ECSM quantified the uncertainty in the magnitude of the change in emissions over time for manure management systems. As was the case for the enteric fermentation method, for the long-term trend, emissions for 1990 and 2013 were calculated simultaneously, allowing only time-dependent parameters to vary independently in the estimates. A more detailed description of the trend analysis is found in section A3.4.2.4. The parameters that were allowed to vary independently for the manure management system trend analysis were animal populations, milk production and fat content in dairy cattle animals, body weights in beef cattle and AWMS (noted by a superscript g in Table A3.4–9 and superscript e in Table A3.4–19). Before 2004, lower boundaries for liquid AWMS were calculated based on the rate of adoption of liquid systems and the number of years that have passed since the survey by Marinier et al. (2005), as in the case of upper boundaries. This approach resulted in non-symmetrical distributions for all manure management systems; and for the trend analysis, it also modified the symmetry of probability distributions around liquid systems between the base year and the current year. Trend uncertainty for the 2018 inventory was based on the 2012 trend analysis.

The summary of results of the uncertainty analysis on emissions reported under Manure Management is reported in Chapter 5. Briefly, the uncertainty range used to derive the uncertainty reported in Chapter 5 for the 2014 emissions from manure management is 60% (-32% to +27% of the mean). As was the case with the enteric fermentation results, emission factors account for the majority of uncertainty. Emission factors lie within an uncertainty range of -34% to +62% for the Non-Dairy Cattle category and a range of -60% to +50% for Dairy Cattle. The emission factors for the Swine category, the largest single contributor to manure management emissions, lie within an uncertainty range of -51% to +43%. All other animals contribute little to the emission totals, i.e., 0.19 Mt CO_2 eq within an uncertainty range of 0.13 (-35% of the mean) to 0.23 (+15% of the mean). Overall, as was the case with enteric fermentation results, mean emissions for both the Dairy Cattle and Non-Dairy Cattle categories estimated using the stochastic model are slightly higher than those calculated from non-stochastic models and tend to be slightly skewed towards the lower boundary, indicating a tendency towards higher emissions. However, mean emissions from swine and other animals estimated using the stochastic model are slightly lower than emissions estimates, and the distribution of emission estimates tends to be slightly skewed towards the upper boundary, indicating a tendency towards lower emissions. This skewed distribution is evident when looking at the range of uncertainty around the emission factors (e.g. 34% to +62% for Non-Dairy Cattle). The asymmetry of the uncertainty range is likely due to a combination of the skewed probability distributions for manure management systems and the same factors that influenced the distribution of enteric fermentation emission estimates for cattle, specifically the skewed distributions for backgrounding of slaughter animals and the uniform distribution used for net energy mobilized from weight loss during lactation in Dairy Cattle.

Based on the trend analysis, there has been no detectable increase in emissions from manure management since 1990, where change from 1990 could range from a decrease of 10% to an increase of 8%, though it is most likely that there has been an increase in emissions of roughly 5.5%. The assumption that liquid manure storage and other manure storages have increased over time affects the trend. For example, for dairy cattle livestock in Ontario in 1990, the triangular distribution used around the percentage of manure treated in liquid manure management systems had a lower boundary of 16%, a most likely value of 40% and an upper boundary of 42%; in 2010, the lower boundary was 37%, the most likely value was 40% and the upper boundary 59%. The use of a skewed distribution indicating a higher probability that fewer animals were raised on liquid manure management systems in the past balances the increase in animal populations. As a result, it is improbable overall that there is an increase in manure management emissions over time, particularly from cattle.

The uncertainty range of the analysis carried out in 2012 was slightly smaller than that of the previous analysis (2%), likely due to a combination of lower uncertainty for census animal populations and modifications in the uncertainty bounds around AWMS systems with the addition of two years from the time of the original survey. Overall, the uncertainty range around manure management emissions produced by this analysis is slightly smaller than the data reported by Karimi-Zindashty et al. (2012), as the proportions of manure treated by different manure management systems were distributed to the provincial level in this analysis, whereas a national average was used in

the 2012 publication. Monni et al. (2007) estimated CH_4 manure management emission factor uncertainty to be roughly ±30% based strictly on expert opinion. As was the case with enteric fermentation, Karimi-Zindashty et al. (2012) demonstrated that most uncertainty in the manure management model is associated with the use of default IPCC model parameters that are applied at the national level, specifically the MCF. By deriving MCF factors for different regions and different storage structures, uncertainty would be significantly reduced. Further work on uncertainty will focus on the development of trend uncertainty and the refinement of probability distributions around country-specific parameters already existing in the model. As the MCF factor is driving uncertainty for the Manure Management category, it is not suspected that changes to the dairy or swine models would have a large impact on the national manure management uncertainty. However, the introduction of a time series of AWMS for the Dairy and Swine sectors may play an important role in influencing the trend uncertainty for manure management system emissions.

A3.4.4. N_2O Emissions from Manure Management

N_2O emissions from manure management systems result from mineralization of organic materials, and the nitrification and denitrification of mineral nitrogen directly and indirectly.

A3.4.4.1. Direct N_2O Emissions from Manure Management

Three factors are required to estimate N_2O emissions from manure management systems using the IPCC Tier 1 method: (1) N excretion rates for various animal categories and subcategories, (2) types of AWMS and (3) emission factors associated with manure management systems.

As previously described in section A3.4.3, default emission factors or country-specific information sources are sometimes used for minor livestock categories as logical proxies based on species similarities when no other information is available. The following proxies and expert judgement are used in the calculation of N_2O emissions, in addition to those already listed in A3.4.3:

- The nitrogen excretion rate for Swine is used to represent wild boars.
- The nitrogen excretion rate for Sheep is used to represent lambs, as well as llamas and alpacas.
- The nitrogen excretion rate for Buffalo is used to represent bison.
- The nitrogen excretion rate for Other Cattle is used to represent Deer and Elk.

Nitrogen Excretion Rates for Various Domestic Animals

For the Dairy Cattle category, the Tier 2 methodology from the 2006 IPCC guidelines is used. Nitrogen intake from feed has increased steadily since 1990 in order to meet the protein requirements of increased milk production (Table A3.4–4) and, as a result, a corresponding increase in dairy cow N excretion rates (Table A3.4–20) was calculated.

For the Non-Dairy Cattle category, annual live weights (see section A3.4.1.1) were multiplied by the IPCC default N excretion rate (IPCC, 2006) to produce a time series of manure N excretion rates (Table A3.4–20).

For the Swine category, distinct parameters were used to estimate N excretion from subcategories of breeding animals and market animals. In the case of market

Table A3.4–20 **Time Series of Manure N Excretion Rates for Cattle (kg N/head/year)**

	(kg N/head/year)							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter [a]	Steers [a]	Calves
1990	107	72	88	58	45	45	48	27
1995	110	72	99	65	50	55	57	27
2000	114	73	103	70	54	60	61	27
2005	116	73	102	68	52	61	61	26
2010	123	76	113	69	53	62	63	27
2011	122	76	112	69	53	62	64	27
2012	122	76	114	69	53	65	65	27
2013	126	76	99	69	53	64	65	27
2014	125	76	103	70	53	63	64	27
2015	123	76	111	74	56	65	66	27
2016	123	76	112	75	58	66	67	27
2017	121	76	114	75	57	65	66	26
2018	122	76	108	75	57	65	67	26
2019	122	76	107	74	57	66	68	26

Notes:

N excretion rate for non-dairy cattle is 0.31 kg N-1000 kg^{-1}-day^{-1} (IPCC, 2006, Table 10.19). Data source – IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

a. Values are adjusted for the life-span of slaughter animals.

swine, increases in growth rates and live weights were used to develop a country-specific time series of animal mass per production stage, which was multiplied by an N excretion rate derived from Table 10.19 in the 2006 IPCC guidelines. For breeding animals, the IPCC default N excretion rate was multiplied by the IPCC default animal mass.

Annual manure N excretion rates for all other types of animals vary by livestock category according to IPCC Tier 1 default values (IPCC, 2006). Poultry have high excretion rates (Table A3.4–22), while horses and bison have the lowest excretion rates. However, on a per-head basis, bison have the highest N excretion rates due to their size. Tier 1 default values for fur-bearing animals and rabbits have exceptionally high excretion rates relative to their size (Table A3.4–22), but are understood to be based on breeding stock and attribute all manure produced on the farm to the breeding stock.

Table A3.4–21 **Time Series of Manure N Excretion Rates for Swine (kg N/head/year)**

	(kg N/head/year)				
Year	Sows	Boars	Pigs (<20 kg)	Pigs (20–60 kg)	Pigs (>60 kg)
1990	17	17	1.6	7.3	15.0
1995	17	17	1.7	7.3	15.2
2000	17	17	1.7	7.3	15.6
2005	17	17	1.7	7.2	15.7
2010	17	17	1.7	7.2	16.2
2011	17	17	1.7	7.1	16.2
2012	17	17	1.7	7.1	16.4
2013	17	17	1.7	7.1	16.5
2014	17	17	1.7	7.2	16.6
2015	17	17	1.7	7.1	16.7
2016	17	17	1.7	7.1	16.9
2017	17	17	1.7	7.1	16.9
2018	17	17	1.7	7.0	17.0
2019	17	17	1.7	7.1	17.2

Notes:

N excretion rate for breeding swine is 0.24 kg N-1000 kg^{-1}-day^{-1} (IPCC, 2006, Table 10.19). Data source – IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

N excretion rate for market swine is 0.53 kg N-1000 kg^{-1}-day^{-1} and was calculated based on market value of 0.24, overall swine excretion of 0.50, and weighting proportion indicated in the footnote of Table 10.19. Data source – IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

Table A3.4–22 **Manure N Excretion Rates for All Other Animals**

Animal Categories	N Excretion Rate [a] (kg N/1000 kg/day)	Average Body Weight [b] (kg)	Annual Manure N (kg N/head/year)
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
Bison	0.32	580	67.7
Hens	0.83	1.8	0.5
Broilers	1.1	0.9	0.4
Turkeys	0.74	6.8	1.8
Elk and Deer	0.31	120	13.6
Wild Boars [c]	0.5	61	11.1
Foxes	12.1	1.8	7.9
Mink	4.6	1.8	3.0
Rabbits	8.1	1.6	4.7
Mules and Asses	0.3	245	26.8

Notes:

a. Data source – IPCC (2006).

b. For buffalo, average live weight was taken from the U.S. NIR.

c. Equivalent to overall swine excretion rate of 0.50 kg N-1000 kg^{-1}-day^{-1} (IPCC, 2006, Table 10.19). Data source – IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Use.

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 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 6, were used to estimate emissions. For livestock from the Dairy and Swine sectors, weighted N_2O emission factors are calculated using the proportion of manure in each AWMS subsystem (see section A3.4.3.3) and the corresponding default emission factors (Annex 6), to produce a time series of N_2O emission factors by AWMS.

Table A3.4–15 summarizes the distribution of manure management systems in Canada by animal category. N_2O emissions from manure on pasture, range and paddock systems are not included under the Manure Management category, as they are reported under the Agricultural Soils category (section A3.4.5.1). Animal population data are detailed in section A3.4.1.

Direct N_2O emissions from manure management are estimated using the IPCC Tier-1 method (Equation A3.4–9), as follows:

Equation A3.4–9

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

$N_2O_{D(mm)}$	=	emissions for all AWMS and livestock categories, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/year
$N_{i,T}$	=	population for the T^{th} animal category or subcategory in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3.4–15)
$N_{EX,T}$	=	N excretion rate for the T^{th} animal category or subcategory (see Table A3.4–20 for cattle and Table A3.4–22 for non-cattle), kg N/head/year
EF_{AWMS}	=	N_2O emission factors from manure management for each specific AWMS (see Annex 6), kg N_2O-N/kg N
$44/28$	=	coefficient converting N_2O-N to N_2O

A3.4.4.2. Indirect N_2O Emissions from Manure Management

During animal manure storage and handling, losses of N occur through the following indirect pathways: (1) volatilization of manure N as NH_3 and NO_x and subsequent re-deposition and (2) leaching and runoff of N. Leaching is estimated only for the Dairy and Swine sectors, where country-specific information on the fraction of nitrogen loss due to leaching and runoff was available. These losses of manure N can result in N_2O emissions (Equation A3.4–10 and Equation A3.4–11).

In the case of the Dairy and Swine sectors, the introduction of a manure management time series that considered a wider variety of manure storage conditions results in changes in the fraction of manure N that is lost over the reporting period (Table A3.4–23). A shift from solid manure storage to liquid, an increase in the number of covered manure storage systems and, in the case of the Dairy sector, a shift in time in pasture, resulted in a decrease in the proportion of total N lost to the environment over time.

Equation A3.4–10

$$N_2O_{G(mm)} = \sum_i \sum_{AWMS} \left(N_{i,T} \times N_{i,AWMS} \times N_{EX,T} \times Frac_{GasMS(T,AWMS)}\right) \times EF_4 \times \frac{44}{28}$$

$N_2O_{G(mm)}$	=	indirect N_2O emissions due to NH_3 volatilization for managed manure, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/year
$N_{i,T}$	=	population for livestock category or subcategory, T in province i
$N_{i,AWMS}$	=	percentage of manure N handled by each AWMS in province i, fraction (see Table A3.4–15)
$N_{EX,T}$	=	N excretion rate for livestock category or subcategory, T (see Table A3.4–20 for cattle and Table A3.4–22 for non-cattle), kg N/head/year
$Frac_{GasMS(T,AWMS)}$	=	fraction of managed manure N for livestock category, T that volatilizes as NH_3 and NO_x in the manure management system, AWMS (see Table A3.4–23 and Table A3.4–24)
EF_4	=	emission factor from atmospheric deposition of N, 0.01 kg N_2O-N/(kg NH_3-N + NO_x-N volatilized) (IPCC, 2006)
$44/28$	=	coefficient converting N_2O-N to N_2O

Table A3.4–23 **Total N, NH_3- and NO_x-N Losses Associated with Various Livestock and Manure Management Systems**

Animal Category	Manure Management Systems	$Frac_{(LossMS)}$ (%) [a]	NH_3-N and NO_x-N Loss (%) [a, b, c] ($FRAC_{GasMS}$)
Non-Dairy Cattle	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	40 (20–50)	30 (20–50)
	Pasture and Range	-	20 (5–50)
Sheep, Lamb, Llamas and Alpacas	Solid Storage	15 (5–20)	12 (5–20)
	Pasture and Range	-	20 (5–50)
Goat and Horse	Solid Storage	15 (5–20)	12 (5–20)
	Pasture and Range	-	20 (5–50)
Elk and Deer	Solid Storage	15 (5–20)	12 (5–20)
Wild Boars	Solid Storage	15 (5–20)	12 (5–20)
Foxes	Solid Storage	15 (5–20)	12 (5–20)
Mink	Solid Storage	15 (5–20)	12 (5–20)
Rabbits	Solid Storage	15 (5–20)	12 (5–20)
Mules and Asses	Solid Storage	15 (5–20)	12 (5–20)
Poultry	Liquid	50	50
	Solid Storage	53 (20–80)	48 (10–60)
	Pasture and Range	-	20 (5–50)

Notes:

a. Numbers in parentheses indicate a range.

b. Data sources: Hutchings et al. (2001); U.S. EPA (2004); Rotz (2004).

c. Leaching loss from pasture, range and paddock is reported under indirect N_2O emissions from agricultural soils and is calculated using the same parameters as manure N spread to agricultural soils.

Equation A3.4–11

$$N_2O_{L(mm)} = \sum_i \sum_{AWMS} \left(N_{i,T} \times N_{i,AWMS} \times N_{EX,T} \times Frac_{LeachMS(T,AWMS)}\right) \times EF_5 \times \frac{44}{28}$$

$N_2O_{L(mm)}$ = indirect N_2O emissions due to leaching and runoff from managed manure, excluding emissions from urine and dung deposited on pasture, range and paddock, kg N_2O/year

$N_{i,T}$ = population for livestock category or subcategory, T in province i

$N_{i,AWMS}$ = percentage of manure N handled by each AWMS in province i, fraction (see Table A3.4–15)

$N_{EX,T}$ = N excretion rate for livestock category or subcategory, T (see Table A3.4–20 for cattle, Table A3.4–21 for swine, and Table A3.4–22 for all other livestock), kg N/head/year

$Frac_{LeachMS(T,AWMS)}$ = fraction of managed manure N losses for dairy (see Table A3.4–24) and swine (see Table A3.4–25) and other livestock (see Table A3.4–23) for livestock category T due to leaching and runoff during solid and liquid storage of manure, AWMS

EF_5 = emission factor from N leaching and runoff, 0.0075 kg N_2O-N/(kg N leaching/runoff) (IPCC, 2006)

$44/28$ = coefficient converting N_2O-N to N_2O

Table A3.4–24 **Total N, NH_3- and NO_x-N Losses Associated with Dairy Cattle and Manure Management Systems**

	$Frac_{(LossMS)}$ (%)			Leaching Loss (%) ($Frac_{LeachMS}$)			NH_3-N and NO_x-N Loss (%) ($Frac_{GasMS}$)		
Year	Liquid	Solid	Other [a]	Liquid	Solid	Other	Liquid	Solid	Other
1990	12	23	0	0	3	0	11	16	0
1995	12	23	0	0	3	0	11	16	0
2000	13	23	0	0	3	0	11	16	0
2005	13	23	37	0	3	7	12	16	23
2010	10	23	35	0	3	5	9	17	24
2011	10	23	35	0	3	5	8	17	24
2012	10	23	35	0	3	5	8	17	24
2013	10	23	35	0	3	5	8	17	24
2014	10	23	35	0	3	5	8	17	24
2015	10	23	35	0	3	5	8	17	24
2016	10	23	35	0	3	5	8	17	24
2017	10	23	35	0	3	5	8	17	24
2018	10	23	35	0	3	5	8	17	24
2019	10	23	35	0	3	5	8	17	24

Note:

a. Other in the case of Dairy Cattle refers only to composting of solid manures.

Table A3.4–25 **Total N, NH_3- and NO_x-N Losses Associated with Swine Manure Management Systems**

	$Frac_{(LossMS)}$ (%)		Leaching Loss (%) ($Frac_{LeachMS}$)		NH_3-N and NO_x-N Loss (%) ($Frac_{GasMS}$)	
Year	Liquid	Solid	Liquid	Solid	Liquid	Solid
1990	23	31	0	3.3	21	23
1995	23	31	0	3.3	21	23
2000	23	31	0	3.4	21	23
2005	23	31	0	3.3	21	23
2010	20	30	0	3.1	19	23
2011	19	30	0	3.0	18	23
2012	20	30	0	3.0	18	23
2013	20	30	0	3.0	18	23
2014	20	30	0	2.9	18	23
2015	20	30	0	2.9	18	23
2016	20	30	0	2.9	18	23
2017	20	30	0	2.9	18	23
2018	20	30	0	2.9	18	23
2019	20	30	0	2.9	18	23

A3.4.5. N_2O Emissions from Agricultural Soils

Emissions of N_2O from agricultural soils consist of direct and indirect emissions. N_2O emissions 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 (1) volatilization of inorganic N fertilizers and manure N as NH_3 and NO_x and subsequent deposition, and (2) leaching and runoff of N.

Nitrogen is allocated to the landscape according to the following procedure: (1) region-specific N application rates are calculated for each crop type; (2) a "recommended" amount of nitrogen is allocated to each of 405 ecodistricts in Canada based on the application rate and the area of each crop type within the ecodistrict; (3) the total amount of manure N available to be applied to agricultural soils is calculated based on the population of livestock within the ecodistrict; (4) biosolids are applied to select crop types according to remaining "recommended" N, after subtracting the available manure N from step 3; (5) Manure N is applied to crops in each ecodistrict, according to remaining crop requirements following biosolids application; (6) the amount of organic N applied (manure + biosolids) is subtracted from the initial "recommended" amount to calculate the amount of "theoretical" crop N requirements not met by organic sources alone; and (7) the amount of "theoretical" N is scaled to match total provincial fertilizer sales reported by Statistics Canada, and this corrected amount represents inorganic N fertilizer applied to each ecodistrict.

A3.4.5.1. Direct N_2O Emissions from Agricultural Soils

Direct sources of emissions from agricultural soils include inorganic N fertilizers, organic N fertilizers, urine and dung deposited on pasture, range and paddock by grazing animals, crop residues, mineralization associated with loss of soil organic matter and cultivation of organic soils. Tillage practices, summerfallow and irrigation can also influence soil N_2O emissions. 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 emission (Rochette et al., 2008).

The approach involves determining base emission factors "EF_{BASE}" for each of 405 ecodistricts,[21] using long-term growing season 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 A3.4–12).

Equation A3.4–12

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

EF_{BASE}	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kgN^{-1} yr^{-1}
EF_{CT}	=	emission factor, estimated at actual P/PE in an ecodistrict, kg N_2O-N kgN^{-1} (see Figure A3.4–3)
$EF_{CT,\,P/PE=1}$	=	emission factor of 0.017 estimated at P/PE = 1, kg N_2O-N kgN^{-1}
F_{TOPO}	=	fraction of the ecodistrict area in the lower section of the toposequence—see Rochette et al. (2008)
P	=	long-term mean precipitation from May to October in an ecodistrict, mm
PE	=	long-term mean potential evapotranspiration from May to October, mm

Base N_2O Emission Factor (EF_{BASE})

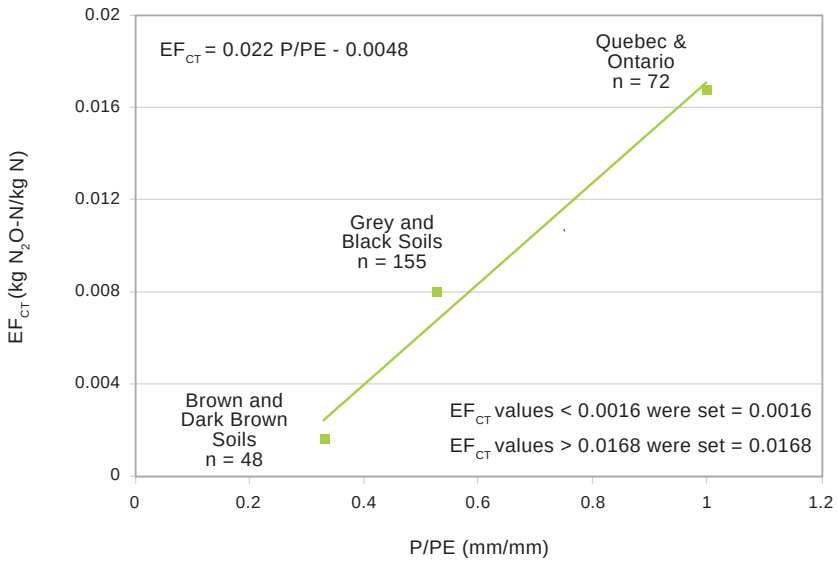
Nitrous oxide is produced mainly during denitrification and is therefore greatly influenced by soil oxygen status. Accordingly, in moisture-limited conditions, N_2O emission factors have been shown to increase with increased rainfall (Dobbie et al., 1999) and climate-variable emission factors have been used in estimating soil N_2O 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 A3.4–4). 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_2O emissions versus N fertilizer rate" relationship. The EF_{BASE} was estimated for the three regions where field N_2O 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_2O emissions versus fertilizer N relationship determined for the Quebec-Ontario region has a similar slope (0.012 kg N_2O-N kgN^{-1}) (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 Prairies region, low and variable N_2O emissions were measured across the range of N fertilizer rates (Brown and Dark Brown soils = 0.0016 kg N_2O-N kgN^{-1}; Grey and Black soils = 0.008 kg N_2O-N kgN^{-1}). These observations suggest that soil N_2O production in the Prairies region is not limited by mineral N availability, but rather by the low denitrification activity under well-aerated soil conditions. Despite the uncertainty in the determination of emission factors in the Prairies region, this approach is deemed a valid option to account for the influence of moisture limitations on N_2O emissions in that region.

To account for a topographical effect, an EF_{BASE} of 0.017 kg N_2O-N kgN^{-1} (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_2O emission estimates, based on the observations that N_2O 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 where they are imperfectly and poorly drained with mottles[22] 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_2O emission estimates (Rochette et al., 2008).

21 "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.

22 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.

Figure A3.4–4 **EF_{CT} as a Function of Long-Term Ratio of Precipitation over Potential Evapotranspiration (P/PE) from 1971 to 2000**



N_2O Emissions During Winter and Spring Thaw

Field measurements of N_2O 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_2O production (Grant and Pattey, 1999; Wagner-Riddle and Thurtell, 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 N_2O emissions in that region. Rochette et al. (2008) reported mean N_2O emissions during the winter and spring thaws in southern Ontario to be 1.2 kg N_2O-N ha^{-1} (Wagner-Riddle et al., 2007; Wagner-Riddle and Thurtell, 1998); these emissions were added to emissions calculated through the relationship between EF_{CT} and P/PE shown in Figure A3.4–4.

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 the 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.[23] These stations (80º00′N–41º55′N, 139º08′W–52º40′W) located across Canada (758 stations) and the United States (200 stations) were used to interpolate precipitation and potential evapotranspiration from May to October from 1971 to 2000 to the ecodistrict centroids. The Meteorological Service of Canada, Environment and Climate Change Canada provided the Canadian weather data.

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., 2002a; 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 A3.4–13). A value of 0.8 was assigned to the $RF_{TEXTURE\text{-}COARSE}$ and $RF_{TEXTURE\text{-}MEDIUM}$ and 1.2 for $RF_{TEXTURE\text{-}FINE}$ (Rochette et al., 2008). $RF_{TEXTURE}$ could not be estimated in regions other than Quebec, Ontario and the Atlantic provinces. The assumption of a low influence of soil texture on N_2O emissions ($RF_{TEXTURE}$ =1) is likely justified under dry climates such as in the Prairies region, where low soil water content results in low N_2O emissions, regardless of the soil texture.

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

Equation A3.4–13

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

$RF_{TEXTURE,i}$ = a weighted soil texture ratio factor of N_2O for an ecodistrict i for Ontario, Quebec and the Atlantic provinces

$RF_{TEXTURE\text{-}FINE,\ i}$ = a ratio factor of N_2O for fine-textured soils for an ecodistrict i

$FRAC_{TEXTURE\text{-}FINE,\ i}$ = fraction of fine-textured soils in an ecodistrict i

$RF_{TEXTURE\text{-}COARSE,\ i}$ = a ratio factor of N_2O for coarse-textured soils for an ecodistrict i

$FRAC_{TEXTURE\text{-}\ COARSE,\ i}$ = fraction of coarse-textured soils in an ecodistrict i

$RF_{TEXTURE\text{-}MEDIUM,\ i}$ = a ratio factor of N_2O for medium-textured soils for an ecodistrict i

$FRAC_{TEXTURE\text{-}MEDIUM,\ i}$ = fraction of medium-textured soils in an ecodistrict i

Organic Nitrogen Fertilizers

N_2O emissions from organic N sources include emissions from the application of sewage sludge (biosolids), manure from drylot and solid storage, liquid and other waste management systems on agricultural soils. A country-specific Tier 2 methodology was used for estimating N_2O emissions from organic N fertilizers.

Equation A3.4–14

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

N_2O_{ON} = emissions from organic nitrogen fertilizer applied to cropland, kg N_2O/year

$N_{ON\text{-}CROPS,i}$ = organic nitrogen (i.e., biosolids and animal manure) applied as N fertilizers on cropland in ecodistrict i, kg N yr^{-1}

$EF_{BASE,i}$ = a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kgN^{-1} yr^{-1}

$RF_{TEXTURE,i}$ = soil texture N_2O ratio factor for ecodistrict i

$44/28$ = coefficient converting N_2O-N to N_2O

Manure Nitrogen

The methodology is based on the quantity of manure N produced by domestic animals (see section A3.4.4.1) and country-specific $EF_{BASE,}$ taking into account the moisture regime and topographic conditions at the ecodistrict level. Manure was allocated to crops preferentially, based on a modified version of Yang et al. (2011), in order to better reflect practices and to ensure consistency in Canada's manure allocation methodology used in environmental indicators in Canada. Estimates of N_2O emissions from this source are calculated using Equation A3.4–14, in combination with our organic N sources.

The amount of animal manure applied as fertilizer at an ecodistrict level was calculated using Equation A3.4–15. It was assumed that all manure, excluding that deposited on pasture, range and paddock, is applied to cropland soils.

Equation A3.4–15

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

$N_{MAN\text{-}CROPS,i}$ = animal manure applied as N fertilizers on cropland in ecodistrict i, kgN yr^{-1}

N_T = population for animal category or subcategory T, heads

$N_{EX,T}$ = N excretion rate for animal category or subcategory (Table A3.4–20 and Table A3.4–22)

$N_{PRP,T}$ = fraction of manure N on pasture, range and paddock for each animal category or subcategory T in ecodistrict i (see Table A3.4–15)

$FRAC_{(LossMS,T)}$ = fraction of manure N loss during storage and handling (volatilization, leaching, etc.) for each animal category or subcategory T excluding pasture, range and paddock in ecodistrict i (Table A3.4–23 and Table A3.4–24)

Animal population data sources are detailed in section A3.4.1. Annual livestock population data from each animal category or subcategory at the provincial level are disaggregated into ecodistricts based on the livestock population distribution reported from the *Census of Agriculture*. Between two consecutive census years, livestock population proportions at the ecodistrict level are interpolated.

Biosolids Nitrogen

Data on the production and management of biosolids were derived from an Environment Canada–commissioned report (Cheminfo Services Inc., 2017). The data set was generated through a combination of telephone surveys and reports by the municipal wastewater treatment services in 33 Census Metropolitan Areas (CMAs) and from municipal and provincial environment departments/ministries across Canada. This survey represented only 63% of the Canadian population based on the wastewater treatment plants (WWTPs) located in CMAs and did not include PEI and the three Canadian territories. The data were compiled at five-year intervals (1990–2015) and had gaps and inconsistencies owing to a lack of complete management information and changes in provincial regulations on biosolids. Nevertheless, these data are the only known source for a quantitative analysis of biosolids available at a national scale.

Biosolids production data were produced through a series of analytical steps (Figure A3.4–5, Table A3.4–26). First, a provincial-level per capita model was constructed to establish a "baseline biosolids production." Production was assumed to be directly proportional to the population of a geographical area. Different spatially scaled roll-ups of Statistics Canada population estimates were evaluated

for best fit of the data. Population estimates used for testing included CMA populations, aggregated CMA populations and provincial populations. Upon regression analysis, the provincial population-based model was chosen based on the strength of the correlation coefficients. Fortunately, the data generated using this approach were not significantly different from the data reported during the years that Cheminfo Services Inc. (2017) was doing the reporting. Therefore, the smoothed annual provincial biosolids production was derived using the linear model. For PEI, annual estimates for biosolids production were developed based on expert opinion and using a national average per capita figure (22.5 kg / person/yr). This analysis created a complete time series of biosolids production at a provincial scale.

Secondly, the regional rates of land application of biosolids (dry tonnes) were derived using the proportions reported in Cheminfo Services Inc. (2017) adjusted for federal, provincial and municipal regulations, bylaws and restrictions (Table A3.4–26). At the federal level, the regulations imposed by the CCME were applied. Afterwards, provincial restrictions based on the nutrient content of the biosolids and any restrictions on the frequency of biosolids application to lands were incorporated (Table A3.4–26).

Biosolids are typically subject to various digestion and decomposition methods in WWTPs prior to land application. These methods have significant implications for the nutrient content of the biosolids and therefore influence the emission potential when land-applied. Accordingly, as the final step, a combination of survey results and literature analyses was used to identify the major digestion processes, and estimates from Dad et al. (2018) were used to establish the nutrient content of the biosolids.

Figure A3.4–5 **Schematic Details of the Procedures and Data Sources Used to Determine the Time Series of Biosolids Production at a Provincial Scale**

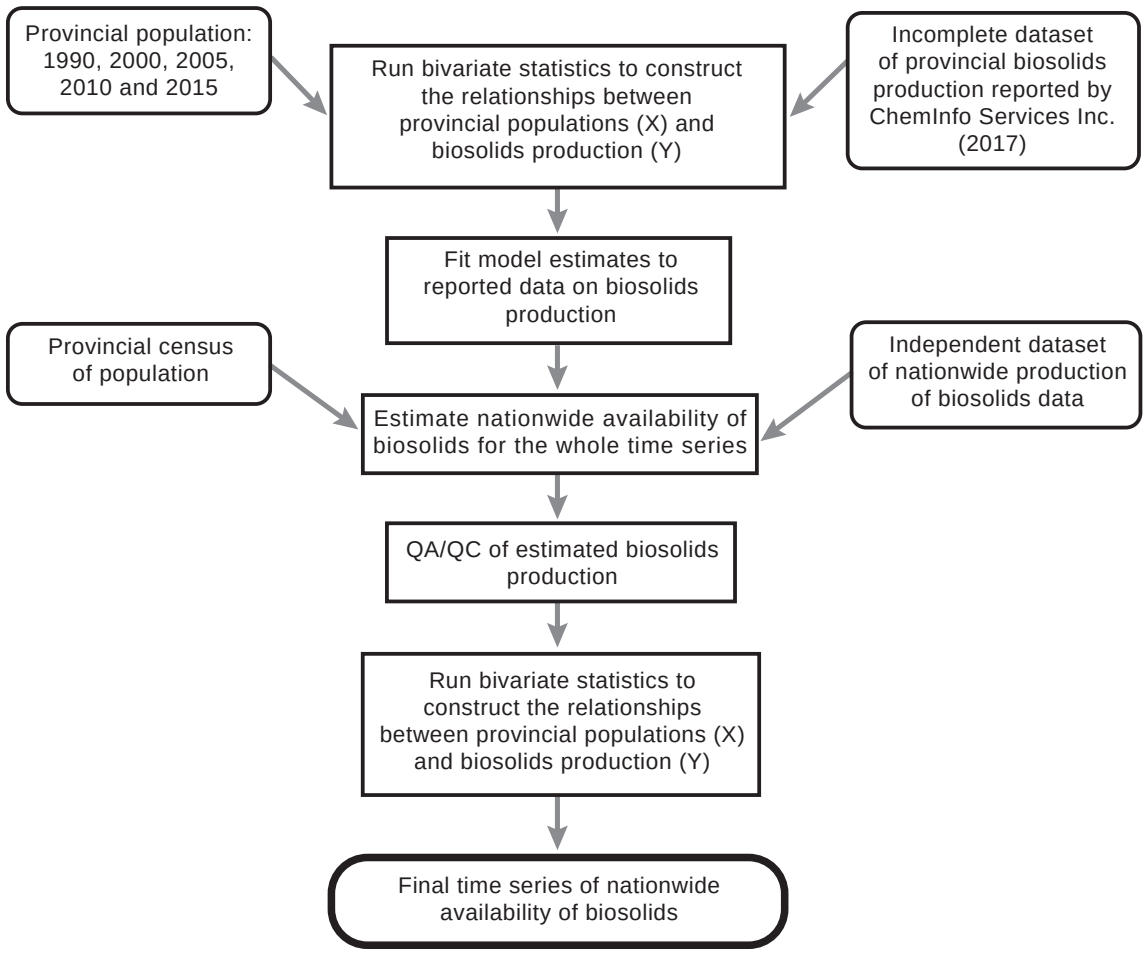


Table A3.4–26 **Data Sources Used for Determination of Annual Biosolids Production and Characteristics at the Provincial Scale**

Category	Data source	Notes/Comments
Biosolid Production	Cheminfo Services Inc. (2017)	Survey data for biosolid production and fractions that are land-filled, incinerated, land applied, and land-reclamation.
CMA population	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710013501	Statistics Canada. Population estimates, July 1, by census metropolitan area and census agglomeration, 2016 boundaries.
Provincial population	https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E	Statistics Canada. Census Profile 2016
Federal and provincial regulations	https://www.ccme.ca/files/Resources/waste/biosolids/pn_1446_biosolids_leg_review_eng.pdf	CCME. A Review of the Current Canadian Legislative Framework for Wastewater Biosolids.
Biosolids—fractions by digestive processes	Cheminfo Services Inc. (2017)	British Columbia commissioned work.
	Hydromantis Ltd. (2007). GPS-X 5.0 software. General Purpose Simulator — default parameters.	
	Environmental Dynamics Inc. (2017). Beneficial Reuse of Biosolids Jurisdictional Review.	
Nutrient content of biosolids under varied digestion/treatment processes	Dad et al. (2018)	

Quality Control and Quality Assurance

For the production data, quality control was conducted at the provincial and national levels. To verify the validity of our data, comparisons were made between the estimated values against independent data points available from literature and from other data sources at the national level. Our data reasonably reflected the production volume of biosolids at the provincial level and represented the changes in provincial regulations that occurred at specific years (Table A3.4–27). At the national level, the data aligned well with the national figures (Figure A3.4–6).

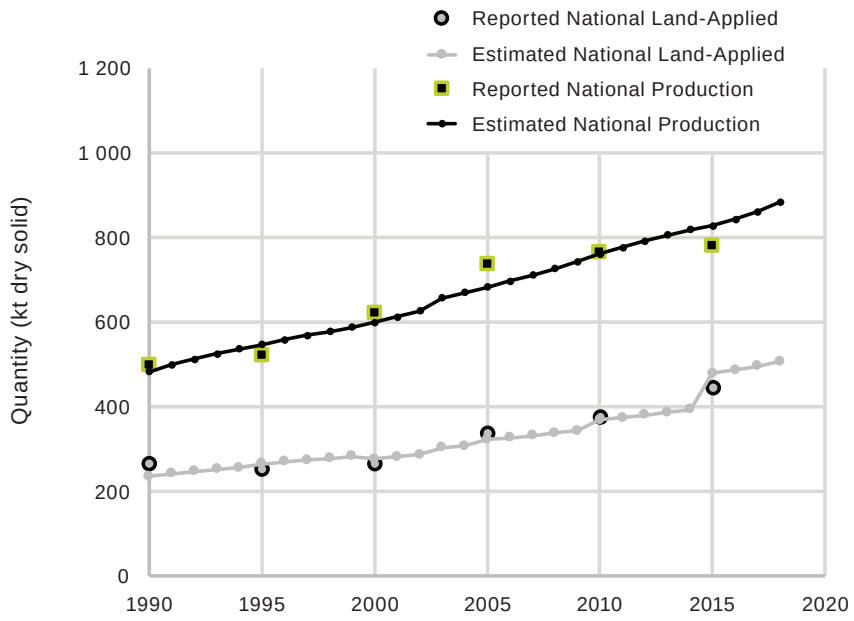
Allocation of Biosolids to Ecodistricts and Crops

The amount of biosolids applied as fertilizer at an ecodistrict level was calculated using Equation A3.4–16. Human population was used as a proxy to distribute provincial land-applied biosolids N to the ecodistrict spatial scale. In order to avoid over-application of N in an ecodistrict, a correction procedure was implemented to coordinate the application of manure and biosolids with recommended crop application rates per ecodistrict. First, the total amount of manure N within each ecodistrict was subtracted from the total amount of N required for crop growth, and compared with the amount of biosolids N initially allocated to the ecodistrict. In cases where biosolids N exceeded remaining crop N requirements, the required amount was applied and the excess N was reallocated to other ecodistricts in the province. Next, biosolids N was applied to select crops within each ecodistrict as per provincial and municipal regulations and bylaws limiting the application of biosolids. The amount of biosolids N applied to each crop in a given ecodistrict was then subtracted from the initial crop N requirements, and the modified parameter was used to distribute manure N to crops, following the manure application methodology.

Table A3.4–27 **Performance Statistics of Estimated Production Data Against Reported Figures at Provincial CMA and City Scale**

Location	Reported Production (kt)	Estimated Production (kt)	% Deviation	Year	Source
Calgary CMA, AB	20.5	23	12.2	Annually	EDI (2017)
City of Edmonton, AB	18	15.6	13.33	1990 to 2004	City of Edmonton (2012)
Halifax CMA, NS	30	13	56.67	Since 2014	EDI (2017)
City of North Battleford, SK	3.5	0.6	82.86	2003–2004	EDI (2017)
City of Toronto, ON	55	64	16.36	Since 2007	AECOM (2009)
City of Kelowna, BC	36.4	3.7	89.84	Since 2006	EDI (2017)

Figure A3.4–6 **National Biosolids Production (kt dry solid) Versus the Estimated Total Biosolids Production**



Equation A3.4–16

$$N_{BIO-CROPS,i} = \sum_i \left[Prod_p \times Frac_{LAND} \times Frac_{POP,i} \times \sum (TN_k \times Frac_{TYPE,k}) \times Frac_{CROP,im} \right]$$

$N_{BIO-CROPS,i}$	=	biosolids applied as N fertilizer on cropland in ecodistrict i, kg N/year
$Prod$	=	Biosolids production by province, p (kg)
$Frac_{LAND}$	=	Fraction of provincial biosolids that are land-applied
$Frac_{POP,i}$	=	Fraction of provincial human population in each ecodistrict i
TN_k	=	Total nitrogen content (%) by biosolids type k
$Frac_{TYPE,k}$	=	Fraction of each biosolids treatment type k
$Frac_{CROP,im}$	=	Fraction of biosolids N applied to crop type m, in ecodistrict i

Inorganic Nitrogen Fertilizers

The method for estimating N_2O emissions from inorganic N fertilizer application on agricultural soils takes into account moisture regimes and topographic conditions. Equation A3.4–17 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 A3.4–17

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

N_2O_{SFN}	=	emissions from inorganic N fertilizers, kg N_2O yr^{-1}
$N_{FERT,i}$	=	inorganic N fertilizer consumption in ecodistrict i, kgN yr^{-1}; N_{FERT} at an ecodistrict level is estimated using Equation A3.4–18
$EF_{BASE,i}$	=	a weighted average of emission factors at ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kgN^{-1} yr^{-1}
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict i
$44/28$	=	coefficient converting N_2O-N to N_2O

Data for inorganic N fertilizer sales are available by province only and were disaggregated to the ecodistrict level. The approach (Equation A3.4–18) was based on the assumption that the amount of inorganic N fertilizers applied (N_{APPLD}) is equal to the difference between recommended N rates (N_{RCMD}) and manure N available for application on cropland ($N_{MAN\text{-}AV,CROPS}$).

Equation A3.4–18

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

$N_{APPLDP,i}$ = total N fertilizer potentially applied in ecodistrict i, kgN yr^{-1}

$N_{RCMD,i}$ = recommended fertilizer application in ecodistrict i, kgN yr^{-1}

$N_{MAN\text{-}AV,CROPS,i}$ = available N from manure applied to crops in ecodistrict i, kgN yr^{-1}

Based on the work of Yang et al. (2007), N_{RCMD} was estimated as the sum of the products of each crop type and the recommended fertilizer application rate for that crop in an ecodistrict (Equation A3.4–19).

Equation A3.4–19

$$N_{RCMD,i} = \sum_{ij} \left(CROPA_{ij} \times N_{RECRT,ij} \right)$$

$N_{RCMD,i}$ = recommended fertilizer application in ecodistrict i, kgN yr^{-1}

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

$N_{RECRTij}$ = recommended annual N application rate for crop type j in ecodistrict i, kgN $ha\text{-}yr^{-1}$

$N_{MAN\text{-}AV,CROPS}$ was calculated as the sum of all manure N from all farm animals (Equation A3.4–20) in the ecodistrict as follows:

Equation A3.4–20

$$N_{MAN\text{-}AV,CROPS,i} = N_{MAN\text{-}CROPS,i} \times (1 - UNAV)$$

$N_{MAN\text{-}AV,CROPS,i}$ = available N from manure applied to crops in ecodistrict i, kgN yr^{-1}

$N_{MAN\text{-}CROPS,i}$ = total amount of manure N applied as fertilizers to cropland in ecodistrict i, kgN yr^{-1}

$UNAV$ = 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 A3.4–21

$$N_{FERT,i} = N_{APPLDi} \times \left[\frac{N_{SALESp}}{\sum_{i}^{n} N_{APPLDi}} \right]$$

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

$\sum_{i}^{n} N_{APPLDi}$ = total fertilizer N potentially applied to all crops in all ecodistricts in a province, kg

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

For years between census years (census years were 1991, 1996, 2001, 2006 and 2011), N_{RCMD} was linearly interpolated to successively estimate annual values of N_{APPLD} and N_{FERT} at the ecodistrict level. The consumption of synthetic N fertilizers in Canada has significantly increased since 1990, from 1.2 Mt to 2.6 Mt N, mainly because of the intensification of cropping systems from 1991 to 1997 and increased conversion from perennial to annual crops due to favourable grain prices since 2007 (Figure A3.4–7).

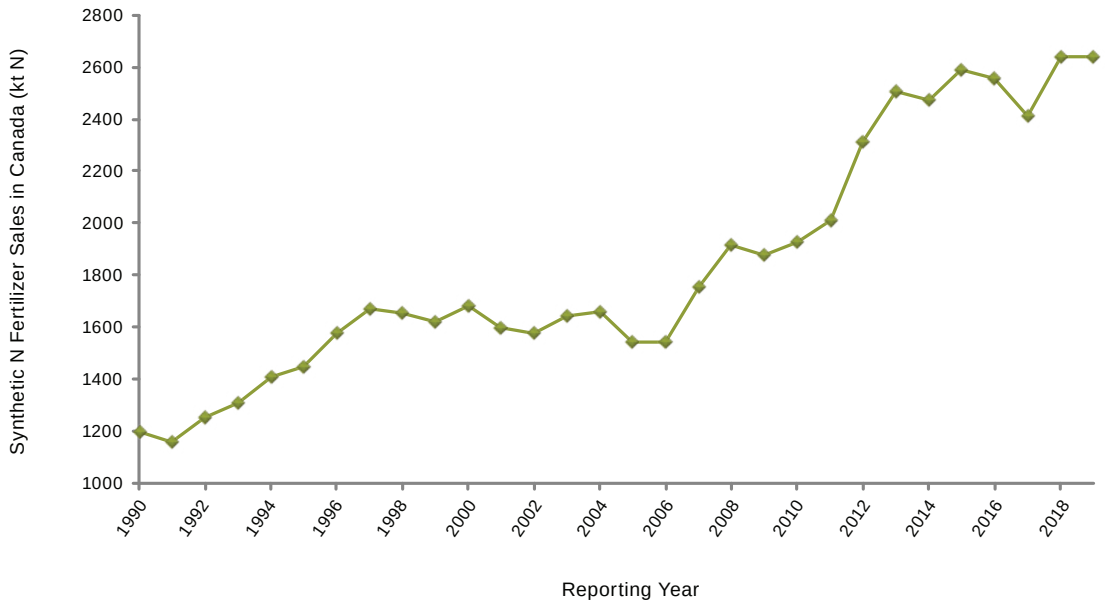
From 1990 to 2002, Agriculture and Agri-Food Canada collected annual fertilizer N consumption data at the provincial level and published *Canadian Fertilizer Consumption, Shipments and Trade*. From 2003 to 2006, fertilizer N data were collected and published by the Canadian Fertilizer Institute.[24] Since 2007, Statistics Canada has collected and published fertilizer sales data annually (Statistics Canada, n.d. [b]).

Urine and Dung Deposited on Pasture, Range and Paddock by Grazing Animals

Canada uses a country-specific method for estimating N_2O emissions from urine and dung deposited on pasture, range and paddock by grazing animals. The N_2O emission factors for all livestock types were determined on the basis of a research project carried out between 2009 and 2011 for dairy cows in Eastern Canada and for beef cattle in Western Canada. Results from dairy manure in Eastern Canada are available in Rochette et al. (2014). Results from beef manure in Western Canada are summarized in Table A3.4–26 (Lemke et al., 2012). In comparison with the IPCC default EF for major livestock (2%), emission factors were 3.2 times lower in Eastern Canada and 46.5 times lower in Western Canada. Lower emission factors observed on the Canadian Prairies compared with the more humid climate in Eastern Canada are consistent with the findings of Rochette et al. (2008), who reported that moisture deficit—defined as the ratio of precipitation to potential evapotranspiration during the growing season—is a major contributing factor for

24 Available online at http://www.statcan.gc.ca/daily-quotidien/150213/dq150213f-eng.htm.

Figure A3.4–7 **Synthetic Nitrogen Fertilizer Sales in Canada from 1990 to 2019**



N_2O emissions on arable cropland in Canada. For Ontario, Quebec and the Atlantic provinces, N_2O EFs are 0.0078 kg N_2O-N/kg N for fine-textured soil, 0.0062 kg N_2O-N/kg N for medium-textured soil and 0.0047 kg N_2O-N/kg N for coarse-textured soil (Rochette et al., 2014). A weighted N_2O EF based on soil texture is calculated for each ecodistrict based on Equation A3.4–13, assuming 75% of excreted N in urine (Rochette et al., 2014). In Western Canada, the N_2O EF is 0.00043 kg N_2O-N/kg N (Table A3.4–28). N_2O emissions are calculated using a fixed emission factor-based approach (Equation A3.4–22).

Equation A3.4–22

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

N_2O_{PRP}	=	emissions from urine and dung deposited 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 A3.4–20 and Table A3.4–22)
$N_{PRP,T}$	=	fraction of manure N excreted on pasture, range and paddock by animal category or subcategory T (Table A3.4–15)
$EF_{PRP,i}$	=	emission factor for manure N deposited by animals on pasture, range and paddock in ecodistrict i
44/28	=	coefficient converting N_2O-N to N_2O

Animal population data and data sources are detailed in section A3.4.1.

Crop Residue Decomposition

The transformation (nitrification and denitrification) of the N released during the decomposition of crop residues results in N_2O emissions into the atmosphere. A country-specific Tier 2 method similar to that for inorganic and organic N fertilizers is used to estimate N_2O emissions from crop residues, based on Equation A3.4–23, Equation A3.4–24 and Equation A3.4–25. The amount of N contained in the aboveground crop residues subjected to field burning at the provincial level is removed from the emission estimate to avoid double counting (see section A3.4.7).

Equation A3.4–23

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

N_2O_{RES}	=	emissions from crop residue decomposition, kg N_2O yr^{-1}
$N_{RES,i}$	=	total amount of crop residue N that is returned to soils for ecodistrict i, excluding N losses due to residue burning, kgN yr^{-1} (see Table A3.4–24)
$EF_{BASE,i}$	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kgN yr^{-1}
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict, i
44/28	=	coefficient converting N_2O-N to N_2O

Table A3.4–28 **Emissions of Nitrous Oxide from Beef Urine and Dung on Pasture in Western Canada**

Site	Treatment	Flux	Target N Rate	Standard Deviation	Emission Factor
		kg N ha^{-1}			kg N_2O-N kg^{-1}N
Swift Current, Saskatchewan	Control	0.07		0.04	
	Dung	0.07	500	0.05	0.000002 ± 0.00003
	Urine	0.79	750	1.56	0.001 ± 0.002
Lacombe, Alberta	Control	0.59		0.33	
	Dung	0.50	500	0.41	0 ± 0.0002
	Urine	0.72	750	0.58	0.0002 ± 0.0003
Overall mean					
	Dung				0 ± 0.0001
	Urine				0.0006 ± 0.0012

Note:

Unpublished data (Lemke et al., 2012); urine and dung applied in spring, summer and fall, and repeated one more time along with three replicates, and N_2O flux measurement frequency varied from three times a week immediately after urine and dung application down to once in four weeks depending on the intensity of the flux and weather conditions.

Equation A3.4–24

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

$N_{RES,i}$ = total amount of crop residue N that is returned to soils for ecodistrict i, excluding N losses due to residue burning, kg N yr^{-1}

$P_{T,i}$ = total production of the Tth crop type that is renewed annually in ecodistrict i, kg DM yr^{-1} (see Equation A3.4–25)

$FRAC_{RENEW,T,i}$ = 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^{-1}

$N_{AG,T}$ = N content of above-ground residues for crop T, kg-N kg-DM^{-1}

$R_{BG,T}$ = ratio of below-ground residues to harvested yield for crop T, kg DM kg^{-1}

$N_{BG,T}$ = N content of below-ground residues for crop T, kg-N kg-DM^{-1}

Equation A3.4–25

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

$P_{T,i}$ = total production of the Tth crop type that is renewed annually in ecodistrict i, kg DM yr^{-1}

$A_{T,i}$ = area under crop type T in ecodistrict i, ha

$Y_{T,i}$ = average crop yield for crop type T in ecodistrict i, kg ha-yr^{-1}

$\sum_{=1}^{n}\left(_{T,i} \times Y_{T,i}\right)$ = sum of total production for crop type T over all ecodistricts in a province

$P_{T,p}$ = total crop production for crop type T in province p, kg DM yr^{-1}

H_2O_T = water content of crop T, kg kg^{-1}

Statistics Canada collects and publishes annual field crop production data by province (Statistics Canada, n.d. [h]). 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, chickpeas 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). Statistics Canada survey data are based on the *Census of Agriculture* (COA), and therefore general revisions to the survey time series may occur when COA data are modified due to refinements of the calibration model or other changes. Survey data are also occasionally revised by Statistics Canada due to error correction, and alignment with other supply and disposition statistics such as exports.

Mineralization Associated with Loss of Soil Organic Matter

The amount of N in mineral soils that is mineralized in association with loss of soil organic matter as a result of changes to land management practices can result in additional N_2O emissions from the Cropland Remaining Cropland category. A database containing soil organic carbon and N for all major soils in Saskatchewan (a data set of about 600) was used to derive an average C:N ratio of 11 with a standard deviation of 1.9. The C:N ratio of agricultural soils is considered to be consistent among regions. The 2006 IPCC Guidelines propose a range of C:N ratios from 8 to 15. A country-specific method is used for emission estimates (see Equation A3.4–26 and Equation A3.4–27).

Equation A3.4–26

$$F_{SOM} = \sum_{LM}[(\Delta C_{Mineral,LM} \times \frac{1}{R}) \times 1000]$$

F_{SOM} = the net annual amount of N mineralised in mineral soils as a result of loss of soil organic carbon through change in land management practices, kg N

$\Delta C_{Mineral,\ LM}$ = average annual loss of soil organic carbon for each land management practice (LM), Mg C

R = C:N ratio of the soil organic matter (11.0±1.9)

Equation A3.4–27

$$N_2O_{FSOM} = \sum_i \left(F_{SOM,i} \times EF_{BASE,i} \times RF_{TEXTURE,i}\right) \times \frac{44}{28}$$

N_2O_{FSOM} = emissions associated with loss of soil organic matter due to changes in land management practices, 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^{-1} yr^{-1}

$RF_{TEXTURE,i}$ = soil texture N_2O ratio factor for ecodistrict, i

$44/28$ = coefficient converting N_2O-N to N_2O

$F_{SOM,i}$ = the net annual amount of N mineralised in mineral soils as a result of loss of soil organic carbon through change in land management practices for ecodistrict i, kg N

Activity data on soil organic carbon loss at an ecodistrict level over the time series that is reported in the LULUCF Cropland Remaining Cropland category are used for soil N_2O estimates associated with the loss of soil organic matter.

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 A3.4–28).

Equation A3.4–28

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

N_2O_H = emissions from cultivated histosols, kg N_2O yr^{-1}

$A_{os,i}$ = 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, 2006)

$44/28$ = coefficient converting N_2O-N to N_2O

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 in Canada was 16 kilohectares (Liang et al., 2004) and remains constant over time.

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-till (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 emissions, 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 (Rochette et al., 2008):

Equation A3.4–29

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

N_2O_{TILL} = change in N_2O emissions resulting from the adoption of NT and RT, kgN_2O yr^{-1}

$N_{FERT,i}$ = inorganic fertilizer N consumption in ecodistrict i, kgN yr^{-1}

$N_{MAN-CROPS,i}$ = amount of manure N applied as fertilizers to cropland in ecodistrict i, kg-N yr^{-1}

$N_{RES,i}$ = amount of crop residue N that is returned to soils for ecodistrict i, kgN yr^{-1}

$EF_{BASE,i}$ = a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kg-N-yr^{-1}

$FRAC_{NT-RT,i}$ = 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

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 4 – Cropland in Annex 3.5). 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 interpolated.

N_2O Emissions Resulting from Summerfallow

Summerfallow is a farming practice typically used on the Prairies to conserve soil moisture by leaving the soil unseeded for an entire growing season of 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 A3.4–30

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

N_2O_{CROP} = emissions from a cropped rotation, kg N_2O yr^{-1}

N_2O_{BACK} = the background soil N_2O emissions that are not due to crop residue-N, inorganic fertilizer-N or manure-N additions

N_2O_{SFN} = emissions from inorganic N fertilizers, kg N_2O yr^{-1}

N_2O_{MAN} = emissions from organic N fertilizers, kg N_2O yr^{-1}

N_2O_{RES} = emissions from crop residue decomposition, kg N_2O yr^{-1}

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 ($N_2O_{FALLOW\text{-}EFFECT}$):

Equation A3.4–31

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

N_2O_{FALLOW} = emissions due to the effect of summerfallow, kg N_2O yr^{-1}

N_2O_{BACK} = background emissions, kg N_2O yr^{-1}

$N_2O_{FALLOW\text{-}EFFECT}$ = emissions due to modifications to the soil environment resulting from summerfallow, kg N_2O yr^{-1}

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, $N_2O_{FALLOW\text{-}EFFECT}$ can be empirically estimated as follows:

Equation A3.4–32

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

N_2O_{SFN} = emissions from inorganic N fertilizers, kg N_2O

N_2O_{RES} = emissions from crop residue decomposition, kg N_2O

N_2O_{MAN} = emissions from organic N fertilizers, kg N_2O

$N_2O_{FALLOW\text{-}EFFECT}$ = emissions occurring under fallow land, kg N_2O

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, inorganic N fertilizers and organic N fertilizers) to the area of the ecodistrict under summerfallow:

Equation A3.4–33

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

N_2O_{FALLOW} = emissions from summerfallow, kg N_2O

$N_2O_{SFN,i}$ = emissions from inorganic N fertilizers in ecodistrict i, kg N_2O

$N_2O_{RES,i}$ = emissions from crop residue decomposition in ecodistrict i, kg N_2O

$N_2O_{MAN,i}$ = emissions from organic N fertilizers in ecodistrict i, kg N_2O

$FRAC_{FALLOW,i}$ = 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 inorganic N fertilizers, organic N 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 summerfallow practice (see section 4 – Cropland in Annex 3.5). Annual $FRAC_{FALLOW}$ between two consecutive census years is adjusted through interpolation.

N_2O Emissions Resulting 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, 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 effects 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 A3.4–34

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

N_2O_{IRRI}	=	emissions from irrigation, kg N_2O yr^{-1}
$N_{FERT,i}$	=	inorganic N fertilizer consumption in ecodistrict i, kgN yr^{-1}
$N_{MAN-CROPS,i}$	=	amount of organic N fertilizers applied to the cropland in ecodistrict i, kgN yr^{-1}
$N_{RES,i}$	=	amount of crop residue N that is returned to the cropland in ecodistrict i, kgN yr^{-1}
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N kgN-yr^{-1} for ecodistrict i
$FRAC_{IRRI,i}$	=	fraction of irrigated cropland in ecodistrict i
$44/28$	=	coefficient converting N_2O-N to N_2O

The fraction $FRAC_{IRRI}$ is derived from the *Census of Agriculture* for each ecodistrict (see section 4 – Cropland in Annex 3.5). Annual $FRAC_{IRRI}$ between two consecutive census years is adjusted through interpolation.

Table A3.4–29 **Coefficients for Crop Type, Inorganic N Fertilizers, Method of Fertilizer Application, Soil Chemical Properties and Climate Developed by Bouwman et al. (2002b)**

Conditions where coefficient used		Coefficients
Crop Type	Annual crops	-0.045
	Perennial crops	-0.158
Fertilizer Type	Urea	0.666
	Urea ammonium nitrate	0.282
	Anhydrous ammonia	-1.151
	Other N sources	-0.238
Method of Application	Broadcast onto surface	-1.305
	Incorporated	-1.895
Soil Chemical Properties	Soil pH<7.25	-1
	Soil pH 7.25 ~ 8.5	-0.608
	Soil CEC <250 mmol kg^{-1}	0.0507
	Soil CEC >250 mmol kg^{-1}	0.0848
Climate	Temperate	-0.402

A3.4.5.2. Indirect N_2O Emissions from Agricultural Soils

Volatilization and Redeposition of Nitrogen

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from volatilization and redeposition of inorganic and organic N. The emission calculation is shown in Equation A3.4–35.

Equation A3.4–35

$$N_2O_{VD} = \sum_i \left[\left(N_{FERT\,TN,i} \times FRAC_{GASF\,NT,i} \right) + \left(MAN_{PRP,iT} \times FRAC_{GasMS-PRP,T} \right) + \left(N_{MAN-CROPS,i} \times FRAC_{GASM,i} \right) \right] \times EF_4 \times \frac{44}{28}$$

N_2O_{VD}	=	emissions from volatilization and redeposition of N, kg N_2O yr^{-1}
$N_{FERT,\,TN,i}$	=	inorganic N consumption for each type of N fertilizers including urea, urea ammonium nitrate, anhydrous ammonia and others in ecodistrict i, kg N yr^{-1}
$FRAC_{GASF\,NT,i}$	=	fraction of inorganic N fertilizers applied to soils that volatilizes as NH_3-N, kg NH_3-N kgN^{-1}, determined by a country-specific method in an ecodistrict i (see Equation A3.4–17)
$MAN_{PRP,iT}$	=	amount of urine and dung N excreted on pasture, range and paddock by animal category or subcategory T in an ecodistrict i, kg N yr^{-1}
$FRAC_{GasMS-PRP,T}$	=	fraction of volatilized manure N deposited on pasture, range and paddock by animal category or subcategory T: 0.2 kg (NH_3-N + NO_x-N) kgN^{-1} (IPCC, 2006) for all livestock categories except Dairy Cattle (Table A3.4–34)
$N_{MAN-CROPS,i}$	=	organic N fertilizers applied on cropland in ecodistrict I, kgN yr^{-1} (see Table A3.4–32)
$FRAC_{GASM,i}$	=	fraction of volatilized organic N fertilizers in ecodistrict i: 0.2 kg (NH_3-N + NO_x-N) kgN^{-1} for all livestock (IPCC, 2006) except the Dairy Cattle and Swine categories (Table A3.4–32).
EF_4	=	emission factor due to volatilization and redeposition: 0.01 kg N_2O-N kgN^{-1} (IPCC, 2006)
$44/28$	=	coefficient converting N_2O-N to N_2O

A country-specific method was used to estimate ammonia emissions from inorganic N application. The method for deriving ammonia emission factors closely follows the approach of Sheppard et al. (2010a), who applied the regression model developed by Bouwman et al. (2002b) to derive regionally specific emission factors for different ecoregions in Canada. This model derives ammonia emission factors based on the type of inorganic N fertilizers, degree of incorporation into soil, crop type and soil chemical properties (Equation A3.4–36).

Equation A3.4–36

$$FRAC_{GASF\ TN,\ i} = 100 \times EXP^{(sum\ of\ relevant\ coefficients)}$$

$FRAC_{GASF\ TN,\ i}$	=	ammonia emission factor for each type of inorganic N fertilizer in ecodistrict i, %
sum of relevant coefficients	=	coefficients for crop type, type of inorganic N fertilizers, method of N application, soil chemical properties and climate, unitless (see Table A3.4–29)
100	=	conversion of fraction to percent
EXP	=	exponential

The method of application for each type of inorganic N fertilizers for Eastern and Western Canada is provided in Sheppard et al. (2010a). Soil properties, pH and cation exchange capacity (CEC) are derived from CANSIS soil polygon information and are based on fractional distributions of soil series having pH < 7.25 and CEC < 250 me/kg, pH < 7.25 and CEC > 250 me/kg, pH > 7.25 and CEC < 250 me/kg, and pH > 7.25 and CEC > 250 me/kg. Statistics Canada (n.d. [b]) has collected and published annual inorganic N fertilizer sales data including urea, urea ammonium nitrate, anhydrous ammonia and others. The application of this equation results in spatially specific emission factors for inorganic N fertilizers applied to annual crops. Provincial averages by fertilizer type (Table A3.4–30) are calculated based on the spatial distribution of soil chemical properties and climate for each individual ecodistrict in each province and, as a consequence, the fraction ($FRAC_{GASF}$) of ammonia volatilized by province varies slightly from year to year based on fertilizer sales (Table A3.4–31). More detail on methods of estimating ammonia emission factors from inorganic N fertilizers can be found in Sheppard et al. (2010a), and simplifications used to convert monthly emissions calculated in the original publication to an annual estimate are documented in Liang (2014). Briefly, based on the data provided in Sheppard et al. (2010a), it is assumed that inorganic N fertilizers are applied in either spring or fall when temperatures are similar. Therefore, a single temperature representing annual applications per ecoregion is used to estimate emissions. According to this approach, the fraction of fertilizers emitted during fertilizer application ranges from roughly 5% to a maximum of 10% (Table A3.4–31), depending on the year and province.

Table A3.4–30 **Ammonia Emission Factors of Inorganic Nitrogen Fertilizers Applied to Annual Crops Weighted Based on Soil Properties for Each Province (%)**

	Annual			
Province	Urea	Anhydrous NH_3	UAN	Other
AB	5	4.2	3.8	5.4
BC	4.8	4	3.7	5.2
MB	5.8	4.9	4.5	6.3
NB	7.4	3.9	4.5	4.5
NL	7.4	3.9	4.5	4.5
NS	7.3	3.9	4.4	4.4
ON	8.2	4.4	5	4.9
PE	7.3	3.9	4.4	4.4
QC	7.4	4	4.5	4.5
SK	5.1	4.2	3.9	5.5

Table A3.4–31 **Fractions of N Volatilized ($FRAC_{GASF}$) as Ammonia Resulting from the Application of Inorganic N Fertilizer, from Select Years, 1990–2019, at a Provincial Scale**

	Implied EF (kg NH_3-N volatilized / kg inorganic fertilizer N applied)									
Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.06	0.09	0.06	0.07	0.00	0.08	0.08	0.06	0.09	0.05
1995	0.06	0.09	0.07	0.07	0.08	0.08	0.08	0.06	0.08	0.06
2000	0.06	0.10	0.07	0.06	0.00	0.07	0.08	0.05	0.08	0.06
2005	0.06	0.10	0.07	0.06	0.07	0.07	0.08	0.06	0.07	0.06
2010	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2011	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2012	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2013	0.06	0.09	0.07	0.06	0.08	0.07	0.08	0.06	0.07	0.06
2014	0.06	0.09	0.06	0.05	0.07	0.06	0.07	0.05	0.07	0.06
2015	0.06	0.09	0.07	0.06	0.07	0.07	0.07	0.05	0.07	0.06
2016	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2017	0.06	0.09	0.07	0.05	0.07	0.06	0.07	0.05	0.07	0.06
2018	0.06	0.08	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2019	0.06	0.08	0.07	0.06	0.07	0.08	0.07	0.05	0.07	0.06

Table A3.4–32 **Fractions of Dairy Cattle N Volatilized as Ammonia Resulting from the Application of Manure N Fertilizer, from Select Years, 1990–2019, at a Provincial Scale**

	Implied EF (kg NH_3-N volatilized/ kg manure N applied)									
Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.14	0.10	0.16	0.20	0.19	0.20	0.18	0.18	0.17	0.15
1995	0.13	0.09	0.16	0.19	0.19	0.19	0.18	0.18	0.17	0.15
2000	0.12	0.09	0.15	0.18	0.19	0.18	0.17	0.18	0.16	0.14
2005	0.11	0.08	0.14	0.17	0.19	0.16	0.17	0.18	0.15	0.13
2010	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2015	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2016	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2017	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2018	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12
2019	0.11	0.09	0.13	0.16	0.19	0.15	0.16	0.17	0.15	0.12

Leaching and Runoff

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

Equation A3.4–37

$$N_2O_L = \sum_i \left[\left(N_{FERT,i} + N_{MAN-CROPS,i} + MAN_{PRP,i} + N_{RES,i} \right) \times FRAC_{LEACH,i} \times EF_5 \right] \times \frac{44}{28}$$

N_2O_L	=	emissions from leaching and runoff of N, kgN_2O yr^{-1}
$N_{FERT,i}$	=	inorganic N fertilizers applied for ecodistrict i, kg N
$N_{MAN\text{-}CROPS,i}$	=	organic N fertilizers applied for ecodistrict i, kg N
$MAN_{PRP,i}$	=	urine and dung deposited on pasture, range and paddock for ecodistrict i, kgN
$N_{RES,i}$	=	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_5	=	leaching/runoff emission factor: 0.0075 kg N_2O-N kgN^{-1} (IPCC, 2006)
$44/28$	=	coefficient converting N_2O-N to N_2O

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. In some farming systems of southern British Columbia, high N inputs in humid conditions may lead to losses greater than 100 kg N/ha-year (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 to 37 kg N/ha, representing between 0% and 20% of N inputs. Leaching losses in most of the Prairies region may be smaller due to lower precipitation and lower N inputs on a per area 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.

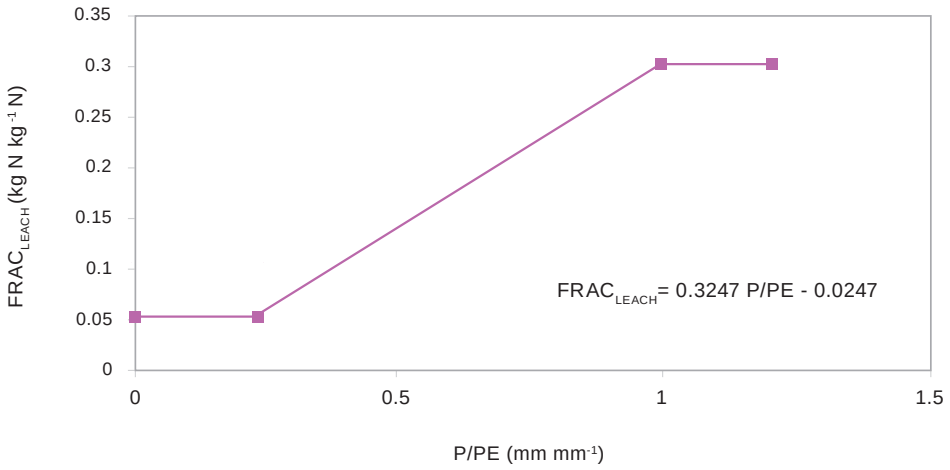
The values for $FRAC_{LEACH}$ can be as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration, such as in the Prairies region of Canada, or as high as 0.3 in humid regions (IPCC, 2006) of Eastern Canada. Accordingly, it was assumed that $FRAC_{LEACH}$ would vary from 0.05 to 0.3, depending on the ecodistrict.

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 of 0.3 (IPCC, 2006) 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 from 0.23 to 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 A3.4–8).

Data sources for N_{FERT}, $N_{MAN\text{-}CROPS}$, MAN_{PRP} and N_{RES} (section A3.4.5.1) 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.

Figure A3.4–8 **Determination of the Ecodistrict $FRAC_{LEACH}$ Values**



A3.4.6. Uncertainty Estimates of N_2O Emissions

A comprehensive uncertainty analysis was completed for all methodologies used in the calculation of N_2O from livestock and agricultural soils for 2010 (Karimi-Zindashty et al., 2014). The analysis has not yet been published, and limited depth of analysis could be carried out due to the size of the Canadian N_2O model and the upper limits of the data processing capability of the Analytica software. However, the analysis did provide the uncertain bounds around the principal emission source categories. For this submission, the uncertainty ranges (percentages) developed for 2010 means were applied to means for the current year. In the analysis, a stochastic reproduction of the complete N_2O emission model was built in Analytica© at the ecodistrict scale, and a Monte Carlo simulation (MCS) was run according to the methodology proposed in the Good Practice Guidance (IPCC, 2000). A sensitivity analysis was carried out to identify the parameters that contributed most to different emission source categories.

The parameters used in the calculation of N_2O emissions can be divided into three categories: (1) those associated with information at the ecodistrict scale, (2) provincial-scale data and (3) IPCC/national-scale parameters (Table A3.4–33). The majority of national-scale parameters are taken directly from the 2006 IPCC Guidelines (IPCC, 2006) or from the original country-specific methodological development work carried out by Rochette et al. (2008), derived either analytically

Table A3.4–33 **Fractions of Swine N Volatilized as Ammonia Resulting from the Application of Manure N Fertilizer, from Select Years, 1990–2019, at a Provincial Scale**

	Implied EF (kg NH_3-N volatilized / kg manure N applied)									
Year	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.14	0.22	0.14	0.28	0.23	0.28	0.21	0.28	0.26	0.15
1995	0.13	0.22	0.12	0.27	0.23	0.27	0.21	0.27	0.25	0.13
2000	0.13	0.22	0.11	0.26	0.23	0.25	0.20	0.26	0.25	0.12
2005	0.12	0.22	0.11	0.25	0.23	0.24	0.20	0.25	0.24	0.12
2010	0.12	0.21	0.11	0.24	0.23	0.23	0.20	0.25	0.24	0.12
2011	0.12	0.21	0.11	0.24	0.22	0.24	0.20	0.25	0.24	0.13
2012	0.12	0.21	0.11	0.24	0.22	0.24	0.20	0.25	0.24	0.13
2013	0.13	0.21	0.11	0.24	0.22	0.24	0.20	0.25	0.24	0.13
2014	0.13	0.21	0.11	0.24	0.22	0.25	0.20	0.25	0.24	0.13
2015	0.13	0.21	0.11	0.25	0.22	0.25	0.20	0.25	0.24	0.13
2016	0.13	0.21	0.11	0.25	0.23	0.25	0.20	0.25	0.24	0.13
2017	0.13	0.21	0.11	0.24	0.23	0.25	0.20	0.25	0.24	0.13
2018	0.13	0.21	0.11	0.24	0.23	0.25	0.20	0.25	0.24	0.13
2019	0.13	0.21	0.11	0.24	0.23	0.25	0.20	0.25	0.24	0.13

Table A3.4–34 **Fractions of Dairy Cattle N Volatilized as Ammonia Resulting from Deposition on Pasture, Range and Paddock, in 2019, at a Provincial Scale**

Province	Implied EF (kg NH_3-N volatilized / kg manure N)
AB	0.035
BC	0.042
MB	0.036
NB	0.039
NL	0.036
NS	0.039
ON	0.042
PE	0.039
QC	0.036
SK	0.036

or through expert opinion based on a panel of four experts in agricultural GHG emissions. Provincial-scale parameters include fertilizer sales and characteristics of crop production, the source of uncertainty being the Statistics Canada survey uncertainty and expert opinion on characteristics of crop production. The uncertainty of livestock populations and management parameters for animal categories were identical to that discussed in sections A3.4.2.4 and A3.4.3.9; the distributions used to define uncertainties can be found in Table A3.4–9 and Table A3.4–19. Landscape-scale parameters were derived from the agricultural soil landscape parameter database developed by AAFC and used in the production of cropland estimates for LULUCF. Specific landscape-parameter uncertainty was based on the general rules used in the production of uncertainty estimates for cropland carbon, which postulates that the uncertainty of a parameter at the landscape scale is inversely proportional to the relative size of the landscape unit, i.e., smaller parameters associated with smaller ecodistricts have greater uncertainty. The bounds of the uncertainty for different parameters varied. For example, uncertainties around animal distribution was ±30% for small ecodistricts and ±5% for large ecodistricts, whereas for the fraction of lowland soil in a given ecodistrict, variability was bounded as ±10% for small ecodistricts and ±1.25% for large ecodistricts. The current analysis does not include new country-specific emission factors for N_2O emissions from animal manure deposited on pasture, range and paddock, but does include the analysis of emissions considering the 2006 IPCC Guidelines leaching emission factor.

The summary results of the uncertainty analysis on emissions of N_2O are reported in Chapter 5. The relative uncertainty range for N_2O emissions from agricultural sources is 56% (-27% to +29% of the mean). Most uncertainty is associated with indirect emissions and specifically with the indirect emission factors for volatilized and leached N, with the estimate of indirect emissions uncertainty of 126% (-58% to +68% of the mean). The emissions are skewed to the lower end of the emission probability distribution, because emission factor uncertainty is bounded by zero and emission factor variability is expressed as a factor on the lower scale; a change from 1% to 0.2% has a smaller impact on total emissions than a change from 1% to 5% at the upper end of the probability distribution. The uncertainty range of direct N_2O emissions from agricultural soils is 69% (-31% to +38% of the mean). There have been few complete studies of uncertainty from emissions of N_2O in the literature. In a study directly comparable to this particular uncertainty analysis, Monni et al. (2007) estimated that total N_2O emissions in Finland ranged from -50% to +70% of the mean emission estimate. Their methodology included a mixture of country-specific and default Tier 1 methodology to produce emission estimates. In a recent study of uncertainty in the United Kingdom, Milne et al. (2013) observed high uncertainty ranges for direct, indirect and total N_2O emissions, specifically -56% to +140%, -91% to +370%, and -55% to +110%, respectively. Our parameter uncertainty was similar to that used by the UK researchers, but it is suspected that the high degree of spatial disaggregation in the Canadian N_2O model resulted in slightly lower overall uncertainty. The uncertainty associated with the fraction of emission(s) from inorganic N fertilizers would be reduced from ±200% by the IPCC default (IPCC, 2006) given the country-specific approach applied in this submission. However, because the uncertainty associated with EF_4 (N volatilization and re-deposition) is ±400% (IPCC, 2006), it is unlikely that the overall uncertainty of N_2O emissions would decrease.

Sensitivity analysis indicated that indirect EF uncertainties were the largest contributors to overall uncertainty. Uncertainty of direct soil emissions was dominated by the use of uncertainty in the Tier 1 emission factor for emissions from pasture, range and paddock (PRP), the slope of P/PE regression equation and the emission factor modifier for tillage and texture (RF_{TILL}, RF_{TEXT}). The EF for solid manure systems was the largest source of uncertainty in the estimate of N_2O emissions from AWMS. Reduction of uncertainty will require the replacement of Tier 1 default emission factors and modifiers in the methodology.

Table A3.4–35 **Uncertainty Parameters Used in the Calculation of Agricultural N_2O Emissions**

Parameter	Coefficient/Parameter Source	Distribution Type	Uncertainty Range	Most Likely Value[b]	Uncertainty Distribution Source and Notes
IPCC and National Scale Parameters					
Animal populations and characterization data[a]					Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication
N excretion	2006 IPCC Guidelines	Normal	±50%	IPCC default	
$FRAC_{GAS}/FRAC_{LOSSMS}$		Triangular	IPCC default	IPCC default	See Table 10.22/10.23 of 2006 IPCC Guidelines
AWMS emission factor		Triangular	Liquid 0.0005–0.002 PRP -0.007–0.06	Minimum liquid 0.001 Maximum PRP -0.02	2006 IPCC Guidelines variable depending on the manure storage type
Crop characteristics					
H_2O content	Janzen et al. (2003)	Normal	±15%		Expert consultation
Relative DM allocation of residue (product, aboveground and belowground)					
$FRAC_{Renew}$ (duration)					
N concentration in residue (aboveground and belowground)					
Direct and indirect emission factors/modifiers					
P/PE regression parameters	Rochette et al., 2008	Normal	Intercept ±54% Slope ± 21%		Expert consultations
$FRAC_{LEACH}$ calculation parameters			Intercept ±54% Slope ±21%		
F_{TILL}			±100%		
$RF_{TEXTURE}$			±30%		
EF_{LEACH}	2006 IPCC Guidelines	Triangular	0.002–0.12	0.025	2006 IPCC Guidelines
EF_{VD}			0.002–0.05	0.01	
EF_{HIST}			2–24	8	
Provincial – Scale Parameters					
Fertilizer application rate (kg/ha)	Factors are drawn from common usage in AAFC[c] literature and modelling studies	Normal	±15%		Expert consultation
Provincial fertilizer sales	Statistics Canada	Normal	±15%		Interpretation of data quality evaluation in Statistic Canada Report
Ecodistrict – Scale Parameters					
P and PE	Weather Station Data	Normal	5–15%		Based on individual weather station data, 30-year average
Total ecodistrict area	AAFC[c] geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1990–2011	Normal	Function of Relative Ecodistrict Size: maximum uncertainty of 30% for small ecodistricts, decreases to minimum of 3% for largest ecodistricts, maximums and minimums vary depending on the parameter		Based on the uncertainty methodology used in the carbon quantification methodology for croplands
Crop areas					
Animal population distribution to ecodistrict					
FTOPO (proportion of lowland soils in ecodistrict)					
Extent of organic soils					
Irrigated soil area					
Annual soil texture					
Perennial soil texture					

Note:

a. Uncertainty associated with most livestock parameters can be found in section A3.4.2.4 and section A3.4.3.8, and the distributions used to define uncertainties can be found in Table A3.1–7 and Table A3.2–8.

b. Reported where applicable when using a triangular distribution.

c. Agriculture and Agri-Food Canada.

A3.4.7. CH_4 and N_2O Emissions from Field Burning of Agricultural Residues

Crop residues are sometimes burned in Canada, for convenience and as a means of disease control through residue removals, although expert opinion suggests that 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 A3.4–38

$$Q_{BURN} = \sum_{T} (PRODUCTION_T \times (1 - MOISTURE_T) \times RatioAR/P_T \times PCB_T \times RATIO_{SCALE})$$

Q_{BURN} = quantity of crop residue burned from crop T for each province, Mg dry matter yr^{-1}

$PRODUCTION_T$ = total production of crop T, Mg yr^{-1}

$MOISTURE_T$ = 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 = percent 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 collected in 2001 and 2006 by Statistics Canada through its Farm Environmental Management Survey (FEMS)[25] include crop residue burning. 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 are summarized in Table A3.4–36. To establish a complete time series of activity data, additional information on crop residue burning for 1991 and 1996 has been gathered through expert consultations (Coote et al., 2008). Thus, a crop that was subject to field burning in 2006 was also assumed to be subject to field burning for the entire time series.

The intensity of crop residue burning in each province for 1991, 1996 and 2001 was adjusted as a ratio based on the average burning for 2006. Janzen et al. (2003) report basic characteristics of crops, such as moisture content of crop product and ratio of aboveground crop residue to crop product. Annual production of each crop subject to residue burning is available (Statistics Canada, n.d. [h]).). Other parameters, such as fraction of biomass actually burned, and emission factors required for emission estimates, were obtained from the 2006 IPCC Guidelines.

N_2O and CH_4 emissions from crop residue burning are estimated using the following equation:

Equation A3.4–39

$$EMISSION_{BURN} = \sum (Q_{BURN,i} \times C_F \times G_{EF}) / 1000$$

$EMISSION_{BURN}$ = 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 burned from province i, Mg, dry matter yr^{-1}

C_F = fuel efficiency (IPCC, 2006), unitless

G_{EF} = emission factor (IPCC, 2006), 0.00007 kg N_2O or 0.0027 kg CH_4/kg of dry matter burned

1000 = converting Mg to kt

25 Available at http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5044.

Table A3.4–36 **Burning of Crop Residues by Crop Types in 2006**

	Spring Wheat	Winter Wheat	Oats	Barley	Mixed Grains	Flaxseed	Canola
	% of Crop Residue Burned (by Weight)						
AB	0	0	0	0	0	8	0
BC	0	0	0	0	0	0	0
MB	2	3	3	1	0	17	1
NB	0	0	1	0	0	0	0
NL	0	0	0	0	0	0	0
NS	33	0	0	0	0	0	0
ON	0	0	0	1	2	0	0
PE	3	0	0	1	0	0	0
QC	0	0	1	0	0	0	0
SK	0	0	0	0	0	15	1

Table A3.4–37 **Crop Residue Burning by Province in Canada for 1991, 1996, 2001 and 2006**

	1991	1996	2001	2006
	% of Crop Residue Burned (by Weight)			
AB	0.8	0.7	0.2	0.2
BC	0	0	0	0
MB	12.6	10.1	8.9	2.3
NB	0.5	0.5	0.5	0.5
NL	0	0	0	0
NS	0.5	0.5	0.5	0.5
ON	0.7	0.7	0.7	0.3
PE	0.4	0.4	0.4	0.4
QC	0.4	0.4	0.4	0.3
SK	8.1	5.8	3.9	1.5

Note:

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

A3.4.8. CO_2 Emissions from Liming and Urea Fertilization

A3.4.8.1. CO_2 Emissions from Liming

Limestone (C_aCO_3) is often used to neutralize acidic soils, increase the availability of soil nutrients, in particular phosphorus, reduce the toxicity of heavy metals 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 CO_2 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 of lime applied annually.

The amount of C released as a result of limestone application is calculated using the default IPCC Tier 1 approach (IPCC, 2006).

Equation A3.4–40

$$CO_2 - C\ Emission = \sum(M_{Limestone/dolomite,i} \times EF_{Limestone/dolomite})$$

$CO_2 - C\ Emission$ = annual C emissions from lime application, Mg C yr^{-1}

$M_{Limestone/dolomite,i}$ = annual amount of limestone and dolomite consumption in province i, Mg yr^{-1}

$EF_{Limestone//dolomite}$ = 0.12, limestone emission factor or 0.13 dolomite emission factor

The quantity of lime and dolomite used for agricultural purposes is not collected through the *Census of Agriculture* by Statistics Canada, but rather through Natural Resources Canada's *Canadian Minerals Yearbook* (1990 to 2006). For more recent years, this information is only available on request.[26] This data source provides a consistent and complete time series of activity data on agricultural lime consumption in Canada. As this data source provides no information on the ratio of dolomite to limestone, the ratio from data collected through consultation with the Canadian Fertilizer Institute was used.

The 95% confidence limits associated with annual lime consumption data were estimated to be ±30%. This uncertainty was assumed to include the uncertainty of lime sales, the uncertainty of when lime sold is actually applied, and thus the uncertainty in the timing of emissions. The uncertainty in the emission factor was assumed to be -50% based on the 2006 IPCC Guidelines.

A3.4.8.2. CO_2 Emissions from Urea Fertilization

When urea or urea-based nitrogen fertilizer is applied to soil to augment crop production, CO_2 is released upon hydrolysis as follows:

$$(NH_2)_2CO + H_2O \rightarrow NH_4^+ + OH^- + CO_2$$

In addition to urea, Canadian farmers also use significant amounts of urea ammonium nitrate (28-0-0) with a mixture of 30% $CO(NH_2)_2$. CO_2 emissions from urea fertilization can be estimated using Equation A3.4–41:

Equation A3.4–41

$$CO_2 - C\ Emission = \sum(M_{Urea,i} \times EF_{Urea})$$

$CO_2 - C\ Emission$ = annual C emissions from urea application, Mg C yr^{-1}

$M_{Urea,i}$ = annual amount of urea fertilization, Mg yr^{-1}

EF_{Urea} = 0.20, emission factor

Statistics Canada collects and publishes annual fertilizer shipment data, including urea and urea ammonium nitrate (Statistics Canada, n.d. [b]). The uncertainty estimate associated with the emissions is assessed based on simple error propagation using survey uncertainty of ±15% for the activity data and an uncertainty of -50% associated with the EF specified in the 2006 IPCC Guidelines.

26 [NRCan] Natural Resources Canada. 2007–2016. Canada, Production of Limestone – Stone. Unpublished data. Natural Resources Canada, Mineral & Mining Statistics Division.

A3.5. Methodology for the Land Use, Land-Use Change and Forestry Sector

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

As in Chapter 6, the structure of this annex attempts to maintain the land-based reporting categories, while grouping related data collection and estimate development methodologies. Section A3.5.1 summarizes the spatial framework for estimate development and area reconciliation. The general approach for estimating carbon (C) stock changes, emissions and removals in all forest-related categories, including Forest Land, Forest Land converted to other land uses and Land Converted to Forest Land, is briefly described in section A3.5.2; this description is not repeated under the Forest Land Converted to Cropland, Forest Land Converted to Wetlands and Forest Land Converted to Settlements subcategories. Section A3.5.3 describes the approach for estimating emissions associated with the use and disposal of harvested wood products (HWP) from wood harvested in Canada and section A3.5.4 describes the methods used to quantify the effect of management practices on agricultural land for the Cropland category. Likewise, the sections on the Grassland (A3.5.5), Wetlands (A3.5.6) and Settlements (A3.5.7) categories focus on category-specific estimation methodologies.

A3.5.1. 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. Differences exist in the spatial framework specific to each land category, and these differences create a risk that activity data and estimates would be spatially inconsistent. A hierarchical spatial framework was agreed upon by all partners contributing to the LULUCF sector to ensure the highest possible consistency and spatial integrity of inventory estimates.

The LULUCF sector of the GHG inventory reports information in 18 reporting zones (Chapter 6, Figure 6–1). These reporting zones are essentially the same as the ecozones of the National Ecological Framework, a hierarchical, spatially consistent national ecosystem classification (Marshall et al., 1999). For the purpose of reporting LULUCF estimates, three ecozones are split into smaller land units: 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. Land and water areas for each reporting zone are compiled according to McGovern (2014) and reported annually in Chapter 6.

Analysis units are the finest level of spatial resolution and are specific to each estimation system. In managed forests, the analysis units are the geographic intersection of reporting zones (Chapter 6, Figure 6–1) and provincial/territorial forest management units. For the purpose of this assessment, managed forests were classified into 607 analysis units across 12 provinces and territories; Nunavut was excluded because there is no managed forest area in this northern region (Table A3.5–1). Changes in the number of spatial analysis units may occur from one submission to the next and reflect refinements in the integration of multiple spatial layers. For example, the modification 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.

The most suitable spatial framework for GHG monitoring of cropland are the polygons of the Soil Landscapes of Canada[27] (SLC). A soil landscape describes a group of soils and their associated landscapes and provides information, such as surface form, slope, typical soil C content under native and dominant agricultural land use, and water table depth. Soil landscapes are spatially associated with SLC polygons (the analysis units) that may contain one or more distinct soil landscape components. SLC polygons are also the basic units of Canada's National Ecological Framework, a hierarchical, spatially consistent national classification system within

27 Available online at http://sis.agr.gc.ca/cansis.

Table A3.5–1 **Spatial Analysis Units of Managed Forests**

Province/Territory	Number of Analysis Units
Newfoundland and Labrador	24
Prince Edward Island	1
Nova Scotia	1
New Brunswick	1
Quebec	129
Ontario	52
Manitoba	70
Saskatchewan	40
Alberta	181
British Columbia	65
Yukon	13
Northwest Territories	30
Nunavut	0
Canada	**607**

which ecosystems of various scales can be described, monitored and reported on (Marshall et al., 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. SLC polygons span in the order of 1000 to 1 000 000 hectares (ha) and are appropriate for mapping at the scale of 1:1 million.

Analysis units for estimating the areas of forest converted to other land uses are the result of the spatial intersection of forest conversion strata (Figure A3.5–6) 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 analysis units to be as consistent as possible with respect to the patterns of forest conversion and large enough to provide an acceptable sample size, given the predetermined sampling rate.

The analysis units of different land-use categories can overlap. Most often, the exact location of events 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 (RUs), 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 level of analysis units during estimate development and at the level of RUs during estimate compilation.

A3.5.2. Forest Land and Forest-related Land-Use Change

A3.5.2.1. Carbon Modelling

The estimation of C stock changes, emissions from and removals by managed forests, forest conversion to other land uses and land converted to forest land is 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 dates back to the late 1980s (Kurz et al., 1992). The model integrates forest inventory information (stand age, area and species composition), curves of merchantable volume over age, equations to convert stand merchantable volume into total biomass, data on natural and anthropogenic disturbances, and simulations of C transfers between pools and exchanges with the atmosphere that are associated with ecosystem processes and various events.

The ecosystem processes modelled by the CBM-CFS3 to generate the estimates submitted in this report are growth, litterfall, 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 clear-cut, shelterwood harvest, seed tree harvest, selection harvest, commercial thinning, precommercial thinning, salvage logging, residential firewood harvest and the burning of harvest residues. Different practices of forest conversion are also simulated, including controlled burning.

The forest C pools represented in the CBM-CFS3 can be matched with the Intergovernmental Panel on Climate Change (IPCC) forest C pools (Table A3.5–2). Although not shown here, living biomass pools are further subdivided into two sets, for each of hardwood and softwood tree species.

Annual ecosystem process events are simulated as C transfers between C pools executed at each time step (annually) in every inventory record (Figure A3.5–1). During annual processes, C is taken up in the biomass pool and some biomass C is transferred to dead organic matter (DOM) pools. The decay of DOM results in C 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. (2009). Rates of C 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 either 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 Q_{10} 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. Each of the records (roughly 3 million) in the 607 analysis units of the forest inventory is associated with a yield curve that defines the dynamics of gross 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 between provinces and territories. Curve libraries for each province and territory in Canada are similar to those used by resource management agencies in the forest planning processes and are derived from permanent or temporary sample plots or from forest inventory information.

Conversion of gross 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.

Modelling of C transfers triggered by disturbances is 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 represented by a disturbance matrix, which specifies, for one or more disturbance types, the proportion of C in each ecosystem pool that is transferred to other pools, released to the atmosphere or transferred to Harvested Wood Products (Figure A3.5–2). In the current submission, the simulation uses a total of 191 disturbance matrices. The number of different disturbance matrices is dependent on the availability of activity data (e.g., the spatial and temporal resolution

Table A3.5–2 **Forest Carbon Pools in IPCC and CBM-CFS3**

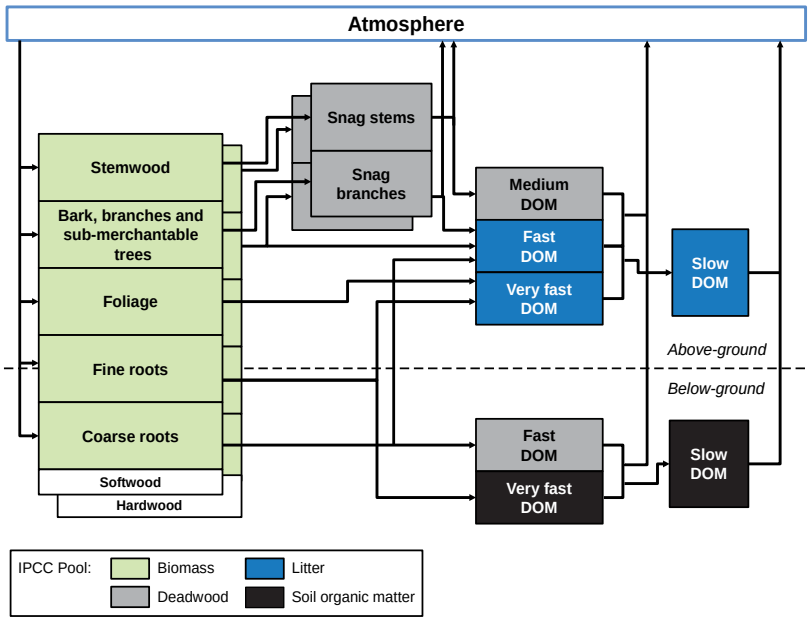
IPCC Carbon Pools		Pool Names in CBM-CFS3
Living Biomass	Above-ground biomass	Merchantable stemwood Other (submerchantable stemwood, tops, branches, stumps, non-merchantable trees) Foliage
	Below-ground biomass	Fine roots Coarse roots
Dead Organic Matter (DOM)	Deadwood	Above-ground fast Below-ground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

Notes:

a. Below-ground very fast pool includes dead and decaying fine roots, which in practice cannot be separated from soil.

b. Black carbon and peat are currently not estimated.

Figure A3.5–1 **Carbon Pools and Transfers Simulated by the CBM-CFS3**



Note: Source – White et al. (2008), updated

of disturbance data) and on the knowledge required to parameterize the matrices for more distinct regions or intensities of disturbance.

Within disturbed lands, the amount of C emitted as CO_2 from each pool at the time of disturbance, documented 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 C emitted in each C-containing GHG (CO_2, CO and CH_4) due to fire is constant: 90% of C is emitted as CO_2, 9% as CO and 1% as CH_4 (Cofer et al., 1998; Kasischke and Bruhwiler, 2003).

Carbon emissions emitted as CO oxidize in the atmosphere resulting in indirect CO_2 emissions. Amounts of C emitted as CO and indirect CO_2 are calculated by multiplying total C by, respectively, 28/12 and 44/12. More details on the reporting of these indirect CO_2 emissions can be found in Chapter 6 and Annex 7.

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

A3.5.2.2. Forest drainage

Forest drainage is used to lower the water table, thereby improving soil aeration and promoting root development and tree growth on low-productivity organic soils. A consultation with forestry industry experts and an extensive literature review carried out in 2015 and 2016 suggested that the only province in Canada where operational drainage of organic soils for forestry occurred was Quebec (Gillies, 2016). This management activity occurred from the 1980s through to the mid-2010s on a small percentage of peatlands corresponding to three RUs (11, 12 and 15) on both private and public lands. Forest drainage has progressively declined since 2003 due to the end of government subsidies and changes to Quebec's forest management tenure.

Data on forest drainage were compiled from a combination of historical documents, consultations and provincial statistics to develop a time series from 1980–2018 of annual peatland areas drained for forestry on both private and publicly owned forests of Quebec. Provincial statistics (Gouvernement du Québec, 2018) were reported by administrative region (AR) for 1994–2008 and by province for 1986–1993 and for 2009–2017. Drainage data for 1980–1985 were assumed to be constant, resulting in a cumulative area drained equivalent to the 1986 value reported by Quebec statistics, which was also consistent with values cited in

Figure A3.5–2 **Disturbance Matrix Simulating the Carbon Transfers Associated with Clear-Cut Harvest and Salvage Logging Applicable in All Ecozones Except Those in Alberta and Quebec**

	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-merchantable			1							
5. Softwood coarse roots			0.5	0.5						
6. Softwood fine roots	0.5	0.5								
7. Hardwood merchantable					0.15					0.85
8. Hardwood foliage	1									
9. Hardwood other			1							
10. Hardwood sub-merchantable			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	

Hillman (1987). Given the absence of drainage activity data for 2018 (Gouvernement du Québec, 2018) and the fact that there were no areas drained in 2016 and 2017, drained areas were assumed to be zero after 2017. Estimates of drained areas by AR (1994–2008) were allocated to the three RUs by overlaying the AR to create a spatially weighted area average that was applied to the provincial values for all years.

Emissions of CO_2, CH_4 and N_2O from drained organic soils were calculated using a Tier 1 method and emission factors from Tables 2.1, 2.2 and 2.3, respectively, of the 2013 Wetland Supplement to the 2006 IPCC Guidelines (IPCC, 2014). Emission factors are associated with the temperate (RUs 11 and 12) and boreal (RU 15) climate zones. The fraction of area covered by ditches was also determined using the default values for drainage ditches from Table 2.3 of the 2013 Wetland Supplement (IPCC, 2014).

A3.5.2.3. Data Sources

Managed Forest Land

Canada's forests are classified as "managed" or "unmanaged" based on the occurrence of management activities for timber or non-timber and on the level of protection against disturbances (Figure A3.5–3). Managed forests occur within all provinces and territories of Canada, with the exception of Nunavut (Figure A3.5–4). 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 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. (2011).

The model tracks managed forest lands disturbed by harvesting before and after 1990, lands affected by various natural disturbances since 1990 and lands not affected by any disturbances since 1990. Lands not affected by disturbances since 1990 are broken down into stands originating after harvesting or following stand-replacing wildfires prior to 1990. All areas of land in 1990 that were not identified as being of harvest origin were assumed to be of wildfire origin (given that insect disturbances are not stand replacing). These distinctions are used to separate stands dominated by anthropogenic and natural emissions and removals (see section A3.5.2.4).

Forest management activities are documented in the National Forestry Database[28] and additional information on specific activities is obtained directly from provincial and territorial forest management agencies. The Canadian provincial and territorial governments, whose jurisdiction includes natural resource management, provide essential information—notably detailed forest inventory data, details on forest management activities and practices, disturbance information including prevention or control, regional yield tables (volume / age curve), site indices—and regional expertise (Table A3.5–3). The forest inventory data in Canada's National Forest Inventory

28 National Forestry Database, available online at http://nfdp.ccfm.org/en/index.php.

Figure A3.5–3 **Decision Tree for the Determination of Managed Forest Area**

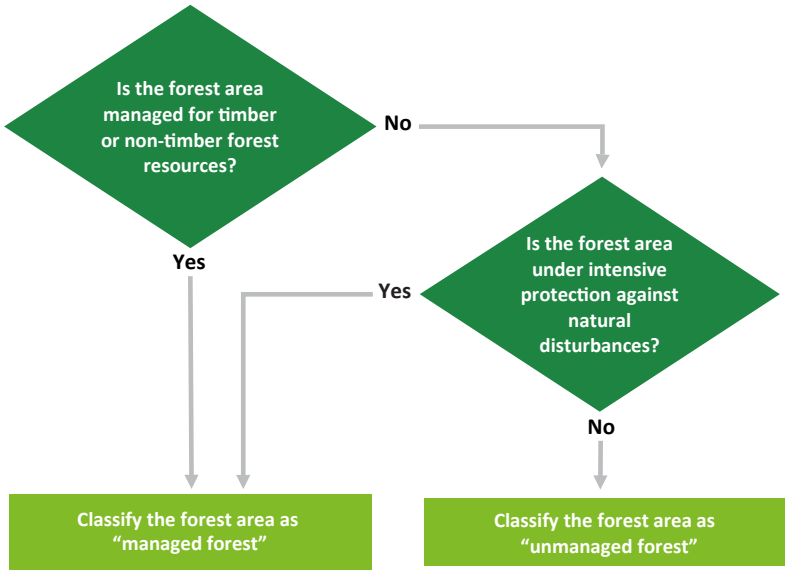


Table A3.5–3 **Main Sources of Information and Data, Managed Forests**

Description	Source	Spatial Resolution	Temporal Coverage	Reference
Climate data	CFS	Analysis units	1961–1990 normals	McKenney et al., 2001
Forest inventories and merchantable volume data[a]	Canada's National Forest Inventory (CanFI)	CanFI grid cell	1949–2004	https://nfi.nfis.org/index.php
	Newfoundland	Analysis units	1991–2006	Provincial experts
	Prince Edward Island	Analysis units	2000	Provincial experts
	Nova Scotia	Analysis units	2006	Provincial experts
	Quebec	Analysis units	2000	Provincial experts
	Ontario	Analysis units	2000	Provincial experts
	Alberta[b]	Analysis units	1949–1999	Provincial experts
	British Columbia	Analysis units	2011	Provincial experts
Conventional harvest data[c]	National Forestry Database	Provincial boundaries	1990–2018	http://nfdp.ccfm.org/
	National Forestry Database	Analysis units	1990–2016	http://nfdp.ccfm.org/
Slash burning	National Forestry Database and British Columbia	Provincial boundaries	1990–2018	Provincial experts and http://nfdp.ccfm.org/
Residential firewood harvest data	Energy Sector data for residential firewood use	Reconciliation Units	1990–2019	Sections A3.1.4.1.4 and A3.5.3
Insect data	Forest Insect and Disease Survey	Spatially explicit	1990–2017	Atlantic Forestry Centre and Pacific Forestry Centre
	Newfoundland	Spatially explicit	2000–2003	Provincial experts
	Quebec	Spatially explicit	1985–2018	Provincial experts; https://www.donneesquebec.ca/recherche/fr/dataset/donnees-sur-les-perturbations-naturelles-insecte-tordeuse-des-bourgeons-de-lepinette
	Manitoba	Spatially explicit	1985–2019	Provincial experts and provincial forest health aerial overview surveys; National Forest Pest Strategy Information System
	Saskatchewan	Spatially explicit	1985–2019	Provincial experts; National Forest Pest Strategy Information System
	Alberta	Spatially explicit	1985–2019	Provincial experts; Alberta Forest Health Aerial Overview
	British Columbia	Spatially explicit	1990–2019	Provincial experts; BC Forest Insect and Disease Survey; BC Aerial Overview Survey
	Yukon	Spatially explicit	1994–2005	Provincial experts; Yukon Forest Health Aerial Overview
	Northwest Territories	Spatially explicit	1985–2019	Provincial experts; Northwest Territories Forest Health Survey
Fire data	National Burned Area Composite	Spatially explicit	2004–2018	http://www.nrcan.gc.ca/node/13159
	Canadian National Fire Database	Spatially explicit	1959–2003	http://www.nrcan.gc.ca/node/13159
Drainage data[d]	Quebec	Province of Quebec boundaries	1980–1985	Provincial experts; historical records; Hillman, 1987; Gillies, 2016
	Ministère des Forêts, de la Faune et des Parcs du Québec	Province of Quebec boundaries	1986–1994	https://mffp.gouv.qc.ca/les-forets/connaissances/statistiques-forestieres
	Ministère des Forêts, de la Faune et des Parcs du Québec	Administrative regions of Quebec	1994–2008	https://mffp.gouv.qc.ca/les-forets/connaissances/statistiques-forestieres
	Ministère des Forêts, de la Faune et des Parcs du Québec	Province of Quebec boundaries	2008–2018	https://mffp.gouv.qc.ca/les-forets/connaissances/statistiques-forestieres

Notes:

a. Forest inventory B5:F36 and merchantable wood volume yield data were obtained from Canada's National Forest Inventory and/or from provincial experts where specified.
b. Alberta's forest inventory database comprises provincial forest inventory for the province's Forest Management Areas, and CanFI inventory for the remainder of the managed forest landbase.
c. Given the absence of complete harvest data for the most recent reporting year for all provinces and territories, 2019 harvest data are estimated by assuming them to be equal to 2018 values.
d. No new drainage activity has been registered in the Province of Quebec since 2016.

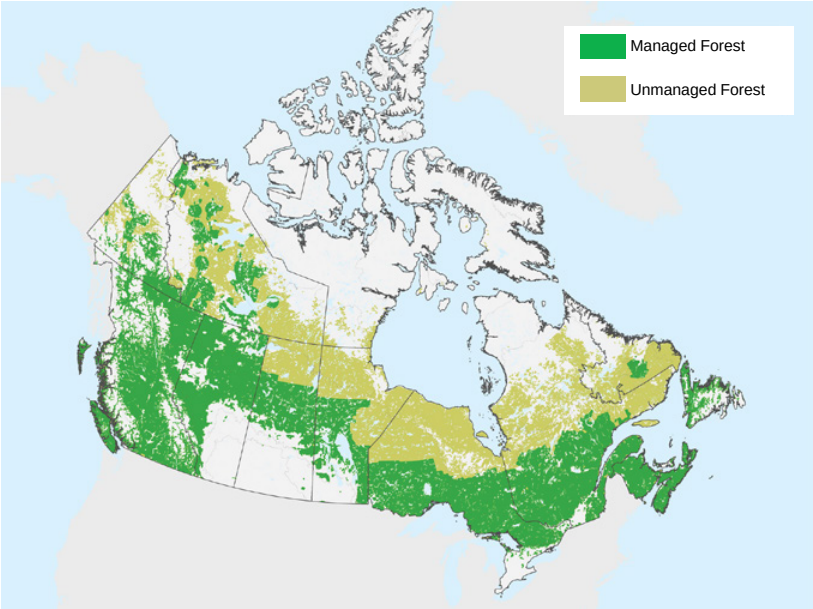
(CanFI 2001) were used for New Brunswick, Manitoba, Saskatchewan, Yukon and the Northwest Territories. More recent and higher-resolution inventory data were provided by Prince Edward Island, Newfoundland and Labrador, Nova Scotia, Quebec, Ontario, British Columbia and Alberta. A series of "method papers" 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., 2011).

Activity data for the burning of harvest residues ("slash") are obtained from the National Forestry Database for all regions except specific areas of British Columbia where expert opinion is used.[29]

Collection of firewood for residential heating is a common practice in Canada, with an estimated 93% of annual firewood taken from forested lands and the rest from agricultural woodlands and urban trees. Improvements implemented in this inventory submission to estimate the

29 In British Columbia, expert opinion indicates that the proportion of areas harvested using clear-cut where slash burning is applied is 15% on the coast and 50% for the rest of the province.

Figure A3.5–4 **Lands with Managed and Unmanaged Forests in Canada**



impact of this activity on the C balance of Canadian forests include the development of a set of rules to disaggregate these volumes into several components (Hafer et al. 2020, Doyon et al., 2019): softwood, hardwood and mixedwood collected from the forested lands, woody biomass collected from croplands, urban trees from settlement lands, pellets and manufactured logs (the latter four components modelled under Harvested Wood Products, see A3.5.3). For the forested-land target components and based on survey data, a list was developed for the spatial analysis units within each RU from which the firewood to be collected should be taken.

Regional firewood harvest practices in Canada and regionally-differentiated disturbance matrix parameters were implemented in the CBM-CFS3 model for three conceptual "firewood collection zones": (i) Mixedwood-Acadian (MWA), comprised of the Atlantic Maritime and Mixedwood Plains ecozones; (ii) agricultural (AGR), comprised of the Subhumid- and Semi-arid Prairie ecozones; and (iii) boreal-montane (BOR), comprised of all other forest ecozones. Firewood collection in both the MWA and AGR zones is assumed to be via light thinning (30% removal), while firewood collection in the BOR zone is assumed to be via clear-cut harvesting (85% removal). Inventory records selected for firewood collection are disturbed in decreasing order of total snag content, to ensure that a reasonable (though unspecified) proportion of the firewood is collected as dead wood

Data on biomass used as residential firewood are obtained from surveys of residential wood use and origin. Sections A3.1.4.1.4 and A3.5.3 of the present report provide additional information on these surveys and the methodology used to convert the consumption and use data collected to volumes of firewood. Areas specifically attributed to firewood harvest are defined by the model based on those volume estimates.

Areas disturbed by wildfires were extracted from the Canadian National Fire Database for the years 1990 to 2003 and from the Canadian Wildland Fire Information System's National Burn Area Composite (NBAC) for the years 2004 to the current inventory year (Table A3.5–3). The NBAC is a composite of low- and medium-resolution remote sensing data and fire mapping data prepared by the Canadian Forest Service and combined with data provided by resource management agencies from across Canada. The NBAC provides complete mapping of wildfires using medium-resolution remote sensing data when available; data from resource management agencies are given second priority; and low-resolution remote sensing data are used only where no other fire mapping data are available.

Insect disturbances are monitored by aerial surveys (Table A3.5–3), which record the area impacted by the disturbance and assign an impact severity class that indicates the degree of tree mortality or defoliation. The area of impact is assigned to the appropriate analysis unit and host species within it, and the severity of the impact is reflected in the parameters of the disturbance matrix applied (Kurz et al., 2009).

Areas drained for forestry (Table A3.5–3) on private and publicly owned forests in Quebec are estimated using historical documents, consultations and Quebec statistics. Spatial allocation by RU was performed using Quebec statistics.

A3.5.2.4. Quantifying Anthropogenic Emissions and Removals

Interannual variations and trends in emissions and removals from managed forests in Canada are dominated by the impact of wildfires and periodic forest insect outbreaks, making it difficult to detect trends due to human actions in the forest (Kurz et al., 2008a,b; Stinson et al., 2011; Kurz et al., 2013).

The IPCC does not currently provide default methods for separating anthropogenic emissions and removals from those occurring due to natural disturbances, although it has recognized the issues of reporting emissions from natural disturbances for some countries (IPCC, 2010). Furthermore, the IPCC (2010) has encouraged countries that use Tier 3 methodologies to work towards the development of new approaches that can improve the identification of anthropogenic emissions and removals. The CBM-CFS3 model now has the capability to track and separate emissions and removals in managed forest stands dominated by the impact of anthropogenic activities from those in which emissions and removals result from a significant natural disturbance that has masked the legacy of human management and affected the commercial value of the stand.

The management and natural disturbance history of each individual stand (inventory record) in the managed forest area is used to assign stands to two groups. Emissions and removals are identified as being anthropogenic when (i) a stand's growth trajectory has been significantly modified by human intervention—this definition includes commercial clear-cut and partial harvest, commercial and pre-commercial thinning, salvage logging, site preparation, and rehabilitation and planting on stands that have undergone both stand replacement and partial natural disturbances; and (ii) regardless of its origin, a stand has attained commercial maturity and therefore is actively considered within forest management planning scenarios (eligible to be scheduled for harvest). Once a stand originating from natural disturbance has reached this age, emissions and removals are switched to the reported category.

In contrast, emissions and removals resulting from natural disturbance are defined as originating from (i) stands that have been affected by a stand replacing natural disturbance up to the period that stands reach commercial maturity, or (ii) stands that have been affected by partial disturbance resulting in reduced standing biomass until that stand has attained pre-disturbance equivalent biomass. Only partial disturbances causing more than 20% mortality are included in the natural disturbance category.

In the initial implementation of this approach in the 2017 NIR, a fixed value of 60 years was assumed to be generally applicable to represent a minimum return period to commercial maturity across Canada. Since the 2018 NIR, regionally specific return periods based on differences in forest management practices, species distributions and stand dynamics among regions have been used.

To develop regionally representative definitions of commercial maturity, a questionnaire was distributed to provinces and territories in March 2017. The objective of this consultation process was to document forest management practices across Canada, with a focus on the treatment of naturally disturbed forest stands in operational planning. As such, work with provincial experts provided a minimum return period to commercial maturity ranging from 45 to 99 years, with an average of 76 years. In most cases, provincial agencies defined species-specific commercial maturity based on the maximum mean annual increment of species-specific yield curves for a high productivity site class in a given region. Other provincial agencies used empirical data based on observed regional minimum harvest ages or an age to achieve a specific piece size. Based on the species-specific commercial age, a weighted minimum return period was determined for each reporting zone using the proportional breakdown of the commercial species that were attributed a minimum operable age, or minimum harvest age, in that area. Greater detail on the methodological approach used to track anthropogenic emissions and removals can be found in Kurz et al. (2018).

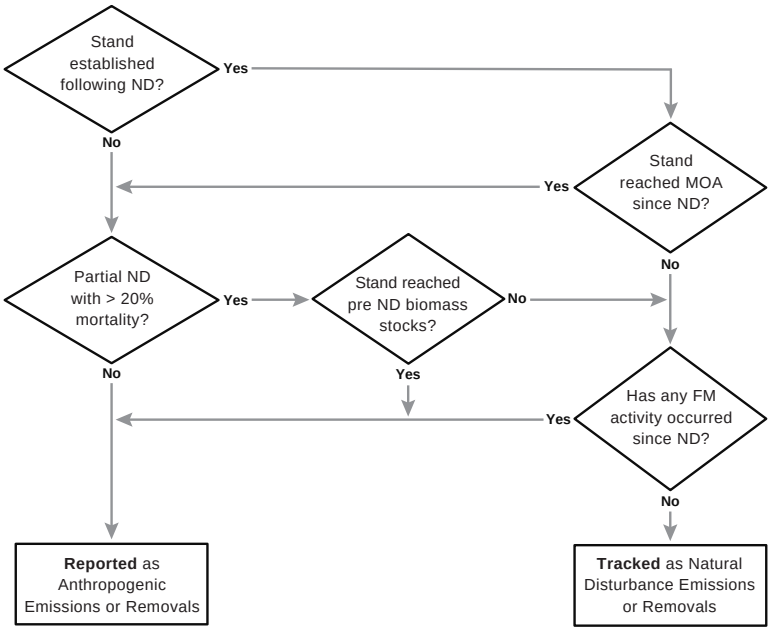
In the current modelling framework, partial natural disturbances occur mainly due to insect infestations. In these cases, above-ground biomass recovery was used to define a recovery period, as the growth trajectory of the stand is only temporarily modified. Stands subject to insect disturbances causing less than or equal to 20% biomass mortality are not deemed to be dominated by natural disturbances; at this low mortality level, disturbances are considered agents that contribute to stand density reductions.

This improvement in the reporting approach ensures that emissions from stands affected by uncontrollable natural disturbances and the subsequent removals by the regrowth of these stands are tracked separately from commercially managed stands. This allows for improved differentiation of emissions and removals associated with direct forest management actions from non-anthropogenic emissions and removals occurring due to natural disturbances.

Tracking stands in which emissions and removals are dominated by natural disturbance dynamics is carried out by querying model results based on a decision-tree approach in which key decision points are based on stand origin, type of disturbance (partial or stand replacing) and an annual assessment of post-disturbance status, either commercial maturity threshold or pre-disturbance biomass (Figure A3.5–5).

After exclusion of the non-anthropogenic emissions and removals, the final reported values represent all forest stands in the managed forest land base that have attained commercial maturity or have had their growth

Figure A3.5–5 **Decision Tree for Differentiating Emissions and Removals from Anthropogenic and Natural Origin**



Notes: ND = Natural disturbance, MOA = Minimum operable age, FM = Forest management.

trajectory modified by a direct anthropogenic management action in the forest. The area temporarily excluded from reporting in any given year remains relatively constant, within a variation of +2.9/-3.6 million hectares (Mha), as stands undergoing natural disturbance in a given year are removed from reporting and lands that were disturbed historically re-enter reporting. The sum total of each of the stand categories included and excluded is equivalent to the sum of emissions and removals quantified using the methodological approach for reporting total emissions from the managed forest in previous inventory submissions.

A3.5.2.5. Forest Conversion

In order to account for long-term residual effects of forest conversion, conversion rates were estimated starting in 1970. The approach for estimating forest areas converted to other land 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 been implemented across the country.

The core method involves remote sensing mapping of forest conversion based on samples from Landsat images dated circa 1975, 1990, 2000, 2007, 2011 and 2016. 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 whether the land cover of the candidate event was initially forest (at Time 1) and the actual land-use change at Time 2 (Leckie et al., 2002, 2010b). This forest conversion interpretation process is strongly supported by additional spatial 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; Dyk et al., 2015). 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 forest type, maturity and density prior to forest conversion is interpreted,[30] 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

30 See Chapter 6 for the definitional parameters of "forest."

range from complete mapping to systematic sampling over the entire analysis unit of interest to a representative selection of sample cells within a systematic grid. For example, in populated areas of southern Quebec, in the Prairie fringe and in British Columbia a 12% sampling rate in earlier time periods was generally achieved, with 3.5 km by 3.5 km sample cells at the nodes of a 10 km by 10 km grid (Figure A3.5–7). A lower sampling rate is used in some of the forest activity zones characterized by low population density, where the main economic activities are forestry and other resource extraction. Special cases of known, localized and large forest conversion activities are 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 A3.5–6), with spatially complete mapping.

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 a large portion of the Canadian land base, approximately 346 Mha. This total area was mapped over different time periods, of which over 17 Mha were mapped for 1975–1990, 41 Mha were mapped for 1990–2000, 22 Mha were mapped for 2000–2008, 23 Mha were mapped for 2008–2013 and 15 Mha were mapped for 2013–2018 (Figure A3.5–6). Mapping is updated on a roughly five-year time cycle for both the sampling and individual larger events and may be integrated progressively by project for the most recent time period.

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 sometimes used to aid in the validation of estimates made through image interpretation. In particular, early mapping for British Columbia used records data to provide estimates of conversion activity for power lines and oil and gas activity. Remote sensing image interpretation is used to assess the areas of forest converted as a result of hydroelectric development.

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 each sequential mapped time period (i.e., 1975–1990, 1990–2000, 2000–2008,and the most recent time periods are measured on a circa 5 year cycle) area estimate. 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., 2010a; Dyk et al., 2015). For most estimates now—and certainly for those with large impact—estimates are derived directly from remote sensing samples.

Figure A3.5–6 **Forest Conversion Strata and Areas Sampled in 2013–2018**

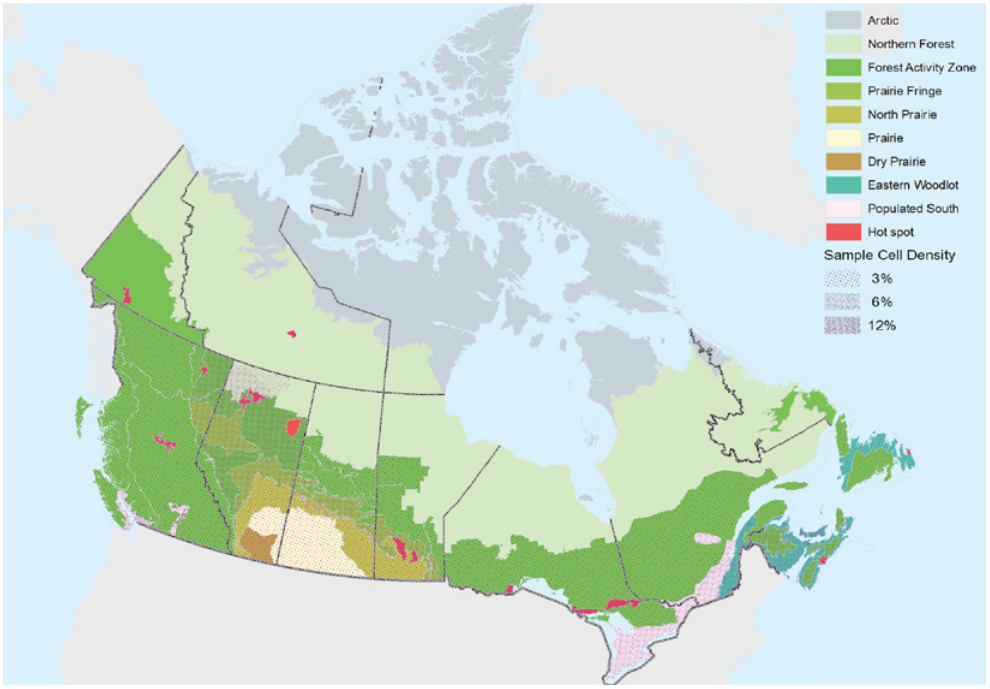


Figure A3.5–7 **Three Sampling Rates over Satellite Imagery for Forest Conversion Mapping**

Note: Background imagery: Area near Fort Nelson, British Columbia (ESRI World Imagery). Denser grid cells at the center represent a 12% sampling density; lighter grid on the right is 6% intensity and sparse grid on the left is 3% intensity.

The activity data are compiled and summarized initially by analysis unit. All conversion events are assembled into a database. A compilation is made to summarize events for detailed post-conversion classes for each RU. 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 forest conversion rate (ha/year) based on the time interval between the images. Since the available imagery was not necessarily dated a specific year, the rates cover different time periods. At the data compilation phase, forest conversion events are assigned a time period, 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 categories when recompiled by RU.

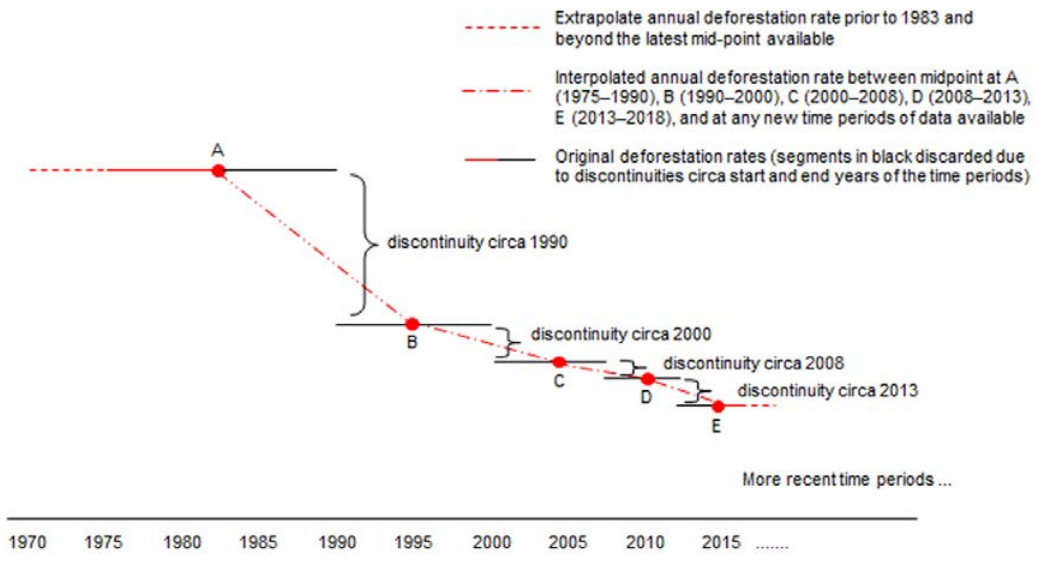
The remote sensing data are derived using medium-resolution imagery from circa 1975, 1990, 2000, 2007, 2011, 2016 and more recent years as new imagery has become available, whereas records data are annual or summarized over time periods. As explained, the remote sensing core method provides, to date, five distinct average rates of forest conversion for the mapped time periods, but no annual estimates of these rates. The preparation of annual forest conversion rates for 1970 to the current inventory year requires the simultaneous application of two procedures: (i) extrapolation of annual rates prior to 1983 and beyond the mid-point of the latest time period available, and (ii) linear interpolation between the mid-points in the mapped time periods and recent analyses that are completed at the time of submission (Figure A3.5–8). Added to the interpolated data are individual large events for which actual disturbance information is known either from records information or a detailed mapping activity. One example of this would be the case of hydroelectric reservoirs.

Quality Assurance / Quality Control 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., 2010b; Dyk et al., 2015), 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 and 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., 2015).

Figure A3.5–8 **Procedure for Developing a Consistent Time Series of Rates of Forest Conversion**



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 each new submission (Dyk et al., 2015). 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 earlier estimates, current estimates benefit from several years of experience and knowledge gained through the development of previous estimates (Leckie, 2011; Dyk et al., 2015). Specific improvements include:

- expanded data sets with additional Earth observation (EO) data, Landsat, Sentinel 2, SPOT-5, aerial photography and high-resolution satellite imagery
- expansion of the sampled area for targeted and other areas
- analysis and validation of records data with high-resolution imagery (for example, co-disturbance of pipelines and access roads)
- extension of the temporal coverage to the most recent time period
- review of the 1970–2004 deforestation time series based on more current spatial analysis
- 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 the forest type being converted, 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 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 forest conversion rates for each RU 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 down the uncertainty into subcomponents and then combines them 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 post-2000 time periods, commission errors are likely to be greater than omission errors, particularly because of an insufficient post-disturbance time lapse to confirm that areas are in fact permanently deforested.

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/RU). The sampling process is a mixture of wall-to-wall mapping and systematic sampling. In some areas, the sample coverage and design differed between all of the mapping periods. 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 (Leckie et al., 2015). 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.

The ±30% range is an overall estimate considering all time periods, regions and forest conversion 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, or 10 years for reservoirs (land areas reported in the CRF tables).

A3.5.2.6. Land Converted to Forest Land

Records of land conversion to forest land in Canada were available for 1990–2002 from the Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) 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 was included for 2004 and 2005, and an environmental scan was performed to identify additional sources of information on afforestation rates from 2000 to 2008. Additional afforestation activity data were obtained through a data sharing agreement with Forests Ontario. A validation exercise on Forests Ontario plantation sites (5 456 spatially-explicit planting records covering 12 466 ha) resulted in 10 390 ha being classified as afforestation events from 2007 to 2016.

Each event, regardless of date, source, type or location, was converted to an inventory record for the purposes of C modelling. All events were compiled in a single data set of afforestation activity in Canada from 1970 to 2016. For 1990–2016, the area planted was stratified by ecozone, province and tree 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 RU.

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. Growth curves for the Forests Ontario plantation sites were developed using the Forest Vegetation Simulator-Ontario (Woods and Robinson, 2007), which is a variant of the United States Forest Service's simulator adapted for use in Ontario. 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. It was assumed that no woody biomass is present on the site prior to afforestation. Changes in soil C stocks are highly uncertain. It was assumed that the ecosystem would generally accumulate soil C 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 is minimal.

A3.5.2.7. Estimation of Carbon Stock Changes, Emissions and Removals

At the beginning of each annual time step and when an afforestation or forest conversion event is processed, the CBM-CFS3 first assigns the new land-use classification before the impacts of that event are recorded to ensure that the impacts of land-use change (conversion to forests and conversion of forests) are reported in the new land category. 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 simulates forest growth, litterfall and turnover, and decomposition as well as the associated C transfers (annual processes) for all records (managed forest, land converted to forest and land converted from forest), including both stocked and non-stocked stands. The model output consists of C stock changes, fluxes and immediate emissions from

burning from which the net GHG balance of managed forests can be calculated. Component fluxes include growth, immediate emissions due to disturbances (C stock changes, C 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 outputs are available on converted forest lands (except tree growth), but are reported in the new land category—e.g., the Forest Land Converted to Cropland (CRF Table 4.B subcategory 2.1), Land Converted to Wetlands (CRF Table 4.D subcategories 2.1 and 2.2.1) and Forest Land Converted to Settlements (CRF Table 4.E subcategory 2.1) categories. Exceptions consist of estimates of soil organic matter emissions on forest land converted to cropland and peat extraction fields, which are developed separately; methods are described in sections A3.5.4.3 and A3.5.6.1. Likewise, estimation methods for emissions (as opposed to C stock changes) from forest land converted to flooded lands are described in section A3.5.6.2 and for emissions from the use and disposal of forest products are described in section A3.5.3.

A3.5.2.8. 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 and 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.

The general approach to uncertainty assessment emphasizes model inputs and parameters as the main sources of uncertainty. The specific uncertainty sources are forest inventory data, influential model parameters and the initialization of soil and DOM C stocks prior to model runs. Additional randomization steps are also fed into the development of confidence intervals, by randomly selecting 10 000 bootstrap samples of the output from 100 national-scale Monte Carlo runs (Metsaranta et al., 2017). Not all sources of uncertainty have been captured. Importantly, the analysis did not consider the impact of processes that are currently not simulated (Kurz et al., 2013); hence, the results should not be used to assess potential bias (or accuracy) of estimates. 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 is assumed. In addition to managed forest areas, it incorporates 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 forest C dynamics as a whole. Disturbances affect emissions and removals of C in the short term as well as in the long term through residual decay and age-class distribution. Uncertainties of 10% and 25% are assumed on the areas of managed forests subject annually to wildfires and insect infestations, respectively. The limited total forestry drainage area suggests that the impact of the uncertainty associated with this activity is minimal.

The uncertainties about the C removed in harvested material are regionally specific and incorporate error ranges in harvested volume (±1%) and standard deviations about roundwood-specific gravity and the bark adjustment factor (Table A3.5–4). No error was assumed for the C proportion of biomass. The annual coefficient of variation was multiplied by 2 to approximate a normal distribution with a triangular one.

Table A3.5–4 **Uncertainty Ranges for Harvested Carbon, by Canadian Province and Territory**

Province or Territory	Minimum Multiplier	Maximum Multiplier
Newfoundland	0.96	1.04
Prince Edward Island	0.88	1.12
Nova Scotia	0.88	1.12
New Brunswick	0.92	1.08
Quebec	0.86	1.14
Ontario	0.92	1.08
Manitoba	0.86	1.14
Saskatchewan	0.92	1.08
Alberta	0.90	1.10
British Columbia	0.92	1.08
Yukon	0.84	1.16
Northwest Territories	0.74	1.26

Note:
Source – Metsaranta et al. (2014)

The assessment also provides uncertainties about emissions due to forest conversion that are subsequently used in Tier 1 uncertainty reporting for national estimates in conjunction with the 30% uncertainty for areas converted annually equally used in this analysis. The "Forest Conversion" section of this annex describes the derivation of this value (see A3.5.2.5).

Soil and DOM pools contain a considerable amount of C. Previous work has 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 C emissions from the DOM 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 C 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 are 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 are triangular. A gamma probability distribution function is used for fire intervals (Metsaranta et al., 2014).

It is thought that significant uncertainty in the modelling framework may result from the random selection of forest stands subject to fire and deforestation disturbances (Kurz et al., 2008b), which interacts with the uncertainty about forest inventory data. The random effect of stand selection algorithms is 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 by the pre-conversion standing C stocks, the parameters of the disturbance matrices that reallocate C among pools or "release" it to the atmosphere and the post-conversion decay rates. Hence, uncertainties about estimates cannot be obtained from a simple combination of "activity data" and "emission factor" uncertainties.

Uncertainty estimates are developed for both reported emissions and removals representing anthropogenic drivers and non-reported emissions and removals due to natural disturbances. In years where there are no substantial changes, no comprehensive uncertainty analysis using Monte Carlo simulation is performed. Instead, confidence intervals for each category for the current year of submission are statistically extrapolated for both forest and HWP estimates. These extrapolations use the results of the previous submission, where numerical estimates of uncertainty were derived using Monte Carlo simulations as explained above and further described in Metsaranta et al. (2017; 2020). Total uncertainty estimates are allocated to the reported and non-reported categories using the same categorization procedures used to estimate reported and excluded values (see section A3.5.2.4).

Additional considerations may be warranted to identify the direct human-induced effects, and their uncertainties, on forest C dynamics. Improvements are expected to occur over coming years, due to better knowledge, refined procedures, improved computer software implementations and access to more computing capacity.

A3.5.3. Harvested Wood Products

The LULUCF sector of the inventory includes an estimate of the CO_2 emissions associated with the use and disposal of HWP manufactured from wood resulting from forest harvest, forest conversion and firewood collection activities in Canada and consumed either in Canada or elsewhere in the world, in accordance with the general framework of the Simple Decay Approach, as described in the Annex to Volume 4, Chapter 12, of the 2006 IPCC Guidelines (IPCC, 2006). The approach is similar to the Production Approach, but differs from it in that the HWP pool is treated as a C transfer related to wood harvest and hence does not assume instant oxidation of wood in the year of harvest. The approach tracks the fate of C in all woody biomass harvested domestically and taken off-site. Emissions of CO_2 from HWP use and disposal are estimated and reported by the LULUCF sector, while CH_4 and N_2O emissions from HWP combustion or domestic decomposition are estimated and reported by the Energy and Waste sectors.

General Approach and Methods

A country-specific model, called the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP), was developed to estimate and report on the fate of C harvested in Canada's forests.

Model Inputs and Data Sources

Input to the model includes the annual mass of C transferred to forest products that result from conventional forest harvesting and residential firewood harvesting in forest lands and from forest conversion activities since 1990. It is spatially distributed by RUs (see section A3.5.1), as calculated by the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3, see section A3.5.2.1), thus ensuring there are no gains or losses as C flows from forests to products.

Data on the annual volume of residential firewood and industrial wood waste used for bioenergy are provided by the Energy sector. In the case of residential firewood, the consumption data were collected through a survey of residential wood use for the years 1997, 2003, 2007, 2015 and 2017 (Statistics Canada 1997, 2003, 2007, 2015, 2017). Pellet and manufactured log consumption data were collected for the years 1996, 2006, 2012, and 2017 (Canadian Facts 1997; TNS 2006, 2012; Statistics Canada, 2017). These data were collected only for the provinces (i.e. not for the territories) and grouped into eight major appliance-type categories: fireplaces, fireplace inserts, wood stoves, wood furnaces, pellet stoves, hydronic heater, water heater and other equipment. The 2017 survey also collected data on the type of wood used for firewood that was spatially aggregated by RU (Trégaro, 2020). As a result, species-dependant wood densities could be applied (Blondel and Tracey, 2018) which were maintained constant throughout the time series. The 2017 also collected pellet and manufactured log consumption data on a mass basis. These data were interpolated and extrapolated to other years using the number of heating degree days in each province in relation to the survey years (see section A3.1.4.1.4 for more details on these surveys). Data on firewood consumption for the territories come from fuelwood and firewood harvest statistics provided by the National Forestry Database[31] and data on industrial consumption of fuelwood (biomass and spent pulp liquors) come from the annual *Report on Energy Supply and Demand in Canada* (RESD).

For historical harvest, the C input comes from commodity production data from Statistics Canada at a national level of spatial resolution and covering the 1941–1989 period. For the 1900–1940 period, the C inputs are backcast based on historical production data by extrapolating information from the 1941–1989 period, while the consumed and exported magnitudes are calculated using average proportions from statistics in the five-year period from 1961 to 1965.

Model Flow and Parameters

The model uses a conceptual flow network describing the movement and transformation of harvested wood. (Figure A3.5–9). The model takes the C inputs and, in annual time steps, exports some of the harvested roundwood, converts all harvested wood into commodities (sawnwood and other-industrial roundwood, wood-based panels, pulp and paper, pellets and manufactured logs used for bioenergy, and residuals referred to as "milling residue"), exports some of the commodities produced, and keeps track of the additions to and retirements from HWP in-use and used for bioenergy. The complete model consists of 15 such networks—one for each province and territory (except Nunavut), plus one each for the United States and Japan, and one that combines all other importers of Canadian wood products. The on-site decay of harvest residues continues to be captured in C stock changes in the DOM pool of the Forest Land category.

Recent statistics available in the FAO databases of Forestry Production and Trade[32] and Forestry Trade Flows[33] were used to determine the proportion of Canadian roundwood and commodity production exported to three main destinations. For example, according to current statistics from the FAO, in any given year, around 98% of industrial roundwood from domestic harvest remains in Canada for further transformation, of which about 70% is converted to sawnwood, wood-based panels, other industrial roundwood or pulp and paper products. Likewise, over the entire time series, around 33% of sawnwood, between 19% and 65% of wood-based panels and less than 13% of pulp and paper are used domestically. The proportion of HWP transferred out of the in-use pool is determined through the application of Equation 12.1 from the IPCC 2006 Guidelines (IPCC, 2006). Upon being retired from the in-use pool, all C is assumed to be instantly oxidized. Emissions from residential firewood use and industrial processes flowing from milling residue (e.g., industrial bioenergy) have been represented separately to prevent any potential overlap with estimates reported by the Energy sector.

Manufacturing efficiencies determine the proportion of industrial roundwood biomass converted into commodities—the unused fraction being milling residue. These proportions are calculated using a mass-balance approach that reconciles domestic harvest with FAO data on commodity production and trade. Manufacturing efficiencies are calculated annually for each commodity type: for Canada, the United States and Japan separately; and jointly for all other export destinations. Default bark expansion factors and wood C content were used for all countries (Table A3.5–5). Default parameters were used to convert product volume to units of C for countries other than Canada and the United States and where country-specific parameters

31 National Forestry Database, available online at: http://nfdp.ccfm.org/en/data/harvest.php

32 FAOSTAT Forestry Production and Trade, available online at: http://www.fao.org/faostat/en/#data/FO

33 FAOSTAT Forestry Trade Flows, available online at: http://www.fao.org/faostat/en/#data/FT

are not available for Canada or the United States (Table A3.5–6). Canada-specific wood density values were used for domestic roundwood, sawnwood, other industrial roundwood and panels, and default values were used for domestic pulp and paper market. Country-specific values were used for all domestic quantities for the United States. Default values were used for domestic and imported quantities for Japan and elsewhere. It is assumed that all wood fibre feedstock produced in a given year is processed by the forest products manufacturing sector in the same year.

All wood transferred from the forest to the HWP pool is included in the HWP model, but some of the products associated with portions of the wood, such as wood chips and pellets, are not explicitly identified in the data. Contrary to other HWP wood, chips and pellets are estimated from firewood consumption surveys. Wood used for bioenergy, such as pellets and chips, is assumed to be sourced from "milling residue" output category in the HWP model (see Figure A3.5–9). This C is quantified and allocated to bioenergy but is undifferentiated from other residual waste, all of which is assumed to be oxidized on disposal. The export of wood chips/pellets is currently not considered in the model.

The model starts the pool in 1900 and applies product in-use half-life parameters to wood product types based on geographic location. Half-life parameters are sourced directly from Table 3a.1.3 of IPCC (2003) or derived from that table using production-weighted averages to fit the wood product categories of the NFCMARS-HWP (Table A3.5–7).

Table A3.5–5 **Default Parameter Values Used in HWP Analysis**

Description	Units	Value	Source
Bark expansion factor, Softwoods	dimensionless	1.11	IPCC, 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Hardwoods	dimensionless	1.15	IPCC, 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Mixedwoods	dimensionless	1.13	IPCC, 2006 (Vol. 4, Table 12.5)
C content of wood	tonnes C/od tonne [a]	0.5	IPCC, 2006 (Vol. 4, Table 12.4)

Note:

a. Tonnes carbon per oven dry tonne of wood material.

Table A3.5–6 **Wood Densities of Commodities**

Country/Countries	Description	Units	Value	Source
Canada	Species-weighted average density, Roundwood	od tonne/m^3	0.386	Derived
Canada	Species-weighted average density, Sawnwood	od tonne/m^3	0.481	Derived
Canada	Species-weighted average density, Other industrial roundwood	od tonne/m^3	0.583	Derived
Canada	Species-weighted average density, Panels	od tonne/m^3	0.643	Derived
Canada	Species-weighted average density, Bioenergy	od tonne/m^3	0.523	Derived
U.S.	Coniferous (C) roundwood	od tonne/green m^3	0.455	FAO, 2010
U.S.	Nonconiferous (NC) roundwood	od tonne/green m^3	0.527	FAO, 2010
U.S.	C+NC roundwood	od tonne/green m^3	0.465	FAO, 2010
U.S.	Hardwood (HW) plywood & veneer	tonnes C/m^3	0.28	Skog, 2008
U.S.	Softwood (SW) lumber	tonnes C/m^3	0.22	Skog, 2008
U.S.	HW lumber	tonnes C/m^3	0.26	Skog, 2008
U.S.	Particle board	tonnes C/m^3	0.29	Skog, 2008
U.S.	Hardboard	tonnes C/m^3	0.42	Skog, 2008
U.S.	Medium density fibreboard	tonnes C/m^3	0.32	Skog, 2008
U.S.	Fibreboard, compressed	tonnes C/m^3	0.37	Derived
U.S.	Pulp, paper & board	tonnes C/ad tonne	0.42	Skog, 2008
U.S.	Insulating board	tonnes C/m^3	0.45	Skog, 2008
All	Sawnwood – C	od tonne/m^3	0.45	IPCC, 2006 (Vol. 4, Table 12.4)
All	Sawnwood – NC	od tonne/m^3	0.45	IPCC, 2006 (Vol. 4, Table 12.4)
All	Panels, structural	od tonne/m^3	0.628	IPCC, 2006 (Vol. 4, Table 12.4)
All	Panels, non-structural	od tonne/m^3	0.628	IPCC, 2006 (Vol. 4, Table 12.4)
All	Paper	od tonne/ad tonne	0.9	IPCC, 2006 (Vol. 4, Table 12.4)
All	Wood pulp	od tonne/ad tonne	0.9	IPCC, 2006 (Vol. 4, Table 12.4)

Notes:

od tonne = oven dry tonne of wood material

ad tonne = air dry tonne of product

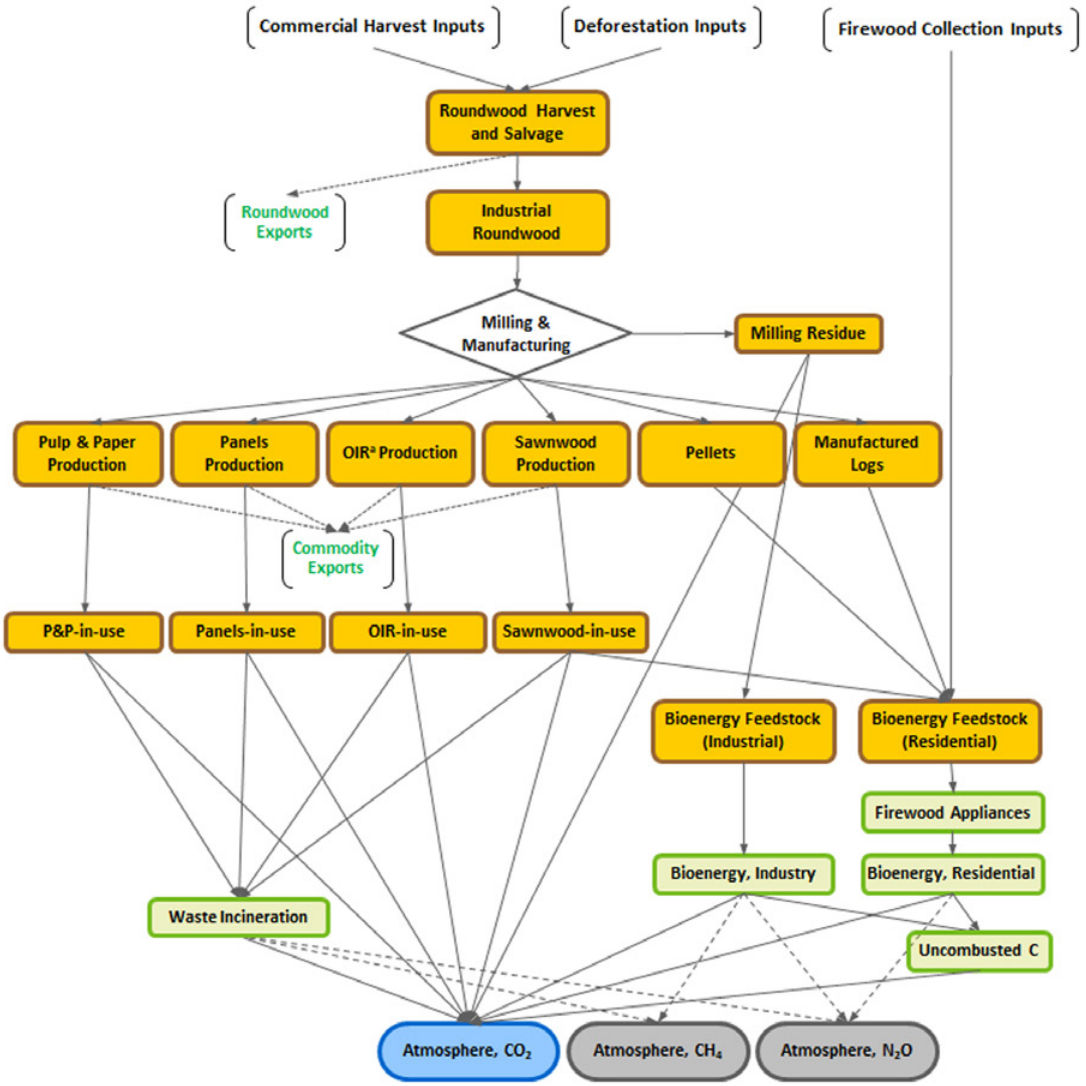
Table A3.5–7 **Half-Life Parameters (Years) of Harvested Wood Products In-Use**

Country/Countries	Description[a]	Value	Source
Canada	Sawnwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Wood panels	25	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Pulp and paper	2	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Other industrial roundwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Sawnwood	40	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Wood panels	27	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Pulp and paper	3	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Other industrial roundwood	40	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Sawnwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Wood panels	25	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Pulp and paper	2	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Other industrial roundwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)

Note:

a. Firewood and mill residue assumed to be burned for the former, or disposed of for the latter, in the year of harvest.

Figure A3.5–9 **A Simplified Schematic of Carbon Flows in Harvested Wood Products**



Note:

a. OIR = Other Industrial Roundwood

Biomass Combustion

Biomass emissions as reported in the Energy sector are grouped into three main sources: (i) residential firewood, (ii) industrial wood wastes (including spent pulp liquors), and (iii) fuel ethanol/biodiesel (assumed not to come from wood waste or pulp liquors).

Residential firewood combustion produces CO_2, CH_4, N_2O and some remaining unaccounted C likely found in VOCs, unburned hydrocarbons and charcoal assumed to be instantly oxidized, in amounts that are dependent on the combustion technology used. Emissions are derived by multiplying the amount of wood burned in each appliance type by the emission factor for that appliance type. The relevant emission factors are given in Table A6.6–1 expressed as grams of gas emitted per kilogram of fuel combusted, which for the purpose of the model have been converted to tonnes of C per kilogram of fuel.

Emissions from industrial use of wood-based energy (managed as "milling residue" in the model) are assumed to result from the combustion of wood wastes (i.e., hog fuel) and spent pulping liquors by the pulp and paper manufacturing sector. As with residential bioenergy use, emissions from industrial use of biomass energy are derived by multiplying the amount of fuel consumed by the emission factor for that fuel type. The emission factors for both industrial wood waste and spent pulp liquors are also given in Table A6.6–1. Note that the emission factors for industrial wood waste and spent pulp liquors are expressed as grams of gas emitted per kg of fuel consumed, assuming 0% moisture content of the fuel.

The processing of residential firewood data ensures consistency with the Energy sector and that the impacts of this type of harvest on the forest and other wooded ecosystems are represented in land emission modelling at the finest possible spatial resolution (Trégaro, 2020). All biomass C inputs to the firewood pool are based on the annual volumes provided by the Energy sector. Specifically, annual quantities of residential bioenergy consumption (in tonnes C) are calculated for each RU, for each of seven (7) allocation categories: (i) softwood collected from forest, (ii) hardwood collected from forest, (iii) mixedwood collected from forest, (iv) woody biomass collected from croplands, (v) firewood collected from urban trees in settlement lands, (vi) pellets, and (vii) manufactured logs, representing the targets of firewood collection to be implemented in the models (Trégaro, 2020, Trégaro et Blondel, 2019, Hafer et al., 2020). Targets for the first three categories in the list were implemented in the CBM-CFS3 simulations (see A3.5.2.3), while targets for the last four categories were implemented in the HWP model. Impacts of firewood harvest on Cropland and Settlements land-use categories were estimated (see sections A3.5.4.1 and A3.5.7.1 for more details).

Uncertainty

Uncertainty estimates associated with this category are mainly based on the uncertainty of the C inputs, namely (i) the C estimated as forest products from forest harvest and forest conversion in the CBM-CFS3 model, (ii) the volume of residential firewood provided by the Energy sector, and (iii) available statistics of pre-1990 commodity production.

The implementation of the uncertainty analysis updated for this inventory submission (Metsaranta et al., 2020) divides the uncertainty into three categories: (i) uncertainties in assumptions and approaches, e.g. the assumption that disposal of HWP follows the exponential decay pattern, (ii) uncertainties in factors or parameters that are not derived from activity data, e.g. half-lives of commodity-in-use pools and landfill pools, and (iii) uncertainties in input and allocation parameters that refer to C mass inputs (e.g. roundwood harvest) and partitioning parameters derived from activity data.

A sensitivity analysis was carried out to filter out parameters whose variation are unlikely to cause significant changes to the emission results prior to the Monte Carlo analysis. Uncertainty distributions and ranges were based on literature where possible and where no distributions were available were based on expert judgement.

Additional parameters were added to the Monte Carlo analysis for this submission including uncertain distributions for historical inputs (pre-1990 harvest), contemporary inputs (harvest since 1990) and five allocation parameters related to bioenergy that were added to the HWP model structure. The historical inputs are directly allocated to commodity-in-use pools and are varied using a multiplier which is assigned a uniform distribution with a range between 0.75 and 1.25. Contemporary inputs are acquired from the outputs of the CBM-CFS3 model, which correspond to a range of C mass. These outputs are used as inputs for the uncertainty analysis for HWP. Three sets of pools with their corresponding events and parameters were also added to the analysis for this submission: pellets, manufactured logs and bioenergy (residential and industrial). The sample size (n) for the Monte-Carlo runs was 100.

As already noted in A3.5.2.8, in years where there are no substantial changes, no comprehensive uncertainty analysis is performed and, instead, confidence intervals for each category for the current year of submission are statistically extrapolated using the results of the previous submission.

A3.5.4. Cropland

The methodologies described in this section apply to C stock changes in mineral soils subject to cropland management and to the conversion of land in the Forest Land and Grassland categories to the Cropland category, CO_2 emissions from the cultivation of histosols, changes in the biomass of woody perennial crops, and N_2O emissions from soil disturbance upon conversion to cropland. The estimation methodologies for C stock changes and GHG emissions from the biomass and DOM pools upon conversion of forest land to cropland are provided in section A3.5.2.7.

A3.5.4.1. 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 C 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 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 to be 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 in 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 strongly 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 SLC polygon 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 A3.5–1

$$\Delta C = F \times A$$

ΔC	=	change in SOC stock for inventory year, Mg C
F	=	average annual change in SOC subject to LMC, or C factor, 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 additive.

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 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 starting points for developing C factors were the SOC values in the SLC polygon attribute database (CanSIS) (Figure A3.5–10 and Figure A3.5–11). These 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 (ΔC_{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 A3.5–2

$$\Delta C_{LMC}(t) = \frac{\Delta C}{P_{LMC}}$$

$\Delta C_{LMC}(t)$	=	the change in SOC between land management systems in year “t” (Mg SOC/ha)
ΔC	=	the change in SOC due to the LMC (Mg SOC)
P_{LMC}	=	the proportion of the land area under a given land management system subject to the LMC, ha

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.

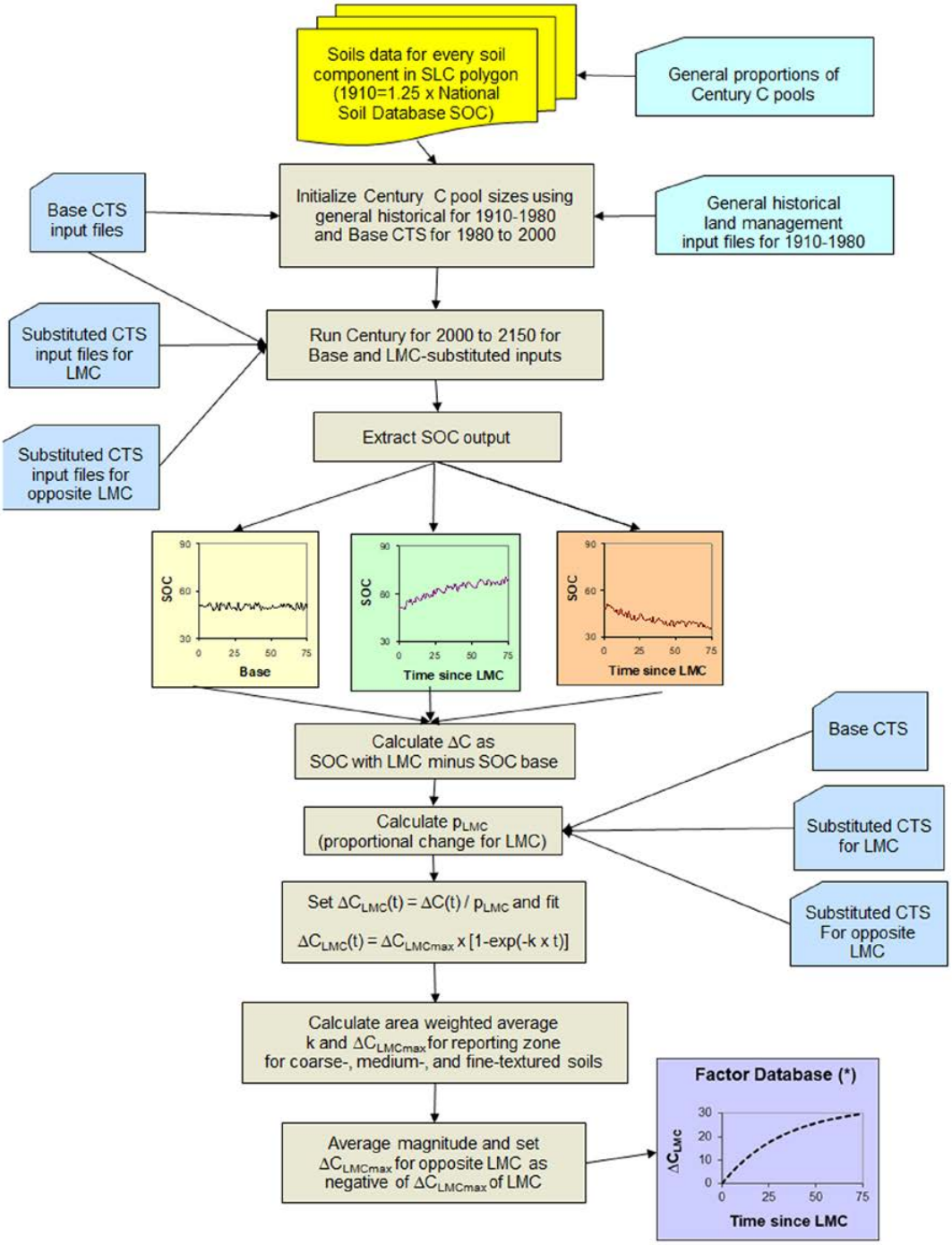
Equation A3.5–3

$$P_{LMC} = P_{LMbase} - P_{LMnew}$$

P_{LMC}	=	the proportion of the land area under a given land management system subject to the LMC
P_{LMbase}	=	the fraction of land management of interest in the base land management system
P_{LMnew}	=	the fraction of land management of interest in the new land management system

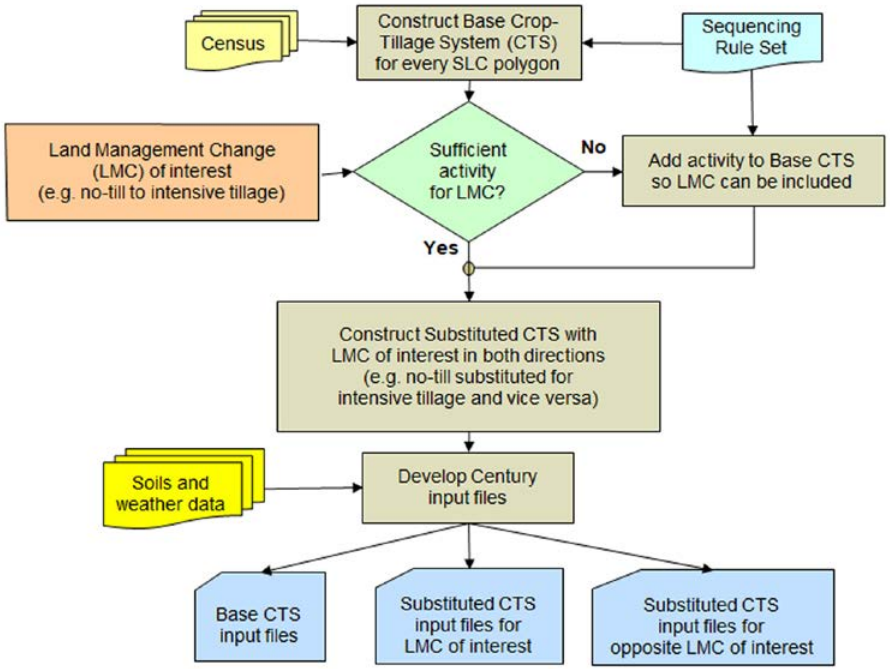
The following provides an example of Century runs for a Lethbridge loam (Orthic Dark Brown Chernozem) in the Semiarid Prairies reporting zone. A base model run

Figure A3.5–10 **Method for Deriving Carbon Factors for a Land Management Change of Interest**



Note: (*) Factor is per ha of activity change (i.e. LMC)

Figure A3.5–11 **Method for Deriving Land Management Input Files to Use with Century Model to Estimate the Carbon Factor for a Land Management Change of Interest**



was made using a 10-year base mix of crops based on the 1996 *Census of Agriculture* and weather data covering the years 1951–2000. Century simulations of SOC were made by substituting perennial crops for the 7 annual crops out of 10 in the base mixture. As a separate exercise, NT was substituted for IT 4 years out of 10 in the base mixture (Figure A3.5–12). 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 A3.5–2). Finally, the $\Delta C_{LMC}(t)$ was calculated as the proportion of area of farming system divided by the P_{LMC}. In this particular case of the time series of ΔC_{LMC}, the respective values of P_{LMC} for the IT to NT reduction and for the addition of perennial crops were 4/10 and 7/10 (Figure A3.5–13).

SOC dynamics are believed to be governed by first-order kinetics, and thus C change can be expressed as:

Equation A3.5–4

$$\Delta C_{LMC}(t) = \Delta C_{LMCmax} \times [1 - exp^{(-k \times t)}]$$

$\Delta C_{LMC}(t)$	=	the change in SOC due to the LMC at a time, t (Mg C ha^{-1})
ΔC_{LMCmax}	=	the maximum SOC change induced by the LMC (Mg C ha^{-1})
k	=	the rate constant, $year^{-1}$
t	=	year after LMC

In practice, the exponential equations are fit statistically using methods of least squares. The slope of the natural log transformed 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 A3.5–5

$$F_{LMC}(t) = \Delta C_{LMCmax} \times [exp^{(-k \times [t-1])} - exp^{(-k \times t)}]$$

$F_{LMC}(t)$	=	the instantaneous C factor value due to the LMC at a time t, Mg C ha^{-1} $year^{-1}$
ΔC_{LMCmax}	=	the maximum SOC change induced by the LMC (Mg C ha^{-1})
k	=	the rate constant, $year^{-1}$
t	=	year after LMC

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 A3.5–14).

Figure A3.5–12 **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**

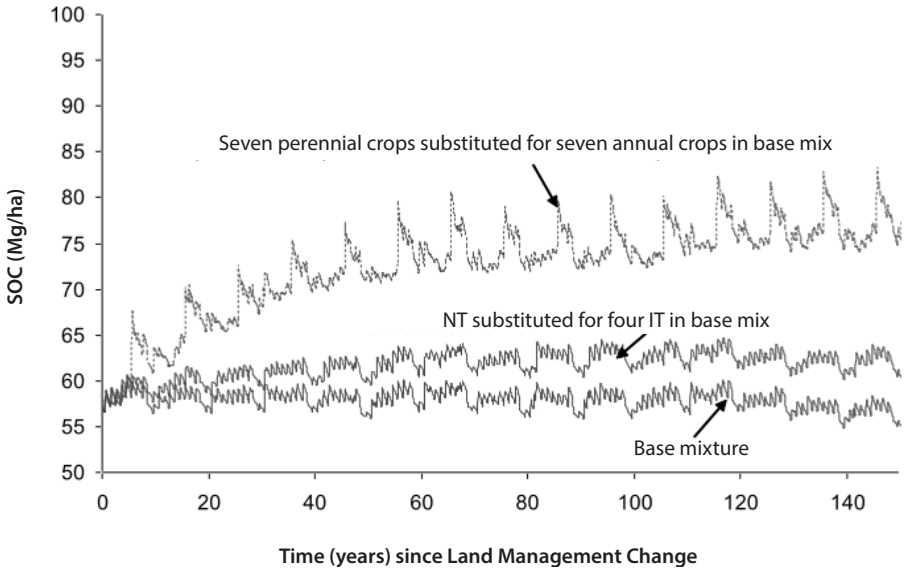
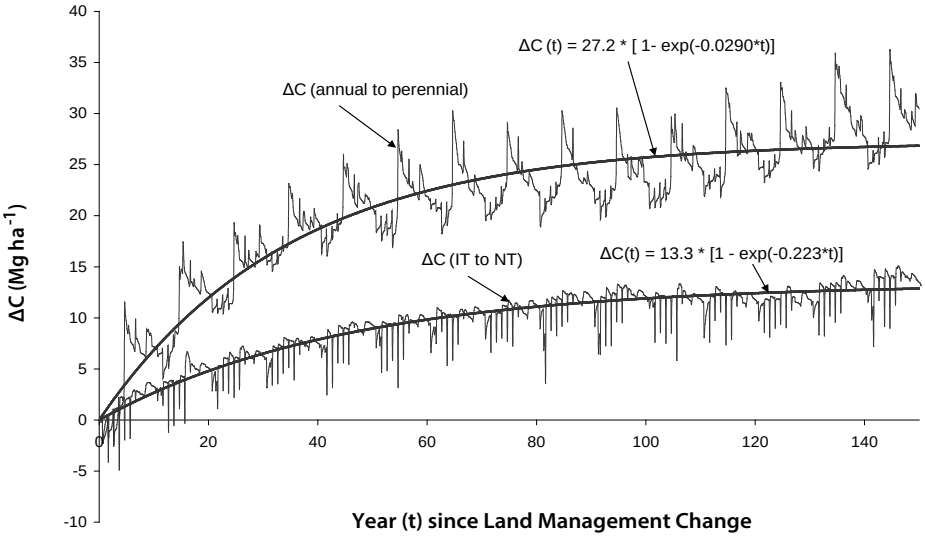


Figure A3.5–13 **Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix**



Estimating Mean k and ΔC_{LMCmax} for Practical Factor Calculations

The ΔC_{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 represented 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 A3.5–8). 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 resulted from the fit to ΔC_{LMC}; the k and ΔC_{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 ΔC_{LMCmax} from the Century simulations, the ΔC_{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.

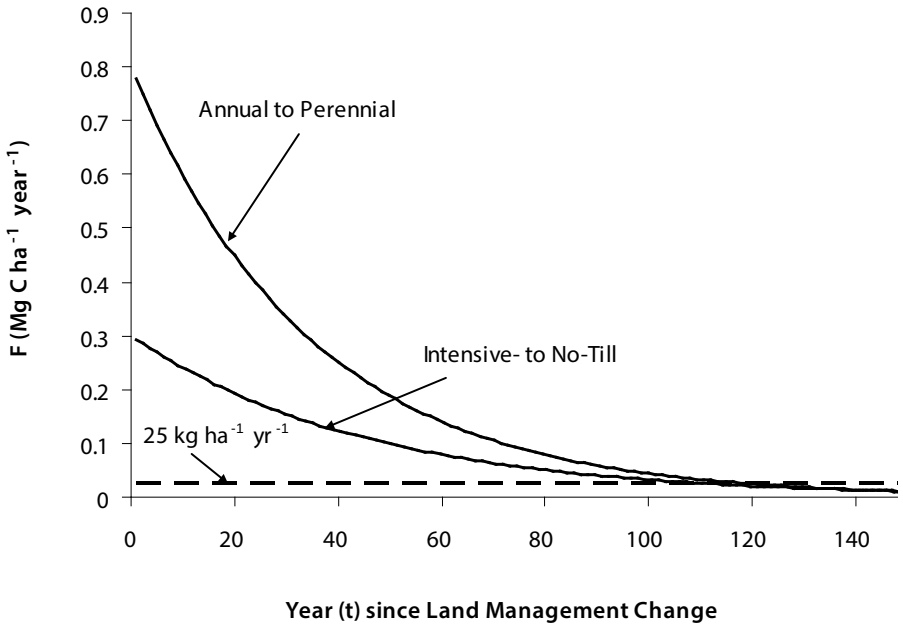
Generally, rates of SOC losses following an LMC are expected to be greater than rates of SOC gain following the reverse LMC. However, this effect is highly dependent on the relative SOC amount at the time of the LMC. Documenting SOC at the time of all LMCs is currently impossible. Hence, for transparency and simplicity, the reversibility assumption was imposed, whereby 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 derived from 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, which 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 zones (Table A3.5–8). In Eastern Canada, only two empirical change factors were available in the East Central zone, but they appeared to be in line with the modelled values (0.60–1.07 Mg SOC/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled).

Figure A3.5–14 **Carbon Factors as a Function of Time**



For conversion of crop fallow to continuous cropping, the rate of C storage was more than double the average rate of 0.15 ± 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 all inventory years since 1990. Because the effect of LMCs declines over time, a time period 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 calculated using an IPCC Tier 2 approach as follows:

Equation A3.5–6

$$\Delta C_{LMC} = \sum_{1951-n} \sum_{ALLSLC} (\Delta C_{TILL} + \Delta C_{SF} + \Delta C_{CROPPING})$$

ΔC_{LMC} = change in SOC stocks due to LMC for a specific year since 1951 until year n (latest inventory year)

$ALLSLC$ = all soil landscapes of Canada polygons that contain land management practices in cropland remaining cropland

ΔC_{TILL} = change in SOC stocks due to change in tillage practices from each SLC, since each particular tillage change

ΔC_{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 A3.5–15 provides a schematic of the method for C estimation.

Table A3.5–8 **Effective Linear Coefficients of Soil Organic Carbon for Land Management Change (LMC)**

Zone [a]	LMC [b,c]	k/year	ΔC_{LMCmax} (Mg/ha)	Final Year of Effect after LMC [d]	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:

Effective Linear Coefficients of SOC were generated using $F_{LMC(t)} = \Delta C_{LMCmax} \times [1 - \exp(-k \times t)]$.

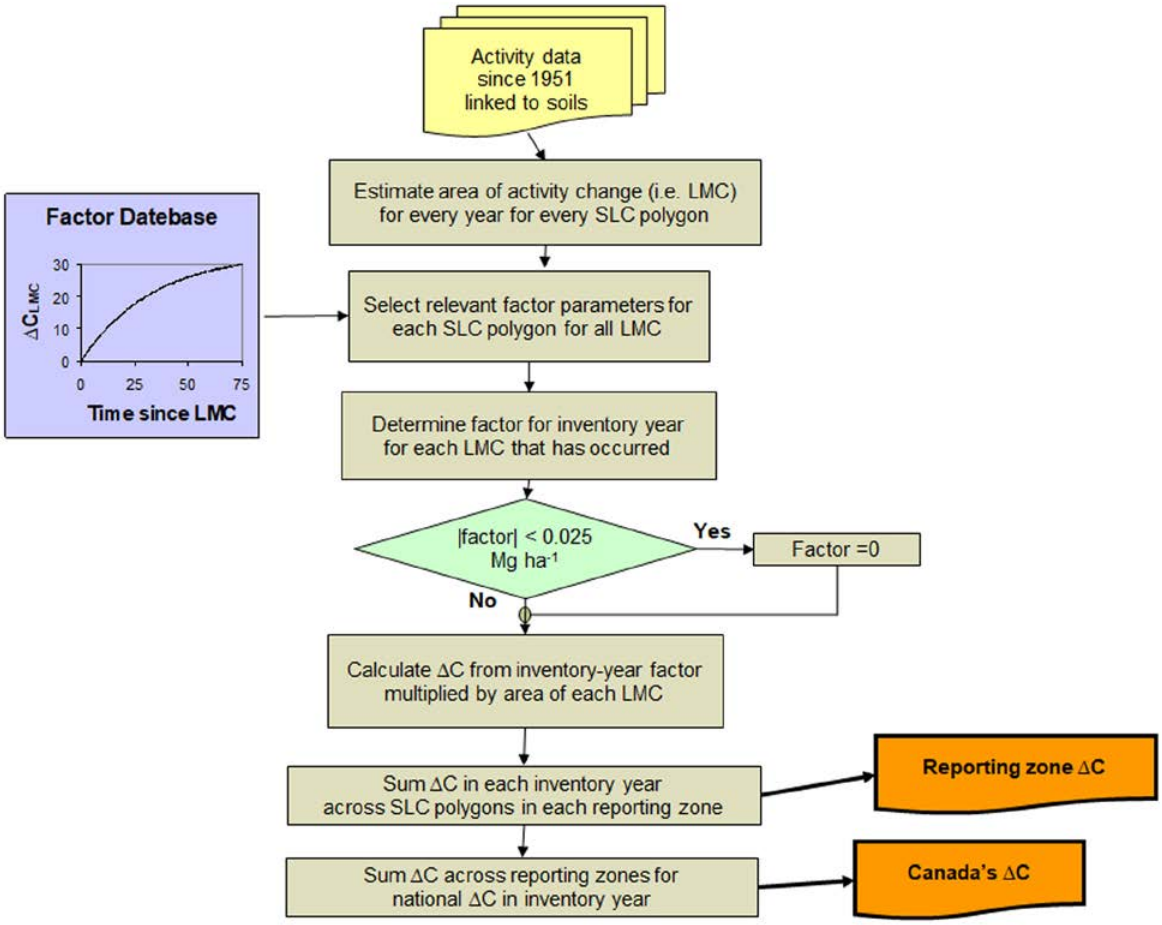
a. Area-weighted summary: East Atlantic is the Atlantic Maritime reporting zone plus the Boreal Shield reporting zone in Newfoundland and Labrador; East Central is the Mixedwood Plains reporting zone plus the Boreal Shield East reporting zone in Ontario and Quebec; Parkland is the Subhumid Prairies, 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.

b. For LMCs in the opposite direction to that listed, the F_{LMCmax} will be the negative of the value listed.

c. IT = intensive tillage, RT = reduced tillage, NT = no-till

d. No further C changes once the absolute value of the rate of change is less than 25 kg C/ha per year.

Figure A3.5–15 **Method of Using Factors for Land Management Change to Estimate Carbon Change over Large Areas**



Data Sources

Carbon stock change estimates rely on C factors and a time series of land management data in the *Census of Agriculture*. There are two types of data used for either deriving C factors (modelling) or computing the actual estimates of soil C stock change. The main data used for modelling C factors include SLC, crop-tillage systems derived from the *Census of Agriculture*, crop yields, climatic data and activity data from other surveys and databases. The main data used for estimating annual soil C stock changes are data on land management practices from the *Census of Agriculture*.

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.[34] The SLC was chosen for the LULUCF inventory because of its national scope and standardized structure, which ensure that all areas of the country are treated in a consistent manner with regard to inventory assessment procedures. The current version of the SLC in the National Soil Database (NSDB) data holdings is version 3.2. The extent of the soil attribute information in this coverage is restricted primarily to the agricultural areas of Canada. In instances where agricultural land was mapped outside the coverage of SLC v3.2, then soil attribute information was extracted from SLC v2.2, an older but complete coverage of soils in Canada. 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.

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

34 Available online at http://sis.agr.gc.ca/cansis.

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 Land and Grassland, to modelled C factors. The estimated areas of cropland and other land-use practices on an SLC polygon basis were derived from EO-based maps for 1990, 2000 and 2010.

Analysis Units

There are 3404 SLC polygons in which agricultural activities occur. Since the SLC polygons have several soil landscape components, the finest spatial resolution for analysis of agricultural activities is 13 771 unique combinations of soils, landforms and slope positions 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 be used for specific 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. In this way, annual crop production is linked to those soils with a high rating. If there was insufficient area with high likelihood of being under annual cropland to be assigned to annual crop production, the remaining annual crop production will be assigned to components with moderate likelihood of being under annual crop production and, if required, to low-ranked components. After the annual crop production area was linked, 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. Several publications are released at strategic points in the crop year. 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 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 database archived by Agriculture and Agri-Food Canada (AAFC). Long-term normals of monthly maximum and minimum temperatures (ºC) and precipitation (mm) from 1951 to 2000 for all ecodistricts were used for modelling C factors. AAFC-archived weather data were provided by Environment and Climate Change Canada's Meteorological Service of Canada.

Earth Observation and the *Census of Agriculture*

Activity data for C estimation in the Cropland Remaining Cropland category rely mainly on a combination of data from the *Census of Agriculture* and area estimates based on EO analyses. The *Census of Agriculture* is conducted every five years to develop a statistical portrait of Canada's farms and agricultural operators. For confidentiality reasons, the smallest area for which Statistics Canada externally releases data from the *Census of Agriculture* is the dissemination/enumeration area level (of which there are approximately 52 000 in Canada). To provide a biophysical basis on which to model, data at this level were attributed to the SLC polygons (McConkey et al., 2007a).

Mapping data based on EO were used to provide area estimates of all land-use practices within each of the agricultural SLCs in Canada. Land-use maps based on EO information were generated for 1990, 2000 and 2010 (Huffman et al., 2015a). Using SLC polygons as the level of spatial stratification, data were compiled into seven primary land cover categories: cropland, grassland, forest land, settlements, wetlands, water, and other land. From 1990 to the latest inventory year, annual estimates of land-use areas were generated by interpolating between EO years and extrapolating beyond 2010. Agricultural land-use estimates prior to 1990 were generated using the *Census of Agriculture* and the relative change in cropland and grassland areas between census periods. Land-use estimates for 1981 were generated by calculating the relative change in agricultural land use with the use of data from the 1991 and 1981 censuses and applying this change to the 1990 EO data. Then, moving progressively back through periods between census years, the relative changes were used to generate agricultural land-use estimates back to 1951. To minimize spatial variability associated with known issues related to reporting land-use areas based on farm headquarters, the relative change in land-use estimates was calculated at the spatial scale of the ecodistrict and applied to all SLC polygons nested within.

The EO-based cropland attributes were estimated using ratios of cropland area attributes to total cropland area from the *Census of Agriculture*. To reduce differences between EO and census estimates of provincial crop areas, EO cropland categories (i.e., cropland, pasture,

orchards and vineyards) were reconciled using provincial scaling factors. Reconciliations were constrained by the total area of agricultural land within SLC polygons, as interpreted through EO analysis. Data on tillage management practices were taken from the *Census of Agriculture* according to the following categories: IT– tillage that incorporates most of the crop residue into the soil, RT– tillage that retains most of the crop residue on the surface, and NT– no-till seeding or zero-till seeding. For summerfallow, the following tillage categories were used: NT– the area on which chemicals only were used for weed control, IT– the area on which tillage only was used, and RT– the area on which a combination of tillage and chemicals was used. More technical details on the methodological approach used to create the EO-based agricultural activity data are provided in Cerkowniak (2019).

Uncertainty

The derivation of uncertainties about estimates of CO_2 emissions or removals requires estimates of uncertainties for LMC areas and the C factors associated with changes in fallow, tillage and annual/perennial crops (McConkey et al., 2007b). The uncertainty described in this report is based on the 2014 submission methodology and has not yet been updated for the new EO methodology.

The uncertainty of area of change was determined for ecodistricts. 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 the activity is not occurring within the ecodistrict. Therefore, area uncertainty can be more reliable when 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.[35]

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 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, it is infeasible to describe their relationship given the complexity of the large number of possible interactions between deviations due to process uncertainty and those due to situation uncertainty. 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 of this analysis are provided in Chapter 6.

CO_2 Emissions and Removals from Woody Biomass

Estimates of emissions and removals from woody biomass on croplands include those originating from trees and shrubs in agricultural land as well as vineyards, fruit orchards and Christmas trees. A remote sensing-based sampling approach was used to determine areas of trees and shrubs over the reporting period, whereas the *Census of Agriculture* was used to acquire area estimates of vineyards, fruit orchards and Christmas trees.

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-

35 Huffman T. 2006. Personal communication (from Huffman T, Agriculture and Agri-Food Canada to McConkey BG, Agriculture and Agri-Food Canada).

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, linear rates of above-ground and below-ground biomass accumulation in trunks and roots were set at 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 biomass. Upon a decrease in vineyard areas, an instantaneous loss of 4.9 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 range of standing biomass per area for apple and peach trees varied narrowly 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 10-year growth period at 1.6 Mg C/ha per year. The same rate, multiplied by a root to shoot ratio of 0.4 (Bartelink, 1998), was used to estimate C sequestration in below-ground biomass. 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). With a root to 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.

Trees and shrubs in agricultural land include perennial woody cover types in farmyards, shelterbelts and hedgerows. Carbon storage on the landscape in woody biomass changes over time as trees and shrubs grow and die, or areas of lands with woody biomass change due to planting or colonization of cropland areas or the clearing of trees.

The EO-based sampling approach used to quantify changes in woody biomass on Canadian croplands was developed by Huffman et al. (2015b). Briefly, the national ecological framework (Marshall et al., 1999) was used to develop a spatially stratified random sampling approach. A target of 30 sample sites per ecozone was identified. High-resolution historical aerial photos from the National Air Photo Library of Natural Resources Canada and from provincial databases were selected to digitize trees and shrubs land cover within a 2 km by 2 km plot for circa 1990, circa 2000 and circa 2010 at 1:10000 scale. The “trees” land cover class was defined as having less than 25% crown closure and being less than 1 ha in size. The “shrubs” land cover class represents non-agricultural woody plants that would not be expected to meet the forest or “trees” definition when mature. Wood volume yield estimates for each ecozone were derived based on published literature and consultations with provincial forestry and agriculture specialists, conservation associations and academia. Overall, estimates of above-ground wood volume varied between 99.3 and 181.7 m^3/ha across ecozones, and mean annual increments varied between 1.2 and 3.8 m^3 ha^{-1} year-1. With the addition of a new dataset in 2020, the growth, loss and gain in the biomass of trees and shrubs (in tonnes of C) were calculated for two time periods: 1990-2000 and 2000-2010 in croplands. The analysis, coefficients and parameters used to estimate C stock changes were based on the methodology described by Huffman et al. (2015b) for both time periods.

Analysis of firewood production suggested that agricultural lands serve as an important source for residential bioenergy production in Canada (Doyon et al., 2019). Based on this analysis, a portion of the tree biomass loss from cropland was transferred to the HWP pool as firewood input to meet regional residential bioenergy requirements (refer section A3.5.3) at the RU level. Further in regions where there was a shortage of supply in the forest biomass in a given RU, fractions of lost tree biomass from cropland were assumed to be sourced from the neighbouring RU. To avoid double counting of emissions between the Cropland and Harvested Wood Products categories, the amount of C transferred to the HWP pool was not reported as C loss under Cropland, normally being reported as instant oxidation. As a result an apparent increase in the sink or reduced emissions from woody biomass is reported, though once considering the transfer to HWP, no net change in total C emissions or removals occurs.

Uncertainty

Poorly growing orchards and vineyards 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 uncertainty for vineyards, orchards and Christmas trees. Therefore, the default uncertainty of ±75% for woody biomass on cropland from the 2006 IPCC Guidelines was used for these land cover types. An error propagation approach described in Huffman et al. (2015b) was applied for trees and shrubs. 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 A3.5–7

$$C = \sum(A_i \times EF)$$

C	=	carbon emissions from cultivation of organic soils (Mg C year^{-1})
A_i	=	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%. The 95% confidence limits of the emission factor provided in the 2006 IPCC Guidelines (IPCC, 2006) is ±90%.

A3.5.4.2. Grassland Converted to Cropland

Conversion of native grassland to cropland 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. According to a recent study on the burning of managed grassland in Canada by Bailey and Liang (2013), C changes from above-ground or below-ground biomass or DOM upon conversion are generally insignificant. The authors reported that the average above-ground biomass was 1100 kg ha^{-1} in the Brown Chernozem and 1700 kg ha^{-1} in the Dark Brown Chernozem. The above-ground biomass for the managed grassland would be lower than its yield under crop production (Liang et al., 2005).

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 their 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 of the native grassland, 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 the land was broken.

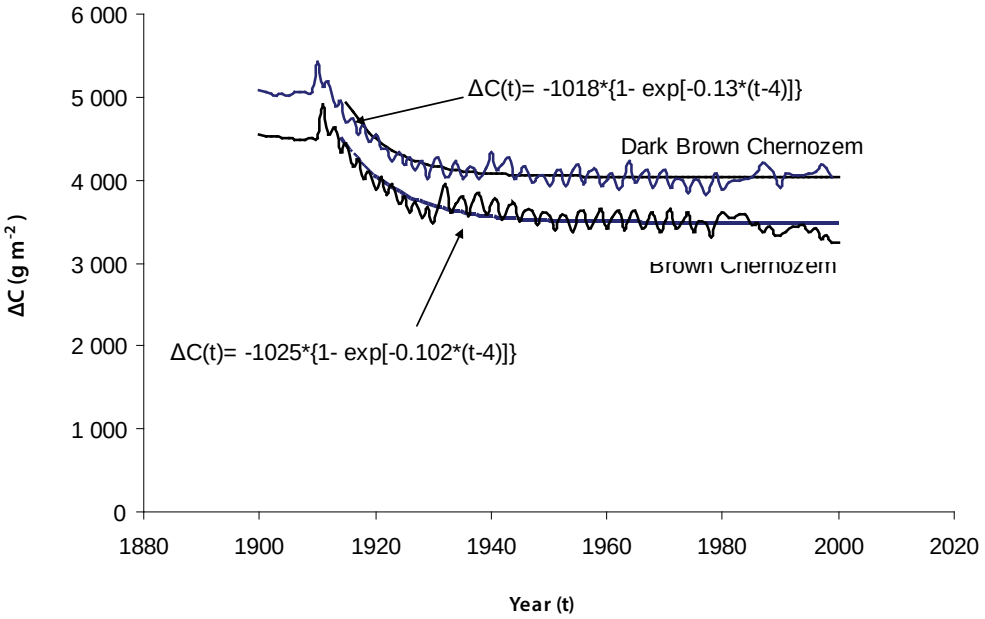
The SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils (Figure A3.5–16) can be estimated with the Century model (Version 4.0). Shortly after breaking, there is an increase in soil organic matter, as below-ground biomass of the grass becomes part of SOC. 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 A3.5–8

$$\Delta C(t) = \Delta C_{Bmax} \times [1 - exp^{(-k[t-t_{lag}])}]$$

$\Delta C(t)$	=	change in SOC for the tth year after conversion, Mg C/ha
ΔC_{Bmax}	=	ultimate change in SOC from grassland to cropland, Mg C/ha
k	=	rate constant for describing the decomposition, year^{-1}
t	=	time since breaking of grassland, years
t_{lag}	=	time lag before ΔC becomes negative, years

Figure A3.5–16 **Century-Simulated SOC Dynamics after Breaking of Grassland to Cropland for Brown and Dark Brown Chernozemic Soils**



Assuming that the 22% loss at about 50–60 years after initial breaking represents the total loss, the ΔC_{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 A3.5–9

$$\Delta C(t) = 0.28 \times SOC_{agric} \times [1 - exp^{(-0.12 \times t)}]$$

$\Delta C(t)$	=	change in SOC for the t[th] year after conversion, Mg C/ha
t	=	time since breaking, years
SOC_{agric}	=	0- to 30-cm SOC from the National Soil Database within CanSIS 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 A3.5–10

$$\Delta C_{GLCL} = \sum_{1951-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{GLCL})$$

ΔC_{GLCL}	=	losses of SOC in the inventory year n due to conversion of grassland to cropland since 1951 until year n, Mg C
$ALLSLC$	=	all soil polygons that contain grassland conversion to cropland
t	=	time after grassland conversion, years
ΔC_t	=	change in SOC for the t[th] year after conversion, Mg C/ha
$AREA_{GLCL}$	=	area of grassland converted to cropland annually since 1951, ha

Losses of Soil Organic N and N_2O 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 N_2O in grassland converted to cropland were calculated using an IPCC Tier 2 approach:

Equation A3.5–11

$$N_2O_{GLCL} = \sum_{1951-n} \sum_{ALLSLC} \sum_{t} (\Delta C_{GLCL} \times AREA_{GLCL}) \times 0.06 \times EF_{BASE} \times \frac{44}{28}$$

N_2O_{GLCL}	=	emissions of N_2O in the year n due to the conversion of grassland to cropland since 1951 until year n, kt
$ALLSLC$	=	all soil polygons that contain grassland conversion to cropland
t	=	time after grassland conversion, years
ΔC_{GLCL}	=	change in SOC for the t^{th} year after grassland conversion, Mg C/ha
$AREA_{GLCL}$	=	area of grassland converted to cropland annually since 1951, ha
EF_{BASE}	=	N_2O emission factor, defined as a function of long-term climate normals (precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (see section A3.4.6)
0.06	=	ratio of ON to OC losses
$44/28$	=	coefficient converting N_2O-N to N_2O

Data Sources

The area of grassland reported in the category Grassland Remaining Grassland was estimated using a combination of data from the *Census of Agriculture* and EO data. Area estimates reported in the category Grassland Converted to Cropland were based on reconciling changes in land area between Grassland Remaining Grassland and land in cropland management. To avoid issues associated with farm headquarters reporting, data were aggregated to the ecodistrict level prior to the land reconciliation process. Ecodistrict estimates of area of grassland converted to cropland were then apportioned back to SLC polygons.

Within an SLC, areas under Grassland Remaining Grassland were allocated to soil components identified as "low" for "likelihood of being cropped." Soil C data from the National Soil Database were used to calculate an average SOC content for soils within the SLC polygon.

Uncertainty

The conversion of agricultural grassland to cropland occurs, but the reverse does not. 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 category. The factor scaling coefficient was assumed to be the same as for annual-perennial crop conversions (McConkey et al., 2007b).

A3.5.4.3. Forest Converted to Cropland

Emissions of CO_2 and N_2O from Soils

Clearing forest to increase agricultural land is a declining but still significant practice in Canada. This section describes the methodology for estimating CO_2 and N_2O emissions associated with the resulting soil disturbance. The method for estimating emissions from biomass upon conversion is presented in sections A3.5.2.1 and A3.5.2.5. For SOC change, it is necessary to differentiate between Eastern and Western Canada.

Eastern Canada

There are many observations that compare SOC for land under forest with SOC for 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 to that found in the soil database in CanSIS (Table A3.5–9), indicating that, on average, SOC for the uppermost 30 cm of soil under agriculture was 20.5% less than that of soil under forest.

Although the SOC for forested land accounts for C in the litter layer above mineral soil, in practice there is always uncertainty in quantifying the litter layer C and organic 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 (Figure A3.5–17). In the first years after 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 falls below the amount that existed before forest conversion. The rate of SOC decline gradually decreases with time.

The following equation was fit to the Century results in Figure A3.5–15, neglecting the initial SOC increase:

Equation A3.5–12

$$\Delta C(t) = \Delta C_{Dmax} \times [1 - exp^{(-k \times [t - t\_lag])}]$$

$\Delta C(t)$	=	change in SOC for the t^{th} year after conversion, Mg C/ha
ΔC_{Dmax}	=	maximum change in SOC from forest conversion to agriculture, Mg C/ha
k	=	rate constant for describing the decomposition, $year^{-1}$
t	=	time since conversion of forest land, years
t_{lag}	=	time lag before ΔC becomes negative, years

In the case of simulated SOC after conversion of deciduous forest to cropland (Figure A3.5–17), 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 (Figure A3.5–14) is used to estimate SOC loss with time lag set to 0 after fitting.

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 approximately 100 years after forest conversion. The ΔCDmax is therefore corrected by a factor of 1/0.927, where it is assumed that only 92.7% of the C has been lost after 100 years, based on the integration of Equation A3.5–13, resulting in a ΔC_{Dmax} value of 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 A3.5–13

$$\Delta C(t) = 0.284 \times SOC_{agric} \times [1 - exp^{(-0.0262 \times t)}]$$

$\Delta C(t)$	=	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, Mg C/ha
-0.0262	=	rate constant for describing the decomposition, $year^{-1}$
t	=	time since conversion, years

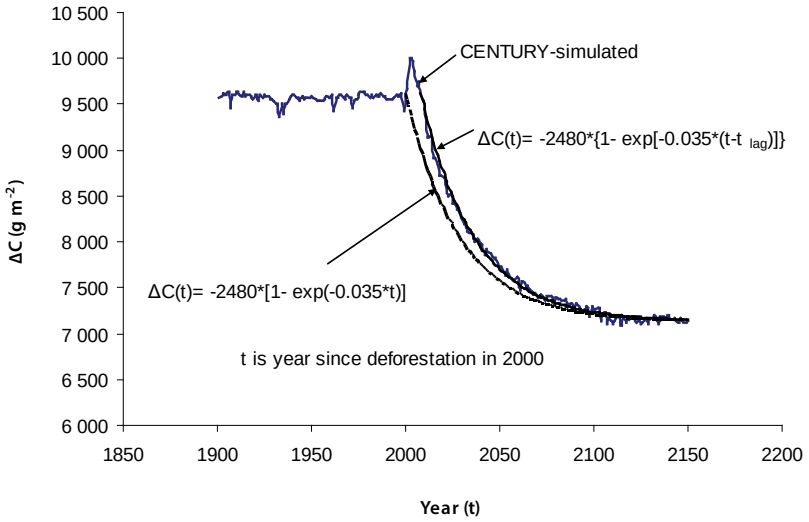
Table A3.5–9 **Soil Organic C for Forested and Agricultural Land in Eastern and Western Canada from the Canadian Soil Information System Database (0- to 30-cm soil depth)**

Soil Texture	Soil Organic Carbon (Mg C/ha)		Difference (%)
	Forested Land[a]	Cropland[a]	
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:

a. Standard deviation in parentheses.

Figure A3.5–17 **Century-Simulated Soil Organic Carbon Following Conversion of Deciduous Forest to Cropland**



Thus, the total amount of SOC lost from forest land converted to cropland is estimated using the following equation:

Equation A3.5–14

$$\Delta C_{FLCL} = \sum_{1970-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL})$$

ΔC_{FLCL}	=	total SOC loss in year n from the conversion of forest land to cropland since 1970 until year n, Mg C/ha
t	=	time after the conversion, year
$ALLSLC$	=	all soil polygons that contain forest land converted to cropland
ΔC_t	=	change in SOC for the tth year after conversion, Mg C/ha (see Equation A3.5–13)
$AREA_{FLCL}$	=	area of forest land converted to cropland annually since 1970, ha

Note that the SOC loss predicted by Equation A3.5–14 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 C 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 the conversion of forest land to cropland are estimated using the following equation:

Equation A3.5–15

$$N_2O_{FLCL} = \sum_{1970-n} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL}) \times 0.02 \times EF_{BASE} \times \frac{44}{28} \times 1 \times e^{-3}$$

N_2O_{FLCL}	=	emissions of N_2O subject to conversion of forest to cropland since 1970 until year n (latest inventory year), kt
$ALL\ SLC$	=	all soil polygons that contain forest land conversion
ΔC_t	=	change in SOC for the tth year after conversion, Mg C/ha per year
$AREA_{FLCL}$	=	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 (precipitation divided by potential evapotranspiration from May to October; P/PE) at an ecodistrict level (see section A3.4.5)
t	=	time after the conversion, year
$44/28$	=	coefficient converting N_2O-N to N_2O
e^{-3}	=	Converting from Mg to kt

Western Canada

Much of the current agricultural soil in Western Canada was grassland prior to cultivation. Hence, forest conversion has involved primarily 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 numerous comparisons of SOC under forest with that under cropland (Table A3.5–9). 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, C loss from forest conversion to agriculture is lowest 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-ground and below-ground tree biomass and coarse woody DOM that existed in the forest at the time of conversion. Similarly, average organic N 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 A3.5.2.1).

Data Sources

The approach used to estimate the area converted from forest to cropland is described in section A3.5.2.3. The annual forest conversion by RU 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 RU.

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.

A3.5.5. Grassland

Land in the agricultural Grassland category is defined as unimproved pasture used for grazing domestic livestock, but only in geographical areas where grassland would not naturally grow into forest if abandoned, i.e., 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, the agricultural Grassland category consists of extensively managed native range in Canada.

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. Methodologies for estimating emissions or removals of CO_2 as a result of direct human activities and for estimating CH_4 and N_2O emissions from natural or prescribed fires on agricultural grassland in Canada are presented in the following section.

A3.5.5.1. Grassland Remaining Grassland

The development of the CO_2 estimate method is based on the premise that on long-existing managed grassland, 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.

Equation A3.5–16

$$SOC = SOC_{REF} \times F_{MG} \times F_I$$

SOC	=	soil organic carbon stock at any particular time since management and input change, Mg C ha^{-1}
SOC_{REF}	=	the reference soil organic carbon stock, Mg C ha^{-1}
F_{MG}	=	carbon stock change factor for management regime, dimensionless
F_I	=	carbon stock change factor for input of organic matter, dimensionless

The total area of managed grassland is calculated as follows:

Equation A3.5–17

$$A_n = GLGL_{1990} - \sum_{1990}^{n} GLCL$$

A_n	=	the total area of grassland remaining grassland in the inventory year n, ha
$GLGL_{1990}$	=	the area of grassland remaining grassland in 1990, ha
$GLCL$	=	the area of grassland converted to cropland since 1990, ha

Therefore, the net change in SOC because of management and input changes from Grassland remaining Grassland can be estimated using the IPCC tier-1 method as follows:

Equation A3.5–18

$$\Delta C_{GGMineral} = [(SOC_0 - SOC_{0\text{-}T}) \times A] / t$$

$\Delta C_{GGMineral}$	=	the net change in SOC due to management and input from grassland remaining grassland, Mg C ha^{-1}yr^{-1}
SOC_0	=	soil organic carbon stock in the inventory year, Mg C ha^{-1}
$SOC_{0\text{-}T}$	=	soil organic carbon stock T years prior to the inventory year, Mg C ha^{-1}
A	=	area of change in management and input from grassland remaining grassland, ha
t	=	inventory time period, years (default 20 years)

If no change in management practices or input occurs, the C stocks are assumed to be at equilibrium, and the change in C stocks is therefore deemed to be zero.

There are a number of studies on 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 as well as effects on C input to soil from both above-ground 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.

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).

Grasslands managed for grazing in Western Canada in the Brown and Dark Brown soil zones of Alberta, Saskatchewan and British Columbia are occasionally burned by wildfire and by prescribed burning for purposes such as brush management, habitat management, the removal of decadent vegetation, and military training exercises. Burning from managed grassland is a net source of CH_4, CO, NO_x and N_2O.

Equation A3.5–19

$$EMISSION_{BURN} = \sum(AREA_i \times FUELLOAD_i \times C_{F,i} \times G_{EF}) / 1000$$

$EMISSION_{BURN}$	=	emissions of CH_4 or N_2O from prescribed and non-prescribed burning of managed agricultural grassland, kt CH_4 or N_2O
$AREA_i$	=	area of the ith managed agricultural grassland subject to burning, ha
$FUELLOAD_i$	=	average fuel load for the i^{th} managed agricultural grassland subject to burning, Mg DM ha^{-1}
$C_{F,i}$	=	combustion efficiency for the i^{th} managed agricultural grassland subject to burning, fraction, unitless
G_{EF}	=	emission factor of CH_4 (2.7 g CH_4 kg^{-1} dry matter burnt) or N_2O (0.07 g N_2O kg^{-1} dry matter burnt) (IPCC, 2006)
1000	=	conversion of Mg to kt

Data Sources

As discussed in the section Grassland Converted to Cropland, the area reported for the subcategory Grassland Remaining Grassland was estimated using a combination of data from the *Census of Agriculture* and EO, as described in section A3.5.4.1. There are no detailed comprehensive activity data over time on management change for Canadian agricultural grassland, except for wild and prescribed fires. Activity data on area, fuel load and combustion efficiency for each burning event for managed agricultural grassland were collected through consultations (Bailey and Liang, 2013). Activity data from 2013 to 2015 were updated in 2017 and were kept constant after the sampling period.

A3.5.6. Wetlands

A3.5.6.1. Peat Extraction

General Approach and Methods

Peat extraction in Canada is for the production of horticultural peat products and related applications, and not for use as fuel. Since the 1970s, the vacuum harvesting technique has been the dominant method of peat extraction. This technique requires an extensive network of drainage ditches to dry the peat for harvesting by heavy vacuum harvesters. Prior to the implementation of vacuum harvesting, manual block-cutting was used to extract peat blocks with shovels, resulting in topography of high baulks and low trenches. Although these manual methods are no longer used, numerous abandoned block-cut sites remain in the landscape.

Emissions of CO_2, CH_4 and N_2O were estimated for the conversion and management of peatlands for peat extraction using an IPCC Tier 2 method in accordance with guidance from a combination of the 2006 IPCC Guidelines and the 2013 IPCC Wetlands Supplement (IPCC, 2014). The approach is based on domestic science and land management practices specific to peat extraction activity in Canada. Emission estimates include on-site CO_2, CH_4 and N_2O emissions, off-site CO_2 emissions from extracted peat, and waterborne C losses of dissolved organic carbon (DOC) from drained and rewetted sites.

Domestic GHG flux studies at peat extraction sites in Canada were reviewed and measurements compiled to develop country-specific emission factors and parameters (Table A3.5–10). As the majority of flux measurements were reported for the growing season, annual CO_2 emission factors were developed by adding measured winter values from Strack and Zuback (2013), consistent with drained peatlands having higher winter CO_2 emissions than natural peatlands. Annual CH_4 emission factors were developed assuming that non-growing season fluxes are 15% of annual totals based on natural peatland sites (Saarnio et al., 2007).

Owing to the extraction technology and desired properties of sphagnum peat, preference with respect to site selection is given to open bog (nutrient poor – ombrotrophic) peatlands, which are classified as Other Land under Canada's land categorization framework for the LULUCF sector. Therefore, only approximately 5% of pre-conversion area meets the definition of the Forest Land category. Emission estimates are separated into the subcategories Land Converted to Peat Extraction and Peat Extraction Remaining Peat Extraction. In calculating emissions from land conversion, a land-use change period of one year is used to represent the land conversion practices of draining and clearing the surface vegetation layer (acrotelm) in preparation for peat extraction. Subsequently, emissions from the ongoing management of peat extraction sites,

as well as their decommissioning through abandonment, rehabilitation, or rewetting and restoration, are all reported under Peat Extraction Remaining Peat Extraction. The following sections describe the sources of GHG emissions and removals through the peat extraction land management phases.

Biomass Clearing and Drainage

At extraction sites, vegetation removal and drainage result in a loss of CO_2 uptake, enhanced peat decomposition, and DOC export resulting in increased CO_2 emissions. Emissions of CH_4 decrease substantially from drained fields, but drainage ditches, which occupy 5% of the drained area, become CH_4 hot spots (Waddington and Day, 2007). Enhanced peat decomposition also increases N_2O emissions. CO_2 and CH_4 emission factors for drained areas were derived from domestic studies (Table A3.5–10), but due to a lack of domestic N_2O measurements, the default emission factor for peat extraction sites from the 2013 IPCC Wetlands Supplement (IPCC, 2014) was used.

Sites that are no longer economical for extraction are decommissioned or abandoned. The altered hydrology and peat properties of these sites hinder natural regeneration, resulting in persistent CO_2 emissions (Waddington et al., 2002). However, revegetation occurs more frequently at abandoned block-cut sites, although total vegetation coverage is low and moss regeneration is limited to wetter trench depressions (Poulin et al., 2005). The CO_2 emission factor for abandoned block-cut areas is lower than for areas drained for vacuum harvesting, while the CH_4 emission factor is higher, likely due to greater revegetation and wetter conditions at block-cut sites.

At some abandoned sites, rehabilitation measures are undertaken to establish another type of environment. Given the lack of flux measurements for these sites, the emission factors for drained areas are generally used for rehabilitated areas. However, the uptake of CO_2 by trees in tree plantations is calculated on the basis of measurements at a tree plantation study (Garcia Bravo, 2015). Tree plantations may increase CO_2 sequestration in tree biomass, but this does not offset the large CO_2 emissions from drained peat.

Peat Stockpiling and Product Production

Harvested peat is left in stockpiles before being processed into various peat products. Emissions from peat stockpiles are calculated as an exponential decay for half a year (Cleary et al., 2005). Once it is packaged into products, Canadian peat is transported off-site, largely to the United States, for non-energy uses such as horticulture, where it is assumed to decay in an aerobic environment. Due to the lack of information on decay rates by end use, it is assumed that all peat is emitted in the extraction year. Emissions of CO_2 are calculated based on an estimate of total organic C in the peat using a country-specific C fraction parameter (Table A3.5–10) derived from laboratory analysis of pure peat products with moisture contents ranging from 27% to 64% (Hayne et al., 2014).

Rewetting and Restoration

An increasing number of decommissioned sites are rewetted and restored. Rewetting practices increase anaerobic conditions, which reduce peat decay and DOC export, thereby decreasing CO_2 emissions while increasing CH_4 emissions (Strack and Zuback, 2013). Since the 1990s, the moss layer transfer technique has been used in Canada for the restoration of peatlands dominated by *Sphagnum* mosses with the aim of restoring sites to peat-accumulating ecosystems. This technique consists of rewetting and sowing fields with fresh moss spores and spreading a layer of straw mulch to support moss regeneration (Rochefort et al., 2003). Long-term monitoring of restoration sites indicates that rewetting and restoration success varies due to management (e.g., effectiveness of blocking secondary drainage network, timing of restoration procedures and quality of plant material spread) and weather conditions post-restoration (González and Rochefort, 2014). Domestic GHG research at sites restored for 10 years or less has shown that there is high variability among sites ranging from sources to sinks. Given the range of success among sites and the variability in flux measurements, average emission values are used to best represent the net flux of rewetted and restored sites.

Data Sources

An EO mapping approach based on manual delineation and interpretation of aerial photography, satellite imagery and ancillary data was developed to map the extent of peatland areas disturbed by peat extraction for circa 1990, 2007 and 2013 time periods. Through image interpretation, the total disturbed area was allocated into the following four land management subcategories: active extraction areas, abandoned areas, rehabilitated areas, and restored areas. Geospatial data developed by the Peatland Ecology Research Group and information provided by industry experts were utilized to aid subcategory allocation. In addition, for a subset of sites, the pre-disturbance land cover class (forest, shrubby or open bog peatland) was determined in order to identify the land category types converted (Forest Land or Other Land).

Annual area estimates were developed using interpolation between mapped time periods and extrapolation after 2013. Annual area estimates for various land management categories were then refined based on secondary data sources. The two main secondary data sources were industry statistics on peatland areas managed for peat extraction in 2015 compiled by the Canadian Sphagnum Peat Moss Association (CSPMA) and a survey of abandoned peat extraction sites in the provinces of Quebec and New Brunswick (Poulin et al,. 2005). Secondary data sources were used to provide a comparative check of total areas converted to peat

extraction historically and current production areas, and to complement limitations in the ability of the mapping approach to identify land management subcategories. National peat production statistics were used to represent the annual amount of extracted peat transported off site (NRCan, 2019).

Uncertainty

Given the increased availability and quality of EO imagery and ancillary information over time, it is assumed that there is a decrease in uncertainty in the mapped areas for the later mapping periods. The use of high-resolution satellite imagery for the 2013 time period reduced uncertainty in the overall estimate of the total areas converted for peat extraction. However, there is considerable uncertainty associated with identifying land management subcategories. Uncertainty in the 2015 CSPMA industry statistics is associated with different interpretations of land management category definitions (e.g., restoration) and incomplete coverage of lands not managed by industry association members.

There is a lack of domestic GHG measurements for the various categories of decommissioned sites. Therefore, emission factors may not represent the full range and success rates of applied rehabilitation and restoration techniques. The large variation in moisture content among peat products may contribute substantially to the uncertainty of off-site CO_2 emission estimates from extracted peat.

A3.5.6.2. Flooded Lands

General Approach and Methods

Following the 2006 IPCC Guidelines, 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. (2014). It is believed that the default approach, assuming that all biomass C would be emitted

Table A3.5–10 **Parameters and Emission Factors for Estimating Emissions from Peat Extraction**

Emission Factor/Parameter	Unit	Value	Sources
Biomass Clearing			
Forest land biomass cleared	t C ha^{-1}	19.2	Hayne and Verbicki, 2011
Other land biomass cleared	t C ha^{-1}	2.8	Hayne and Verbicki, 2011
Drainage			
CO_2 from drained areas	t CO_2 ha^{-1} yr^{-1}	11.4	Moore et al., 2002, as cited in Cleary, 2003; Glatzel et al., 2003; Waddington et al., 2010; Strack and Zuback, 2013; Strack et al., 2014
CO_2 -DOC from drained areas	t CO_2 ha^{-1} yr^{-1}	0.60	Waddington et al., 2008; Strack and Zuback, 2013
CH_4 from drained fields	t CH_4 ha^{-1} yr^{-1}	0.008	Moore et al., 2002 as cited in Cleary, 2003; Waddington and Day, 2007; Strack and Zuback, 2013; Strack et al., 2014
CH_4 from drainage ditches	t CH_4 ha^{-1} yr^{-1}	0.15	Waddington and Day, 2007
N_2O from drained areas	t N_2O ha^{-1} yr^{-1}	0.00047	IPCC, 2014 (Table 2.5, Default value for Boreal & Temperate climate zone)
CO_2 from abandoned block-cut areas	t CO_2 ha^{-1} yr^{-1}	8.6	Waddington and Price, 2000; Waddington and Warner, 2001; Waddington et al., 2002; McNeil and Waddington, 2003
CH_4 from abandoned block-cut areas	t CH_4 ha^{-1} yr^{-1}	0.012	Waddington and Price, 2000
CO_2 tree plantation biomass uptake	t CO_2 ha^{-1} yr^{-1}	-0.32	Garcia Bravo, 2015
Peat Stockpiling and Product Production			
Amount of stockpiled peat	t C ha^{-1}	50	Cleary, 2003
Exponential decay constant, stockpiled peat		0.05	Cleary, 2003
Carbon fraction of peat products	t C t air-dry $peat^{-1}$	0.26	Hayne et al., 2014
Rewetting and Restoration			
CO_2 from restored areas	t CO_2 ha^{-1} yr^{-1}	7.60	Moore et al., 2002 as cited in Cleary, 2003; Petrone et al., 2001; Petrone et al., 2003; Waddington et al., 2010; Strack and Zuback, 2013; Strack et al., 2014
CO_2-DOC from restored areas	t CO_2 ha^{-1} yr^{-1}	0.13	Waddington et al., 2008; Strack and Zuback, 2013
CH_4 from restored fields	t CH_4 ha^{-1} yr^{-1}	0.03	Moore et al., 2002 as cited in Cleary, 2003; Waddington and Day, 2007; Strack and Zuback, 2013; Strack et al., 2014
CH_4 from restored ditches	t CH_4 ha^{-1} yr^{-1}	0.28	Waddington and Day, 2007; Strack and Zuback, 2013
N_2O from restored areas	t N_2O ha^{-1} yr^{-1}	N/A	IPCC, 2014, Default assumption of no N2O emissions from rewetted/ restored areas

Note: All units where the greenhouse gas (GHG) is specified use units of the relevant GHG (CO_2, CH_4 or N_2O) instead of C and N.

upon flooding, would overestimate immediate forest conversion 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 forest C pools are estimated with the CBM-CFS3 (see section A3.5.2.1). Emissions from forest clearing for infrastructure development are reported under the subcategory Forest Land Converted to Settlements. Emissions resulting from the use and disposal of wood products that are harvested before flooding are reported under the category Harvested Wood Products (see section A3.5.3).

In the absence of evidence of forest clearing, it was assumed that all vegetation was simply flooded, leading to the emission—as CO_2—of a fraction of the submerged C 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 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 of measurement procedures and measurement comparability. The emission curve was developed from 25 reservoirs and a total of 34 measurements (Figure A3.5–18). It is important to note that each of these measurements (data points in Figure A3.5–18) 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 A3.5–20

$$CO_{2\ rate\ L\_reservoir} = b_0 + b_1 \times In(t)$$

$CO_{2\ rate\ L\_reservoir}$	=	rate of CO_2 emissions from land converted to wetlands (reservoirs), mg m^{-2} per day
b_0, b_1	=	curve parameters, unit less
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:

Equation A3.5–21

$$CO_{2\ L\_reservoirs} = \sum(CO_{2\ rate\ L\_reservoir} \times A_{reservoir} \times Days_{ice\ free} \times 10^{-8})$$

$CO_{2\ L\_reservoirs}$	=	emissions from lands converted to flooded lands (reservoirs), Gg CO_2 yr^{-1}
$CO_{2\ rate\ L\_reservoir}$	=	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
10^{-8}	=	conversion factor from mg to Gg

Reservoir area 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 (NRCan, 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. 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.

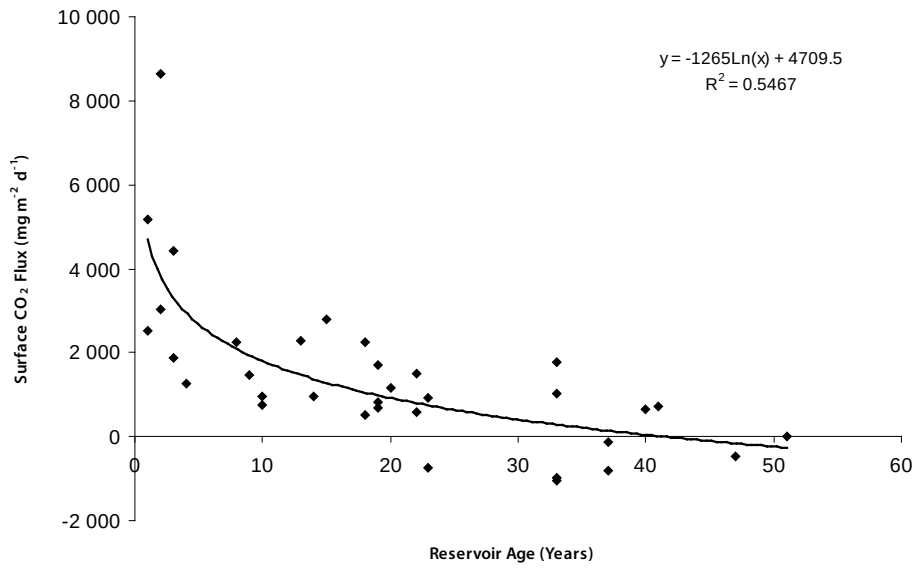
Data Sources

The three main data sources used to develop area estimates were information on forest conversion due to reservoir impoundment in reporting zones 4 and 5 (see section A3.5.2.3, Forest Conversion), the Canadian Reservoir Database (Duchemin, 2002), and official industry numbers derived from industry correspondence (Eichel, 2006; Tremblay[36]).

The Canadian Reservoir Database contains records of 282 hydro reservoirs. 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 commissioning of a dam and the date when a hydroelectric facility was refurbished without any changes to the reservoir area.

36 Tremblay A, Hydro-Québec. 2010. Personal communication dated November 19, 2010, to Dominique Blain, Environment Canada.

Figure A3.5–18 **Logarithmic Curve Fit for National Reservoir Emission Factors**



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 converted (less than 10 years ago) to reservoirs and older reservoirs (more than 10 years old), whose areas are thus transferred out of the accounting. The reporting system does not encompass all 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, important sources of uncertainty still remain:

- **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).

A3.5.7. Settlements

This category comprises estimates of removals of CO_2 from land classified as Settlements Remaining Settlements (C sinks in urban trees) and emissions from Land Converted to Settlements (conversion of forest land and of unmanaged grassland to Settlements). The following sections describe the approaches developed to estimate C sequestration by urban trees, emissions from the conversion of non-forest land (unmanaged grassland or tundra) to settlements in the Canadian Arctic and sub-Arctic and estimation of areas of conversion from cropland to settlements. Approaches, methods and data sources for estimating emissions from the conversion of forest land to settlements are covered in sections A3.5.2.1 and A3.5.2.3.

A3.5.7.1. Settlements Remaining Settlements

General Approach and Methods

In Canada, the management and monitoring of urban trees is done at the level of individual municipalities, and there is no centralized authority or organization with responsibility for compiling national-scale urban tree information. Taking into consideration the lack of specific species class information and the considerable resources it would require to develop such information, an approach based on urban tree crown (UTC) cover area was developed to estimate CO_2 sequestration by urban trees in Canada. The approach involves the sampling of digital air photos and high-resolution satellite imagery to estimate the proportion of UTC

cover in Canada's major urban areas. The growth of urban trees in Canada was estimated using an IPCC Tier 2A approach (IPCC, 2006):

Equation A3.5–22

$$\Delta C_G = \sum AT \times CRW$$

ΔC_G = annual carbon accumulation attributed to biomass increment of urban trees in settlements remaining settlements, tonnes C yr^{-1}

AT = total crown cover area of urban trees, ha

CRW = crown cover area-based growth rate for urban trees, tonnes C (ha crown cover)$^{-1}$ yr^{-1}

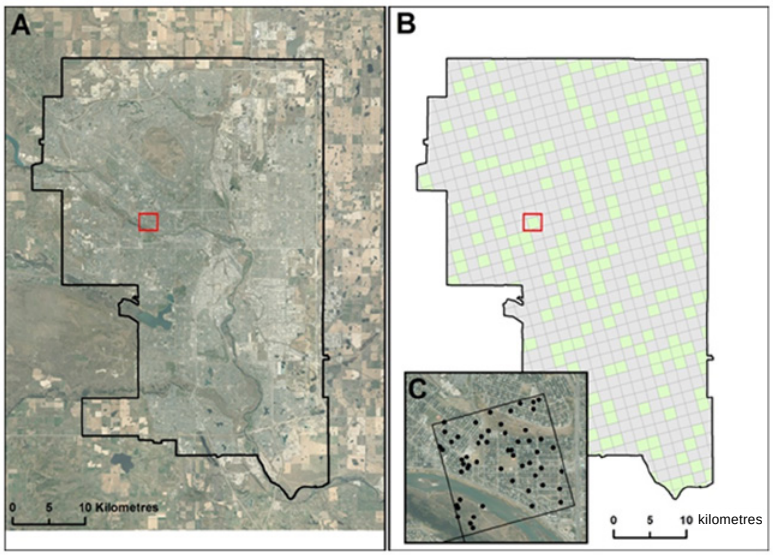
The total urban area of Canada in 2012 was estimated using the boundaries of Statistics Canada's 2011 populated place digital boundary layer,[37] as it was the most nationally consistent delineation of urban areas available. The urban boundaries of 1990 were based on Statistics Canada 1990 polygon layer, but manually edited through visual interpretation of aerial photos and the 1990 GeoCover (MDA-Federal, 2004) ortho-rectified image data set, to reduce known over-bounding errors (Statistics Canada, 2010). The resulting 1990 urban layer represented a smaller total area (1.53 Mha) than the total urban area identified for 2012. Of the 947 population centres (2.42 Mha) in Canada, 69 (1.53 Mha) were extracted from the Statistics Canada data set that had populations greater than 30 000 individuals. This subset captures all major Canadian cities and represented 62% and 67% of the total urban area in 1990 and 2012, respectively. Furthermore, this subset holds the urban centres that represented approximately 79% and 76% of Canada's population in 1990 and 2012, respectively (Statistics Canada, 2011; McGovern and Pasher, 2016). While the population centres selected did not completely represent all populated places in Canada, many of the smaller communities that were filtered out are parts of an overall matrix of forest or agricultural land that may be captured under other land categories.

The 69 population centres were spatially allocated to 18 of the 60 reconciliation units (RUs) (see section A3.5.1). The 18 RUs encompassed 97% and 99% of the total area and population, respectively, of the total of 947 population centres. Estimates of the proportion of UTC cover were developed for each RU using a point-based sampling approach (Pasher et al., 2014). A grid cell approach was used to ensure good spatial distribution of sampling cells (Figure A3.5–19). Random points at a density of 55 points/km^2 on digital air photos or high-resolution satellite imagery were interpreted manually and classed into broad categories of tree crown or non-tree crown.

The same sampling point locations were used for both the 1990 and 2012 UTC assessments, although sampling cells and points which fell outside the 1990 urban boundary were not included in order to ensure that sampling was

37 Statistics Canada Populated Place spatial data and information available online at: http://www12.statcan.gc.ca/census-recensement/2011/geo/bound-limit/bound-limit-2011-eng.cfm.

Figure A3.5–19 **Sampling Grids and Point Sampling over Georeferenced Air Photo**



Note: Background imagery: (A) Calgary, Alberta urban area boundary, (B) 1 km × 1 km grid cells representing a 25% sampling rate with randomly selected grid cells shown in green, and (C) close-up of a single grid cell (20 pts/km^2 sampling). Orthophoto courtesy of City of Calgary.

restricted so as to represent urban areas for that time period. A quality control process was implemented which involved random checks by alternative interpreters or reinterpretation. The percent UTC for each RU was calculated as the proportion of all points identified as tree canopy out of the total points that were assessed within the RU. The national-scale UTC estimate was 28.5% in 1990 and 27% in 2012.

The total crown cover area of urban trees for each RU was estimated by multiplying the % UTC by the total urban area estimates for the associated RU in 1990 and 2012. Although the urban area boundary has increased by 6% from 1990 to 2012, the national-scale estimate of crown cover changed little, with regional variation in trends. Gains in crown cover area (e.g., tree growth and planting) tended to balance with losses (e.g., tree removal, mortality and urban land-use change).

The crown cover area-based growth rate (CRW) values for the 18 RUs (see Table A3.5–11) are derived from assessments carried out in 16 Canadian cities using the same methodology used to develop CRW values for the United States. In RUs where cities were not assessed using that approach, values from proxy cities were used based on an ecologically similar Canadian RU, with the exception of RU 41, Pacific Maritime, for which the assessment for the U.S. city of Seattle was used (Steenberg et al., 2021). These assessments take into consideration the tree species, age and environmental conditions for each RU to determine gross sequestration rates. Net C sequestration was estimated as 74% of gross sequestration, accounting for urban tree growth characteristics and tree mortality and decomposition (Nowak et al., 2013). These growth and sequestration rates are applied to the 18 RUs and, as a result, estimates of UTC cover area and the sequestration rate are the main drivers of overall removal estimates. Interpolation and extrapolation were used to develop a consistent time series for the period 1990 to the latest inventory year.

Table A3.5–11 **Carbon Storage and Sequestration Densities in Urban Trees for Canadian RUs**

Reconcilliation Unit (RU)	Carbon Storage (t C ha^{-1} yr^{-1})	Carbon Sequestration (t C ha^{-1} yr^{-1})
1 NF – Boreal Shield East	40	3.0
5 NS – Atlantic Maritime	62	3.4
6 PE – Atlantic Maritime	62	3.4
7 NB – Atlantic Maritime	62	3.4
11 QC – Atlantic Maritime	62	3.4
12 QC – Mixedwood Plains	58	2.4
15 QC – Boreal Shield East	40	3.0
16 ON – Boreal Shield West	40	3.0
17 ON – Mixedwood Plains	58	2.4
19 ON – Boreal Shield East	40	3.0
24 MB – Subhumid Prairies	55	2.9
28 SK – Boreal Plains	40	3.0
30 SK – Semiarid Prairies	55	2.9
34 AB – Boreal Plains	40	3.0
35 AB – Subhumid Prairies	55	2.9
37 AB – Semiarid Prairies	55	2.9
41 BC – Pacific Maritime	97	6.9
42 BC – Montane Cordillera	23	1.4

Note:
Source – Steenberg et al., 2021

Analysis of the fate of urban tree mortality (Tree Canada 2019) suggested that approximately 13% of mortality in urban centres is used for firewood. As a result, the volume of firewood collected from urban trees was estimated by multiplying the C stocks for individual population centres by a 2.4% mortality rate of urban trees taken from (Tree Canada, 2018) and 13% of C from dead trees was assumed to be used as firewood (Tree Canada 2019). The firewood supply was aggregated by RU and supplied a portion of the firewood demand estimated from consumption surveys described in section A3.5.3. To avoid double counting of emissions between the Settlements and Harvested Wood Products categories, the amount of C transferred to the HWP pool was attributed to the difference between the gross and net annual sequestration rates estimated by the i-tree model. As a consequence the apparent sink in C under Settlements is increased due to the combustion of this C as residential firewood being reported under Harvested Wood Products.

Uncertainty

The uncertainties associated with the estimates of urban area, UTC and C sequestration rate all contribute to the overall uncertainty of the estimates of CO_2 removals by urban trees. The result of these combined uncertainties using a Tier 2 Monte Carlo analysis approach provides an estimated total uncertainty of 39% for 1990 and 2012.

The uncertainties associated with 1990 and 2012 urban areas were not quantified by Statistics Canada. An error estimate of 10% was used for the 2012 urban area following the approach used in the United States' 2012 national GHG inventory report (U.S. EPA, 2013). The error associated with the 1990 urban area estimate was assumed to be slightly higher at 15% than for 2012, based on expert judgement. This approach is similar to the uncertainty estimate for boundary delineation (15%) used for developing forest conversion estimates (Leckie, 2011).

The uncertainty associated with UTC estimates was based on the standard error of the sampling approach calculated for each sampling period (1990/2012). Standard errors for the UTC estimates were low (0.2% for the national UTC estimate) given the very high number of sampling points used.

The uncertainty estimate for the national gross C sequestration rate (27%) was developed from a Monte Carlo analysis associated with each RU for the urban tree field data collected in Canada and for the city of Seattle. This uncertainty estimate does not include the estimation error related to the use of biomass equations or conversion factors or to measurement error (Nowak et al., 2013).

A3.5.7.2. Cropland Converted to Settlements

Data Sources

Urban and industrial expansion has been one of the main drivers of cropland conversion in Canada. Areas of cropland conversion to settlements were estimated based on the land-use maps for 1990, 2000 and 2010 developed in Huffman et al. (2015a). Areas of conversion for the 1990–2000 and 2000–2010 periods were calculated through spatial analysis for each reporting unit and divided by the number of years in order to develop constant annual conversion rates. Areas of conversion were extrapolated after 2010. The total area of cropland converted to settlements for the 1990–2000 and 2000–2010 time periods was 184 kha and 115 kha, respectively, with the majority of change due to urban expansion in reporting zones 7 and 11. This is largely due to urban expansion in the main populated centres, such as Toronto, Hamilton, Oshawa, Montreal and Edmonton.

Uncertainty

Given that the highest conversion rates are caused by urban expansion, an independent assessment was conducted on the areas of conversion by comparing the land cover in each map against visual interpretation of ortho-rectified Landsat imagery over urban centres. The sampling strategy for this assessment was to perform the analysis on five main census metropolitan areas (CMA[38]), which contribute to 45% of the total area change from Cropland to Settlements. Polygons from the 2011 census were used to define the boundary of each CMA, and over 400 stratified random points were used to verify the land cover class in areas in which there were examples of either change or no-change from Cropland to Settlements, separated by a minimum distance of 1 km, to avoid statistical bias. The minimum mapping unit for the accuracy analysis was defined as a circle with radius of 100 m to prevent errors due to the presence of noise in each classified map. The class in each location was assigned based on the class of the majority of the pixels, to account for changes in land use. An overall accuracy of 80% and 84% was obtained for the areas of change computed from these maps, which concurs with the accuracy assessment carried out in Huffman et al. (2015a).

A3.5.7.3. Grassland Converted to Settlements

General Approach and Methods

Nearly half of Canada's land mass is in the Arctic and sub-Arctic regions and includes all land categories (IPCC, 2006), excluding Cropland. An approach was developed specifically for capturing the associated emissions by finding the land-use change and the amount of biomass stocks in this vast and remote landscape and included the following components: (i) manual digitizing of land-use polygons in Canada's Arctic/sub-Arctic for 1990, 2000 and 2010 based on ortho-rectified Landsat imagery and assessment of land-use change over about 359 million hectares, including areas in reporting zones 1, 2, 3, 4, 5, 8, 10, 13, 16, 17 and 18, north of 60°N latitude; and (ii) estimation of above-ground biomass based on field samples taken in Canada's Arctic/sub-Arctic regions between 2004 and 2010, covering the northern part of the Boreal Cordillera, Taiga Plains, Taiga Shield East, Taiga Shield West, Southern Arctic, Northern Arctic, and Arctic Cordillera.

A comprehensive, wall-to-wall analysis of land-use circa 1990, 2000 and 2010 was carried out based on image interpretation followed by manual digitization of the sites undergoing change (McGovern et al., 2016). A wide range of human disturbances such as airstrips, roads, power lines, seismic lines, urban areas, mines, reservoirs and even smaller features like well sites and some roadside clearings were identified using snow- and ice-free imagery. Analysis of existing GIS data sets denoting the occurrence of anthropogenic development were used to guide the search for areas with high probability of land-use change. Mapping was then expanded outwards from these regions based on the observation of additional disturbances. The resulting spatial data set provided the most comprehensive and complete mapping product for human disturbances in Canada's Northern region, and builds on previous boreal disturbance mapping activities conducted by Environment and Climate Change Canada (ECCC). An interpretation guide similar to that of the Canadian Forest Service (Dyk et al., 2015) was used to guarantee consistency in the detection, digitization and categorization of disturbances. A total of 1135 scenes were used for the interpretation process (395 for 1990, 348 for 2000 and 392 for 2010).

Land-use change was derived from the difference in polygon areas for each date, providing an area of change between the time periods (i.e.,1990–2000, 2000–2010), which was divided by the total years in the time period to produce a constant annual rate of change. The same annual rate of land-use change was applied for the years prior to 1990 and following 2010. The pre-conversion land-use type for each of the land-use change polygons was based on available land cover maps (Wulder et al., 2008; Hermosilla et al., 2016), visual interpretation and vegetation indices of concurrent imagery to avoid including areas in other land-use categories (e.g., Forest Land, Cropland, Wetlands and Other Land). Furthermore, deforestation events above 60 degrees latitude were also used to confirm that areas determined to be forest conversion to settlements were excluded, to avoid double-counting.

The biomass lost was derived from statistical analysis of field samples surveyed between 2004 and 2011 over the Canadian north (Figure A3.5–20). Over 116 samples were collected in different land cover types (e.g., shrubs, grass tundra, wetland, forest and barren land) in eight reporting

38 This term has been defined by Statistics Canada as the area consisting of one or more neighbouring municipalities with a population of 100 000 inhabitants or more.

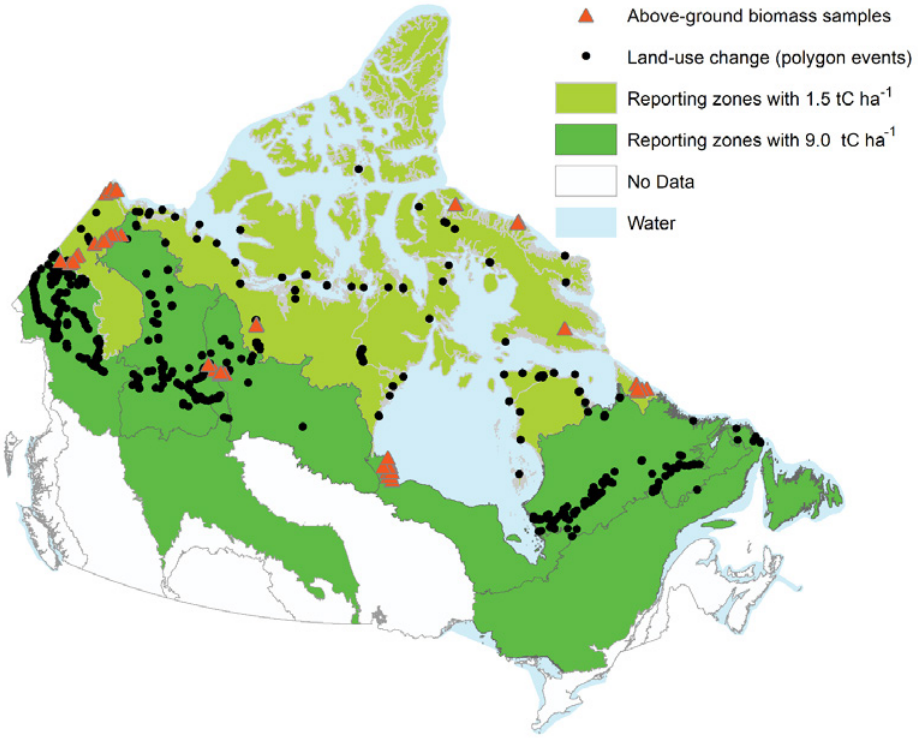
zones. The vegetation in this region consists of forest patches in the Boreal Cordillera and Taiga Plains, but predominantly low vegetation composed of sparse shrubs, mixed grass-dwarf shrub, lichen, moss tussock sedge, bare soil and Arctic willow tundra for the remaining reporting zones. Due to diversity of vegetation types and landscapes over the extent of this region, field samples on forest were excluded and the remaining samples were grouped into two classes: high and low vegetation. This grouping was based on the fact that, after statistical examination of the above-ground biomass values, there was significant variability in the sampled vegetation types between reporting zones. As an initial implementation, the mean of the samples for reporting zones 1 (Arctic Cordillera), 2 (Northern Arctic), 3 (Southern Arctic) and 17 (Taiga Cordillera) was used to obtain a single value of above-ground biomass (1.5t C/ha) that was applied to all of them—areas with "low" vegetation types. Similarly, a single average value (9 tC/ha) from all samples in the remaining reporting zones (Taiga Plain, Taiga Shield West, Boreal Cordillera and Hudson Plains) was used and applied for the remaining areas—areas with "high" vegetation. Reporting zones with land-use change data but without field samples (i.e., Taiga Shield East, Boreal Shield East and Boreal Plains) were assigned to either of the two groups of low or high vegetation based on an analysis of vegetation indices. Emissions from land-use change were estimated by multiplying the annual area of land-use change by their respective biomass lost factor to obtain C stock changes. Annual area rates and emissions for years after 2010 were extrapolated from the 2000–2010 period, assuming a constant yearly rate.

The biomass factor obtained for each of the two vegetation groups was assessed based on the vegetation characteristics of each ecozone (Marshall et al., 1999) and values in the literature (Shaver and Chapin, 1991; Hudson and Henry, 2009; Gould et al., 2003) and was also compared against values reported by the IPCC for the boreal and cool temperate regions. All land-use change activities involved conversion of Arctic tundra vegetation to settlements, and all pre-conversion biomass C was deemed emitted upon clearing.

Uncertainty

The error propagation approach was used to estimate uncertainty using a 95% confidence interval. The percentage of uncertainty for the above-ground biomass volume was 70% for ecozones with low vegetation and 80% for all the other ecozones, based on the coefficient of variation. The uncertainty of the total land-use change area was estimated to be 30%, based on random sampling and image interpretation. A 20% uncertainty was used for the C content, estimated to be 50% of the dry biomass weight, based on the IPCC guidelines. Using these values, an overall uncertainty of 87% was estimated for this category.

Figure A3.5–20 **Location of Land-Use Events and Field Samples of Above-Ground Biomass in Canada's North**



Note: More southerly reporting zones are attributed to the 9 tC ha^{-1} biomass class, as some sites border on the northernmost boundary of these reporting zones.

A3.6. Methodology for Waste Sector

The Waste sector consists of four categories: Solid Waste Disposal (Landfills), Biological Treatment of Solid Waste, Incineration and Open Burning of Waste, and Wastewater Treatment and Discharge. This section of Annex 3 details the accounting methodologies that are used to describe the greenhouse gas (GHG) emission estimates for these categories with a focus on the following categories and gases:

- CH_4 emissions from solid waste disposal (municipal solid waste and industrial wood waste landfills)
- CH_4 and N_2O emissions from biological treatment of solid waste (composting and anaerobic digestion)
- CO_2, CH_4, and N_2O emissions from waste incineration (municipal solid waste, hazardous, clinical and sewage sludge waste)
- CH_4 and N_2O emissions from wastewater treatment (municipal and industrial)

A3.6.1. Emissions from Solid Waste Disposal (Landfills)

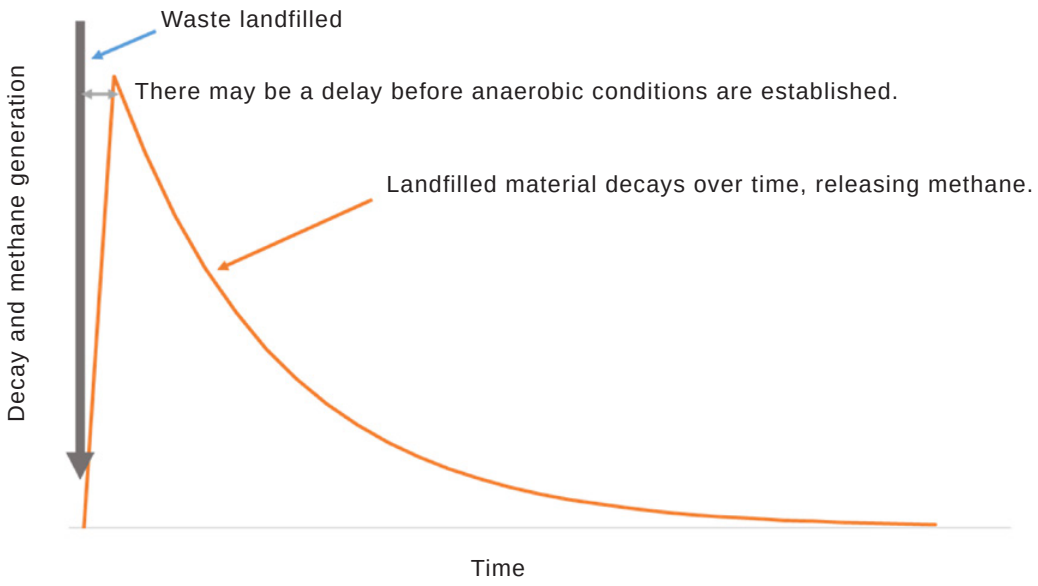
A3.6.1.1. General Approach and Methods

In Canada, the Solid Waste Disposal (Landfills) category comprises two types of landfills: municipal solid waste (MSW) landfills and industrial wood waste (WW) landfills. The treatment and disposal of solid waste produces significant amounts of CH_4, in addition to smaller amounts of CO_2. However, as the CO_2 is primarily from biogenic sources, it is not included in total waste emissions. Emissions of N_2O from landfills are not estimated as they are not significant, and no quantification methodology is provided by the IPCC (IPCC 2006; IPCC 2019).

Emissions for MSW and WW landfills are calculated separately at the provincial and territorial level. Emissions from MSW landfills are reported to the UNFCCC under category 5.A.1, Managed Waste Disposal Sites, while emissions from WW landfills are reported under category 5.A.2, Unmanaged Waste Disposal Sites.

Methane generated from landfills is calculated using a first-order decay (FOD) model, in accordance with Volume 5, Chapter 3, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, hereafter referred to as the 2006 IPCC Guidelines (IPCC 2006). The FOD model considers that waste deposited in any given year decays over several decades at an initially high-rate, which decreases over time (Figure A3.6–1).

Figure A3.6–1 **Representation of First Order Decay Emissions from One-Time Waste Deposition in Landfill**



Landfill gas capture, flaring, and utilization practices are increasingly common in Canadian landfills. The amount of methane in landfill gas captured by facilities is subtracted from the total amount generated within the landfill to determine the amount that is actually released annually from the decomposing waste. A small amount of methane is released from flaring and utilization of landfill gas (combustion for heat or energy). The amount of CH_4 ultimately emitted by a landfill is further reduced by the oxidation of some of the CH_4 into CO_2 by methanotrophic bacteria in landfill cover material.

The calculation of CH_4 emissions from waste landfilled can be summarized with Equation A3.6–1. The stepwise calculations that make up the FOD model are represented by Equation A3.6–2 to Equation A3.6–5. Methane generation is calculated by material.

Equation A3.6–1 **(modified from the 2006 IPCC Guidelines Eq. 3.1)**

$$CH_4\ emitted_T = [CH_4\ generated_T - R_T] \times (1 - OX) + (CH_4\ flared_T \times (1 - Efcy_{flr}))$$

$CH_4\ emitted_T$	=	CH_4 emitted from landfills in year T (tonne)
T	=	inventory year
$CH_4\ generated_T$	=	CH_4 generated by landfilled waste in year T (tonne)
R_T	=	CH_4 recovered through landfill gas capture in year T (tonne)
OX	=	oxidation factor (fraction)
$CH_4\ Flared_T$	=	amount of CH_4 flared in year T (tonne)
$Efcy_{flr}$	=	flaring efficiency (fraction)

Note:

Methane emitted from utilization of landfill gas for energy are calculated and reported as part of the Energy section.

Equation A3.6–2 **(modified from 2006 IPCC Guidelines Eq. 3.2)**

$$DDOC_{m,T} = Waste\ deposited_{m,T} \times DOC_m \times DOC_{fm}$$

$DDOC_{m,T}$	=	mass of decomposable degradable organic carbon from material m that is deposited in year T (tonne)
m	=	type of waste material type deposited (e.g., food, paper)
T	=	year
$Waste\ deposited_{m,T}$	=	mass of waste material m deposited in year T (tonne)
DOC_m	=	fraction of degradable organic carbon in waste type m
$DOC_{f,m}$	=	fraction of DOC that can/does decompose, for waste type m

Equation A3.6–3 **(modified from the 2006 IPCC Guidelines Eq. 3.4)**

$$DDOCma_T = DDOCmd_y + (DDOCma_{y-1} \times e^{-k})$$

T	=	inventory year
$DDOCma_T$	=	DDOCm (decomposable degradable organic carbon, from waste material m) accumulated in the landfill at the end of year (tonne)
$DDOCma_{T-1}$	=	DDOCm accumulated in the landfill at the end of year (T-1) (tonne)
$DDOCmd_T$	=	DDOCm deposited into the landfill in year T (tonne)
k	=	decay rate constant (year^{-1})

Equation A3.6–4 **(modified from the 2006 IPCC Guidelines Eq. 3.5)**

$$DDOCm\ decomp_T = DDOCma_{T-1} \times (1 - e^{-k})$$

$DDOCm\ decomp_T$	=	DDOCm (decomposable degradable organic carbon, from waste material m) that decomposed in the landfill in year T (tonne)
T	=	inventory year
$DDOCma_{T-1}$	=	DDOCm accumulated in the landfill at the end of year (T-1) (tonne)
k	=	decay rate constant (year^{-1})

Equation A3.6–5 **(2006 IPCC Guidelines Eq. 3.6)**

$$CH_4\ generated = DDOCm\ decomp_{m,T} \times FracCH_4 \times 16/12 \times MCF$$

$CH_4\ generated$	=	amount of CH_4 generated from decomposable material
$DDOCm\ decomp_{m,T}$	=	DDOCm (decomposable degradable organic carbon, from waste material m) that decomposed in year T (tonne)
$FracCH_4$	=	fraction of CH_4, by volume, in landfill gas
$16/12$	=	molecular weight ratio CH_4/C
MCF	=	methane correction factor

The parameters used, including material-specific DOC and DOC_f values and decay rate constants, are presented in section A3.6.1.1 for municipal solid waste landfills and in section A3.6.1.3 for industrial wood waste landfills. For more details on the parameters themselves, such as how they are developed and guidance on selecting appropriate values, see Volume 5, Chapter 3, of the 2006 IPCC Guidelines (IPCC 2006).

A3.6.1.2. Municipal Solid Waste (MSW) Landfills

A3.6.1.2.1. Model Parameters for MSW Landfills

Degradable Organic Carbon

The degradable organic carbon (DOC) represents the portion of the organic carbon in the waste that is available for decomposition. It is a characteristic of the materials deposited. DOC is generally measured as a fraction of wet weight of the waste material, with the exception of sewage sludge, which is measured in dry weight. The total DOC is determined by the composition of the waste entering into the landfill. The material-specific DOC values used are shown in Table A3.6–1.

Fraction of Degradable Organic Carbon Which Decomposes

The decomposable degradable organic carbon (DOC_f) is an estimate of the amount of DOC in waste that actually decomposes in the landfill. The material-specific DOC_f values are taken primarily from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019). The values are shown in Table A3.6–1.

Waste classifications varied over time with each characterization study. In other words, a given waste type might only be used in one characterization, but not used in others characterizations. Some examples are "Rubber and Leather" which were grouped together in the characterization study by SMi (SMi 2016), or the category "Other Inert," which is the remainder of non-organic waste from the SMi study, which only characterized waste that had organic components.

Methane Correction Factor

The methane correction factor (MCF) accounts for the decomposition of waste under different management practices. It is used to account for the fact that unmanaged landfills produce less CH_4 from a given amount of waste than anaerobic managed landfills (IPCC 2006). All municipal solid waste landfills in Canada are assumed to be anaerobic managed landfills (MCF = 1.0).

Decay Rate Constant (k)

The decay rate constant, k, represents the rate at which CH_4 is generated in the FOD reaction after waste has been landfilled. The value of k can be affected by moisture content, nutrient availability, temperature and pH, among other factors. The 2006 IPCC Guidelines decay rate constants, k, for the boreal-temperate wet and dry climate zones are used (IPCC 2006). The "wet" and "dry" climates are defined by the ratio of mean annual precipitation to potential evapotranspiration: wet climates have a mean annual precipitation that is greater than the potential evapotranspiration, while dry climates have a

Table A3.6–1 **Waste Material Degradable Organic Carbon (DOC) Content and Fraction of Degradable Organic Carbon That Does Decay (DOC_f)**

Material	DOC	DOC Source	DOC_f	DOC_f Source
Food	0.15	IPCC 2006	0.7	IPCC 2019 Refinement
Paper	0.4	IPCC 2006	0.5	
Textiles	0.24	IPCC 2006	0.5	
Wood	0.43	IPCC 2006	0.1	
Yard and Garden	0.2	IPCC 2006	0.7	
Other Organics	0.5	IPCC 2006 Bulk	0.7	
Leather	0.39	IPCC 2006	0.1	
Rubber	0.39	IPCC 2006	0	IPCC 2006 Guidelines Footnote Table 2.4 (Natural rubber doesn't decompose in landfill)
Diapers	0.24	IPCC 2006	0.5	IPCC 2019 Refinement "moderately decomposable"
Pet Waste	0.24	ECCC estimate	0.5	
Construction Debris	0.22	ECCC estimate	0.5	IPCC 2006/2019 Default (bulk waste)
Other – Unknown	0.5	IPCC 2006 Bulk	0.5	
Plastics	0	IPCC 2006	0	
Oils Paints and Solvents	0	ECCC estimate	0	ECCC estimate
Unknown (Presumed Inert)	0	ECCC estimate	0	
Glass	0	IPCC 2006	0	
Metals	0	IPCC 2006	0	
Hazardous	0	ECCC estimate	0	
Concrete	0	IPCC 2006	0	
Asphalt	0	ECCC estimate	0	
Other Inert	0	ECCC estimate	0	
Electronics	0	ECCC estimate	0	
Soil and Dirt	0.5	IPCC 2006 Bulk	0.1	
Sewage Sludge	0.3	IPCC 2019 Refinement	0.5	IPCC 2006/2019 Default (bulk waste)

mean annual precipitation that is less than the potential evapotranspiration. The material-specific decay rate constants, by climate, are shown in Table A3.6–2. The estimates of waste landfilled by climate zone, for each province, is discussed in section A3.6.1.2.2.

Applying decay rate constants by material, rather than as bulk averages for all waste, better captures both the differences between materials and the variations in waste composition over time. For example, food waste has a decay rate constant of 0.185 or a half life 3.7 years in wet climates, whereas paper has a decay rate constant of 0.06 or a half life 11.6 years in the same climate. Each material will produce emissions at different rates after initial deposition in landfills. Again, taking the example of food and paper, food will exhibit rapid decay and release of emissions early on, dropping off more quickly. In contrast, paper will initially produce less emissions, but those emissions will not decrease as quickly, resulting in relatively higher rates at later periods.

Fraction of Landfill Gas that is CH_4

The FracCH_4 value in Equation A3.6–5 represents the methane fraction of landfill gas generated by anaerobic decomposition within the landfill, by volume. The 2006 IPCC Guidelines (IPCC 2006) recommended default of 0.5 is used for all time periods and regions.

Methane Recovery

Methane emissions are reduced by the recovery of landfill gas, which is commonly practiced in Canada. A study commissioned by ECCC found that approximately 90% of medium- and large-sized landfills surveyed currently employ landfill gas capture technologies (GHD 2017). Methane in landfill gas is destroyed (oxidized to CO_2) by flaring or when combusted for energy purposes. Methane escaping flaring due to combustion inefficiencies are included in the emission totals. Methane escaping combustion for energy purposes due to inefficiencies are estimated and reported as part of the Energy sector and are not included in the Waste totals.

Emissions from Flaring and Utilization

Combustion by flaring is considered to be 99.7% efficient. CH_4 released from flaring is added to the CH_4 released from landfills to obtain the total CH_4 emitted. CH_4 released from combustion (utilization) of landfill gas is reported in the Energy sector.

Oxidation through Landfill Cover

Methane emissions from landfills are reduced further by the oxidation of CH_4 into CO_2 by methanotrophic bacteria in landfill cover material. A broad range of provincial regulations mandate that Canadian landfills be capped with a daily cover of material such as soil, compost, woody material or fill. When a landfill is no longer operational, it is capped with a final, more robust cover.

The 2006 IPCC Guidelines' (IPCC 2006) default factor of 0.1 for managed landfills covered with CH_4 oxidizing material is used for all regions and time periods.

Table A3.6–2 **Decay Rate Constants and Half-Lives of Waste Materials, by Climate**

Material	Decay Rate, k (yr^{-1})		Half-Life (yr)		Source
	Dry	Wet	Dry	Wet	
Food	0.06	0.185	11.6	3.7	IPCC 2006 Guidelines
Paper	0.04	0.06	17.3	11.6	IPCC 2006 Guidelines
Textiles	0.04	0.06	17.3	11.6	IPCC 2006 Guidelines
Wood	0.02	0.03	34.7	23.1	IPCC 2006 Guidelines
Yard and Garden	0.05	0.1	13.9	6.9	IPCC 2006 Guidelines
Other Organics	0.05	0.1	13.9	6.9	IPCC 2006 Guidelines, Moderately Degrading Waste
Leather	0.01	0.01	69.3	69.3	ECCC estimate
Rubber	0.01	0.01	69.3	69.3	ECCC estimate
Diapers	0.06	0.185	11.6	3.7	IPCC 2006 Guidelines, Sewage Sludge
Pet Waste	0.06	0.185	11.6	3.7	
Sewage Sludge (dry wt)	0.06	0.185	11.6	3.7	
Construction Debris	0.02	0.03	34.7	23.1	IPCC 2006 Guidelines, Wood
Soil and Dirt	0.05	0.09	13.9	7.7	IPCC 2006 Guidelines, Default Bulk Waste
Plastics	0.05	0.09	13.9	7.7	
Other – Unknown	0.05	0.09	13.9	7.7	
Oils Paints and Solvents	0.05	0.09	13.9	7.7	
Glass	0.05	0.09	13.9	7.7	
Metals	0.05	0.09	13.9	7.7	
Hazardous	0.05	0.09	13.9	7.7	
Concrete	0.05	0.09	13.9	7.7	
Asphalt	0.05	0.09	13.9	7.7	
Electronics	0.05	0.09	13.9	7.7	

A3.6.1.2.2. Data Sources Municipal Solid Waste (MSW) Landfills

Waste deposited in municipal landfills in Canada is an aggregate of waste from industrial, commercial and institutional (ICI), construction and demolition (C&D) and residential sources, but also includes sewage sludge, which is a by-product of wastewater treatment (section A3.6.4).

There is no consistent and comprehensive data set of waste landfilled in Canada. There are, however, data available on the total amount of municipal solid waste (MSW) disposed, which is the solid waste from residential, ICI and C&D sources that is landfilled, incinerated and exported. Note that waste disposed does not include sewage sludge (which must be quantified separately), or waste diverted at source for recycling or compost.

The total waste landfilled can be determined from the amount disposed after accounting for amounts incinerated and amounts exported, and adding the amount of sewage sludge landfilled.

Equation A3.6–6 **Waste Landfilled in Municipal Landfills**

$$Total\ Waste\ Landfilled = [MSW_{Disposed} - MSW_{Incinerated} - MSW_{Exported}] + Sewage\ Sludge_{Landfilled}$$

$Total\ Waste\ Landfilled$	=	mass of waste landfilled, tonnes
$MSWDisposed$	=	mass of municipal solid waste (MSW) disposed in Canada, which includes solid waste landfilled, incinerated and exported, tonnes
$MSWIncinerated$	=	mass of MSW incinerated in Canada, tonnes
$MSWExported$	=	net mass of MSW exported (imported) to (from) the United States, tonnes
$Sewage\ Sludge_{Landfilled}$	=	mass of sewage sludge landfilled, tonne

Quantity of Waste Disposed

Municipal solid waste (MSW) disposed includes waste from institutional, commercial and industrial (ICI), construction and demolition (C&D) and residential sources. MSW disposal data are required from 1941 onward. Two primary data sources and calculation approaches are used: per-capita disposal rates from 1941 to 1993, and reported disposal quantities from 1994 onward.

Waste disposal data from 1994 onward are obtained through Statistics Canada's biennial Waste Management Industry Survey (Statistics Canada, no date [a]) *which* compiles waste disposal data for every even year. Disposal quantities are linearly interpolated for intermediary years (e.g., 1995, 1997, etc.). When survey data have not yet been released for the latest inventory year, the most recent survey results are held constant.

Waste disposal quantities for PEI and the territories are suppressed for the years 1994 to 2016 in Statistics Canada tables, for confidentiality reasons, but available from 2018. Waste disposal data for PEI has been obtained from the province for the years 1995 to 2000 and 2004 to 2018. Data gaps were bridged through linear interpolation. Waste disposal for the territories from 1994 onward is estimated using the 2018 per-capita waste disposal rate of 0.73 tonnes/capita/year for the three territories.

Waste disposal amounts for 1941 to 1980 for all provinces and territories are calculated using national per-capita disposal rates obtained from Levelton (Levelton 1991) and population from Statistics Canada (Statistics Canada, no date (d), Statistics Canada, no date [e]). Levelton presented per-capita disposal rates at 5- to 20-year increments. Disposal rates were linearly interpolated for intermediary years. Disposal rates for 1985 and 1990 were published in the report, but these were an extrapolation at the time and are not used. Disposal rates for the provinces and territories from 1981 to 1993 are linearly interpolated between the per-capita disposal rate in 1980 from Levelton (1991) and the per-capita disposal rate in 1994 (1995 in PEI) from Statistics Canada.

Waste Incinerated

Data on the amount of waste incinerated are discussed in section A3.6.3.

Waste Exported

Waste exports are not directly tracked by Canada. An ECCC internal database of waste exports to the United States since 1989 has been compiled from U.S. state databases and congressional reports and by contacting state officials. Where data are not available for the most recent reporting years, the last data point is held constant.

Waste Landfilled

The total amount of waste landfilled is calculated from the municipal solid waste disposed, accounting for exports and incineration and quantities of sludge landfilled. The final amount of waste landfilled, as determined from waste disposed, incinerated and exported, is shown in Table A3.6–3.

Sewage Sludge Landfilled

Sewage sludge produced is estimated as part of the wastewater treatment organics flow calculations. The amount of sewage sludge landfilled can be estimated in a manner similar to that used for MSW, accounting for incineration and export, but also anaerobic digestion, compost and land application. Accounting to determine sewage sludge landfilled is shown in section A3.6.4 and Equation A3.6–28 Sludge Volatile Suspended Solids Fraction After Anaerobic Digestion.

Table A3.6–3 **Waste Landfilled in Municipal Solid Waste Landfills 1990–2019 (tonnes)**

Year	Food	Other Organics	Paper	Diapers and Pet Waste	Textiles	Rubber and Leather	Sludge (Dry Wt)	Yard and Garden	Wood	Construction Debris	Other	Inert	Total
1990	2.77	0.00	6.16	0.00	0.22	0.25	0.17	2.74	0.86	0.96	1.79	3.80	19.72
1991	2.82	0.00	6.23	0.00	0.22	0.26	0.17	2.79	0.87	0.97	1.82	3.85	20.00
1992	2.73	0.00	5.94	0.00	0.22	0.26	0.17	2.70	0.83	0.94	1.77	3.69	19.25
1993	2.89	0.00	6.31	0.00	0.23	0.27	0.17	2.85	0.89	0.99	1.88	3.91	20.39
1994	3.05	0.00	6.71	0.00	0.24	0.28	0.16	3.02	0.94	1.05	1.98	4.15	21.58
1995	2.98	0.00	6.60	0.00	0.24	0.27	0.16	2.95	0.93	1.02	1.93	4.08	21.16
1996	2.83	0.00	6.25	0.00	0.23	0.26	0.16	2.79	0.87	0.97	1.81	3.87	20.04
1997	2.84	0.00	6.29	0.00	0.22	0.26	0.15	2.80	0.88	0.97	1.82	3.89	20.12
1998	2.84	0.00	6.29	0.00	0.22	0.26	0.15	2.80	0.88	0.97	1.82	3.89	20.12
1999	3.01	0.00	6.73	0.00	0.23	0.26	0.15	2.97	0.95	1.02	1.93	4.15	21.40
2000	3.09	0.00	6.93	0.00	0.23	0.27	0.15	3.05	0.98	1.05	1.98	4.27	22.00
2001	3.06	0.00	6.84	0.00	0.23	0.27	0.14	3.02	0.97	1.04	1.96	4.22	21.75
2002	4.11	0.00	5.77	0.43	0.58	0.17	0.13	1.20	2.45	0.00	0.71	6.60	22.15
2003	4.09	0.00	5.63	0.43	0.58	0.17	0.12	1.22	2.41	0.00	0.69	6.45	21.79
2004	3.99	0.00	5.26	0.44	0.58	0.17	0.12	1.24	2.63	0.00	0.65	6.66	21.74
2005	4.05	0.00	5.31	0.45	0.60	0.18	0.12	1.31	2.69	0.00	0.65	6.73	22.09
2006	4.24	0.00	5.49	0.50	0.62	0.18	0.11	1.45	2.69	0.00	0.67	6.83	22.78
2007	4.23	0.00	5.54	0.50	0.62	0.18	0.11	1.45	2.69	0.00	0.69	6.85	22.86
2008	4.21	0.00	5.59	0.49	0.62	0.18	0.10	1.50	2.63	0.00	0.71	6.68	22.71
2009	4.19	0.00	5.61	0.49	0.61	0.18	0.10	1.48	2.63	0.00	0.71	6.70	22.70
2010	4.19	0.00	5.48	0.50	0.62	0.18	0.10	1.48	2.48	0.00	0.69	6.52	22.24
2011	4.24	0.00	5.61	0.50	0.63	0.18	0.09	1.48	2.52	0.00	0.71	6.66	22.62
2012	4.26	0.00	5.63	0.51	0.63	0.19	0.08	1.47	2.44	0.00	0.71	6.62	22.54
2013	4.08	0.00	5.24	0.50	0.61	0.18	0.08	1.45	2.33	0.00	0.66	6.23	21.36
2014	4.03	0.00	5.17	0.50	0.62	0.18	0.07	1.45	2.40	0.00	0.65	6.29	21.36
2015	5.01	1.41	2.42	1.22	0.30	0.27	0.07	0.97	2.18	1.99	1.70	4.18	21.72
2016	4.93	1.38	2.37	1.22	0.29	0.27	0.07	0.99	2.06	1.90	1.65	4.07	21.20
2017	4.85	1.36	2.33	1.20	0.29	0.27	0.07	0.98	2.03	1.88	1.62	4.01	20.89
2018	5.02	1.41	2.41	1.25	0.30	0.28	0.07	1.00	2.10	1.94	1.69	4.17	21.64
2019	5.18	1.45	2.49	1.30	0.31	0.28	0.07	1.03	2.17	1.98	1.74	4.30	22.30

Notes:

a. Inert includes Glass, Metals, Ash, Concrete, Asphalt, Plastics, Other Inert, Electronics

b. Full data set, by Province, Territory and climate region available on request

Municipal Solid Waste Characterization

Waste characterization is the quantification of the material composition of the waste. Municipal solid waste is characterized after accounting for exports and incineration. Sewage sludge is added to the totals landfilled afterwards and is not included in or impacted by the characterization.

Waste characterization studies with sufficient scope to describe waste composition across all regions of Canada are challenging and costly. As a result, they tend to be infrequent. Ideally, waste is characterized separately for every region (province and territory) and for all waste streams or sources. Waste sources, which are available from the Statistics Canada Waste Management Industry Survey and which are used for some characterizations, consist of industrial, institutional and commercial (ICI), construction and demolition (C&D) and residential waste streams.

The level of detail and material classifications vary between characterization studies. Some studies provide regional characterizations, or even characterization by region and waste source. Each characterization study uses slightly different classifications for waste material. For example, some group rubber and leather, others do not; only the most recent characterization study (ECCC 2020[a]) includes pet waste.

The characterization study by NRCan (2006) included details for both waste disposed and recycling. Municipal recycling in Canada only started in earnest in the 1990s. To reflect the waste composition before recycling, the recycling characterization and waste characterization from NRCan (2006) were combined for the 1976 to 1989 period. The characterization by Bond and Straub (1973) is for the United States and was used on the assumption that the Canadian waste profile at the time was reasonably similar. The SMi characterization did not quantify material classes deemed to have low or negligible organic content (SMi 2016).

A full characterization of waste landfilled by waste source, including sewage sludge, is shown in Chapter 7, figure 7.1. Sources used and applicable timeframes for each source are summarized by general waste type in Table A3.6–4.

Waste Deposited by Climate Region

The 2006 IPCC Guidelines (IPCC 2006) define a wet climate as having a mean annual precipitation greater than the mean annual potential evapotranspiration and a dry climate as having a mean annual precipitation less than the mean annual potential evapotranspiration. To determine the proportion of waste landfilled in either wet or dry climate zones (by province), the known quantities of waste disposed of at the largest (approximately 300) landfills were mapped against long-term mean annual precipitation and mean annual potential evapotranspiration (1941 to 2018; Climate Research Unit, University of East Anglia, 0.5 degree spatial resolution; CRU Version 4.03; Figure A3.6–2). The resulting proportions of wet and dry climate for each province and territory are found in Table A3.6–5.

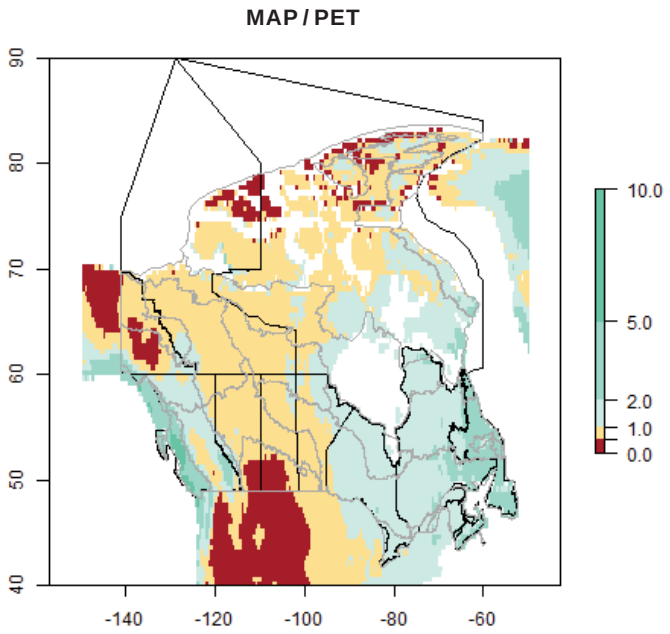
Methane Recovery

Landfill gas capture at large municipal solid waste facilities is common across Canada. Given its relatively high concentration of CH_4, captured landfill gas can be used for heat and/or electricity production. Facilities may also choose to simply flare the captured gas. Note that any emissions resulting from the production of heat or electricity using landfill gas are reported under the Energy sector. See Chapter 7, figure 7-1, and Table A3.6–6 for methane recovery totals.

Table A3.6–4 **Waste Characterization Sources Used in the Inventory—Characterizations Describe the Composition of Waste Disposed Over Given Time-Periods (They Sometimes Describe Composition by Region or Waste Source)**

Characterization	From	To	Characterized By	Notes
Bond and Straub 1973	1941	1975		Composition is not specific to Canada
NRCan 2006 (with recycling re-categorized as disposed)	1976	1989	Region	Recycling added to waste disposed (as recycling only truly began in earnest in Canada in the 1990s).
NRCan 2006	1990	2001	Region	
SMi 2016	2002	2014	Region and Waste Source (Residential, C&D, ICI)	This study only characterized waste with organic content. All other waste was lumped together as "other inert."
ECCC 2020	2015		Region and Waste Source (Residential, C&D, ICI)	

Figure A3.6–2 **Long-Term Climate Regions in Canada, Defined as Wet (Mean Annual Precipitation Greater Than Potential Evapotranspiration) or Dry (Mean Annual Precipitation Less Than Potential Evapotranspiration)**



Data from CRU 4.03, for 1941–2018

Table A3.6–5 **Proportion of Waste Landfilled in Wet or Dry Climate Regions of each Province or Territory**

Region	Dry	Wet
AB	1	0
BC	0.29	0.71
MB	1	0
NB	0	1
NL	0	1
NS	0	1
NT	1	0
NU	0.5	0.5
ON	0.07	0.93
PE	0	1
QC	0	1
SK	1	0
YT	1	0

Data on landfill gas capture are collected through biennial, voluntary surveys conducted by Environment and Climate Change Canada (ECCC 2019). Gaps in the time series for reporting facilities are filled using linear interpolation. If data gaps exist before the earliest record for a facility, the landfill gas recovery is extrapolated back in time to the year when operation of flaring or methane utilization first began at that facility (and not extrapolated if these dates are unknown). If survey results for the latest years are not yet available, the most recent data are held constant.

The amount of methane recovered for each province is calculated from the volume of gas captured by all facilities in that province. National totals are shown in Table A3.6–6.

While flaring of captured landfill gas greatly reduces CH_4 emissions when utilization is not viable, it is not a 100% efficient process. A flaring efficiency of 99.7% is used to calculate the total CH_4 generated from landfills (U.S. EPA 1995). Methane emissions from utilization are reported in the Energy section.

A3.6.1.2.3. Emissions Estimates for MSW Landfills

Methane emissions are the net result of methane generated (estimated using the first-order decay model) minus methane recovery and oxidization and emissions from flaring and utilization. Emissions from methane utilization for energy are reported in the Energy section, and not included in Waste sector totals. Estimates are presented in Table A3.6–6.

Table A3.6–6 **Methane Generated, Recovered and Emitted from Municipal Solid Waste Landfills in Canada**

Year	CH_4 Generated in Landfills (kt)	CH_4 Flared (kt)	CH_4 Emitted from Flaring (kt)	CH_4 Utilized[a] (kt)	CH_4 Oxidized by Landfill Cover (kt)	Total CH_4 Recovery (Flaring + Utilization) (kt)	Total CH_4 Emitted (kt)
1990	985.5	53.1	0.2	0.0	93.2	52.9	839.4
1991	1 033.5	53.9	0.2	0.0	98.0	53.7	881.8
1992	1 078.7	79.3	0.2	0.0	99.9	79.1	899.7
1993	1 115.2	79.5	0.2	0.1	103.6	79.4	932.3
1994	1 155.8	76.2	0.2	0.7	107.9	76.6	971.2
1995	1 200.2	57.7	0.2	21.7	112.1	79.2	1 008.9
1996	1 238.2	43.0	0.1	58.9	113.6	101.7	1 022.8
1997	1 265.6	69.7	0.2	178.8	101.7	248.3	915.7
1998	1 291.7	57.6	0.2	204.4	103.0	261.8	926.9
1999	1 315.9	64.7	0.2	182.0	106.9	246.5	962.4
2000	1 346.3	70.2	0.2	179.1	109.7	249.1	987.5
2001	1 378.2	109.7	0.3	176.0	109.3	285.3	983.7
2002	1 406.1	108.3	0.3	174.0	112.4	282.0	1 011.8
2003	1 410.8	121.6	0.4	167.1	112.2	288.3	1 010.3
2004	1 412.6	124.9	0.4	161.9	112.6	286.4	1 013.5
2005	1 408.9	142.3	0.4	152.1	111.4	294.0	1 003.4
2006	1 405.9	134.3	0.4	177.5	109.4	311.4	985.1
2007	1 407.5	151.4	0.5	184.9	107.1	335.8	964.5
2008	1 408.4	154.4	0.5	192.6	106.1	346.6	955.7
2009	1 408.9	206.7	0.6	190.8	101.1	396.8	911.0
2010	1 409.3	219.9	0.7	201.6	98.8	420.8	889.7
2011	1 408.2	225.8	0.7	205.3	97.7	430.4	880.1
2012	1 408.9	239.9	0.7	203.5	96.6	442.7	869.7
2013	1 410.0	224.0	0.7	214.4	97.2	437.7	875.1
2014	1 404.6	209.2	0.6	233.1	96.2	441.7	866.7
2015	1 398.2	185.6	0.6	243.1	96.9	428.2	873.1
2016	1 425.3	202.1	0.6	250.9	97.2	452.3	875.7
2017	1 446.5	204.6	0.6	255.3	98.7	459.2	888.6
2018	1 463.1	200.4	0.6	261.7	100.1	461.5	901.5
2019	1 483.1	200.4	0.6	261.7	102.1	461.5	919.6

Note:

a. CH_4 emitted from combustion for utilization as heat and power is captured in Energy.

A3.6.1.3. Industrial Wood Waste Landfills

A3.6.1.3.1. Data Sources

Wood waste estimates are based on the amount of wood waste residuals estimated to be disposed of in private landfills. This category captures wood waste that does not enter waste management streams in Canada and thus is not accounted for in the MSW component of the Solid Waste Disposal (Landfills) category.

Wood waste disposed of in Canada is assumed to come from two sources; the solid wood industry and the pulp and paper industry. Quantities of wood waste residuals from 2005 onwards are derived from a literature review, from consultations with industry experts, and from survey data prepared by the National Council for Air and Stream Improvement (ECCC 2020(b), NCASI 2020). Given that the repurposing of wood waste is increasingly preferred over landfilling, it is assumed that the amount of wood waste disposed of is decreasing rapidly. Specific to Canadian sawmills, the combination of increasingly lower surplus residues, combined with their use as a resource (energy or otherwise) and the necessity in maintaining profit margins, there is little incentive for facilities to landfill any waste residues. As a result, it is believed that sawmills have landfilled little to no waste residuals since 2010. However, landfilling of residuals in the pulp and paper sector in Canada is ongoing; the quantity of residuals landfilled for this sector is based on NCASI survey data. As this data was only available at the national level, provincial level ratios were developed using waste emissions reported by facilities to the Greenhouse Gas Facility Reporting Program that were then applied to the national values.

Quantities of wood waste disposed of between 1990 and 2004 for the pulp and paper sector and between 1990 and 2010 for the solid wood industry are based on three studies published by Natural Resources Canada (NRCan, 1997, 1999, 2005). For this time period, it is estimated that 80% of wood waste is disposed of by the solid wood industry, while the remaining 20% is disposed of by the pulp and paper industry (MWA Consultant Paprican 1998). Of the total volume of waste disposed, the amount sent to private landfills is assumed to be 15% for the solid wood industry and 86% for the pulp and paper industry (NRCan 1997). The estimated amount of wood waste disposed of is then converted from “bone dry” units to “hydrated” units using a wood waste moisture content of 20% (Tchobanoglous et al. 1993). Given the lack of historical data, quantities used for the time period 1970–1990 are assumed to be the same as 1990 levels. The national values for wood waste disposed of and landfilled are shown in Table A3.6–7. The final estimated amount of wood waste landfilled by province is shown in Table A3.6–8.

Table A3.6–7 **Quantity of Industrial Wood Waste Landfilled in Canada (1990–2019)**

Year[a]	Landfilled		
	Pulp and Paper[b] (BDt)	Solid Wood (BDt)	Total[b] (Hydrated Tonnes)
1970–1990	1 557 513	1 086 637	3 305 188
1991	1 478 924	1 030 904	3 137 286
1992	1 400 335	976 718	2 971 316
1993	1 321 746	922 531	2 805 346
1994	1 243 157	868 344	2 639 376
1995	1 164 567	814 157	2 473 406
1996	1 085 978	759 970	2 307 436
1997	1 007 389	705 784	2 141 466
1998	928 800	648 000	1 971 000
1999	852 484	597 410	1 812 367
2000	776 167	543 223	1 649 238
2001	699 851	489 037	1 486 110
2002	623 535	434 850	1 322 981
2003	547 219	380 663	1 159 852
2004	470 902	328 537	999 299
2005	164 768	272 289	546 322
2006	126 333	218 103	430 545
2007	87 898	163 916	314 767
2008	80 848	109 729	238 221
2009	73 798	55 542	161 676
2010	66 748	1 355	85 130
2011	59 699	0	74 623
2012	52 649	0	65 811
2013	45 599	0	56 999
2014	38 549	0	48 186
2015	37 228	0	46 535
2016	35 907	0	44 884
2017	49 848	0	62 310
2018	63 789	0	79 737
2019	63 789	0	79 737

Notes:

BDt = Bone dry tonnes

a. Where no data was available, linear interpolation was used between data points. For the year 2019, the 2018 value was used.

b. Converted from bone-dry tonnes (BDt) to hydrated tonnes using a moisture content of 20%.

Table A3.6–8 **Wood Waste Landfilled by Province (Hydrated Tonnes)**

Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC
1970–1990 [a]	49 702	674	50 587	32 527	418 671	285 928	21 592	89 629	472 427	1 883 451
1991	47 178	639	48 017	30 874	397 403	271 402	20 495	85 076	448 428	1 787 772
1992	44 682	606	45 477	29 241	376 380	257 045	19 411	80 575	424 705	1 693 195
1993	42 186	572	42 936	27 608	355 356	242 687	18 326	76 075	400 982	1 598 617
1994	39 690	538	40 396	25 974	334 332	228 329	17 242	71 574	377 259	1 504 040
1995	37 194	504	37 856	24 341	313 309	213 971	16 158	67 073	353 537	1 409 462
1996	34 699	470	35 316	22 708	292 285	199 613	15 074	62 572	329 814	1 314 885
1997	32 203	436	32 776	21 074	271 262	185 255	13 990	58 072	306 091	1 220 308
1998	7 884	0	21 681	65 043	601 155	165 564	7 884	17 739	329 157	754 893
1999	7 249	0	19 936	59 808	552 772	152 239	7 249	16 311	302 665	694 137
2000	6 597	0	18 142	54 425	503 018	138 536	6 597	14 843	275 423	631 658
2001	5 944	0	16 347	49 042	453 263	124 833	5 944	13 375	248 180	569 180
2002	5 292	0	14 553	43 658	403 509	111 130	5 292	11 907	220 938	506 702
2003	4 639	0	12 758	38 275	353 755	97 428	4 639	10 439	193 695	444 223
2004	9 993	0	9 993	-	39 972	39 972	9 993	59 958	179 874	649 544
2005	3 404	0	3 404	7 453	39 305	28 971	8 062	23 667	104 810	327 247
2006	2 726	0	2 726	5 714	30 603	22 680	6 298	18 846	82 460	258 491
2007	2 049	0	2 049	3 976	21 901	16 388	4 534	14 025	60 111	189 735
2008	1 372	0	1 372	3 657	18 092	13 022	3 657	9 822	46 056	141 172
2009	694	0	694	3 338	14 284	9 655	2 781	5 619	32 000	92 610
2010	17	0	17	3 019	10 475	6 289	1 904	1 416	17 945	44 047
2011	0	0	0	2 700	9 308	5 564	1 688	1 176	15 777	38 410
2012	0	0	0	2 381	8 209	4 907	1 488	1 037	13 914	33 874
2013	0	0	0	2 063	7 110	4 250	1 289	898	12 051	29 338
2014	0	0	0	1 685	8 354	2 289	1 067	280	10 428	24 084
2015	0	0	0	1 580	5 989	1 810	906	871	12 429	22 950
2016	0	0	0	1 488	5 544	1 731	1 154	331	12 474	22 161
2017	0	0	0	2 012	10 864	1 658	893	438	14 875	31 569
2018	0	0	0	3 227	14 651	2 797	1 408	449	19 431	37 774
2019	0	0	0	3 227	14 651	2 797	1 408	449	19 431	37 774

Note:

a. Values for 1990 are used for 1970–1990.

A3.6.1.3.2. Model Parameters

Degradable Organic Carbon

It is assumed that all waste sent to private wood waste lots is composed entirely of wood. Therefore, the recommended 2006 IPCC Guidelines (IPCC 2006) default degradable organic carbon (DOC) value for wood, i.e., 0.43, is used for all regions and time periods.

Fraction of Degradable Organic Carbon Which Decomposes

The 2006 IPCC Guidelines (IPCC 2006) recommended default value of 0.5 for degradable organic carbon which decomposes (DOC_f) is used for all regions and time periods.

Methane Correction Factor

The 2006 IPCC Guidelines (IPCC 2006) recommended default methane correction factor (MFC) value of 0.8 for unmanaged deep landfill sites was selected, as it best represents industry practices.

Reaction Constant

The default decay rate constant (k) value of 0.03/year recommended by the National Council for Air and Stream Improvement Inc. for estimating the wood products industry's landfill CH_4 emissions was used for all regions and time frames (NCASI 2003).

Fraction of Landfill Gas that is CH_4

The default fraction (F) of 0.5 recommended by the 2006 IPCC Guidelines (IPCC 2006) is used for all time periods and regions.

Oxidation Factor

The 2006 IPCC Guidelines (IPCC 2006) recommended default oxidation factor (OX) of 0.1 is used for all time periods and regions.

Table A3.6–9 **Methane Generated, Oxidized and Emitted from Wood Waste Landfills in Canada (1990–2019)**

Year	CH_4 Generated (kt)	CH_4 Oxidized by Landfill Cover (kt)	CH_4 Emitted (kt)
1990	170 998	17 100	153 898
1991	177 145	17 715	159 431
1992	182 542	18 254	164 288
1993	187 216	18 722	168 495
1994	191 190	19 119	172 071
1995	194 485	19 448	175 036
1996	197 119	19 712	177 407
1997	199 113	19 911	179 201
1998	200 485	20 049	180 437
1999	201 240	20 124	181 116
2000	201 434	20 143	181 291
2001	201 070	20 107	180 963
2002	200 164	20 016	180 147
2003	198 731	19 873	178 858
2004	196 789	19 679	177 110
2005	194 359	19 436	174 923
2006	190 466	19 047	171 420
2007	186 296	18 630	167 667
2008	181 857	18 186	163 671
2009	177 290	17 729	159 561
2010	172 598	17 260	155 338
2011	167 785	16 779	151 007
2012	163 080	16 308	146 772
2013	158 483	15 848	142 635
2014	153 992	15 399	138 593
2015	149 604	14 960	134 644
2016	145 341	14 534	130 806
2017	141 197	14 120	127 077
2018	137 235	13 724	123 512
2019	133 450	13 345	120 105

Methane Recovery

It is assumed that no landfill gas capture technologies are used at private wood lots. Use of these sites is rapidly decreasing, and it is unlikely that facilities would invest in such infrastructure given the more popular practice of repurposing wood waste.

Methane Emitted

Table A3.6–9 outlines the final estimated CH_4 emissions from wood waste landfills in Canada.

A3.6.2. Biological Treatment of Solid Waste (5.B)

The Biological Treatment of Solid Waste category consists of the following two emission sources: composting and anaerobic digestion.

A3.6.2.1. Composting (5.B.1)

The greenhouse gas emissions estimated from composting in Canada include CH_4 and N_2O. Since CO_2 emissions released by composting result from the decomposition of organic material from biomass sources, these emissions are not included in the national total.

A3.6.2.1.1. Methodology

A Tier 3 method is used to estimate emissions from composting. Feedstock-specific emission factors developed through an in-house literature review are applied to quantities of treated compost, as shown in Equation A3.6–7 and Equation A3.6–8. Emissions are calculated at a facility level and combined to create emissions estimates at provincial and national levels..

Equation A3.6–7 **CH_4 Emissions from Composting**

$$CH_4 Emissions = \sum_i (M_i \cdot EF_i) \cdot 10^{-3}$$

CH_4 *Emissions*	=	total CH_4 emissions in inventory year, Gg CH_4
M_i	=	mass of organic wet waste treated by type *i*, Gg
EF	=	emission factor for treatment *i*, g CH_4/kg waste treated by waste type
i	=	composting feedstock at facility *i*

Emission factors for various feedstocks include those for yard waste (1.72 g/kg), municipal solid waste (1.51 g/kg), biosolids/manure (3.54 g/kg) and a mixture of the aforementioned wastes co-composted (1.09 g/kg) based on wet weight (ECCC, 2020[c]).

Equation A3.6–8 **N_2O Emissions from Composting**

$$N_2O\ Emissions = \sum_i (M_i \cdot EF_i) \cdot 10^{-3}$$

N_2O *Emissions*	=	total N_2O emissions in inventory year, Gg N_2O
M_i	=	mass of organic wet waste treated by type *i*, Gg
EF	=	emission factor for treatment *i*, g N_2O/kg waste treated by waste type
i	=	composting feedstock at facility *i*

Emission factors for various feedstocks include those for yard waste (0.25 g/kg), municipal solid waste (0.18 g/kg), biosolids/manure (0.18 g/kg) and a mixture of the aforementioned wastes co-composted (0.11 g/kg) based on wet weight (ECCC, 2020[c]).

A3.6.2.1.2. Data Sources

The activity data used to estimate CH_4 and N_2O emissions from composting are based on commercial/municipal facility-level information collected from industry surveys (from 1992 forward), technical reports, and facility websites. Home composting is not included in the Canadian inventory at this time due to lack of available data. To address the missing data years at the facility level, the last data point was carried forward to the next available data point, with the exception of the 1992 survey results being carried backward to develop a complete time series from 1990.

A3.6.2.2. Anaerobic Digestion at Biogas Facilities (5.B.2)

The greenhouse gas emissions estimated from anaerobic digestion of solid waste in Canada include CH_4. N_2O is considered to be negligible according to the 2006 IPCC Guidelines and is therefore not estimated for this sector. Since CO_2 emissions released by anaerobic digestion result from the decomposition of organic material from biomass sources, these emissions are not included in the national total.

A3.6.2.2.1. Methodology

Greenhouse gas emissions from anaerobic digestion of solid waste at biogas facilities are estimated for Canada using a Tier 3 method. The Tier 3 method includes determination of the methane component of the biogas at the facility-level, a portion of which is lost through on-site leakages in the system.. The loss from on-site leakages in the system is calculated at 2.1% of the methane in the biogas produced. This value was developed from compiling losses found in primary literature and survey data from municipal, industrial and wastewater digesters (ECCC, 2020[d]). Losses from biogas upgrading and incomplete combustion are not included in on-site leakage loss. Losses from venting are not reported as they are considered sporadic in nature and are avoided as much as possible in Canada; it is believed these emissions are negligible. Emissions are calculated according to Equation A3.6–9.

Equation A3.6–9 **CH_4 Emissions from Anaerobic Digestion**

$$CH_4\ Emissions = \sum_i (M_i \cdot D) \cdot (EF) \cdot 10^{-3}$$

$CH_4\ Emissions$	=	total CH_4 emissions in inventory year, Gg
M_i	=	biogas production by *i*, m^3
D	=	density of biogas at normal temperature and pressure
EF	=	emission factor for treatment *i*, as percentage of total biogas produced that is lost through onsite leakages
i	=	facility *i*

A3.6.2.2.2. Data Sources

The activity data is based on facility level biogas production reported through in-house and industry based surveys. In the absence of facility reported data for biogas production, a conversion factor by feedstock type is used to generate biogas production from initial feedstock input. Only municipal and industrial anaerobic digestion facilities are reported under 5.B.2, whereas wastewater anaerobic digesters are reported under CRF category 5.D. On-farm anaerobic digesters are currently not included in our Canadian inventory, but will be considered in future inventories.

A3.6.3. Incineration and Open Burning of Waste (5.C)

Waste incineration is defined in the 2006 IPCC Guidelines as the combustion of solid and liquid waste in controlled incineration facilities. Incineration emissions in Canada come from municipal solid waste (MSW) incineration, hazardous waste incineration, clinical waste incineration and sewage sludge incineration. Open burning of waste occurs mainly in rural areas and includes burning garbage in backyard barrels and/or open pits. This section of Annex 3 details the accounting methodologies that are used to describe the GHG emission estimates for these categories.

In keeping with the 2006 IPCC Guidelines (IPCC 2006), only CO_2 emissions resulting from oxidation of carbon in waste of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents, and waste oil) are considered net emissions and are included in the national CO_2 emissions estimate. CO_2 emissions from combustion of biomass materials (e.g., paper, food, and wood waste) contained in the waste are biogenic emissions and are not included in national total emission estimates.

Some facilities generate energy in the form of electricity and/or heat from waste incineration. These facilities are referred to as energy-from-waste (EFW) facilities. Other facilities simply incinerate waste for disposal purposes and are referred to as non-energy-from-waste (non-EFW) facilities. In accordance with the 2006 IPCC Guidelines,

emissions from waste incineration with energy recovery are reported in the Energy sector, while emissions from waste incineration without energy recovery are reported in the Waste sector. The following section describes the methodology used for all incinerators, though final emissions are reported under the appropriate sector (Figure A3.6–3).

The Greenhouse Gas Reporting Program (GHGRP) has significant coverage of the incineration sector in more recent years. Over time, incineration practices have changed from many small facilities treating waste on site, to large specialized central facilities treating waste shipped in from across the provinces. Where GHGRP does not have coverage, facility-specific emission estimates were developed using the best available information. This bottom-up, facility-specific approach to developing emissions estimates was implemented for the MSW sector for Canada's 2019 National Inventory Report submission. New for this submission is that the other incineration sectors are calculated using the same approach, such that all incineration types are reported in a consistent manner.

Some facilities in Canada burn waste from multiple waste sources. For example, clinical waste is often burned alongside MSW waste. Emissions from facilities that treat more than one type of waste have been calculated according to the specific waste type but are reported under the facilities' primary waste sector. Therefore, if a facility treats small quantities of clinical waste alongside MSW, it is considered an MSW facility and the clinical waste emissions will be reported under MSW.

A3.6.3.1. Data Sources

Tonnage of Waste Incinerated

The total amount of waste incinerated is only directly used for facilities that do not report to the GHGRP. It is important to note that these data are also used to isolate the amount of waste landfilled in Canada from the amount of waste disposed of, as discussed in section A3.6.1.2.2. Therefore, even where a facility reports GHG emission totals to GHGRP, annual tonnage incinerated is still collected. The amount of waste incinerated at facilities across Canada is obtained through voluntary biennial surveys of incineration facilities conducted by ECCC. The survey has collected data every two years since 2008, with the most recent data collection occurring in the summer of 2020.

Supplemental data sources are used for facilities not included in the survey either due to non-response or because the facility closed before the first survey cycle in 2008. Tonnage is estimated using old reports (Sawell et al. 1996; Environment Canada 1999, 2003[b]). Other sources include progress reports prepared by the Canadian Council of Ministers of the Environment on issues related to dioxins, furans and mercury emissions, as clinical waste incineration was formerly a major source of these pollutants (CCME 2006, 2007 and 2010). A report on solid waste incineration in Canada prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b) was also used. Quantities of material incineration in Canada are found in Table A3.6–10.

Figure A3.6–3 **Decision Tree for Collecting, Estimating and Reporting GHG Emissions from Incineration Facilities**

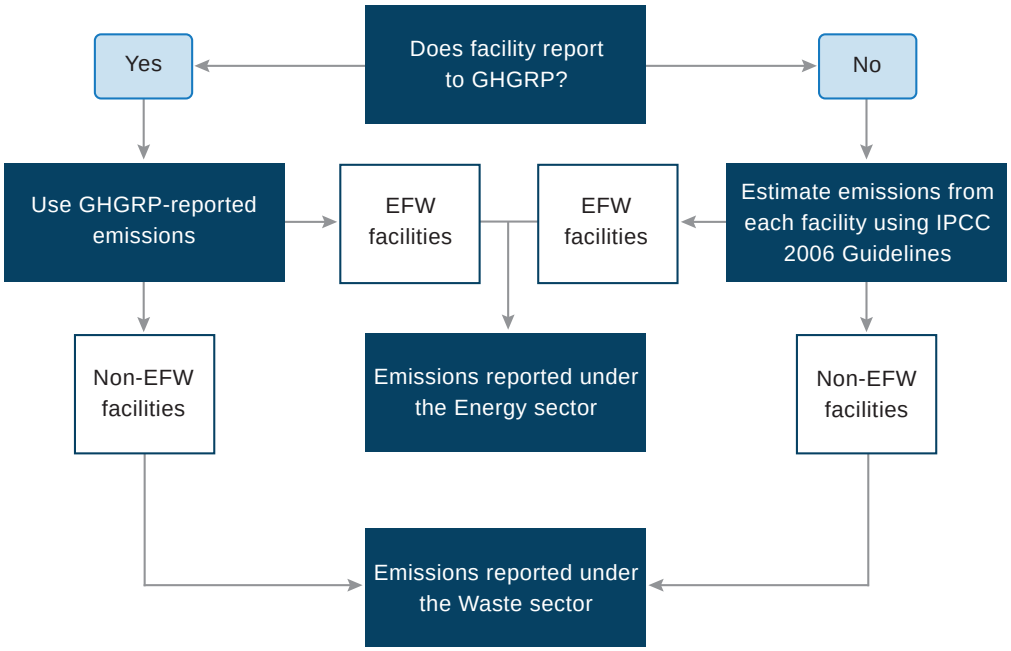


Table A3.6–10 **Estimated Tonnes of Waste Incinerated by Waste Source 1990–2019**

Year	Non-EFW Facilities				EFW Facilities
	MSW	Clinical Waste	Hazardous Waste	Sewage Sludge	MSW
1990	1 197 622	1 279	100 762	128 402	1 071 051
1991	1 194 730	1 291	109 111	137 375	1 068 478
1992	1 355 028	1 300	117 879	144 575	1 226 525
1993	1 224 413	2 868	125 109	152 557	1 098 529
1994	1 029 607	2 879	142 050	168 795	901 510
1995	1 020 171	2 929	164 727	169 091	907 344
1996	1 042 754	2 937	146 125	187 196	926 637
1997	1 014 789	2 944	132 348	180 380	899 973
1998	1 013 078	2 943	155 511	179 186	909 667
1999	1 027 135	2 947	140 820	189 185	919 051
2000	1 015 348	3 039	168 379	187 889	907 473
2001	1 003 547	3 828	179 525	192 546	896 178
2002	1 030 485	3 957	184 845	206 450	923 902
2003	900 056	3 914	144 036	196 049	793 462
2004	908 199	4 519	161 891	195 525	814 834
2005	887 064	5 001	157 788	192 699	806 924
2006	840 855	5 452	147 775	196 287	760 637
2007	830 635	3 986	134 878	195 058	752 372
2008	835 676	5 606	147 528	190 919	764 102
2009	798 612	5 784	133 356	192 681	751 868
2010	734 087	5 020	137 830	193 360	699 119
2011	811 542	5 400	130 319	207 415	788 144
2012	809 464	5 032	84 785	202 062	782 115
2013	803 351	5 240	90 090	201 486	780 712
2014	781 360	5 208	107 810	209 675	760 124
2015	824 859	5 046	122 911	217 696	805 496
2016	876 088	3 635	124 695	205 774	863 445
2017	904 134	3 416	124 747	206 135	860 963
2018	892 867	3 423	121 105	209 105	869 729
2019	891 112	3 431	118 757	218 722	868 244

Where the time series of tonnage incinerated is incomplete for the operational lifetime of a facility, the nearest data are carried forward or backward. Facilities in the clinical waste incineration sector are treated slightly differently as it used to be common practice to have small batch incinerators located at hospitals. Over time, provinces underwent mass closures of their small batch hospital incinerators and switched to shipping waste to central specialized facilities. Missing data points for these small hospital incinerators are estimated based on interpolation using provincial population numbers.

Contents of MSW waste incinerated include paper, glass, metal, plastic, food waste, yard waste, textiles, rubber, wood and other materials. The types of clinical waste incinerated in Canada include cytotoxic waste, human or animal anatomical waste and pharmaceutical waste (Stericycle 2014). Hazardous waste incineration includes contaminated substrates such as soils, wood, metal and other material. The hazardous waste quantities may also include inorganic wastes such as aqueous solutions containing heavy metals, or wastes such as water-based urethanes, as opposed to solvent-based urethane wastes that have high fossil fuel carbon content. Sewage sludge incineration is the incineration of biosolids resulting from the processing of municipal sewage.

A3.6.3.1.1. Methodology

Emission estimates are compiled at a facility level, and a distinction is made between EFW facilities and non-EFW facilities. Where GHGRP emissions are available, they are used. Where GHGRP emissions are not available, facility-specific emissions are estimated using methodologies prescribed in the 2006 IPCC Guidelines (IPCC 2006).

Facilities Reporting to the GHGRP

GHGRP facility data are available annually from 2004 onwards, though most MSW incinerators started reporting in 2009. Where facilities were operating before 2009, the emissions time series was completed by assuming that tonnage incinerated is directly correlated with emissions. The "Surrogate Data" method prescribed in Volume 1, Chapter 5.3.3.2, of the 2006 IPCC Guidelines (IPCC 2006) is used to complete the time series of emissions using annual tonnage incinerated by the facility, obtained through surveys and/or reports, as well as GHGRP data for all years for which such data are available.

Note that GHGRP reporting guidelines require that facility-reported CO_2 emissions are derived only from wastes of fossil origin (e.g., plastics, certain textiles, rubber, liquid

solvents and waste oil). CO_2 from the biogenic portion of waste (e.g., food, wood, garden waste) are excluded from emissions totals.

Non-reporting Facilities

There are a large number of incinerators that either closed before the GHGRP was launched or operated below the reporting threshold. Many of these facilities that are classified under MSW were small incinerators across Newfoundland and Labrador, but also include some larger facilities in Ontario, Quebec, British Columbia and Alberta. Estimates for these facilities were developed using the 2006 IPCC Guidelines and the best available parameters for each facility.

CO_2 Emissions

Emissions of CO_2 from MSW incineration are estimated using the mass-balance approach prescribed by Equation A3.6–10 (modified from 2006 IPCC Guidelines Equation 5.2), equivalent to Equation 5.2 in the 2006 IPCC Guidelines.

Where available, facility-specific waste characterization data was used to determine the different materials of waste in the waste incinerated (factor "WFj" in Equation A3.6–10). Where facility-specific characterization data were not available, provincial characterization data were taken from Environment Canada (1996). This report contains waste characterization data for EFW and non-EFW streams of waste incineration. Table A3.6–11 contains the default factors from the 2006 IPCC Guidelines that were used to determine the CO_2 emissions from each waste type incinerated. The default values of 60% for total carbon (% of dry weight) and 40% for fossil carbon as a percentage of total carbon was used for clinical waste, and a carbon content of 50% and fossil carbon of 90% as a percentage of total carbon were used for hazardous waste. These values come from the 2006 IPCC Guidelines (IPCC 2006).

A default factor of 1 is used as the oxidation factor (OF) for all waste types and facilities.

Table A3.6–11 **Default Factors Used in Equation A3.6–12 to Determine CO_2 from Incineration**

Waste Type	Dry Matter Content (% Wet Weight)	Total Carbon (% Dry Weight)	Fossil Carbon (% Total Carbon)
Paper	0.90	0.46	0.01
Textiles	0.82	0.59	0.20
Food	0.40	0.38	0.00
Wood	0.85	0.50	0.00
Yard	0.40	0.70	0.10
Organics[a]	0.40	0.44	0.00
Nappies	0.40	0.70	0.10
Rubber	0.82	0.59	0.20
Plastic	1.00	0.75	1.00
Metal	1.00	0.00	0.00
Glass	1.00	0.00	0.00
MSW Other[b]	1.00	0.34	0.35
Clinical	0.65	0.60	0.40
Hazardous Waste	1.00	0.50	0.90
Sewage Sludge	1.00	0.45	0.00
Inorganics	1.00	0.03	1.00
Fossil Liquid Waste	1.00	0.80	1.00
Solvents	1.00	0.80	0.80
Industrial Wood	0.85	0.41	0.01
Other Industrial Waste	1.00	0.50	0.90

Notes:

a. In cases where facility waste characterization includes organics in general, the organics parameters are used. If the facility distinguishes between food and garden waste, those specific factors are used.

b. Many facilities report "other" waste, without identifying what it includes. Therefore, an average of textiles, food, garden, rubber and inert waste are used in these cases. Note that paper and plastic are always characterized separately and so are not incorporated into the "other" parameter.

Equation A3.6–10 **(modified from 2006 IPCC Guidelines Equation 5.2)**

$$CO_2\ Emissions = Waste \times \sum(WF_j \times dm_j \times CF_j \times FCF_j \times OF) \times 44/12$$

$CO_2\ Emissions$	=	CO_2 emissions in inventory year
$Waste$	=	total amount of waste incinerated
J	=	component of MSW incinerated, such as paper/cardboard, textiles, food waste, wood, plastic, garden waste, plastics, metal, glass, etc.
WF_j	=	fraction of waste type/material *j* in total MSW waste incinerated
dm_j	=	dry matter content of component *j* in total MSW waste incinerated
CF_j	=	fraction of carbon in the dry matter (i.e., carbon content) of component *j*
FCF_j	=	fraction of fossil carbon in the total carbon of component *j*
OF	=	oxidation factor
$44/12$	=	conversion factor from C to CO_2

CH_4 Emissions

CH_4 emissions from incineration are determined for each facility using default emission factors from the 2006 IPCC Guidelines. Emission factors are multiplied by the total annual waste incinerated at the facility (Equation A3.6–11). Emission factors vary depending on how the incinerator is fed (continuous, semi-continuous, or batch-type incineration) and on the incinerator type (stoker vs fluidized bed). The most appropriate emission factor was chosen for each facility. In the absence of IPCC default emission factor values for hazardous waste, CH_4, emission factors were derived using data from one hazardous waste incineration facility that had provided total emissions based on direct measurements taken in 2007. The site emitted 0.03 tonnes of N_2O and burned 177 tonnes of hazardous waste. Therefore, the emission factor 169 g CH_4/ tonnes of hazardous waste was determined. CH_4 emissions from sewage sludge are derived using the emission factor of 9.7 kg/kt of total dried solids for fluidized bed sewage incinerators obtained from the U.S. Environmental Protection Agency

(U.S. EPA 1995). 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.

Equation A3.6–11 **(modified from 2006 IPCC Guidelines Equation 5.4)**

$$CH_4\ Emissions = \sum(W_f \times EF_f)$$

$CH_4\ Emissions$	=	CH_4 emissions from waste incineration in inventory year
W_f	=	total amount of waste incinerated at facility *f*
EF_f	=	emission factor most appropriate for facility *f*

N_2O Emissions

As with CH_4 emissions, N_2O emissions from incineration are determined for each facility using default emission factors from the 2006 IPCC Guidelines. Emission factors are multiplied by the total annual waste incinerated at the facility (Equation A3.6–12). Emission factors vary depending on the feed type of the incinerator (continuous, semi-continuous, and batch-type incineration) Solid waste default emission factors were used in accordance with the IPCC Good Practice Guidance (IPCC 2000) as no clinical-waste-specific values are provided. The N_2O emissions for a given site were therefore calculated using the stoker default emission factors for continuous incineration (50 g N_2O/t waste incinerated) and batch-type incineration (60 g N_2O/t waste incinerated) provided in IPCC 2006. Emissions of N_2O from sewage sludge incineration have been updated using the IPCC 2006 default emission factor 0.99 kg/t of dried sewage sludge incinerated (IPCC 2006). Hazardous waste N_2O emission factors were derived using the same methodology as CH_4. Direct measurements of 0.56 tonnes N_2O for 177 tonnes of hazardous waste burned in 2007 result in an emission factor of 3164 gN_2O/tonne HW.

Note that although the 2006 IPCC Guidelines provide a MSW incinerator emission factor for open burning, it is assumed that no MSW incineration facilities in Canada practice open burning. The most appropriate emission factor was chosen for each facility.

Equation A3.6–12 **(modified from 2006 IPCC Guidelines Equation 5.5)**

$$N_2O\ Emissions = \sum(W_f \times EF_f)$$

$N_2O\ Emissions$	=	N_2O emissions from MSW incineration in inventory year
W_f	=	total amount of MSW incinerated at facility *f*
EF_f	=	emission factor most appropriate for facility *f*

The full list of emission factors used can be found in Table A3.6–12.

Table A3.6–12 **Default CH_4 and N_2O Emission Factors for Incineration Facilities**

Waste Type	Feed Type	Incinerator Type	CH_4 Emission Factor	N_2O Emission Factor	Units
Municipal Solid Waste	Continuous	Stoker	0.20	50.00	g/t
Municipal Solid Waste	Continuous	Fluidized Bed	0.00	50.00	g/t
Municipal Solid Waste	Semi Continuous	Stoker	6.00	50.00	g/t
Municipal Solid Waste	Semi Continuous	Fluidized Bed	188.00	50.00	g/t
Municipal Solid Waste	Batch	Stoker	60.00	60.00	g/t
Municipal Solid Waste	Batch	Fluidized Bed	237.00	60.00	g/t
Hazardous Waste	Continuous	Stoker	169.49	3 163.84	g/t
Hazardous Waste	Batch	Stoker	169.49	3 163.84	g/t
Sewage Sludge	Continuous	Fluidized Bed	9.70	990.00	g/t
Sewage Sludge	Continuous	Stoker	9.70	990.00	g/t
Clinical Waste	Continuous	Stoker	0.20	50.00	g/t
Clinical Waste	Batch	Stoker	60.00	60.00	g/t
Clinical Waste	Semi Continuous	Stoker	0.20	50.00	g/t
Other Sludge	Continuous	Stoker	0.20	450.00	g/t
Other Sludge	Batch	Stoker	60.00	450.00	g/t
Fossil Liquid Waste	Continuous	Stoker	0.20	100.00	g/t
Fossil Liquid Waste	Batch	Stoker	60.00	100.00	g/t
Industrial Waste	Continuous	Stoker	0.20	50.00	g/t
Industrial Waste	Continuous	Fluidized Bed	0.00	50.00	g/t
Industrial Waste	Semi Continuous	Stoker	6.00	50.00	g/t
Industrial Waste	Semi Continuous	Fluidized Bed	188.00	50.00	g/t
Industrial Waste	Batch	Stoker	60.00	60.00	g/t
Industrial Waste	Batch	Fluidized Bed	237.00	60.00	g/t

Total Emissions

Table A3.6–13 summarizes emissions from EFW and non-EFW facilities. The EFW emissions are reported under the Energy sector, while the non-EFW emissions are reported under the Waste sector.

A3.6.3.2. Open Burning of Waste (5.C.2)

Canada does not currently estimate GHG emissions from open burning of waste. While open burning at landfills is banned by regulation in most provinces and territories, there is anecdotal evidence that some open burning still occurs in rural areas of the country. However, this is a minor source of emissions relative to other activities. The likely level of emissions from open burning of MSW in Canada (as estimated for 2010) was nearly 100 kt or 0.015% of total national emissions. This is less than 0.05% of total emissions and less than the 500 kt threshold as specified in paragraph 37(b) of the UNFCCC Annex I Inventory Reporting guidelines. As this emissions value can be considered representative for all years, this source can be considered insignificant.

Table A3.6–13 **National Summary of Kilotonnes of CO_2e Emissions from Incineration (1990–2019)**

Year	Non-EFW Facilities				EFW Facilities MSW
	MSW	Clinical Waste	Hazardous Waste	Sewage Sludge	
1990	41	1	192	39	371
1991	40	1	202	42	370
1992	41	1	216	44	431
1993	40	2	214	46	394
1994	41	2	243	51	335
1995	37	2	280	51	337
1996	37	2	251	56	346
1997	36	2	227	54	332
1998	33	2	258	54	336
1999	33	2	260	57	341
2000	33	2	275	57	338
2001	33	2	288	58	332
2002	33	2	266	62	341
2003	33	2	269	59	298
2004	28	3	262	59	305
2005	23	3	255	58	303
2006	23	3	236	59	286
2007	23	2	241	59	283
2008	21	4	253	57	286
2009	15	6	209	58	283
2010	12	4	230	58	260
2011	8	5	226	62	286
2012	9	5	99	61	341
2013	8	5	105	73	334
2014	8	5	83	79	297
2015	7	5	110	76	373
2016	8	5	115	77	414
2017	8	5	114	64	395
2018	8	5	100	67	394
2019	8	5	104	70	399

A3.6.4. Emissions from Wastewater Treatment and Discharge (5.D)

The emissions estimates for the Wastewater Treatment and Discharge category includes CH_4 and N_2O emissions resulting from transformation of organics and nutrients in wastewater systems. CO_2 emissions are not included in totals for this sector because wastewater organics are considered to be of biogenic origin grown in the same year as emissions occur.

CH_4 emissions occur from the treatment of municipal and industrial wastewater, from anaerobic digestion of sludge on-site at wastewater treatment facilities and from the emission of organics remaining in wastewater effluent are estimated in accordance with the methods provided in the 2006 IPCC Guidelines and 2019 Refinement using Tier-2 country-specific factors. N_2O emissions are currently estimated as a function of the total nitrogen in wastewater in accordance with the methods described in the 2006 IPCC Guidelines. Estimates of N_2O emission totals are currently independent of the treatment technology used.

Emissions from municipal wastewater treatment are determined on a per-capita basis. The per-capita organics loading to wastewater and the population served by treatment type are the primary activity data for CH_4 emissions. Nitrogen loading to wastewater, estimated from per-capita protein consumption, is the primary activity data for N_2O emissions.

Most wastewater treatment in Canada occurs at centralized municipal wastewater treatment plants (78% in 1990, 83% in 2019, which receive influent from domestic, commercial and industrial users. There are some coastal municipalities that collect and discharge untreated wastewater to sea. Many Canadians in rural and remote areas, but also in portions of urban centres, use private or communal septic systems for wastewater treatment. Larger industries treat or pre-treat their wastewater on-site and are considered separately from municipal wastewater treatment facilities in the Industrial On-Site Wastewater Treatment category, section A3.6.4.2.

A3.6.4.1. Municipal Wastewater Treatment/ Discharge – CH_4

Emissions estimates for municipal wastewater treatment facilities are calculated using the Tier 2 methods provided in the 2006 IPCC Guidelines and 2019 Refinement, with country-specific factors (IPCC 2006; IPCC 2019). The 2019 Refinement provides updated emission factors and methods for estimating emissions from receiving water bodies.

CH_4 emissions estimates are based on population-based organic loadings, treatment technology used, and receiving water-body characteristics (Figure A3.6–4 Diagram of Wastewater Organics Flow). CH_4 emissions

occur from microbial activity under anaerobic condition that occur during treatment, anaerobic digestion of sludge, and the receiving water body.

The treatment technology used influences the emissions from treatment, the removal of organics as sludge and the quantity of organics remaining in the effluent (which then contributes to emissions from the receiving water bodies). The first-step in estimating CH_4 emission from wastewater is determining the population using each type of treatment technology.

Methane emissions from wastewater treatment facilities occur at three distinct steps (Figure A3.6–4):

- Wastewater treatment
- Anaerobic digestion of sludge
- Discharge to receiving water body

The organics entering the wastewater stream (activity data) are converted to CH_4 (or CO_2) by microbial activity at each of these three steps. The emissions from the wastewater treatment process and the organics removed as sludge or passing to the receiving body with the effluent are a function of the treatment technology.

The total CH_4 emissions from wastewater facilities for each province or territory can be determined from the sum of emissions from each of the three steps, as shown in Equation A3.6–13. National emissions are the sum of all provincial and territorial emissions.

Equation A3.6–13

$$CH_4 = CH_{4\ Treatment} + CH_{4\ AD} + CH_{4\ Receiving\ water\ body}$$

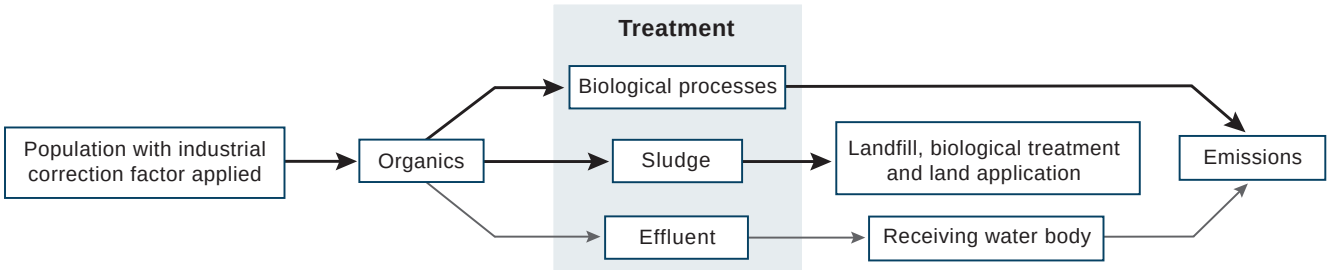
CH_4	=	CH_4 emissions from wastewater, for province, p
$CH_{4\ Treatment}$	=	CH_4 emissions from the process of wastewater treatment (tonne CH_4)
$CH_{4\ AD}$	=	CH_4 emissions from anaerobic digestion of sludge on-site at wastewater treatment facilities (tonne CH_4)
$CH_{4\ Receiving\ water\ body}$	=	CH_4 emissions from the wastewater discharged to receiving water bodies (tonne CH_4)

Methodology

Emissions are ultimately a function of population and treatment technology used. The organic load—the mass of organic material introduced to wastewater—is a function of the population served. The treatment technology to which a wastewater treatment system is connected (if any) dictates the degree of emissions from the treatment process, the amount of organics removed as sludge and the amount of organics remaining in the wastewater effluents. The organics remaining in the effluents also contribute to methane emissions (IPCC 2019). The organics removed as sludge are sometimes processed in anaerobic digesters on-site at the wastewater treatment facilities. In these cases, methane emissions from the anaerobic digestion are included in the wastewater totals.

Organics removed as sludge (after any reductions from on-site anaerobic digestion) may then become inputs for accounting and emissions calculations in other sections, including Biological Treatment of Waste (section A3.6.2), Solid Waste Disposal (Landfills) (section A3.6.1), Incineration (section A3.6.3). Sewage sludge accounting—determining the amounts transferred to each of the aforementioned fates or sections—is discussed in this section.

Figure A3.6–4 **Diagram of Wastewater Organics Flow**



Wastewater system is the term used to denote a sewershed or wastewater collection system. It does not necessarily have a wastewater treatment facility. In some cases, wastewater is collected but discharged to sea. Treatment systems may also employ more than one type of treatment technology, such as different kinds of lagoons cells run in series or in parallel.

Emissions from Wastewater Treatment

Methane emissions are estimated for each province based on organics loading to wastewater, organics removed as sludge and treatment-technology-specific emission factors, as shown in Equation A3.6–14.

Equation A3.6–14

$$CH_{4\ Treatment} = \sum_t [EF_{CH4,t} \times OrganicLoad_t - OrganicsRemovedAsSludge_t]$$

$CH_{4\ Treatment}$	=	CH_4 emissions from wastewater treatment, tonne CH_4
t	=	treatment technology type or category (e.g., facultative lagoon)
$EF_{CH4,t}$	=	CH_4 emission factor for wastewater treatment technology of type t, tonne CH_4/tonne BOD_5
$OrganicLoad_t$	=	organic load to the wastewater treatment/ discharge systems of type t, tonne BOD_5
$Organics\ Removed\ As\ Sludge_t$	=	the organics that are removed from wastewater as sludge, measured as tonne BOD_5

Emission Factor

The emission factor for wastewater treatment and discharge is a function of the theoretical maximum CH_4 production capacity (B_0) for wastewater and a treatment technology-specific methane correction factor (MCF), as shown in Equation A3.6–15 and Table A3.6–14. The maximum methane producing capacity was determined to be 0.36 kg CH_4 per kg BOD_5 by AECOM (2011). The MCF is the fraction of the potential methane that is produced by each treatment type and ranges from 0 to 1 (IPCC 2006), depending on the treatment system type.

Equation A3.6–15

$$EF_{CH4,t} = B_0 \times MCF$$

$EF_{CH4,t}$	=	emission factor for treatment type t, tonne CH_4/tonne BOD_5
B_0	=	theoretical maximum CH_4 producing capacity, tonne CH_4/tonne BOD_5
MCF	=	methane correction factor for treatment type t, fraction

Organic Load

Emissions of CH_4 from municipal wastewater treatment systems are determined based on the organic loading to wastewater, by province (measured as biogeochemical oxygen demand, 5-day test, or BOD_5). The organic loading is determined from the per-capita organics loading rate (BOD_5/capita/day) of 0.06 kg/person/day, and an industrial and commercial input correction factor of 1.25 (IPCC 2006).

The total annual organic loading of each type of wastewater treatment technology in a province is calculated as shown in Equation A3.6–16.

Equation A3.6–16

$$OrganicLoad_t = Pop_t \times IndCor \times PerCapBOD_5 \times 365 \times 0.001$$

$OrganicLoad_{(t)}$	=	annual organic load to the wastewater treatment systems of type t, tonne BOD_5
Pop_t	=	population using (connected to) wastewater systems of technology type t
$IncCor$	=	correction factor for industrial and commercial inputs to municipal wastewater, with value of 1.25 (IPCC 2006)
$PerCapBOD_5$	=	per-capita organic loading to the wastewater system, kg BOD_5/capita/day
365	=	conversion from day to year
0.001	=	conversion from kg BOD_5 to tonne BOD_5

Population Using Each Treatment Technology, By Province

There are over 3800 municipal wastewater treatment or discharge systems (wastewater system) in Canada. On top of that, much of the population uses private septic systems.

The total population using each treatment technology of each province can be determined by summing the number of people served by (connected to) each wastewater system (i.e., sewershed or facility) having each type of treatment. However, few wastewater treatment systems have direct measures of the number of people that they serve. Instead, the population served by each wastewater system must be estimated.

Table A3.6–14 **Emission Factors for CH_4 from Wastewater Treatment and Discharge**

Treatment Category	MCF	EF	Source: MCF	BOD_5 Removal Efficiency	Source: BOD_5 Removal Efficiency	Sludge BOD_5 per BOD_5 Removed from Wastewater	Source: Sludge BOD_5 per BOD_5 Removed from Wastewater
No Treatment	0.1	0.036	IPCC 2006	0	IPCC 2019	0	
Primary	0.018	0.0036	IPCC 2019	0.4	IPCC 2019	1	Envirosim, Table 3
Aerobic Lagoon	0	0	IPCC 2006	0.85	ECCC Internal Analysis	0.01	Envirosim, Table 6
Anaerobic Lagoon	0.8	0.288	IPCC 2006	0.85	ECCC Internal Analysis	0.02	Envirosim, Table 6
Facultative Lagoon	0.2	0.072	IPCC 2006	0.85	ECCC Internal Analysis	0.01	Envirosim, Table 6
Other / Unspecified Lagoon	0.2	0.072	IPCC 2006	0.85	ECCC Internal Analysis	0.01	Envirosim, Table 6
Secondary Anaerobic	0.8	0.288	IPCC 2006	0.85	ECCC Internal Analysis	0.46	Modeling as Secondary Aerobic
Secondary Activated Sludge	0.01	0.0036	IPCC 2019	0.95	IPCC 2019	0.46	Envirosim, Table 2, Secondary with Primary & Nitrification
Trickling Filter	0.01	0.0036	IPCC 2019	0.85	ECCC Internal Analysis	0.6	Envirosim, Table 5
Trickling Filter – High Rate	0.01	0.0036	IPCC 2019	0.85	ECCC Internal Analysis	0.75	Envirosim, Table 5
Rotating Biological Contactor	0.01	0.0036	IPCC 2019	0.85	ECCC Internal Analysis	0.23	Surampalli and Baumann 1995
Sequencing Batch Reactor	0.05	0.018	Taseli 2018	0.9	Literature Review	0.46	Assuming similar to Secondary Activated Sludge. See Mahvi 2008
Secondary Biofiltration	0.018	0.0036	IPCC 2019	0.95	Literature Review	0.46	Assuming similar to Secondary Activated Sludge
Secondary with Biological Nutrient Removal	0.018	0.0036	IPCC 2019	0.98	Literature Review / IPCC 2019 / Envirosim 2019 Assuming primary treatment included	0.46	Envirosim, Table 2, Secondary with Primary & Nitrification
Septic	0.5	0.18	IPCC 2006	1	Assuming dispersal field	0.5	IPCC 2019, Equation 6.3
Septic with Marine Outfall	0.5	0.18	IPCC 2006	0.625	IPCC 2019, Table 6.6B	0.5	IPCC 2019, Equation 6.3
Wetland	0.17	0.0612	IPCC 2014 Wetland Supplement	0.975	Estimate	0	Assuming no dredging
Other / Unknown	0.2	0.072	Modeling as facultative lagoon	0.85	Modeling as facultative lagoon	0.01	Modelling as facultative lagoon

To estimate the population served by each facility, a geographic approach is taken:

1. Map population in each census metropolitan area (CMA) and each census division (CD), excluding overlapping areas with CMA, from 1990 onward, taking account of changing geographic boundaries with each census (Statistics Canada census population from 1991, 1996, 2001, 2006, 2011, 2016 censuses; Statistics Canada census administrative area boundaries [shapefiles or geodatabases] from 1996, 2016 and 2016 censuses).
2. Determine population in each region connected to municipal wastewater treatment systems and population using private or communal septic systems.
3. Distribute the CMA or CD population that discharges to municipal sewer systems between the wastewater treatment systems in that region according to the relative volume of wastewater that the systems process in a year. For example, a facility that treats 30% of the total annual wastewater of a CMA in a given year is assumed to serve 30% of the population of that CMA that is connected to the municipal sewer systems in that year.

The total population using each treatment technology for each province in each year is determined by summing the population of the wastewater treatment system having that technology, according to Equation A3.6–17.

Equation A3.6–17

$$Population\_Using\_System_{t,y} = \sum_{i,y} \frac{Volume\ Treated_{i,t,y}}{TotalVolumeTreated_{region,y}} * Population_{mun\ sewer,region,y}$$

$Population\_Using\_System_{t,y}$	=	the estimated population served by the municipal wastewater treatment system of type t in year y
$VolumeTreated_{i,t,y}$	=	the volume of wastewater treated by, or discharged from, facility *i*
$region$	=	the region (census metropolitan area or census division) in which system *i* is located (note: census geography boundaries change over time)
$TotalVolumeTreated_{region,y}$	=	the total volume of wastewater treated by all municipal wastewater systems in the region in which system *i* is located.
$Population_{mun\_sewer,r,y}$	=	the population of the region in which system *i* is located in year y that live in residences connected to municipal sewer systems (as opposed to private septic systems)

The population discharging their wastewater to municipal sewer systems versus those discharging to private or small communal septic systems is determined from an analysis of the Households and Environment Survey (Statistics Canada. No date [c]). The septic versus sewer use can only be determined at the spatial resolution of census metropolitan area and "the rest of the province." In other words, all census divisions in a province are treated as one for determining septic or municipal treatment use.

The volume of wastewater discharged (volume treated) from most (>2500) wastewater treatment systems in Canada and the treatment technology used are reported through the Effluent Regulatory Reporting Information System (ERRIS) under the *Wastewater Systems Effluent Regulations* of the *Fisheries Act* (Canada 2012). Records from this source begin in 2013. To complete the time series and fill any data gaps, the reported volumes, treatment technology, and details of facility construction, upgrade and decommissioning were also gathered from older national inventories, provincial inventories and reports, annual reports of treatment facilities, municipal websites, engineering reports, scholarly articles, news articles, and other available sources. Notable data sources, in addition to data gathered through ERRIS, include the national inventory of municipal waterworks and wastewater systems in Canada, 1996 (Minister of Supply and Services Canada 1987), the Government of Quebec (Québec 2003, 2005 and 2013), the Ontario Ministry of the Environment (1985), and the Newfoundland Water Resources Portal (accessed 2018).

The data for septic use (and municipal wastewater system use), and volumes treated are not available for every year. Gaps in the time series of provincial and census metropolitan area septic use are linearly interpolated and extrapolated by holding values constant. Gaps in the time series of wastewater volumes are linearly interpolated and extrapolated by scaling from the nearest known value according to regional population changes.

Many small systems have no reported volumes for any year (1426 systems). This may be because the systems are below the mandatory reporting threshold of 100 m^3/day for the *Wastewater System Effluent Regulations* or because they closed before the regulations came into effect in 2014. These systems are given a token treatment volume of 50 m^3/day (which corresponds to populations of approximately 50 to 200 people, varying by region). Even with token volumes assigned, these 'small' systems represent a negligible contribution to the overall volume of wastewater treated in Canada.

The treatment technology of a given wastewater system is extrapolated by holding the earliest and last known technology constant. When the treatment technology of a given system has changed over time and the precise year of change is unknown, the technology type is interpolated by carrying the earlier technology forward until the first recorded of year of the newer technology (i.e., it is assumed that the first instance or record of the newer technology likely corresponds to the year of upgrade).

The estimated population connected to each treatment technology type, by province and territory is shown in Figure A3.6–5. Percentages of Canadian population connected to the wastewater systems of each treatment technology are shown in Table A3.6–15.

Organics Removed As Sludge

Sludge removal is not measured directly at all facilities across Canada and is therefore estimated by modelling it as a function of the treatment technology. In addition to treatment technology, there are many factors at play that will impact sludge removal, from operating temperatures to flow rates. However, on aggregate, and using "typical" operating practices and configurations, average sludge removals across the various treatment technologies in use in Canada can be estimated.

Organics removed from the wastewater as sludge, measured as units of BOD_5, are estimated according to Equation A3.6–18 and Equation A3.6–19, using parameters shown in Table A3.6–14.

Equation A3.6–18

$$Organics\_Removed\_Via\_Treatment_t = OrganicLoading_t \times BOD_5\_Removal\_Efficiency_t$$

$Organics\_Removed\_Via\_Treatment$	=	total amount of organics (measured as BOD_5) removed from the wastewater, for treatment type t, tonne BOD_5
$OrganicLoading_t$	=	organic load to the wastewater treatment/discharge system, tonne BOD_5
$BOD_5\ Removal\ Efficiency_t$	=	average or typical efficiency of wastewater treatment technology, in Canada, at removing BOD_5 from wastewater (Table A3.6–14), fraction

Equation A3.6–19

$$BOD_5\_Removed\_As\_Sludge_t = Organics\_Removed\_Via\_Treatment_t \times SludgeBOD_5\_Per\_BOD_5\_Removed_t$$

$BOD_5\_Removed\_As\_Sludge_t$	=	quantity of BOD_5 (t BOD_5) removed from the wastewater as sludge for treatment type t
$Organics\_Removed\_Via\_Treatment_t$	=	total amount of organics (measured as BOD_5) removed from the wastewater, for treatment type t
$SludgeBOD_5\_Per\_BOD_5\_Removed_t$	=	treatment technology-specific factor for amount of BOD_5 removed from wastewater as sludge per unit of BOD_5 removed from wastewater during treatment (not 1:1 because of other BOD_5 removal mechanisms such as emissions)

Figure A3.6–5 **Population Served by Each Treatment Technology, by Province**

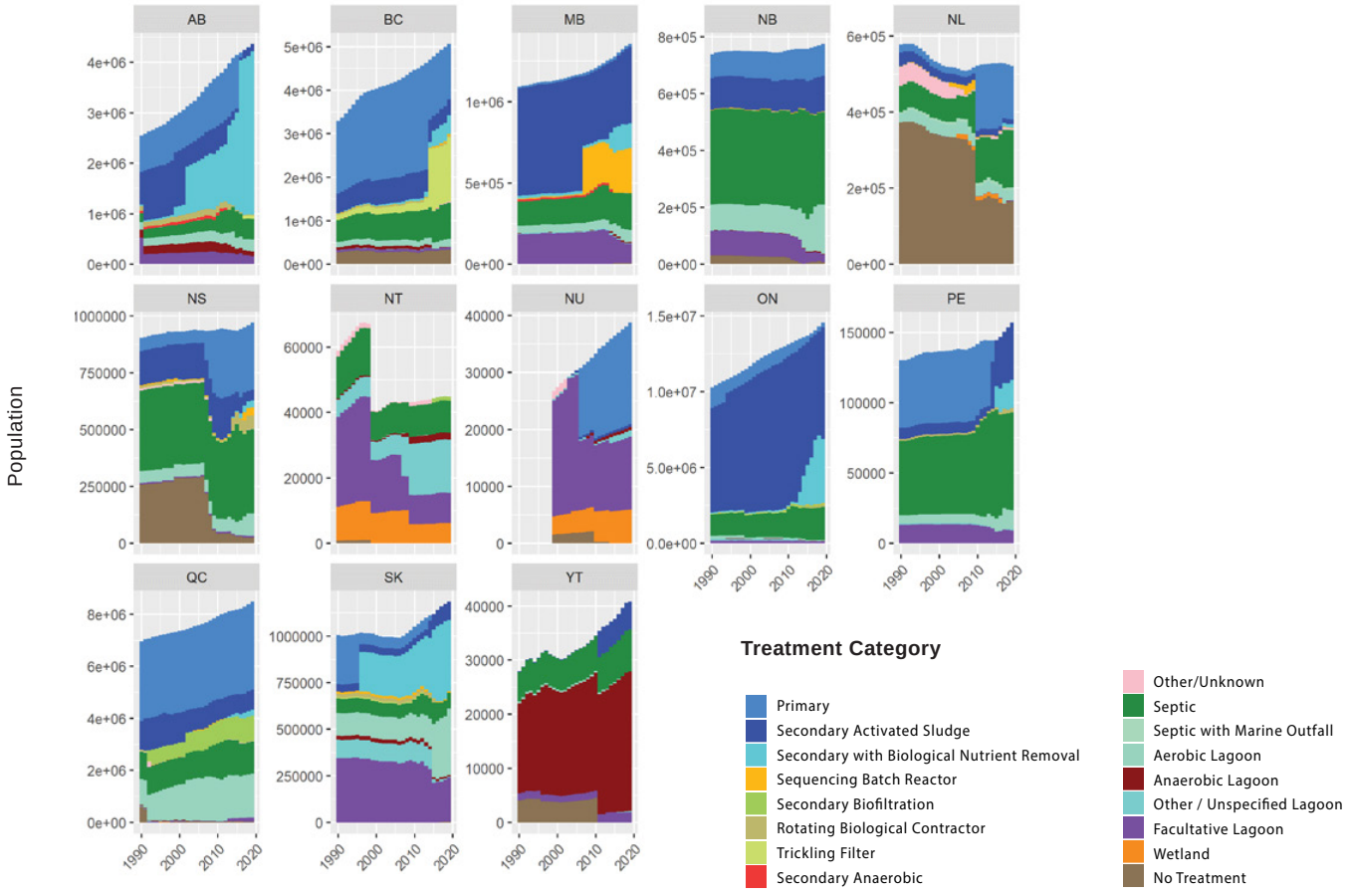


Table A3.6–15 **Percentage of Canadian Population Using Each Wastewater Treatment Technology**

Treatment Category	Year						
	1990	1995	2000	2005	2010	2015	2019
Aerobic Lagoon	6.39	6.7	6.84	7.48	7.12	7.3	7.72
Anaerobic Lagoon	1.05	1.07	1.03	1.01	0.94	0.5	0.45
Facultative Lagoon	5.39	4.13	3.92	3.79	3.47	2.75	2.63
No Treatment	5.61	3.4	3.15	3.06	1.64	1.58	1.54
Other / Unknown	0.32	0.25	0.21	0.11	0.03	0.1	0.14
Other / Unspecified Lagoon	0.9	0.87	0.81	0.75	0.73	0.21	0.08
Primary	26.41	24.34	23.41	23.1	23.66	18.73	14.84
Rotating Biological Contactor	0.58	0.56	0.53	0.55	0.56	0.53	0.53
Secondary Activated Sludge	36.46	39.97	41.02	38.06	36.81	28	25.06
Secondary Anaerobic	0.21	0.21	0.22	0.22	0.21	0	0
Secondary Biofiltration	0.01	1.96	1.8	2.42	2.68	2.77	2.76
Secondary with Biological Nutrient Removal	0.52	0.53	1.81	4.23	4.54	15.54	23.19
Septic	15.24	15.07	14.33	14.17	15.78	16.87	15.73
Septic with Marine Outfall	0.01	0.02	0.02	0.02	0.02	0.02	0.01
Sequencing Batch Reactor	0.15	0.15	0.14	0.25	0.98	0.94	1.13
Trickling Filter	0.71	0.66	0.72	0.7	0.77	4.05	4.14
Wetland	0.04	0.1	0.04	0.08	0.07	0.08	0.04

Note: Values may not add up to 100% because of rounding.

Emissions from Receiving Water Body (Organics Remaining in Effluent)

Canada uses a Tier 1 approach from the 2019 IPCC Refinement (IPCC 2019). The emissions are calculated using Equation A3.6–20 to Equation A3.6–22. The receiving water body types are unknown, but a country specific value for B_0 (of 0.36) is used to determine the emission factor, of 0.0396 kg CH_4 per kg BOD_5 in wastewater effluent discharged to receiving water bodies.

Equation A3.6–20

$$CH_{4,receiving\ wtr\ body} = EF_{CH4,receiving\ wtr\ body} \times OrganicLoad_{effluent}$$

$CH_{4,receiving\ wtr\ body,\ p}$ = CH_4 emissions from receiving water bodies in province p

$EF_{CH4,receiving\ wtr\ body}$ = CH_4 emission factor for wastewater treatment technology, tonne CH_4 / tonne BOD_5

$OrganicLoad_{effluent}$ = organic load to the passing through wastewater treatment and discharged to the receiving water body as effluent, tonne BOD_5

Equation A3.6–21

$$EF_{CH4\ \ Receiving\ water\ body} = B_0 \times MCF$$

$EF_{CH4\ Receiving\ water\ body}$ = emission factor, kg CH_4/kg BOD_5 for wastewater discharged to receiving water bodies

B_0 = theoretical maximum CH_4 producing capacity, 0.36 kg CH_4/kg BOD_5 (AECOM 2011).

MCF = methane correction factor (MCF), fraction. IPCC 2019 Refinement Tier 1 default value of 0.11, for unspecified receiving water body type.

The BOD_5 discharged to receiving water bodies varies by treatment technology. The total BOD_5 discharged to receiving water bodies can be determined as a mass balance based on the removal efficiency of the treatment technology.

Equation A3.6–22

$$OrganicLoad_{effluent} = \sum_t [OrganicLoading_t \times Organics\_Removed\_Via\_Treatment_t]$$

$OrganicLoad_{Effluent}$ = quantity of organics, measured as BOD_5 discharged to receiving water bodies from treatment technology of type t, tonne BOD_5

$OrganicLoad_t$ = organic load to the wastewater treatment/discharge systems of type t, tonne BOD_5

$BOD\ Removal\ Efficiency_t$ = typical efficiency of wastewater treatment technology, in Canada, at removing BOD_5 from wastewater (Table A3.6–14)

Emissions from Anaerobic Digestion of Sludge at Wastewater Treatment Facilities

Emissions from anaerobic digestion occurring at wastewater treatment plants are reported under Wastewater, in accordance with the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019). Anaerobic digestion and composting of sludge occurring off-site from the wastewater treatment plants, however, are reported under Biological Treatment (section A3.6.2).

To calculate emissions from anaerobic digestion, the BOD_5 removed as sludge must be converted to a mass of total suspended solids (TSS), and the fraction of volatile suspended solids (VSS) must be determined. The ratio of TSS sludge produced per unit BOD_5 removed from wastewater as sludge (TSS/BOD_5) and the VSS content of the sludge (VSS/TSS ratio) can be estimated based on the treatment technology used. The TSS/BOD_5 and VSS/TSS ratios are approximate and averaged for a given technology (Equations A3.6–23 to A3.6–27). They are not representative of facility-level operations, which can have a wide variety of operating conditions (temperature, solids retention time, etc.). On aggregate, however, these values are believed to provide a reasonable approximation of the mean sludge characteristics from all facilities in a region of a given type.

Equation A3.6–23

$$TSS_{Sludge} = BOD_5\ Removed\ as\ Sludge \times Sludge\ TSS\ Per\ BOD_5\ Removed$$

TSS_Sludge	=	mass of total suspended solids in sludge removed from wastewater, tonne
$BOD_5\ Removed\ as\ Sludge$	=	BOD_5 removed from wastewater as sludge, tonne BOD_5
$Sludge\ TSS\ Per\ BOD_5\ Removed$	=	conversion factor, mass of TSS per unit of wastewater BOD_5 removed as sludge (tonne / tonne BOD_5); a function of treatment technology (Table A3.6–16)

To date, 89 municipal wastewater treatment facilities have been identified as having on-site anaerobic digestion of sludge. The emissions from anaerobic digestion are calculated at the facility level, based on the estimated population served by that facility and the sludge generated based on the treatment technology employed, then aggregated by province. Uncertainty at the facility level is considered high (not yet quantified) because the parameters used represent general technology averages and not facility-specific configurations. Estimates are likely unreliable until they are aggregated to the provincial level.

Sludge transfers between facilities are also accounted for. In some municipalities sludge may be transferred from smaller wastewater treatment facilities to be processed at larger ones.

Equation A3.6–24

$$CH_{4\ AD\ produced} = TSS_{Reduction_{AD}} \times BiogasGen_{Frac} \times FCH_{4\ Biogas} \times Density_{Biogas} \times 0.01$$

$CH_{4\ ADProduced}$	=	methane generated from anaerobic digestion of sludge (tonne)
$TSS_{Reduction_{AD}}$	=	mass of total suspended solids reduced by anaerobic digestion (kg)
$BiogasGen_{Frac}$	=	volume of biogas generated per unit of TSS consumed in anaerobic digestion (m^3 / tonne)
$FCH_{4Biogas}$	=	fraction of biogas this is CH_4, by mass
$Density_{Biogas}$	=	density of biogas (kg/m^3)
0.01	=	unit conversion kg/m^3 to $tonne/m^3$

Table A3.6–16 **Sludge Characteristics (Conversion from BOD_5 to Total Suspended Solids and Volatile Solids Fraction)**

Treatment Category	SludgeTSS / BOD_5 (kg/kg)	VSS/TSS	Source
No Treatment	N/A		
Primary	1.75	0.83	Envirosim 2019
Aerobic Lagoon	0.17	0.35	Envirosim 2019
Anaerobic Lagoon	0.55	0.45	Envirosim 2019
Facultative Lagoon	0.33	0.33	Envirosim 2019
Other / Unspecified Lagoon	0.33	0.33	Modelling as Facultative Lagoon
Secondary Anaerobic	0.95	0.815	Modelling as Secondary Activated Sludge
Secondary Activated Sludge	0.95	0.815	Envirosim 2019
Trickling Filter	1.08	0.83	Envirosim 2019
Trickling Filter – High Rate	1.23	0.84	Envirosim 2019
Rotating Biological Contactor	1.08	0.83	Modelling as Trickling Filter
Sequencing Batch Reactor	0.95	0.815	Modelling as Secondary Activated Sludge; Mahvi 2008; EPA 1999
Secondary Biofiltration	0.95	0.815	
Secondary with Biological Nutrient Removal	0.95	0.815	Envirosim 2019
Septic	0.25	0.5	ECCC Estimate based on IPCC 2019 and Washington State 2004
Septic with Marine Outfall	0.25	0.5	ECCC Estimate based on IPCC 2019 and Washington State 2004
Wetland	N/A		Assuming no sludge removal
Other / Unknown	0.33		Modelling as facultative lagoon

Anaerobic digestion of sludge consumes the volatile suspended solids portion (VSS) of sludge. The reduction in sludge quantity (mass) is based on the volatile suspended solids fraction.

Equation A3.6–25

$$TSS_{Reduction_{AD}} = TSS_{Sludge} \times \frac{VSS}{TSS} ratio \times FracVSSRemoval_{AD}$$

$TSS_{Reduction_{AD}}$	=	mass of total suspended solids reduced by anaerobic digestion (tonne)
TSS_{Sludge}	=	mass of total suspended solids in sludge (tonne)
$FracVSS$	=	fraction of sludge mass that is volatile suspended solids. FracVSS is a function of the treatment technology from which the sludge originates (Table A3.6–16)
$FracVSSRemoval_{AD}$	=	fraction of VSS that is consumed by anaerobic digestion (fraction)

Methane Recovery

Methane recovery for anaerobic digestion of sludge is universally practiced in Canada. Net emissions will be the result of recovery inefficiencies (combustion inefficiency for flaring or utilization) and fugitive loss. Fugitive loss and methane emissions from recovery inefficiency are assumed to be 2.1% of the methane produced, for anaerobic digestion of sludge at wastewater treatment facilities.

Equation A3.6–26 **Fugitive Emissions from Wastewater Anaerobic Digesters**

$$CH_{4\ AD\ Emission} = CH_{4\ AD\ Produced} \times (1 - FugitiveLoss_{percent}/100)$$

$CH_{4AD\ Emission}$	=	methane emitted from anaerobic digestion of sludge at wastewater treatment facilities (tonne)
$CH_{4\_AD\_Produced}$	=	methane produced from anaerobic digestion of sludge (tonne)
$FugitiveLoss_{percent}$	=	percentage of biogas (and methane) emitted from fugitive loss and combustion inefficiencies

Sludge Available for Other Fates (Sludge Accounting)

Secondary to the wastewater treatment emissions, sludge produced and remaining after anaerobic digestion on-site is used to estimate the quantities of sludge landfilled. The sludge remaining after on-site anaerobic digestion is determined as shown in Equation A3.6–27. Because anaerobic digestion only consumes the VSS portion of sludge, the VSS fraction is updated as shown in Equation A3.6–28.

Equation A3.6–27 **Sludge Mass Total Suspended Solids (Dry Weight) Available After On-Site Anaerobic Digestion**

$$TSS_{Available} = TSS_{Sludge} - TSS_{Reduction_{AD}}$$

$TSS_{Available}$	=	The mass of sludge total suspended solids (in other words the dry weight of sludge) available after wastewater treatment and on-site anaerobic digestion of sludge (kg TSS or kg Dry Weight Sludge).
TSS_{Sludge}	=	mass of total suspended solids in sludge, before anaerobic digestion (kg)
$TSS_{Reduction_{AD}}$	=	mass of TSS reduced by anaerobic digestion (kg)

Equation A3.6–28 **Sludge Volatile Suspended Solids Fraction After Anaerobic Digestion**

$$VSS_{updated} = \frac{TSS_{Sludge} * FracVSS - TSS_{Reduction_{AD}}}{TSS_{SLudge} - TSS_{Reduction_{AD}}}$$

$VSS_{updated}$	=	volatile suspended solids fraction of sludge having undergone anaerobic digestion (fraction)
TSS_{Sludge}	=	mass of total suspended solids in sludge, before anaerobic digestion (kg)
$FracVSS$	=	fraction of sludge mass that is VSS, before anaerobic digestion (fraction)
$TSS_{Reduction_{AD}}$	=	mass of TSS reduced by anaerobic digestion (kg)

The VSS fraction of all sludge produced in a province or territory is determined from the weighted average of sludge produced from each treatment technology after accounting for any on-site anaerobic digestion.

Sludge Distribution

Quantities of sludge incinerated and composted are reported directly from the facilities. Sludge sent to these fates are discussed in section A3.6.2 (Biological Treatment of Solid Waste) and A3.6.3 (Incineration). Sludge sent to landfill or land-applied for agriculture or land-restoration must be estimated. Sludge remaining after point source fates (compost and incineration) is distributed to landfill or land-application according to provincial ratios estimated by Cheminfo (Cheminfo 2018). Estimated fates of wastewater treatment sludge are shown in Figure A3.6–6.

Equation A3.6–29 **Calculation of Sludge Distribution to Landfills As Part of Sludge Flow Accounting**

$$Sludge\ Landfilled = [SS_{Available} - SS_{BiolTrtmt} - SS_{Incinerated} - SS_{Exported}] \times Prop_{LF}$$

$SS_{Available}$	=	mass of sewage sludge available from wastewater treatment, after accounting for reductions from on-site anaerobic digestion at the wastewater treatment facilities
$SS_{BioTrtmt}$	=	mass of sludge sent to biological treatment, which includes composting and anaerobic digestion (the product of which is assumed to not re-enter the pool of sludge potentially destined for landfill)
$SS_{Incinerated}$	=	mass of sludge incinerated, tonne
$SS_{Exported}$	=	mass of sludge exported, tonne
$Prop_{LF}$	=	proportion of sewage sludge remaining that is landfilled, as opposed to land-applied on agricultural land, forest or as part of land-reclamation (varies by province and over time), ratio.

Estimated fates of wastewater treatment sludge are shown in Figure A3.6–6.

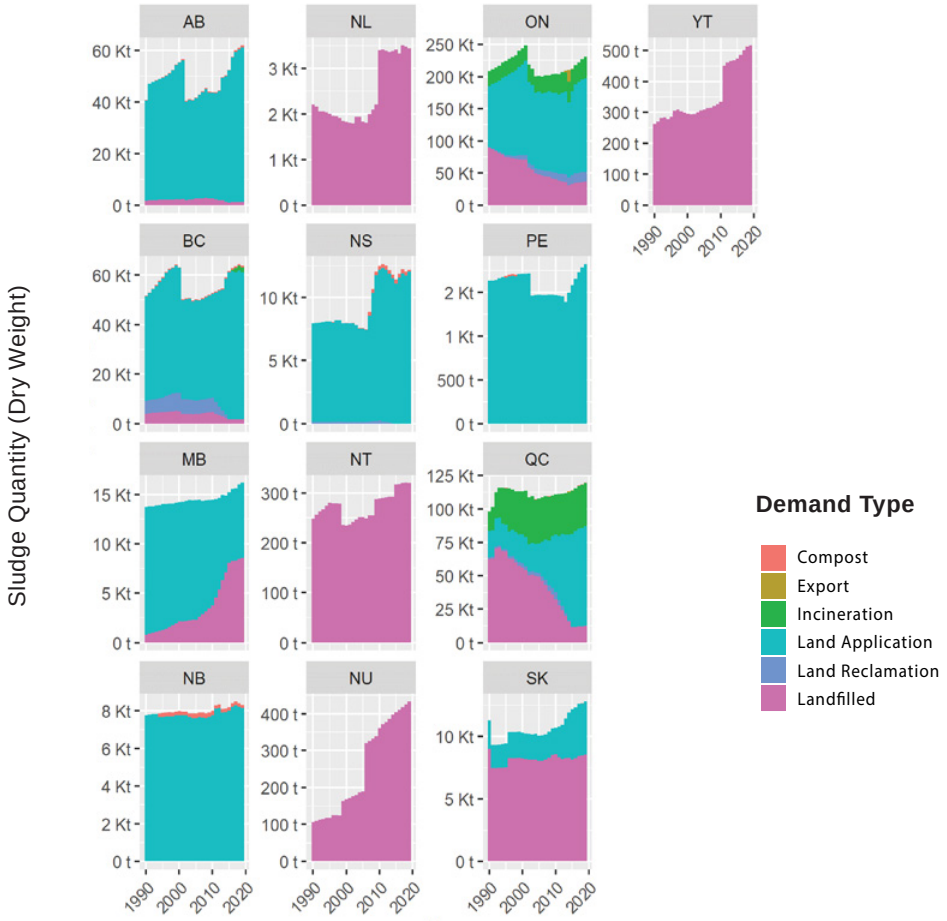
A3.6.4.1.1. N_2O Emissions from Municipal Wastewater Treatment/Discharge

Methodology

Nitrous oxide (N_2O) emissions are estimated using the 2006 IPCC Tier 1 method (IPCC 2006). N_2O is associated with the degradation of nitrogen components in wastewater, which are introduced from urea, nitrate and protein in human sewage as well as inputs from other household wastewater, including inputs from shower drains, sink drains, washing machines, etc. (IPCC 2006).

The N_2O emissions from municipal wastewater treatment facilities are estimated using the amount of nitrogen discharged to the aquatic environment, based on nitrogen introduced to the wastewater stream and an emission factor of 0.005 kg N_2O-N / kg N_2O-N in wastewater, as shown in Equation A3.6–30.

Figure A3.6–6 **Sludge Flow Accounting, Estimated Sludge Fates by Province**



Equation A3.6–30

$$N_2O = EF_{N_2O-N} \times N_{wastewater} \times \frac{44}{28}$$

N_2O	=	N_2O emissions in the inventory year, kg N_2O/year
EF_{N2O-N}	=	emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N.
$N_{wastewater}$	=	nitrogen in wastewater, kg N/yr
$44/28$	=	stoichiometric factor to convert nitrogen to N_2O

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen, namely 0.005 kg N_2O-N/kg N (from a range of 0.0005 to 0.25), is used.

The amount of nitrogen introduced to wastewater sewage is determined on a per-capita basis, based on protein consumption and factors for industrial inputs and other household inputs, as shown in Equation A3.6–31.

Table A3.6–17 **Canadian Protein Consumption**

Year	Protein Consumption (g/capita per day)
1990	66.17
1991[a]	66.17
1992	66.65
1993	67.14
1994	67.62
1995	68.11
1996[a]	68.59
1997	69.46
1998	70.34
1999	71.21
2000	72.09
2001[a]	72.96
2002	73.42
2003	73.88
2004	74.34
2005[a]	71.12
2006[a]	71.03
2007[a]	71.79
2008[a]	70.25
2009[a]	69.85
2010	69.85
…	69.85
2019	69.85

Notes:

Values for intermediary years without data from Statistics Canada are estimated by linear interpolation. Values extrapolated by holding the nearest value constant.

a. Statistics Canada (2009), Food Statistics, Catalogue Number 21-020-X: Total nutrients available adjusted for losses from the Canadian food supply.

Equation A3.6–31

$$N_{wastewater} = (Protein_{Consm} \times Population \times FRAC_{N-PR} \times F_{NON-CON} \times F_{IND-CON}) - N_{SLUDGE}$$

$N_{wastewater}$	=	nitrogen in wastewater, kg N/yr
$Protein_{Consum}$	=	annual per capita protein consumption, kg/capita per year, kg/person/yr
$Population$	=	the human population
$FRAC_{N-PR}$	=	fraction of nitrogen in protein (0.16 kg N/kg protein)
$F_{NON-CON}$	=	factor for non-consumed protein added to the wastewater
$F_{IND-COM}$	=	factor for industrial and commercial co-discharged protein into the sewer system
N_{SLUDGE}	=	nitrogen removed with sludge (taken as the 2006 IPCC Guidelines default value of 0 because of limited data), kg N/yr

Protein consumption is determined from Canadian protein consumption data, which are obtained from the annual food statistics publication (Statistics Canada 2009). Statistics Canada data are provided for the years 1991, 1996 and 2001–2009 from the protein (nutrients) available adjusted for losses from the Canadian food supply, as shown in Table A3.6–17. It is assumed that protein is 16% nitrogen.

Protein consumed accounts for retail, household, and cooking and plate loss, which generally goes to municipal solid waste and composting streams, rather than wastewater. Use of protein available without adjusting for losses would result in an overestimate of wastewater N_2O emissions (AECOM 2012).

The factor for industrial and commercial co-discharged protein to the sewer system ($F_{IND-COM}$) is taken as the 2006 IPCC Guidelines default value of 1.25. The factor for non-consumed protein added to the wastewater ($F_{NON-CON}$), which represents nitrogen inputs from other household sources, such as shower drains, sink drains, washing machines etc., is taken as the IPCC default value of 1.1, for countries with no garbage disposal, interpreted as meaning no in-sink garbage disposal such as garburators. (Although garburators are used in some Canadian districts, most regions do not permit in-sink waste disposal).

Nitrogen removed from sludge is not estimated because of a lack of data on nitrogen concentration in sewage sludge. The 2006 IPCC Guidelines default value of 0 is used.

A3.6.4.1.2. CO_2 Emissions from Municipal Wastewater Treatment/Discharge

CO_2 emissions from wastewater are of biogenic origin. According to the 2006 IPCC Guidelines, CO_2 from the combustion or decay of short-lived biogenic material removed from where it was grown is reported as zero in the Waste sector. Therefore, these emissions are not considered for wastewater treatment.

A3.6.4.2. Industrial Wastewater Treatment – CH_4 and N_2O

Estimates for CH_4 emissions from industrial facilities with on-site wastewater treatment are handled facility by facility following a Tier 3 approach (IPCC 2006). Industrial on-site wastewater treatment systems can receive varying organics loads, depending on industry type, facility size and production levels. Methane recovery varies facility by facility. Therefore, industries with on-site anaerobic systems are estimated individually.

Emissions are not estimated for on-site anaerobic sludge digesters at industrial facilities. N_2O emissions from industrial wastewater treatment are not currently estimated.

A3.6.4.2.1. Data Sources and Methodology

Preliminary inquiries indicated that anaerobic industrial wastewater units were relatively few in Canada. A Tier 3 approach based on information directly collected from individual facilities was deemed more accurate than the default approach. Volumes of wastewater treated, COD or BOD_5 levels, and volumes of biogas flared, used and vented were collected through surveys of industrial facilities either known or likely to be employing anaerobic units to treat their effluent on-site, conducted every two years from 2008 to 2016. Industry sectors considered for the survey include pulp and paper, chemicals and chemical products, food, beverages, petroleum and coal products, rubber products, plastic products, and total textiles.

Nineteen facilities were identified through email exchanges with facility operators and industry associations as having anaerobic systems. The facilities surveyed provided volumes of biogas vented, flared and used for heat or energy purposes. The CH_4 mass of each biogas stream (used, flared, vented) was determined from the facility-reported biogas methane concentration (or a default value of 60% CH_4 if not reported) and the reported biogas density, pressure and temperature. Fugitive losses were estimated to be 0.5%. Methane emissions from the inefficiencies of the flare and utilization devices were also accounted for. The CH_4 destruction efficiencies were estimated to be 99.5% for an enclosed flare and 98% for a boiler (Climate Action Reserve 2009). The total emissions were determined from the sum of CH_4 in vented biogas, CH_4 in piping (fugitive) losses and the quantities of CH_4 circumventing combustion in the flare and boiler.

In the absence of survey-reported data for two facilities known to have anaerobic wastewater treatment systems, design parameters (process wastewater volumes and COD) were used from the engineering firm that supplied the units to these facilities to estimate methane production values. As it is known that the gas is collected, it was assumed that the losses, i.e., emissions, would consist of piping losses and utilization by a boiler.

ANNEX 4

COMPARISON OF SECTORAL AND REFERENCE APPROACHES, AND THE NATIONAL ENERGY BALANCE

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. Section A4.4 contains a general discussion on the merits of using implied emission factors.

A4.1. Comparison of Reference Approach with Sectoral Approach

A comparison of results from the RA and the SA serve as a check of energy available versus that consumed by all sectors, and the corresponding CO_2 emissions from fossil fuel combustion. Checks of RA and SA results for all years from 1990 to 2019 are an integral part of reporting to the United Nations Framework Convention on Climate Change (UNFCCC).

Direct comparison of energy consumption in the RA and SA shows significant discrepancies, since the SA total does not include some of the non-energy use of fossil fuels and feedstocks. Comparison of the RA and SA shows an 11.3% or larger variation in energy. Excluding the non-combustion energy of certain feedstocks and fossil fuels ensures that the RA and the SA are comparing similar sources. When the RA energy amounts include adjustments for non-energy use of fossil fuels and feedstocks, the difference between the SA and adjusted RA varies from -2.15 to 1.25%. Table A4–1 shows a comparison of the original and adjusted RA and SA.

No adjustments were necessary for the emissions estimate in the RA since online CRF Reporting software, supplied by the UNFCCC, correctly removes emissions associated with non-energy and feedstock use and allocates them to industrial processes and product use sectors. Comparison of the RA and SA emission estimates, as seen in Table A4–1, shows an overall -2.05% to 2.43% variation.

A4.2. Reference Approach Methodology

The RA follows the 2006 Intergovernmental Panel on Climate Change (IPCC) Guideline's designated method with the use of country-specific fuel energy contents (in higher heating value [HHV]/gross calorific value [GCV]) and emission factors. Canada and the United States use HHVs to report the energy content of fuels. Fuel supply and demand reported by industries to the various surveys that feed into the compilation of the *Report on Energy Supply–Demand in Canada* (RESD) (Statistics Canada 1990–) are in physical units. Chapter 3, section 3.2.2 International Bunker Fuels, and annex sections A3.2.2.1 Civil Aviation, and A3.2.2.2 Navigation presents fuel allocation for International bunkers.

For primary fuels (crude oil, ethane, natural gas liquids, coal and natural gas), the stock change data have been adjusted to account for inter-product transfers, stock variation and other adjustments, all of which are reported separately in the RESD and all of which directly impact fuel availability. Apparent consumption is determined using this adjusted stock change number. Similarly, the stock change data for secondary fuels takes into consideration inter-product transfers, international bunkers, stock variation and other adjustments.

Once the apparent consumption is determined, country-specific fuel energy contents and carbon emission factors allow for the calculation of carbon content and emissions. Energy content values come from the following sources: RESD (Statistics Canada 1990–), 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), and the 2006 IPCC Guidelines.

Table A4–2 presents the applied emission factor, energy content and oxidation value in the RA. The RESD supplies the energy content values, with the exceptions of bituminous coal, lignite, crude oil, heavy fuel oil, LPGs, natural gas, NGLs, petroleum coke and still gas, where weighted factors, calculated yearly, account for the quantity and variation of energy content at the point

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
Overall Energy Comparison															
Reference Approach (PJ)	7 189	7 010	7 231	7 322	7 552	7 698	8 068	8 301	8 305	8 638	8 964	8 878	9 015	9 229	9 220
Sectoral Approach (PJ)	6 322	6 174	6 403	6 440	6 654	6 825	7 047	7 198	7 256	7 559	7 922	7 817	7 924	8 167	8 095
Percent Difference without Adjustment (%)	13.7	13.5	12.9	13.7	13.5	12.8	14.5	15.3	14.5	14.3	13.1	13.6	13.8	13.0	13.9
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	6 384	6 184	6 389	6 455	6 682	6 804	7 007	7 188	7 213	7 456	7 875	7 771	7 892	8 059	7 967
Percent Difference with Adjustment – 100% x (RA-SA)/SA	**0.97**	**0.17**	**-0.22**	**0.23**	**0.43**	**-0.31**	**-0.57**	**-0.14**	**-0.60**	**-1.37**	**-0.59**	**-0.59**	**-0.41**	**-1.32**	**-1.58**
Adjusted Non-Energy Fossil Fuels and Feedstocks															
Non-Energy Use of Gaseous Fuels (PJ)	*163*	*181*	*172*	*193*	*200*	*198*	*241*	*260*	*255*	*267*	*243*	*205*	*152*	*159*	*171*
Non-Energy Use of Liquid Fuels (PJ)	*539*	*529*	*555*	*561*	*565*	*586*	*711*	*746*	*727*	*803*	*731*	*795*	*865*	*904*	*972*
Non-Energy Use of Solid Fuels (PJ)	*103*	*116*	*115*	*113*	*105*	*110*	*108*	*107*	*110*	*112*	*115*	*107*	*106*	*107*	*111*
Overall Emission Comparison															
Reference Approach (Gg CO_2)	419 240	405 467	417 062	418 302	431 266	438 522	450 470	465 661	469 221	481 821	508 595	502 551	508 708	519 272	511 333
Sectoral Approach (Gg CO_2)	411 271	401 807	414 864	413 524	425 774	437 000	450 507	463 735	469 474	484 887	508 064	502 443	506 166	522 027	518 220
Percentage Difference (%)	**1.94**	**0.91**	**0.53**	**1.16**	**1.29**	**0.35**	**-0.01**	**0.42**	**-0.05**	**-0.63**	**0.10**	**0.02**	**0.50**	**-0.53**	**-1.33**
Liquid Fuels															
Reference Approach (Gg CO_2)	209 694	193 190	195 336	200 058	205 716	204 874	207 480	216 486	218 779	216 805	223 127	224 994	227 998	237 682	241 346
Sectoral Approach (Gg CO_2)	203 146	190 901	194 016	195 791	200 795	203 413	208 250	215 849	219 441	221 492	224 071	227 450	226 862	240 889	248 914
Percentage Difference (%)	**3.22**	**1.20**	**0.68**	**2.18**	**2.45**	**0.72**	**-0.37**	**0.30**	**-0.30**	**-2.12**	**-0.42**	**-1.08**	**0.50**	**-1.33**	**-3.04**
Solid Fuels															
Reference Approach (Gg CO_2)	87 307	90 621	92 759	84 378	88 517	89 620	92 244	99 920	104 642	105 134	114 168	113 663	110 162	108 309	101 156
Sectoral Approach (Gg CO_2)	87 009	90 261	92 689	84 924	89 346	90 769	92 754	99 911	105 744	105 923	115 548	113 826	111 514	110 523	102 787
Percentage Difference (%)	**0.34**	**0.40**	**0.07**	**-0.64**	**-0.93**	**-1.27**	**-0.55**	**0.01**	**-1.04**	**-0.75**	**-1.19**	**-0.14**	**-1.21**	**-2.00**	**-1.59**
Gaseous Fuels															
Reference Approach (Gg CO_2)	121 772	121 254	128 472	133 327	136 370	143 432	150 135	148 807	145 273	159 355	170 741	163 349	169 859	172 643	168 150
Sectoral Approach (Gg CO_2)	120 648	120 243	127 662	132 268	134 970	142 222	148 891	147 523	143 760	156 943	167 882	160 620	167 099	169 975	165 837
Percentage Difference (%)	**0.93**	**0.84**	**0.63**	**0.80**	**1.04**	**0.85**	**0.84**	**0.87**	**1.05**	**1.54**	**1.70**	**1.70**	**1.65**	**1.57**	**1.40**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Overall Energy Comparison															
Reference Approach (PJ)	9 074	9 103	9 518	9 307	8 845	9 136	9 419	9 478	9 541	9 708	9 814	9 614	9 692	10 029	9 803
Sectoral Approach (PJ)	8 079	7 995	8 382	8 225	7 886	8 027	8 274	8 240	8 367	8 422	8 497	8 288	8 472	8 752	8 808
Percent Difference without Adjustment (%)	12.3	13.9	13.6	13.2	12.2	13.8	13.8	15.0	14.0	15.3	15.5	16.0	14.4	14.6	11.3
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	7 943	7 877	8 300	8 178	7 762	7 918	8 125	8 114	8 282	8 528	8 553	8 318	8 508	8 852	8 618
Percent Difference with Adjustment – 100% x (RA-SA)/SA	**-1.68**	**-1.47**	**-0.98**	**-0.56**	**-1.57**	**-1.35**	**-1.80**	**-1.53**	**-1.02**	**1.25**	**0.66**	**0.36**	**0.42**	**1.14**	**-2.15**
Adjusted Non-Energy Fossil Fuels and Feedstocks															
Non-Energy Use of Gaseous Fuels (PJ)	*158*	*162*	*161*	*128*	*142*	*142*	*162*	*165*	*150*	*126*	*154*	*149*	*157*	*134*	*123*
Non-Energy Use of Liquid Fuels (PJ)	*871*	*953*	*948*	*899*	*864*	*990*	*1 026*	*1 098*	*1 021*	*962*	*1 032*	*1 065*	*942*	*956*	*983*
Non-Energy Use of Solid Fuels (PJ)	*102*	*112*	*110*	*101*	*77*	*86*	*106*	*100*	*88*	*92*	*75*	*83*	*85*	*88*	*79*
Overall Emission Comparison															
Reference Approach (Gg CO_2)	511 584	504 979	531 349	519 534	487 668	497 124	502 415	499 905	508 805	522 818	524 466	507 808	518 208	532 746	513 087
Sectoral Approach (Gg CO_2)	516 716	509 573	533 576	520 461	494 144	502 525	510 173	504 917	511 049	510 417	513 957	501 341	511 882	521 221	523 806
Percentage Difference (%)	**-0.99**	**-0.90**	**-0.42**	**-0.18**	**-1.31**	**-1.07**	**-1.52**	**-0.99**	**-0.44**	**2.43**	**2.04**	**1.29**	**1.24**	**2.21**	**-2.05**
Liquid Fuels															
Reference Approach (Gg CO_2)	243 305	237 023	246 596	239 425	231 726	235 425	234 194	238 396	237 847	250 202	248 353	242 703	247 290	260 376	239 909
Sectoral Approach (Gg CO_2)	245 210	242 173	249 404	241 066	236 965	241 447	242 431	241 580	242 276	238 626	240 526	238 517	243 359	250 841	252 627
Percentage Difference (%)	**-0.78**	**-2.13**	**-1.13**	**-0.68**	**-2.21**	**-2.49**	**-3.40**	**-1.32**	**-1.83**	**4.85**	**3.25**	**1.75**	**1.62**	**3.80**	**-5.03**
Solid Fuels															
Reference Approach (Gg CO_2)	102 790	99 277	104 593	99 282	81 101	84 629	74 649	68 858	69 646	64 143	67 901	61 712	62 089	49 224	47 516
Sectoral Approach (Gg CO_2)	104 219	100 545	105 628	99 784	83 472	85 174	75 172	69 578	69 127	65 337	67 086	61 451	61 579	49 082	47 328
Percentage Difference (%)	**-1.37**	**-1.26**	**-0.98**	**-0.50**	**-2.84**	**-0.64**	**-0.70**	**-1.03**	**0.75**	**-1.83**	**1.21**	**0.43**	**0.83**	**0.29**	**0.40**
Gaseous Fuels															
Reference Approach (Gg CO_2)	164 926	168 129	179 507	180 173	174 271	176 501	193 006	191 964	200 681	207 916	207 565	202 763	208 221	222 536	225 050
Sectoral Approach (Gg CO_2)	166 721	166 303	177 888	178 954	173 135	175 333	192 001	193 071	199 013	205 895	205 698	200 744	206 336	220 688	223 239
Percentage Difference (%)	**-1.08**	**1.10**	**0.91**	**0.68**	**0.66**	**0.67**	**0.52**	**-0.57**	**0.84**	**0.98**	**0.91**	**1.01**	**0.91**	**0.84**	**0.81**

of consumption, such as commercial usage or self-generated usage. For example, in provinces with natural gas production, there are two emission factors for natural gas: marketable natural gas, sold to consumers, and non-marketable natural gas, combusted by the producers of natural gas. The composition of non-marketable natural gas includes more complex hydrocarbons unlike marketable natural gas which, typically, contains over 95% CH_4.

A4.3. National Energy Balance

This section provides a general background on the national energy balance and its data quality framework. In Canada, the Energy and Environment Statistics Division (EESD) of Statistics Canada is responsible for the collection, compilation and dissemination of energy data under the authority of the *Statistics Act*.[1] The RESD is the primary source of activity data used to estimate GHG emissions for the Energy sector and is available on Statistics Canada's website.[2] Emission estimates for the Industrial Processes and Product Use sector also use the non-energy and feedstock information from the RESD as a source of activity data. The RESD is an accounting of energy forms in Canada from import and export activities through to production, stock change and domestic consumption (refer to Figure A4–1 for a sample of an energy flow diagram). It 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.

Energy and fossil fuel data are collected using a mix of annual and monthly surveys, along with census data from industry, federal agencies (such as the Canadian Energy Regulator [CER]), provincial energy departments and agencies (such as the Alberta Energy Regulator [AER] and the Alberta Utilities Commissions [AUC]), and the Canadian Energy and Emissions Data Centre (CEEDC). Refer to Figure A4–2, RESD Data Input, for a sample of the energy and fossil fuel data input. The oil and gas information provided by the AER is considered accurate, since it is tied to, oil and gas exploitation permits and federal and provincial royalty schemes.

Various federal departments use the RESD for energy efficiency programs, policy development, energy and emission forecasting, and reporting to the UNFCCC. As such, EESD's quality management system for the RESD includes an internal and external stakeholder review process. Documentation of the quality assurance framework and methodological reports are contained in Statistics Canada's Integrated Meta Database.[3] EESD has also established partnerships with various federal government departments, provincial energy ministries, industrial associations and centres of excellence to assist with their quality assurance process.

1 Statistics Canada. Statistics Act. http://laws-lois.justice.gc.ca/eng/acts/S-19/.

2 Statistics Canada. *Report on Energy Supply and Demand in Canada* (Annual). Catalogue No. 57-003-X http://www.statcan.gc.ca/pub/57-003-x/2017002/tablesectlist-listetableauxsect-eng.htm.

3 Statistics Canada. Quality Assurance Framework. http://www.statcan.gc.ca/pub/12-539-x/manage-gestion/4058322-eng.htm.

Figure A4–1 **Sample of an Energy Balance Flow Diagram for Canada (RESD)**

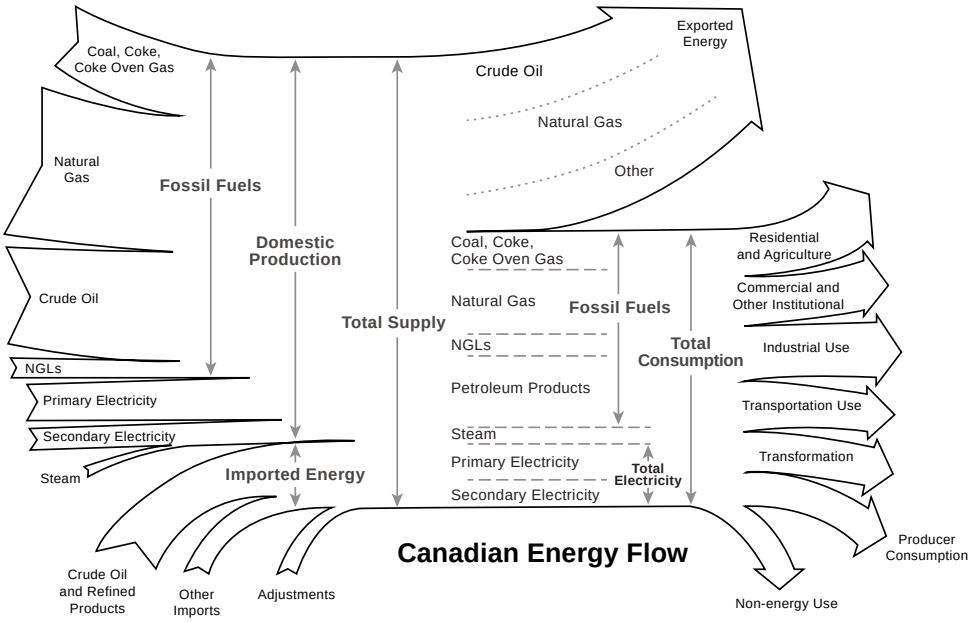


Table A4–2 **Reference Approach Energy Contents and Emission Factors for Canada**

Fuel Types			Energy Content, GCV			Carbon Emission Factor – 2019 Value (t C/TJ GCV)	Reference	Oxidation Factors	Comments
			2019 Value	Unit	Reference				
Liquid	Primary Fuels	Crude Oil	39.5	TJ/ML	See Comments	18.83	Refer to Comments	1.0	Weighted energy content and emission factor are based on country-specific data.
		Ethane	17.22	TJ/ML	4	15.46	2	1.0	Total available ethane is consumed as a feedstock in industrial processes.
		Orimulsion	NA	–	–	NA	–	1.0	
		Natural Gas Liquids	25.34	TJ/ML	–	16.33	–	1.0	Propane and butane from natural gas liquids.
	Secondary Fuels	Bitumen	44.46	TJ/ML	4	21.11	3	1.0	Use of asphalt.
		Gas/Diesel Oil	38.35	TJ/ML	4	19.07	2	1.0	Use of diesel fuel oil.
		Gasoline	33.45	TJ/ML	4	18.81	2	1.0	
		Jet Kerosene	37.4	TJ/ML	4	18.67	2	1.0	Use of aviation turbo fuel.
		Liquefied Petroleum Gases (LPG)	27.13	TJ/ML	4	16.59	2	1.0	Country-specific weighted factors for propane and butane from petroleum refineries.
		Lubricants	39.16	TJ/ML	4	19.66	3	1.0	
		Naphtha	35.17	TJ/ML	4	19.33	3	1.0	
		Other Kerosene	37.68	TJ/ML	4	18.53	2	1.0	
		Other Oil	38.8	TJ/ML	4	19.15	2	1.0	Use of light fuel oil.
		Petroleum Coke	44.95	TJ/ML	4	22.23	4	1.0	Country-specific weighted emission factors based on available emission factors for refining and upgrading (of oil sands to synthetic crude oil).
		Refinery Feedstocks	35.17	TJ/ML	4	19.33	3	1.0	Use of petrochemical feedstock in industrial processes
		Residual Fuel Oil	42.5	TJ/ML	4	20.27	2	1.0	Use of heavy fuel oil.
		Shale Oil	NA	–	–	NA	–	–	
		Still Gas	40.98	TJ/ML	4	14.74	4	1.0	Country-specific weighted emission factor based on factors from refinery and from upgrading (of crude from oil sands to synthetic crude oil) activities.
	Other Liquid Fuels	Aviation Gasoline	33.52	TJ/ML	4	19.24	3	1.0	
		Other Product Feedstocks	39.82	TJ/ML	4	19.84	3	1.0	
Solid	Primary Fuels	Anthracite	27.7	TJ/kt	4	23.45	3	0.988	
		Other Bituminous Coal	28.37	TJ/kt	4	22.04	6	0.995	Use of Canadian bituminous coal
		Sub-bituminous Coal	18.48	TJ/kt	4	26.00	6	0.994	
		Lignite	16.29	TJ/kt	4	24.39	5, 6	0.996	
		Oil Shale	NA	–	–	NA	–	–	
		Peat	NA	–	–	NA	–	–	
	Secondary Fuels	Coke	28.83	TJ/kt	4	30.02	2	1.0	Previously reported as Coking Coal.
		BKB & Patent Fuel	NA	–	–	NA	–	–	
		Coke Oven Gas	19.14	TJ/GL	4	12.52	2	–	
	Other Solid Fuels	Foreign Bituminous Coal	29.82	TJ/kt	4	23.54	5, 6	0.989	
Gaseous	Primary Fuels	Natural Gas	39.86	TJ/GL	4	13.45	2	1.0	Country-specific weighted emission factor based on proportion of marketable and non-marketable natural gas.
Biomass		Municipal Solid Waste	–	–	1	23.94	1	1.0	1) Consists of biomass combustion, for energy purposes, at landfills.
		Solid Biomass	17.87	TJ/kt	4	24.81	7	1.0	1) Consists of industrial and residential biomass consumption.
		Liquid Biomass	16.34	TJ/kt	4	18.82	3, 8	1.0	1) Consists of spent pulping liquor, ethanol and biodiesel.
		Gas Biomass	36.35	TJ/Gl	1	13.54	1	1.0	1) Consists of methane from landfill gas.

Notes:

References – (1) IPCC (2006); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada, #57-003 (2015 data); (5) ECCC (2016); (6) ECCC (2019); (7) US EPA (2003); (8) ICFPA/NCASI (2019).

NA = Not applicable; BKB = Charcoal briquettes; NGL = natural gas liquids; LPG = liquified petroleum gas.

The following quality criteria are essential to the development of the RESD as set out by Statistics Canada: relevance, accuracy and reliability, timeliness and punctuality, accessibility and clarity, coherence and comparability, and interpretability and metadata.

There are also other internal data quality checks of the information collected through provincial energy departments and various supply, disposition and consumption surveys. For example, the quantities of crude oil reported by the producer are compared to reported receipts from pipeline companies, and the volume data reported by pipelines is verified against refinery receipts. EESD also applies both a top-down approach through the supply and disposition surveys and a bottom-up approach through the Industrial Consumption of Energy (ICE) survey to verify the quality of the data for manufacturing industries. The ICE survey collects fuel consumption data directly from manufacturing industries following the North American Industry Classification System. In addition, an annual Survey of Secondary Distributors of Refined Petroleum Products (SSDRPP) collects data on sale volumes for use in reallocating volumes of heavy fuel oil, light fuel oil, diesel, biodiesel blended diesel fuel, and ethanol blended gasoline to the appropriate consuming sectors. The SSDRPP survey was necessary due to the deregulation of allowable sales of these products from only primary producers (refineries) to include secondary resellers/distributers. Prior to this improvement, fuel volumes reported in the commercial sector incorrectly included all sales by refineries to secondary distributors. The deregulation of the sale of these four fuels started around the year 2000. A consistent approach was applied to the historical dataset to address the misallocated fuel volumes between 2000 and 2008 since the SSD only started collecting sale volumes from 2009 onward.

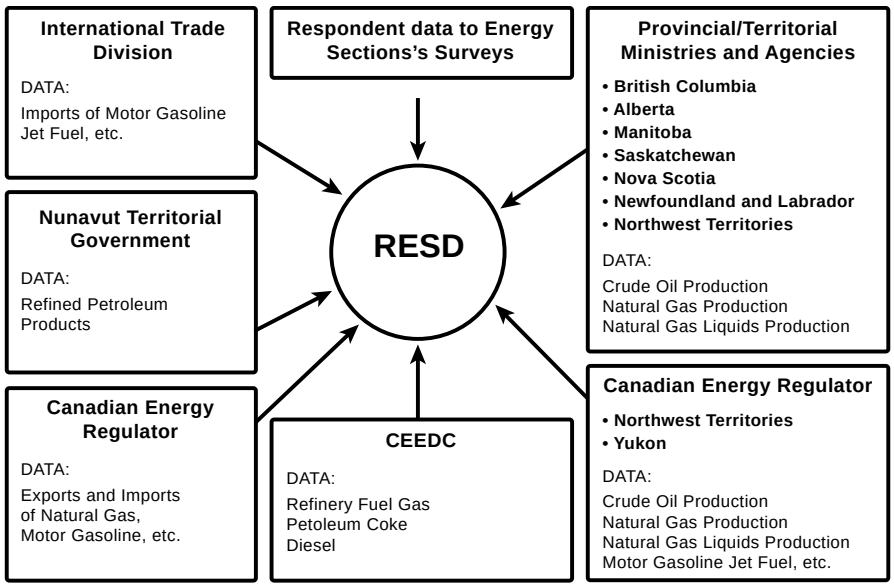
Also, as part of EESD's quality framework, an annual "work-in-progress" review has been established with Environment and Climate Change Canada and Natural Resources Canada to review the ICE estimates and the RESD prior to their official release. Industrial stakeholders also participate in the review of ICE data through the Canadian Industry Program for Energy Conservation group. CEEDC also participates in the review of refinery data and the industrial energy statistics.

A4.4. CRF Implied Emission Factors

The CRF reporting software generates implied emission factors (IEFs) which are used by UNFCCC expert reviewers as an initial check for possible outliers. There is merit in the use of IEF checks, especially for a direct comparison of the same commercial fuel between countries, since each of these fuels meets standardized specifications for quality and composition, with an accepted range of carbon content and heating value. Commercial fuels like motor gasoline, diesel and light fuel oil have similar specifications globally, resulting in IEFs that differ by only a few percentage points. However, the percentage difference for fuels like non-marketable (raw) natural gas, crude oil or coal (i.e. bituminous, sub-bituminous, etc.) can vary greatly due to differences in local geology, deposits or fuel categorizations (the latter being especially true in the case of coal).

These checks for IEF outliers are less reliable when fuels are grouped as solid, liquid, gaseous and biomass in CRF Tables 1A1 to Table 1A4. For countries consuming both

Figure A4–2 **Fossil Fuel and Energy Data Input into the RESD**



commercial and non-commercial fuels, and particularly for energy producing nations where non-commercial/ non-marketable fuels are readily available and consumed in significant quantities, IEF checks can result in more outliers for certain sectors and fuel groupings (i.e. gaseous and liquid fuels). Generally, countries with large primary energy production (crude oil, synthetic oil, natural gas, etc.) will consume a greater proportion of non-commercial fuels compared to countries with little or no primary energy production and who mostly consume commercial fuels. For these situations, recognizing the impact on IEFs of national circumstances by either increasing its range or conducting IEF checks on a fuel by fuel basis would provide more relevant quality checks.

In Canada's case, shifting the focus of IEF checks from groups of fuels to individual fuels allows a better understanding of their influence on the generation of outliers.

- It allows for an appreciation of the relative proportion of commercial and non-commercial fuel consumed within each fuel grouping.
- It demonstrates how the mix of commercial and non-commercial fuels with wide ranging carbon and energy densities affects the IEF for each fuel.

For example, Canada's implied emission factors can be relatively high for liquid fuels due to the combustion of significant quantities of crude oil, petroleum coke and still gas. In the case of gaseous fuels IEFs can also be high, a result of certain energy producers consuming large quantities of non-marketable natural gas.

Information presented in Table A4–2, illustrates the range of carbon content between each group of fuels, and where even within the group of commercial secondary liquid fuels, the carbon content ranges from 14.74 to 22.62 t C/TJ. For CRF categories consuming a greater portion of still gas or petroleum coke (refinery and upgrader fuels) relative to commercial grade refined petroleum products, the overall IEF for liquid fuels will appear to be an outlier since it will be higher than international averages.

As Canada is a country producing large quantities of fossil fuels, the following categories will most likely generate IEF outliers; 1A1b Petroleum Refining, 1A1ci Manufacture of Solid Fuels, and 1A1cii Oil and Gas Extraction. As mentioned, IEF category checks should be on a fuel by fuel basis or by assessing Parties that have a similar industry makeup; this would generate more comparable results and analysis.

ASSESSMENT OF COMPLETENESS

Overall, this inventory report serves as a comprehensive assessment of anthropogenic greenhouse gas (GHG) emissions and removals in Canada. However, emissions for some categories are not estimated (NE) or have been included elsewhere (IE) with other categories for reasons explained in Table A5–1 and Table A5–2. These tables are consistent with Table 9 (Completeness – Information on Notation Keys), for the latest year of the Common Reporting Format (CRF) tables available online here:

https://unfccc.int/ghg-inventories-annex-i-parties/2021

Table A5–1 **Summary of GHG Sources and Sinks Not Estimated**

GHG	Sector	Source/Sink Category	Explanation
$C_{10}F_{18}$	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
C_2F_6	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
C_3F_8	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
C_4F_{10}	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
C_5F_{12}	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
C_6F_{14}	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
CF_4	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
CH_4	Agriculture	3.1 Livestock / 3.A Enteric Fermentation / 3.A.4 Other livestock / Other (please specify) / Fur-bearing Animals	No default emission factors available for Fox and Mink.
CH_4	Agriculture	3.1 Livestock / 3.A Enteric Fermentation / 3.A.4 Other livestock / Other (please specify) / Rabbit	No default emission factors available for Rabbit.
CH_4	Agriculture	3.1 Livestock / 3.A Enteric Fermentation / 3.A.4 Other livestock/Poultry	No default emission factor available for Poultry.
CH_4	Agriculture	3.D Agricultural Soils	Methane emissions from agricultural soils are not estimated because no methodology is available in the 2006 IPCC Guidelines.
CH_4	Energy	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.b Solid Fuel Transformation	The emissions from briquette manufacturing, as a source, has less than 0.05% of total emissions and does not exceed 500 kt CO_2 eq.

Table A5–1 **Summary of GHG Sources and Sinks Not Estimated** (cont'd)

GHG	Sector	Source/Sink Category	Explanation
CH_4	Industrial Processes and Product Use	2.B Chemical Industry / 2.B.1 Ammonia Production	CH_4 emissions assumed negligible.
CH_4	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Asphalt roofing	Country-specific information currently unavailable.
CH_4	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Asphalt roofing	Country-specific information currently unavailable; CH_4 emissions are assumed to be negligible based on 2006 IPCC GL Volume 3, Chapter 14.
CH_4	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Road paving with asphalt	CH_4 Emissions from road paving with asphalt are not estimated. Currently, there are no country-specific information on this. Based on the 2006 IPCC Guidelines (Volume 3, Chapter 4), CH_4 emissions from this category are assumed to be negligible.
CH_4	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Road paving with asphalt	Country-specific information currently unavailable.
CH_4	LULUCF	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Mineral Soils / Rewetted Mineral Soils	Country-specific activity data is currently unavailable to estimate this source category. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CH_4	LULUCF	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Organic Soils / Drained Organic Soils	There is no guidance in 2006 IPCC guidelines to report CH_4 emissions from drained organic soils in Cropland.
CH_4	LULUCF	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Organic Soils / Rewetted Organic Soils	Country-specific activity data is currently unavailable to estimate this source category. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CH_4	LULUCF	4.D Wetlands / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Other Wetlands (please specify)	Currently there are no estimates reported under Other wetlands.
CH_4	LULUCF	4.E Settlements / 4.E.1 Settlements Remaining Settlements	Currently neither country-specific activity data is available nor methodology exists to estimate this source category.
CH_4	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.1 Biogenic / 5.C.2.1.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories. There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
CH_4	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.2 Non-biogenic / 5.C.2.2.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories. There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
CH_4	Waste	5.D Wastewater Treatment and Discharge / 5.D.1 Domestic Wastewater	Not available at this time.
CO_2	Agriculture		CO_2 emissions from indirect sources of non-agricultural origin are not estimated.
CO_2	Energy	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.b Solid Fuel Transformation	The emissions from briquette manufacturing, as a source, has less than 0.05% of total emissions and does not exceed 500 kt CO_2 eq.
CO_2	Industrial Processes and Product Use	2.A Mineral Industry / 2.A.4 Other Process Uses of Carbonates / 2.A.4.a Ceramics	Emission considered insignificant as defined in paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.
CO_2	Industrial Processes and Product Use	2.B Chemical Industry / 2.B.6 Titanium Dioxide Production	Based on a study conducted in 2010, CO_2 emissions from this facility's chloride process is very small, less than 0.01% of the national level, and is therefore considered insignificant (level for insignificance is below 0.05% of national total and below 50.
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Asphalt roofing	Country-specific information currently unavailable.
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Asphalt roofing	Country-specific information currently unavailable; CO_2 emissions are assumed to be negligible based on 2006 IPCC GL Volume 3, Chapter 29.

Table A5–1 **Summary of GHG Sources and Sinks Not Estimated** (cont'd)

GHG	Sector	Source/Sink Category	Explanation
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Other (please specify) / Other and Undifferentiated	Only aggregated CO_2 emissions are included under 2.D.3.
CO_2	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Road paving with asphalt	CO_2 Emissions from road paving with asphalt are not estimated. Currently, there are no country-specific information on this. Based on the 2006 IPCC Guidelines (Volume 3, Chapter 4), CO_2 emissions from this category are assumed to be negligible.
CO_2	LULUCF	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Mineral Soils / Rewetted Mineral Soils	Country-specific activity data is currently unavailable to estimate this source category. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CO_2	LULUCF	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Organic Soils / Rewetted Organic Soils	Country-specific activity data is currently unavailable to estimate this source category. Efforts are underway to develop improved LULUCF AD, which could potentially aid in these estimates.
CO_2	LULUCF	4.D Wetlands / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Other Wetlands (please specify)	Currently there are no estimates reported under Other wetlands.
CO_2	LULUCF	4.G Harvested Wood Products / Approach B / Information Item / HWP in SWDS	Country-specific information on wood and paper waste in solid waste disposal sites is currently unavailable.
CO_2	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.1 Biogenic / 5.C.2.1.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories. There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
CO_2	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.2 Non-biogenic / 5.C.2.2.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories.There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
CO_2	Waste	5.F Memo Items / 5.F.1 Long-term Storage of C in Waste Disposal Sites	Work is ongoing to incorporate long term storage of C in waste disposal sites.
CO_2	Waste	5.F Memo Items / 5.F.2 Annual Change in Total Long-term C Storage	Work is ongoing to incorporate long term storage of C in waste disposal sites.
CO_2	Waste	5.F Memo Items / 5.F.3 Annual Change in Total Long-term C Storage in HWP Waste	Work is ongoing to incorporate long term storage of C in waste disposal sites.
N_2O	Agriculture		N_2O emissions from indirect sources of non-agricultural origin are not estimated.
N_2O	Agriculture	3.D Agricultural Soils / 3.D.1 Direct N_2O Emissions From Managed Soils / 3.D.1.2 Organic N Fertilizers / 3.D.1.2.c Other Organic Fertilizers Applied to Soils	The amount of N in Other Organic Fertilizers Applied to Soils is not available.
N_2O	Energy	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.b Solid Fuel Transformation	The emissions from briquette manufacturing, as a source, has less than 0.05% of total emissions and does not exceed 500 kt CO_2 eq.
N_2O	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Asphalt roofing	Country-specific information currently unavailable.
N_2O	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Road paving with asphalt	Country-specific information currently unavailable.
N_2O	Industrial Processes and Product Use	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Road paving with asphalt	Country-specific information currently unavailable.
N_2O	LULUCF		N_2O emissions from indirect sources of non-agricultural and non-LULUCF origin are not estimated as country-specific information is currently not available.
N_2O	LULUCF	4.A Forest Land 4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization	Direct N_2O emissions associated with loss of soil organic matter in FLFL are not considered to be significant.
N_2O	LULUCF	4.A Forest Land / 4.A.2 Land Converted to Forest Land / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization / 4.A.2.1 Cropland converted to forest land	Management-induced changes in soil organic carbon are not available because country-specific activity data is currently unavailable for the time series.

Table A5–1 **Summary of GHG Sources and Sinks Not Estimated** (cont'd)

GHG	Sector	Source/Sink Category	Explanation
N_2O	LULUCF	4.C Grassland 4.C Grassland / 4.C.1 Grassland Remaining Grassland / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization	Management-induced changes in soil organic carbon from GLGL are not available because country-specific activity data is currently unavailable for the time series.
N_2O	LULUCF	4.D Wetlands / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Other Wetlands (please specify)	Currently there are no estimates reported under Other wetlands.
N_2O	LULUCF	4.E Settlements 4.E Settlements / 4.E.1 Settlements Remaining Settlements / 4(III) Direct N_2O Emissions from N Mineralization/ Immobilization	Emissions of N_2O from urban trees are not reported as country-specific information on net carbon stock change in soils is not currently available.
N_2O	LULUCF	4.E Settlements / 4.E.2 Land Converted to Settlements / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization / 4.E.2.1 Forest land converted to settlements	Management-induced changes in soil organic carbon are not available because country-specific activity data is currently unavailable for the time series.
N_2O	LULUCF	4.E Settlements / 4.E.2 Land Converted to Settlements / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization / 4.E.2.3 Grassland converted to settlements	Management-induced changes in soil organic carbon are not available because country-specific activity data is currently unavailable for the time series.
N_2O	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.1 Biogenic / 5.C.2.1.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories. There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
N_2O	Waste	5.C Incineration and Open Burning of Waste / 5.C.2 Open Burning of Waste / 5.C.2.2 Non-biogenic / 5.C.2.2.a Municipal Solid Waste	Open burning at landfills is banned by regulation in provinces and territories. There is anecdotal evidence that open burning does occur in residential settings amounts in mostly rural areas of the country. However, there is currently no up-to-date methodology to estimate these emissions. It is expected that this is not a large source of emissions relative to other activities in Canada.
N_2O	Waste	5.D Wastewater Treatment and Discharge / 5.D.2 Industrial Wastewater	There is no methodology provided in the 2006 GL for N_2O emissions from industrial wastewater where there is primary discharge.
SF_6	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
Unspecified mix of PFCs	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
c-C_3F_6	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).
c-C_4F_8	Industrial Processes and Product Use	2.G Other Product Manufacture and Use / 2.G.2 SF_6 and PFCs from Other Product Use	Recently collected 2014–2019 sales data from gas distributors indicate some other product use of SF_6. Assessment of significance level underway (previously, internet searches found that CRF category 2.G.2 applications did not exist at a detectable level).

Note:
"Not Estimated" includes sources and sinks which are considered in the 2006 IPCC Guidelines (IPCC, 2006) but are not considered in this inventory.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere**

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Gaseous Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Liquid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Solid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Biomass 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Gaseous Fuels	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Liquefied Petroleum Gases (LPG)	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Gaseous Fuels	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Gaseous Fuels	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Liquefied Petroleum Gases (LPG)	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Gaseous Fuels 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CH_4	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CH_4	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.a Coal Mining and Handling / 1.B.1.a.1 Underground Mines / 1.B.1.a.1.ii Post-Mining Activities	1.B.1.a.1.ii Underground Mines – Mining Activities	1.B.1.a.1.i Underground Mines – Mining Activities	Only aggregated emission factors were available.
CH_4	1.B Fugitive Emissions from Fuels / 1.B.1 Solid Fuels / 1.B.1.a Coal Mining and Handling / 1.B.1.a.2 Surface Mines / 1.B.1.a.2.ii Post-Mining Activities	1.B.1.a.2.ii Surface Mines – Post-Mining Activities	1.B.1.a.2.i Surface Mines – Mining Activities	Only aggregated emission factors were available.
CH_4	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.a Oil / 1.B.2.a.1 Exploration	1.B.2.a.1 Oil – Exploration	1.B.2.a.2 Oil – Production	Only aggregated data were available.
CH_4	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.a Oil / 1.B.2.a.5 Distribution of Oil Products	1.B.2.a.5 Oil – Distribution of Oil Products	1.B.2.a.3 Oil – Transport	Only aggregated data were available.
CH_4	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.b Natural Gas / 1.B.2.b.1 Exploration	1.B.2.b.1 Natural Gas – Exploration	1.B.2.b.2 Natural Gas – Production	Only aggregated data were available.
CH_4	1.D Memo Items / 1.D.2 Multilateral Operations	1.D.2 Multilateral Operations	1.A.3.a Domestic Aviation and 1.A.3.d Domestic Navigation	Multilateral Operations emissions, if occuring, will be reported in either 1.A.3.a Domestic Aviation or 1.A.3.d Domestic Navigation.
CH_4	2.B Chemical Industry / 2.B.10 Other (please specify) / Carbon Black Production – N_2O Emissions	2.B.8.f Carbon Black	2.B.8.f Carbon Black	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.B Chemical Industry / 2.B.10 Other (please specify) / Carbon Black Production – N_2O Emissions	2.B.8.f	2.B.8.f	Refer to 2.B.8.f. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.B Chemical Industry / 2.B.10 Other (please specify) / Ethylene Production – N_2O Emissions	2.B.8.b Ethylene	2.B.8.b Ethylene	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.B Chemical Industry / 2.B.10 Other (please specify) / Ethylene Production – N_2O Emissions	2.B.8.b Ethylene	2.B.8.b. Ethylene	Refer to 2.B.8.b. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.B Chemical Industry / 2.B.10 Other (please specify) / Methanol Production – N_2O Emissions	2.B.8.a Methanol	2.B.8.a Methanol	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CH_4	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.a Steel	2.C.1.a	2.C.1.b Pig Iron	Disaggregated data currently not available.
CH_4	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.c Direct Reduced Iron	2.C.1.c	1.A.2.a	Disaggregated data currently not available.
CH_4	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.d Sinter	2.C.1.d	1.A.2.a	Disaggregated data currently not available.
CH_4	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.e Pellet	2.C.1.e	1.A.2.a	Disaggregated data currently not available.
CH_4	2.C Metal Industry / 2.C.2 Ferroalloys Production	2.C.2	2.C.1.b	Disaggregated data currently not available.
CH_4	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Other (please specify) / Other and Undifferentiated	2.B.8	2.B.8	Only aggregated CO_2 emissions are included under 2.D.3.
CH_4	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2D3 Other and Undifferentiated	2D3 Other and Undifferentiated	Disaggregate data are unavailable.
CH_4	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2D3 Other and Undifferentiated	2D3 Other and Undifferentiated	Disaggregated data are unavailable.
CH_4	4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CH_4	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Mineral Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CH_4	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.
CH_4	4.B Cropland / 4.B.2 Land Converted to Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CH_4	4.C Grassland / 4.C.1 Grassland Remaining Grassland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	AD do not allow the disaggregation of activity into organic and mineral soils.
CH_4	4.C Grassland / 4.C.1 Grassland Remaining Grassland / 4(V) Biomass Burning / Wildfires / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CH_4	4.E Settlements / 4(V) Biomass Burning / Organic Soils	4(V) Biomass Burning – Organic soils	4(V) Biomass Burning – Mineral soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CH_4	4.E Settlements / 4.E.2 Land Converted to Settlements	Table 4, if possible to differentiate	Table 4(V)	Emissions of CH_4 are reported in Table 4(V) Biomass Burning.
CH_4	5.B Biological Treatment of Solid Waste / 5.B.1 Composting / 5.B.1.b Other (please specify)	Included under 5.b.1.a as a single value.	Included under 5.b.1.a as a single value.	Included under 5.b.1.a as a single value.
CH_4	5.B Biological Treatment of Solid Waste / 5.B.2 Anaerobic Digestion at Biogas Facilities / 5.B.2.a Municipal Solid Waste		Included under 5.b.1.a as a single value.	
CH_4	5.B Biological Treatment of Solid Waste / 5.B.2 Anaerobic Digestion at Biogas Facilities / 5.B.2.b Other (please specify)	Included under 5.b.1.a with composting as total emissions for Biological Treatment of Waste.	Included under 5.b.1.a with composting as total emissions for Biological Treatment of Waste.	Included under 5.b.1.a with composting as total emissions for Biological Treatment of Waste.
CO_2	3.G Liming / 3.G.2 Dolomite $CaMg(CO_3)2$	3.G.1 Limestone $CaCO_3$	3.G.1 Limestone $CaCO_3$	Dolomite is included in Limestone.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Gaseous Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Liquid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Solid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Biomass 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Gaseous Fuels	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Liquefied Petroleum Gases (LPG)	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Gaseous Fuels	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Liquefied Petroleum Gases (LPG)	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Gaseous Fuels	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Gaseous Fuels 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
CO_2	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.a Oil / 1.B.2.a.1 Exploration	1.B.2.a.1 Oil – Exploration	1.B.2.a.2 Oil – Production	Only aggregated data were available.
CO_2	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.a Oil / 1.B.2.a.5 Distribution of Oil Products	1.B.2.a.5 Oil – Distribution of Oil Products	1.B.2.a.3 Oil – Transport	Only aggregated data were available.
CO_2	1.B Fugitive Emissions from Fuels / 1.B.2 Oil and Natural Gas and Other Emissions from Energy Production / 1.B.2.b Natural Gas / 1.B.2.b.1 Exploration	1.B.2.b.1 Natural Gas – Exploration	1.B.2.b.2 Natural Gas – Production	Only aggregated data were available.
CO_2	1.D Memo Items / 1.D.2 Multilateral Operations	1.D.2 Multilateral Operations	1.A.3.a Domestic Aviation and 1.A.3.d Domestic Navigation	Multilateral Operations emissions, if occuring, will be reported in either 1.A.3.a Domestic Aviation or 1.A.3.d Domestic Navigation.
CO_2	2.B Chemical Industry / 2.B.10 Other (please specify) / Carbon Black Production – N_2O Emissions	2.B.8.f Carbon Black	2.B.8.f Carbon Black	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry / 2.B.10 Other (please specify) / Carbon Black Production – N_2O Emissions	2.B.8.f	2.B.8.f	Refer to 2.B.8.f. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry / 2.B.10 Other (please specify) / Ethylene Production – N_2O Emissions	2.B.8.b Ethylene	2.B.8.b Ethylene	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry / 2.B.10 Other (please specify) / Ethylene Production – N_2O Emissions	2.B.8.b Ethylene	2.B.8.b. Ethylene	Refer to 2.B.8.b. CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry / 2.B.10 Other (please specify) / Methanol Production – N_2O Emissions	2.B.8.a Methanol	2.B.8.a Methanol	CRF does not allow N_2O emissions to be entered in 2.B.8, therefore this node was added.
CO_2	2.B Chemical Industry / 2.B.8 Petrochemical and Carbon Black Production / 2.B.8.f Carbon Black	2.B.8 Petrochemical and Carbon Black Production / 2.B.8.f Carbon Black2.B.8.f	2.D.3 Other – Other and Undifferentiated	CO_2 emission from category 2.D are estimated based on non-energy fuel use by fuel / feedstock type and not by industrial activity (refer to Annex 3, Section A.3.3.3 for further detail).

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
CO_2	2.B Chemical Industry / 2.B.8 Petrochemical and Carbon Black Production / 2.B.8.f Carbon Black	2.B.8 Petrochemical and Carbon Black Production / 2.B.8.f Carbon Black	2.D.3 Other and Undifferentiated	Refer to 2.D.3 Other and Undifferentiated. Disaggregated data currently not available.
CO_2	2.B Chemical Industry / 2.B.8 Petrochemical and Carbon Black Production / 2.B.8.g Other / Other (please specify) / Styrene	2.B.8.g Other	2.D.3 Other – Other and Undifferentiated	Disaggregated data currently not available
CO_2	2.B Chemical Industry / 2.B.8 Petrochemical and Carbon Black Production / 2.B.8.g Other / Other (please specify) / Styrene	Other (please specify) / Styrene	2.D.3 Other – Other and Undifferentiated.	Other (please specify) / Styrene.
CO_2	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.c Direct Reduced Iron	2.C.1.c	1.A.2.a	Disaggregated data currently not available.
CO_2	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.d Sinter	2.C.1.d	1.A.2.a, 2.D.28	Disaggregated data currently not available.
CO_2	2.C Metal Industry / 2.C.1 Iron and Steel Production / 2.C.1.e Pellet	2.C.1.e	1.A.2.a, 2.D.23	Disaggregated data currently not available.
CO_2	2.C Metal Industry / 2.C.2 Ferroalloys Production	2.C.2	2.C.1.a and 2.C.1.b	Emissions from Ferroalloy Production are included in Steel Production (2C1a) since it is a direct production of specialty steels from iron ore via EAF process using reductants. However, the reductant portion is not disaggregated in Statistics Canada's Rep.
CO_2	2.C Metal Industry / 2.C.5 Lead Production	2.C.5	2.D.3	Disaggregated data currently not available.
CO_2	2.C Metal Industry / 2.C.6 Zinc Production	2.C.6	2.D.3	Disaggregated data currently not available.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.1 Lubricant Use	2.D.3	2.D.3	2D3 disaggregated data unavailable.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.1 Lubricant Use	2.D.1	2.D.3	Disaggregated data currently not available.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.2 Paraffin Wax Use	2.D.1	2.D.3	Disaggregated data currently not available.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2D3 Other and Undifferentiated	2D3 Other and Undifferentiated	Disaggregated data are currently unavailable.
CO_2	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2D3 Other and Undifferentiated	2D3 Other and Undifferentiated	Disaggregated data are unavailable.
CO_2	4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CO_2	4.B Cropland / 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils / Total Organic Soils / Drained Organic Soils	If data are available, under the specific LULUC category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into the specific LULUC category.
CO_2	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Mineral Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.
CO_2	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.
CO_2	4.B Cropland / 4.B.2 Land Converted to Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
CO_2	4.E Settlements / 4(V) Biomass Burning / Organic Soils	4(V) Biomass Burning – Organic soils	4(V) Biomass Burning – Mineral soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
N_2O	3.D Agricultural Soils / 3.D.1 Direct N_2O Emissions From Managed Soils / 3.D.1.7 Other	Not present in the IPCC 2006 Guidelines	3.D.1.1 Inorganic N Fertilizers / 3.D.1.2.a Animal Manure Applied to Soils / 3.D.1.4 Crop Residues	Three country-specific sources / removals of N_2O (conservation tillage, summerfallow and irrigation) are reported with emissions from agricultural soils under 3.D.1.1, 3.D.1.2.a, 3.D.1.2.b and 3.D.1.4. As a result of limitations with the current CRF Reporter Software, it is not currently possible to report these country-specific source / sink categories individually.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Gaseous Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Liquid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Solid Fuels	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco / Biomass 1.AA Fuel Combustion – Sectoral approach / 1.A.2 Manufacturing Industries and Construction / 1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.e Food Processing, Beverages and Tobacco	1.A.2.g.viii Other	Only aggregated data were available.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Gaseous Fuels	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.i Cars / Liquefied Petroleum Gases (LPG)	1.A.3.b.i Cars	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Gaseous Fuels	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.ii Light duty trucks / Liquefied Petroleum Gases (LPG)	1.A.3.b.ii Light duty trucks	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Gaseous Fuels	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.iii Heavy duty trucks and buses	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Gaseous Fuels 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Gaseous Fuel (Natural Gas) emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
N_2O	1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles / Liquefied Petroleum Gases (LPG) 1.AA Fuel Combustion – Sectoral approach / 1.A.3 Transport / 1.A.3.b Road Transportation / 1.A.3.b.iv Motorcycles	1.A.3.b.iv Motorcycles	1.A.3.b.v Other / Propane and Natural Gas Vehicles / Other Liquid Fuels / Propane	Propane emissions for Road Transportation are reported under 1.A.3.b.v Propane and Natural Gas Vehicles.
N_2O	1.D Memo Items / 1.D.2 Multilateral Operations	1.D.2 Multilateral Operations	1.A.3.a Domestic Aviation and 1.A.3.d Domestic Navigation	Multilateral Operations emissions, if occuring, will be reported in either 1.A.3.a Domestic Aviation or 1.A.3.d Domestic Navigation.
N_2O	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Other (please specify) / Other and Undifferentiated	2.B.8	2.B.10	Only aggregated CO_2 emissions are included under 2.D.3.
N_2O	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Other (please specify) / Other and Undifferentiated	2.B.8	2.B.8	Only aggregated CO_2 emissions are included under 2.D.3.
N_2O	2.D Non-energy Products from Fuels and Solvent Use / 2.D.3 Other (please specify) / Solvent use	2D3 Other and Undifferentiated	2D3 Other and Undifferentiated	Disaggregate data are unavailable.
N_2O	4(IV) Indirect N_2O Emissions from Managed Soils / Atmospheric Deposition	Agriculture for agricultural soils, under LULUCF for non-agricultural soils	Agriculture for agricultural soils, NE for non-agricultural soils	N_2O emissions from volatized N of Managed Soils are reported in the Agriculture sector. Indirect N_2O emissions from Leaching and Runoff of N from fertilizers and other N sources are reported in the Agriculture sector. N_2O emissions associated with nitrogen leaching ad runoff of N mineralised in mineral soils as a result of loss of soil organic carbon in FLFL are considered to be insignificant.
N_2O	4(IV) Indirect N_2O Emissions from Managed Soils / Nitrogen Leaching and Run-off	Agriculture for agricultural soils, under LULUCF for non-agricultural soils	Agriculture for agricultural soils, NE for non-agricultural soils	N_2O emissions from volatized N of Managed Soils are reported in the Agriculture sector. Indirect N_2O emissions from Leaching and Runoff of N from fertilizers and other N sources are reported in the Agriculture sector. N_2O emissions associated with nitrogen leaching ad runoff of N mineralised in mineral soils as a result of loss of soil organic carbon in FLFL are considered to be insignificant.
N_2O	4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Inorganic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into this category.
N_2O	4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into this category.
N_2O	4.A Forest Land / 4.A.1 Forest Land Remaining Forest Land / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
N_2O	4.A Forest Land / 4.A.2 Land Converted to Forest Land / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Inorganic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in Agriculture sector	AD available do not allow the disaggregation of activity into this category.
N_2O	4.A Forest Land / 4.A.2 Land Converted to Forest Land / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available does do not allow the disaggregation of activity into the specific LULUCF category.
N_2O	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Mineral Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.

Table A5–2 **Summary of GHG Sources and Sinks Included Elsewhere** (cont'd)

GHG	Source/Sink Category	Allocation as per IPCC Guidelines	Allocation used by the Party	Explanation
N_2O	4.B Cropland / 4.B.1 Cropland Remaining Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Burning of woody biomass in LULUCF, agricultural residue burning in the Agriculture sector.	Agriculture sector	Field burning of agricultural crop residues is reported in the Agriculture sector.
N_2O	4.B Cropland / 4.B.2 Land Converted to Cropland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
N_2O	4.C Grassland / 4.C.1 Grassland Remaining Grassland / 4(V) Biomass Burning / Controlled Burning / Organic Soils	Organic Soils	Mineral Soils	AD do not allow the disaggregation of activity into organic and mineral soils.
N_2O	4.C Grassland / 4.C.1 Grassland Remaining Grassland / 4(V) Biomass Burning / Wildfires / Organic Soils	Organic Soils	Mineral Soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
N_2O	4.D Wetlands / 4.D.1 Wetlands Remaining Wetlands / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization 4.D Wetlands	Table 4(III)	Table 4(II)	Emissions of N_2O from land converted to peat extraction are reported in Table 4(II). Emissions and removals from drainage and rewetting and other management of organic and mineral soils.
N_2O	4.D Wetlands / 4.D.2 Land Converted to Wetlands / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization / 4.D.2.1 Forest land converted to wetlands	Table 4(III)	Table 4(II)	Emissions of N_2O from land converted to peat extraction are reported in Table 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils.
N_2O	4.D Wetlands / 4.D.2 Land Converted to Wetlands / 4(III) Direct N_2O Emissions from N Mineralization / Immobilization / 4.D.2.5 Other land converted to wetlands	Table 4(III)	Table 4(II)	Emissions of N_2O from land converted to peat extraction are reported in Table 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils.
N_2O	4.E Settlements / 4(V) Biomass Burning / Organic Soils	4(V) Biomass Burning – Organic soils	4(V) Biomass Burning – Mineral soils	Only aggregated AD are available and do not differentiate organic and mineral soils.
N_2O	4.E Settlements / 4.E.1 Settlements Remaining Settlements / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Inorganic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into this category.
N_2O	4.E Settlements / 4.E.1 Settlements Remaining Settlements / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into this category.
N_2O	4.E Settlements / 4.E.2 Land Converted to Settlements / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Inorganic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into the specific LULUCF category.
N_2O	4.E Settlements / 4.E.2 Land Converted to Settlements / 4(I) Direct N_2O Emissions from N Inputs to Managed Soils / Organic N Fertilizers	If data are available, under the specific LULUCF category, where emissions actually occur.	Reported in the Agriculture sector	AD available do not allow the disaggregation of activity into the specific LULUCF category.
SF_6	2.C Metal Industry / 2.C.7 Other (please specify)	2.C.7	2.C.4	SF_6 emissions for Mg Casting were included in 2.C.4 as per IPCC guidelines and ERT recommendations.
SF_6	2.G Other Product Manufacture and Use / 2.G.1 Electrical Equipment / SF_6	2.G.1 disaggregated from stocks and from disposal	2.G.1 Electrical Equipment / SF_6 (from stocks)	disaggregation from stocks and from disposal data is not available and the total is reported as "from stocks."

Note:
"Included Elsewhere" includes sources and sinks in this inventory that are allocated to a sector other than that indicated by the 2006 IPCC Guidelines (IPCC, 2006).

ANNEX 6

EMISSION FACTORS

This annex summarizes the development and selection of emission factors used to estimate Canada's annual greenhouse gas (GHG) inventory. Details[1] on sector-specific methodological use of these factors are presented in Annex 3.

A6.1. Fuel Combustion

A6.1.1. Natural Gas and Natural Gas Liquids

A6.1.1.1. Carbon Dioxide (CO_2)

CO_2 emission factors for fossil fuel combustion depend 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 principal fuel types combusted in Canada: marketable fuel (processed for commercial sale) and non-marketable fuel (unprocessed, for internal use). There are regional variations in marketable and non-marketable natural gas use, with nine regions consuming marketable fuel and seven regions consuming non-marketable fuel. Provincial and territorial emission factors (Table A6.1–1) have been developed based on data from chemical analysis of representative natural gas samples (McCann, 2000). Both imported and domestic natural gas were included, where applicable, in the mix of gas samples used for chemical analysis. Generally, non-marketable natural gas emission factors are higher than those of marketable fuels as a result of their raw/unprocess nature; in addition to methane, non-marketable natural gas may include ethane, propane and butane in the fuel mix.

Non-marketable natural gas emission factors for Alberta (Table A6.1–2) were updated using over 400 000 raw gas samples, ranging in date from 1913 to 2016, obtained from the Alberta Energy Regulator (AER) by the Energy and Emissions Research Laboratory (EERL) of Carleton University (EERL, 2020). EERL compiled and analysed the data to provide average gas compositions by township. Gas composition data by township were weighted by township-level fuel gas consumption volumes obtained from Petrinex in 2020, to produce annual average CO_2 emission factors for the province.

CO_2 emission factors (Table A6.1–4) for natural gas liquids (NGL), such as ethane, propane and butane, were developed based on chemical analysis data for marketable fuels (McCann, 2000).

A6.1.1.2. Methane (CH_4)

Emissions of CH_4 from fuel combustion are technology-dependent. Sectoral emission factors (Table A6.1–3 and Table A6.1–4) 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 (U.S. EPA, 1996).

Table A6.1–1 **CO_2 Emission Factors for Natural Gas**

Province	Emission Factor[a] (g/m^3)	
	Marketable[b]	Non-Marketable[c]
NL	1 901	2 494
NS	1 901	2 494
NB	1 901	NO
QC	1 887	NO
ON	1 888	NO
MB	1 886	NO
SK	1 829	2 441
AB	1 928	See NIR Table A6.1–2
BC	1 926	2 162
YK	1 901	2 401
NT (prior to 2012)[d]	2 466	2 466
NT (since 2012)[d]	1 901	2 466

Notes:

NO = Not occurring

a. McCann (2000)
b. The term "marketable" applies to fuel consumed by the Electric Utilities, Manufacturing Industries, Residential/Commercial and Transport subsectors.
c. The term "non-marketable" applies to raw/unprocessed gas consumption, mainly by natural gas producers.
d. Prior to 2012, natural gas consumption was locally-produced non-marketable natural gas. Since 2012, marketable natural gas has been imported from outside the territory.

1 For details, see the *National Inventory Report: Greenhouse Gas Sources and Sinks in Canada* online: http://www.publications.gc.ca/pub?id=9.506002&sl=0.

Table A6.1–2 **Alberta CO_2 Emission Factors for Non-Marketable Natural Gas**

Year(s)	Emission Factor (g/m^3)
1990 to 2009	2 080
2010	2 054
2011	2 062
2012	2 068
2013	2 071
2014	2 075
2015	2 081
2016	2 089
2017	2 093
2018	2 102
2019	2 107

Note: Adapted from EERL (2020) using Petrinex (2020) volumetric data

Table A6.1–3 **CH_4 and N_2O Emission Factors for Natural Gas**

Source	Emission Factor (g/m^3)[a]	
	CH_4	N_2O
Electric Utilities	0.490	0.049
Industrial	0.037	0.033
Producer Consumption (Non-marketable)	6.4[b]	0.060
Pipelines	1.900	0.050
Cement	0.037	0.034
Manufacturing Industries	0.037	0.033
Residential, Construction, Commercial/Institutional, Agriculture	0.037	0.035

Notes:
a. SGA Energy (2000)
b. Adapted from U.S. EPA (1996) and CAPP (1999)

Table A6.1–4 **Emission Factors for Natural Gas Liquids**

Source	Emission Factor (g/L)		
	CO_2	CH_4	N_2O
Propane			
Residential	1 515[a]	0.027[b]	0.108[b]
All Other Uses	1 515[a]	0.024[b]	0.108[b]
Ethane	986[a]	0.024[b]	0.108[b]
Butane	1 747[a]	0.024[b]	0.108[b]

Notes:
a. McCann (2000)
b. SGA Energy (2000)

A6.1.1.3. Nitrous Oxide (N_2O)

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors (Table A6.1–3 and Table A6.1–4) 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).

A6.1.2. Refined Petroleum Products

A6.1.2.1. 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 density (McCann, 2000), to ensure consistency with the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006).

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 A6.1–6) have been developed using emissions and energy content data provided by industry to the Canadian Energy and Emissions Data Centre (CEEDC).[2] 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.

Emission factors for still gas (Table A6.1–6) from refining operations and upgrading facilities were also derived from data provided by industry and reported by CEEDC.

A6.1.2.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors were developed (Table A6.1–5) 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.

The emission factor for still gas from upgraders (Table A6.1–5) was based on the 2006 IPCC default emission factor and was adapted using energy conversion factors published by Statistics Canada (2014). The still gas emission factors for refineries and other industries (Table A6.1–8) were based on the 2006 IPCC default emission factor, which was calculated on an annual basis using energy conversion factors provided by Statistics Canada (2014).

2 Griffin, B. 2020. Personal communication (email from Griffin, B., CEEDC to Tracey, K., Program Engineer, PIRD dated September 25, 2020). Canadian Energy and Emissions Data Centre (CEEDC).

A6.1.2.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for RPP, with the exception of petroleum coke, have been developed (Table A6.1–5) 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 A6.1–7) were based on 2006 IPCC default emission factors and were calculated on an annual basis using energy conversion factors provided by Statistics Canada (2014).

Table A6.1–5 Emission Factors for Refined Petroleum Products

Source	Emission Factor (g/L)		
	CO_2[a]	CH_4[b]	N_2O[b]
Light Fuel Oil			
Electric Utilities	2 753	0.18	0.031
Industrial	2 753	0.006	0.031
Producer Consumption	2 670	0.006	0.031
Residential	2 753	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 753	0.026	0.031
Heavy Fuel Oil			
Electric Utilities	3 156	0.034	0.064
Industrial	3 156	0.12	0.064
Producer Consumption	3 190	0.12	0.064
Residential, Forestry, Construction, Public Administration and Commercial/Institutional	3 156	0.057	0.064
Kerosene			
Electric Utilities	2 560[c]	0.006	0.031
Industrial	2 560[c]	0.006	0.031
Producer Consumption	2 560[c]	0.006	0.031
Residential	2 560[c]	0.026	0.006
Forestry, Construction, Public Administration and Commercial/Institutional	2 560[c]	0.026	0.031
Diesel – Refineries and Others[d]	2 681	0.078	0.022
Diesel – Upgraders[d]	2 681	0.078	0.022
Petroleum Coke	See Table A6.1–6	0.12	See Table A6.1–7
Still Gas – Refineries and Others	See Table A6.1–6	See Table A6.1–8	0.00002
Still Gas – Upgraders	See Table A6.1–6	0.000039	0.00002
Motor Gasoline[e]	2 307	0.100	0.02

Notes:

a. McCann (2000); except Kerosene, Diesel and Motor Gasoline
b. SGA Energy (2000); except Diesel and Motor Gasoline
c. Assumed McCann (2000) aviation turbo-fuel emission factor
d. CO_2 from ECCC (2017b); CH_4 and N_2O from Oak Leaf Environmental Inc. (2017)
e. CO_2 from ECCC (2017b); CH_4 and N_2O adapted from IPCC (2006)

Table A6.1–6 CO_2 Emission Factors for Petroleum Coke and Still Gas

	Emission Factor																	
	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Petroleum Coke	g/L																	
Upgrading Facilities[a]	3 556	3 551	3 481	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494	3 494
Refineries and Others[b]	3 766	3 790	3 706	3 767	3 778	3 806	3 829	3 836	3 853	3 812	3 828	3 801	3 725	3 749	3 753	3 776	3 737	3 761
Still Gas	$g/10^3m^3$																	
Upgrading Facilities[a]	2 310	2 090	2 120	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140
Refineries and Others[b]	1 740	1 800	1 680	1 707	1 741	1 749	1 690	1 711	1 825	1 818	1 718	1 738	1 741	1 762	1 781	1 796	1 847	1 797

Notes:

a. CEEDC (2003)
b. Griffin B. 2020. Personal communication (email from Griffin B to Tracey K, Senior Program Engineer, PIRD dated Sept 25, 2020). Canadian Emissions and Energy Data Centre.

Table A6.1–7 **N_2O Emission Factors for Petroleum Coke**

	Emission Factor											
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001–2019
Petroleum Coke	g/m³											
Upgrading Facilities[a, b]	21.9	22.1	22.3	22.5	22.7	22.7	22.7	23.0	23.5	23.7	24.2	24.0
Refineries and Others[a, b]	24.6	24.8	25.0	25.2	25.5	25.5	25.4	25.8	27.0	27.1	27.6	27.5

Notes:

a. Adapted from IPCC (2006)

b. Energy content from Statistics Canada (2014)

Table A6.1–8 **CH_4 Emission Factors for Still Gas (Refineries and Others)**

	Emission Factor[a]																	
	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Still Gas	g/m³																	
Refineries and Others[a]	0.033	0.033	0.034	0.032	0.032	0.032	0.032	0.032	0.032	0.033	0.031	0.031	0.031	0.033	0.032	0.033	0.032	0.032

Note:

a. Adapted from IPCC (2006) using energy content taken from Griffin B. 2019. Personal communication (email from Griffin B to Tracey K, Senior Program Engineer, PIRD dated Sept 26, 2019). Canadian Emissions and Energy Data Centre.

A6.1.3. Coal and Coal Products

A6.1.3.1. CO_2

CO_2 emission factors for coal combustion depend largely on the properties of the fuel and, to a lesser extent, on the combustion technology. Coal emission factors (Table A6.1–9) were developed for each province on the basis of the rank of the coal and the region of supply. Emission factors were based on data from chemical analysis of coal samples for electric utilities, which account for the vast majority of coal consumption.

Some factors for Canadian bituminous coal presented in Table A6.1–9 were developed based on a statistical analysis, by ECCC (Radovan et al., 2012), 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 with uncertainty estimates, since 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.

An additional study to determine country-specific coal oxidation factors and further investigate the carbon content of coal burned at electric generation facilities was conducted for ECCC by GHD Limited in 2016 (ECCC, 2017a). Based on an analysis of this study and Radovan et al. (2012), updated emission and oxidation factors as well as uncertainty estimates for many coal-types have been determined (ECCC, 2019).

Factors for anthracite imported from the United States are from Annex 2 of the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008 (U.S. EPA, 2010). All coal emission factors in Table A6.1–9 now incorporate Canada-specific oxidation factors (ECCC, 2017a).

Coke and coke oven gas emission factors are presented in Table A6.1–10. The coke emission factor was developed from an iron and steel industry study completed in 2014 (CRA, 2014). 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 McCann (2000) and represents use in the iron and steel industry.

A6.1.3.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors for sectors (Table A6.1–11) 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).

A6.1.3.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for sectors (Table A6.1–11) have been developed based on technologies typically used in Canada. The emission factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy, 2000).

Table A6.1–9 **CO_2 Emission Factors for Coal**

Province	Coal Type	Source	Emission Factor (kg CO_2 / tonne)[a, b, c, d]			Moisture (wt %)
			Mean	Uncertainty (95% CI)		
				Low	High	
NL, PEI (Prior to 2000)	Canadian Bituminous[b]	NS	2 315	-33%	22%	3.2
NL, PEI (2000 onward)	Canadian Bituminous[b]	AB	2 185	-26%	26%	7.7
QC (Prior to 2000)	Canadian Bituminous[b]	NS	2 329	-33%	22%	3.2
QC (2000 onward)	Canadian Bituminous[b]	AB	2 198	-26%	26%	7.7
NS	Canadian Bituminous[b]	NS	2 329	-33%	22%	3.2
NB (Prior to 2010)	Canadian Bituminous[b]	NB	2 319	-14%	14%	3.2
NB (2010 on)	Canadian Bituminous[b]	AB	2 198	-26%	26%	7.7
ON, AB, SK, BC	Canadian Bituminous[b]	AB	2 198	-26%	26%	7.7
NB, NS, PEI and NL	Foreign Bituminous[b]	Non-U.S.	2 540	-7%	7%	8.3
ON, MB	Foreign Bituminous[c]	U.S. (Pennsylvania)	2 651	-7%	7%	N/A
QC, AB, BC	Foreign Bituminous[c]	U.S. (Pennsylvania)	2 662	-7%	7%	N/A
All Provinces and Territories, except SK	Lignite[c]	SK	1 462	-13%	13%	24
SK	Lignite[c]	SK	1 457	-13%	13%	36
QC, ON, MB, NB, NS, PEI	Sub-bituminous[c]	Foreign	1 865	-8%	8%	24
AB, SK, BC	Sub-bituminous[c]	AB	1 763	-11%	11%	21
All Provinces and Territories	Anthracite	--	2 382	-6%	6%	N/A

Notes:
N/A = Not available

a. Factors presented on a "wet basis." Moisture content shown is that for the "weighted average" emission factor.
b. Carbon content, Radovan et al. (2012), oxidation factor, ECCC (2019).
c. Carbon content and oxidation factor, ECCC (2019).
d. 95 % Confidence Intervals, which were determined through statistical analysis of Canadian coal data.

Table A6.1–10 **CO_2 Emission Factors for Coal Products**

Coal Product – Fuel Type	Emission Factor
Coke Oven Gas[a]	687 g/m³
Coke[b]	3 173 g/kg

Notes:
a. McCann (2000)
b. CRA (2014)

Table A6.1–11 **CH_4 and N_2O Emission Factors for Coal**

Source	Emission Factor	
	CH_4	N_2O
	g/kg	
Coal		
Electric Utilities	0.02	0.03
Industry and Heat & Steam Plants	0.03	0.02
Residential, Public Administration	4.00	0.02
Coke	**0.03**	**0.02**
	g/m³	
Coke Oven Gas	**0.04**	**0.04**

Note: Source – SGA Energy (2000)

A6.1.4. Fugitive Emission Factors for Coal Mining

The factors in Table A6.1–12 are for fugitive emissions from coal mining only. Although derived from measurements at individual mines or coal seams, these emission factors are aggregated and weighted, province-wide averages for a given mine type. These weighted emission factors are updated yearly account for the change in production of particular coal types, at individual mines. They should be applied to total gross (not net) quantities of coal mined which includes small quantities of minerals, stone and other inert materials mined with the coal, but later removed before sale or consumption.

Table A6.1–12 **Fugitive Emission Factors for Coal Mining**

Area	Coal Type	Mine Type	Emission Factor	Units
NS	Bituminous	Surface	0.07	t CH_4/kt coal mined
NS	Bituminous	Underground	14.5	t CH_4/kt coal mined
NS	Bituminous	Surface	0.07	t CH_4/kt coal mined
SK	Lignite	Surface	0.07	t CH_4/kt coal mined
AB	Bituminous	Surface	0.53	t CH_4/kt coal mined
AB	Bituminous	Underground	1.69	t CH_4/kt coal mined
AB	Sub-bituminous	Surface	0.24	t CH_4/kt coal mined
BC	Bituminous	Surface	0.93	t CH_4/kt coal mined
BC	Bituminous	Underground	2.78	t CH_4/kt coal mined

Note: Adapted from King (1994), and Cheminfo and Clearstone Engineering Ltd (2014).

A6.1.5. Other Fuels

A6.1.5.1. CO_2

Alternative fuels such as tires, refuse, and waste oil and solvents are used in the cement industry 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. Fuel use data reported by the cement industry, using CO_2 accounting and reporting standards developed by the World Business Council for Sustainable Development (WBSCD, 2005), were used to generate the emission factors in Table A6.1–13.

Some municipal solid wastes and medical wastes are combusted in energy-to-waste facilities. See Annex 6.7.2 for the emission factors associated with these other fuels.

A6.1.5.2. CH_4

CH_4 emission factors for alternative fuels were adapted from the 2006 IPCC Guidelines (IPCC, 2006).

Some municipal solid wastes and medical wastes are combusted in energy-to-waste facilities. See Annex 6.7.2 for the emission factors associated with these other fuels.

A6.1.5.3. N_2O

N_2O emission factors for alternative fuels were adapted from the 2006 IPCC Guidelines (IPCC, 2006).

Some municipal solid wastes and medical wastes are combusted in energy-to-waste facilities. See Annex 6.7.2 for the emission factors associated with these other fuels.

A6.1.6. Mobile Combustion

A6.1.6.1. 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.

A6.1.6.2. 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 Canada, and are summarized in Table A6.1–14. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies. A number of on-road CH_4 emission factors were subsequently refined with updated Canadian and U.S. emissions test results (Environment Canada 2006, 2009; Graham et al., 2008).

Table A6.1–13 **Emission Factors for Alternative Fuels**

Source/Fuel	GHG	Emission Factor (kg/GJ)												
		1990–1994	1995–2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011–2019
Cement Industry Waste Fuel	CO_2[a]	78.8	77.6	78.6	80.6	82.6	81.5	81.2	83.8	87.7	86.3	79.2	80.1	81.5
	CH_4[b]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	N_2O[b]	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004

Notes:

a. Adapted from WBSCD (2005)

b. Adapted from IPCC (2006)

Table A6.1–14 **Emission Factors for Energy Mobile Combustion Sources**

Mode†	Emission Factors (g/L fuel)		
	CO_2	CH_4	N_2O
Road Transport			
Gasoline Vehicles			
Light-duty Gasoline Vehicles (LDGVs)			
Tier 2	2 307.3 [a]	0.14 [c]	0.022 [d]
Tier 1	2 307.3 [a]	0.23 [e]	0.47 [e]
Tier 0	2 307.3 [a]	0.32 [f]	0.66 [g]
Oxidation Catalyst	2 307.3 [a]	0.52 [h]	0.20 [f]
Non-catalytic Controlled	2 307.3 [a]	0.46 [h]	0.028 [f]
Light-duty Gasoline Trucks (LDGTs)			
Tier 2	2 307.3 [a]	0.14 [c]	0.022 [d]
Tier 1	2 307.3 [a]	0.24 [e]	0.58 [e]
Tier 0	2 307.3 [a]	0.21 [h]	0.66 [g]
Oxidation Catalyst	2 307.3 [a]	0.43 [h]	0.20 [f]
Non-catalytic Controlled	2 307.3 [a]	0.56 [f]	0.028 [f]
Heavy-duty Gasoline Vehicles (HDGVs)			
Three-way Catalyst	2 307.3 [a]	0.068 [h]	0.20 [h]
Non-catalytic Controlled	2 307.3 [a]	0.29 [f]	0.047 [f]
Uncontrolled	2 307.3 [a]	0.49 [f]	0.084 [f]
Motorcycles			
Non-catalytic Controlled	2 307.3 [a]	0.77 [c]	0.041 [c]
Uncontrolled	2 307.3 [a]	2.3 [f]	0.048 [f]
Diesel Vehicles			
Light-duty Diesel Vehicles (LDDVs)			
Advanced Control*	2 680.50 [a]	0.051 [f]	0.22 [f]
Moderate Control	2 680.50 [a]	0.068 [f]	0.21 [f]
Uncontrolled	2 680.50 [a]	0.10 [f]	0.16 [f]
Light-duty Diesel Trucks (LDDTs)			
Advanced Control*	2 680.50 [a]	0.068 [f]	0.22 [f]
Moderate Control	2 680.50 [a]	0.068 [f]	0.21 [f]
Uncontrolled	2 680.50 [a]	0.085 [f]	0.16 [f]
Heavy-duty Diesel Vehicles (HDDVs)			
Advanced Control	2 680.50 [a]	0.11 [i]	0.151 [i]
Moderate Control	2 680.50 [a]	0.14 [f]	0.082 [f]
Uncontrolled	2 680.50 [a]	0.15 [f]	0.075 [f]
Natural Gas Vehicles	1.9 [b]	9E-03 [f]	6E-05 [f]
Propane Vehicles	1 515 [b]	0.64 [f]	0.028 [f]
Off-road			
Off-road Gasoline 2-stroke	2 307.3 [a]	10.61 [l]	0.013 [m]
Off-road Gasoine 4-stroke	2 307.3 [a]	5.08 [l]	0.064 [m]
Off-road Diesel <19kW	2 680.50 [a]	0.073 [l]	0.022 [l]
Off-road Diesel ≥ 19kW, Tier 1–3	2 680.50 [a]	0.073 [l]	0.022 [l]
Off-road Diesel ≥ 19kW, Tier 4	2 680.50 [a]	0.073 [l]	0.227 [l]
Off-road Natural Gas	1.9 [b]	0.0088 [f]	0.00006 [f]
Off-road Propane	1 515 [b]	0.64 [f]	0.087 [l]
Railways			
Diesel Train	2 680.50 [a]	0.149 [m]	1.029 [m]
Marine			
Gasoline	2 307.3 [a]	0.21931 [m]	0.06266 [m]
Diesel	2 680.50 [a]	0.25193 [m]	0.07198 [m]
Light Fuel Oil	2 753 [b]	0.2555 [m]	0.073 [m]
Heavy Fuel Oil	3 156 [b]	0.2856 [m]	0.0816 [m]
Kerosene	2 559.70 [p]	0.2471 [m]	0.0706 [m]
Aviation			
Aviation Gasoline	2 325.40 [j]	2.19 [j]	0.23 [j]
Aviation Turbo Fuel	2 559.70 [b]	0.029 [k]	0.0711 [m]
Renewable Fuels			
Ethanol	1 508.04 [a,n]	**	**
Biodiesel	2 472.2 [a, n, o]	***	***

Notes:

† In the context of Transportation Modes, Tiers refer to increasingly stringent emission standards, enabled through advancements in emission control technologies. It should not be confused with IPCC GHG estimation methodologies.

* 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.

a. ECCC (2017b)
b. McCann (2000)
c. Adapted from Environment Canada (2006)
d. Adapted from Environment Canada (2006) and Graham et al. (2009)
e. Adapted from Environment Canada (2009)
f. SGA Energy (2000)
g. Adapted from Barton & Simpson (1994)
h. ICF Consulting (2004)
i. Graham et al. (2008)
j. Jaques (1992)
k. National overall average emission factor for the whole time series based on 2006 IPCC Guidelines (IPCC 2006). Refer to section A3.1.4.2.3 of Annex 3.1 for further information.
l. Oak Leaf Environmental Inc (2017)
m. IPCC (2006) Converted into g/L using gross calorific value where necessary.
n. Refer to section 3.5.1 Chapter 3 for further information.
o. BioMer (2005)
p. Assumed McCann (2000) aviation turbo-fuel emission factor.

Over 50 aircraft-specific aviation turbo fuel CH_4 emission factors from the 2006 IPCC Guidelines (IPCC, 2006) are used in the Tier 3 civil aviation model (Aviation Greenhouse Gas Emission Model – AGEM). Table A6.1–14 displays a national overall average implied emission factor (refer to section A3.4.2.3 for more information on AGEM).

A6.1.6.3. 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. A number of on-road N_2O emission factors were subsequently refined with updated Canadian and U.S. emissions test results (Environment Canada, 2006, 2009; Graham et al., 2008, 2009).

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).

A6.2. Industrial Processes

A6.2.1. Mineral Products

Emission factors used to estimate emissions from the production and use of mineral products are listed in Table A6.2–1.

A6.2.2. Chemical Industry

Table A6.2–2, Table A6.2–3, Table A6.2–4 and Table A6.2–5 present the emission factors used for categories included under the Chemical Industry subsector, as well as the sources from which these factors were obtained.

Table A6.2–1 **Range of Carbon Dioxide (CO_2) Emission Factors for Mineral Products**

Category	Mineral Product	Emission Factor ($g\ CO_2$ / kg of mineral product)
Cement Production	Clinker	521–533[a]
	Total Organic Carbon (TOC)	10.6–13.2[a]
Lime Production	High-Calcium Lime	751–754[b]
	Dolomitic lime	872–889[b]
Other Limestone and Dolomite Use	Limestone	418[c]
	Dolomite	468[c]
Other Uses of Soda Ash	Soda Ash	415[c]
Non-Metallurgical Magnesia Production	Magnesite	522[c]

Notes:

a. Range of year-specific emission factors provided by the Cement Association of Canada (CAC) (2015) and ECCC (2020).
b. Range of year-specific emission factors developed based on information from the Canadian Lime Institute (CLI) (2008) and ECCC (2020).
c. AMEC Earth & Environmental (2006)

Table A6.2–2 **Emission Factors for Ammonia Production**

	Average Ammonia-to-Feed Fuel Factor[a] m^3 natural gas / tonne of NH_3	Emission Factor $g\ CO_2$ / m^3 of natural gas	Emission Recovery Factor $g\ CO_2$ / kg of urea
Ammonia Production	671	Marketable natural gas emission factors found in NIR Table A6.1–1 are used.	728

Note:

a. Facility-specific fuel factors are used and these are confidential.

Table A6.2–3 N_2O Emission Factors for Nitric Acid and Adipic Acid Production

Category	Process Description[a]	N_2O Emission Factor (kg/t)
Nitric Acid Production	Dual-pressure plants with extended absorption "Type 2"	12[b]
	High-pressure plants with non-selective catalytic reduction	0.66[b]
Adipic Acid Production	Oxidation reaction of cyclohexanone and cyclohexanol mixture without N_2O abatement	300[c]

Notes:

a. Emissions from a dual-pressure plant with extended absorption "Type 1" and a high-pressure plant with selective catalytic reduction are estimated using confidential plant-vendor emission factors. Emissions from these two plants after the installation of process-gas catalytic decomposition N_2O abatement systems are estimated using confidential plant-specific annual continuous emission monitoring systems (CEMS) data.

b. Collis G. 1992. *Estimates of Nitrous Oxide (N_2O) Emissions from Canadian Nitric Acid Industry*. Personal communication (letter from Collis G to Jaques A, Greenhouse Gas Division, dated March 23, 1992). Canadian Fertilizer Institute.

c. IPCC (2000)

Table A6.2–4 Emission Factors for Petrochemical Products

Petrochemical Product	Emission Factor	Type
Silicon Carbide	11.6 kg CH_4 / t (tonne) product	IPCC default[a]
Calcium Carbide	4.8 kg CH_4 / t product	Derived from CH_4 emission factor for silicon carbide and the ratio of IPCC default Calcium Carbide CO_2 emission factor to IPCC default Silicon Carbide CO_2 emission factor (i.e. 11.6 (kg CH_4 / t SiC) * (1.09 tCO_2 / $tCaC_2$ / 2.62 tCO_2 / tSiC))
Carbon Black	1.29 kg CH_4 / t product	Sector-wide weighted average[b]
	0.032 kg N_2O / t product	Sector-wide weighted average[b]
Ethylene	0.039 kg CH_4 / t product	Sector-wide weighted average[b]
	0.0055 kg N_2O / t product	Sector-wide weighted average[b]
	0.411 t CO_2 / t product	Sector-wide weighted average[c]
Ethylene Dichloride	0.4 kg CH_4 / t product	IPCC default[a]
Ethylene Oxide	0.5202 t CO_2 / t product	Sector-wide weighted average[b]
	1.79 kg CH_4 / t product	IPCC default[d]
Styrene	4 kg CH_4 / t product	IPCC default[a]
Methanol	0.031 kg CH_4 / t product	Sector-wide weighted average[b]
	0.010 kg N_2O / t product	Sector-wide weighted average[b]
	0.790 t CO_2 / t product	Sector-wide weighted average[c]
Other Uses of Urea	0.733 t CO_2 / t product	IPCC default[d]

Notes:

a. Default value from IPCC/OECD/IEA (1997)

b. Cheminfo Services (2010)

c. Cheminfo Services (2015); emission factors may vary if changes are made to the composition of feed.

d. IPCC (2006)

Table A6.2–5 Emission Factor for By-Product Emissions from Fluorochemical Production

Process	Emission Factor
HCFC-22 production	0.04 t HFC-23 emitted / t HCFC-22 produced[a]

Note:

a. IPCC (2006)

Table A6.2–6 **Range of CO_2 Emission Factors for the Iron and Steel Industry**		
Parameter	Emission Factor	Unit
Iron ore reduction with coke	3.1–3.3[a]	t CO_2 / t (tonne) coke used
Electrode consumption in electric arc furnaces	4.5–7.8[b]	kg CO_2 / t steel
Electrode consumption in basic oxide furnaces	0.2–0.3[b]	kg CO_2 / t steel
Limestone use	418[c]	CO_2 / kg $CaCaO_3$
Dolomite use	468[c]	CO_2 / kg $MgCO_3$

Notes:

a. Range of year-specific emission factors provided in Cheminfo Services (2010) and ECCC (2020).

b. Provided by the Canadian Steel Producers Association and ECCC (2020). Chan K. (2009). Personal communication (email from Chan K to Pagé M, Environment Canada, dated July 21, 2009). Canadian Steel Producers Association.

c. AMEC Earth & Environmental (2006)

A6.2.3. Metal Production

The range of the metallurgical coke emission factors and other parameters used for estimating emissions from Iron and Steel Production are found in Table A6.2–6, Table A6.2–7 and Table A6.2–8.

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 A6.2–8.

Table A6.2–7 **Range of Carbon Contents for the Iron and Steel Industry**	
Parameter	Carbon Contents (%)[a]
Pig iron (production of pig iron) from BFs and DRI plants	4.0–4.7
Pig iron (includes hot metal, cold iron, DRI and pig iron) for steel making	3.2–3.9
Crude steel produced in BOF	0.13
Crude steel produced in EAF	0.14–0.34
Scrap steel	0.1–0.7

Note:

a. Range of values from CSPA (2009) and ECCC (2020).

Table A6.2–8 **Tier 1 Emission Factors for Aluminium Production**			
Cell Technology Type	Emission Factors[a] (kg / t product)		
	CO_2	Carbon Tetrafluoride (CF_4)	Carbon Hexafluoride (C_2F_6)
Side-worked pre-baked	1 600	1.6	0.4
Centre-worked pre-baked	1 600	0.4	0.04
Horizontal stud Söderberg	1 700	0.4	0.03
Vertical stud Söderberg	1 700	0.8	0.04

Note:

a. International Aluminium Institute (IAI) (2006)

A6.2.4. Non-Energy Products from Fuels and Solvent Use

The use of fossil fuels as feedstock or for other non-energy use (NEU) may result in emissions during the life of manufactured products. To estimate CO_2 emissions from NEU of natural gas, an emission factor of 38 g CO_2/m^3 was used. This emission factor excludes the feedstock use of natural gas to produce ammonia, and it is derived from the NEU of natural gas data found in the 2005 Cheminfo Study (Cheminfo Services, 2005).

Table A6.2–9 shows the emission factors used to develop CO_2 emission estimates for non-energy applications of natural gas liquids and non-energy petroleum products, respectively. The emission factors for NEU petroleum coke are found in Table A6.1–5. The 2011 emission factor value for Upgrading Facilities in Table A6.1–5 has been used for Ontario across the time series. For the other provinces, the 2011 emission factor value for Refineries and Others is used across the time series. The emission factors associated with NEU of coal are referenced in Table A6.1–8.

Table A6.2–9 **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[a]	303[b]
Butane	0.8[a]	349[b]
Ethane	0.8[a]	197[b]
Petroleum Products		
Petrochemical Feedstocks[d]	0.8[a]	500[h]
Naphthas[e]	0.75[a]	625[h]
Lubricating Oils and Greases[f]	0.2[c]	2 260[h]
Petroleum Used for Other Products[g]	0.5[a]	1 450[h]

Notes:

a. IPCC/OECD/IEA (1997)
b. McCann (2000)
c. IPCC (2006)
d. Carbon factor for Petrochemical Feedstocks is 680 g of carbon per litre (C/L) (Jaques 1992).
e. Carbon factor for Napthas is 680 g C/L (Jaques 1992).
f. Carbon factor for Lubricating Oils and Greases is 770 g C/L (Jaques 1992).
g. Carbon factor for Petroleum Used in Other Products is 790 g C/L (Jaques 1992).
h. 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).

A6.2.5. Electronics Industry

The use of perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) in integrated circuit or semiconductor manufacturing, electrical environmental testing, gross leak testing and thermal shock testing create GHG emissions of their respective source gases. The use of PFCs and NF_3 in the integrated circuit or semiconductor manufacturing industry can also lead to by-product PFC emissions. The emission factors used for the use of PFCs, SF_6 and NF_3 in the electronics industry is summarized in Table A6.2–10.

A6.2.6. Product Uses as Substitutes for Ozone Depleting Substances

The use of halocarbons in various applications, such as air conditioning (AC), refrigeration, aerosols, foam blowing, solvents and fire extinguishing, result in hydrofluorocarbon (HFC) and PFC emissions.

Table A6.2–11 and Table A6.2–12 summarize emission rates used to estimate HFC and PFC emissions, respectively.

Table A6.2–10 **Emission Factors for the use of PFCs, SF_6 and NF_3 in the Electronics Industry**

Application	GHG Source	IPCC Tier	Emission Rate (%)[a]	By-Product Emission Rate
Integrated Circuit or Semiconductor Manufacturing[b]	CF_4	T2A	90	N/A
	CF_4	T2B – CVD	90	N/A
	CF_4	T2B – Etching	70	N/A
	C_2F_6	T2A	60	0.2 kg CF_4 / kg C_2F_6
	C_2F_6	T2B – CVD	60	0.1 kg CF_4 / kg C_2F_6
	C_2F_6	T2B – Etching	40	0.4 kg CF_4 / kg C_2F_6
	c-C_4F_8	T2A	10	0.1 kg CF_4 / kg c-C_4F_8, 0.1 kg C_2F_6 / kg c-C_4F_8
	c-C_4F_8	T2B – Etching	20	0.2 kg CF_4 / kg c-C_4F_8, 0.1 kg C_2F_6 / kg c-C_4F_8
	SF_6	T2A	20	N/A
	NF_3	T2A	20	0.09 kg CF_4 / kg NF_3
	NF_3	T2B – Etching	20	N/A
Other Emissive Applications	PFCs	T2	50% first year / 50% second year	N/A

Notes:

N/A = Not available

a. IPCC (2006)
b. When available, confidential company/gas/process-specific values are used for the fraction of gas volume fed into process types with emission control technology and the fraction of gas destroyed by the emission control technology (respectively, ai and di in the IPCC Guidelines).

Table A6.2–11 **HFC as ODS Substitute – Assembly, In-Service and End-of-Life Emission Factors (%)**

Application/Sub-Application	Assembly[a]	In-Service[b]	End-of-Life[c]	Life Time (years)
Aerosols[d]	0	50% of orginal charge	100% of remaining charge	2
Blowing agent in foams[d]				
Open-cell foam	100	-	-	-
Closed-cell foam	10	4.5	100	23
Air conditioning (equipment manufactured in Canada)[e]				
Air conditioner units in motor vehicles	0.5	10	75	13
Chillers (specify centrifugal or reciprocating)	1	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	1	4	20	17
Air conditioning (manufactured elsewhere)[e]				
Air conditioner units in motor vehicles	-	10	75	13
Chillers (specify centrifugal or reciprocating)	-	4.7	5	17
Residential (air conditioners, dehumidifiers, etc.)	-	4	20	17
Refrigeration (equipment manufactured in Canada)[e]				
Commercial transport	1	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	1	10	30	17
Industrial (warehouses, process equipment, etc.)	1	10	30	17
Residential (freezers, refrigerators)	0.6	0.5	30	15
Other equipment (specify)	1.0	10.8	30	15
Refrigeration (manufactured elsewhere)[e]				
Commercial transport	-	15	30	13
Commercial and institutional (retail foods, vending machines, etc.)	-	10	30	17
Industrial (warehouses, processes, etc.)	-	10	30	17
Residential (refrigerators, freezers, etc.)	-	0.5	30	15
Other equipment (specify)	-	10.1	30	15
Solvent[d]	0	50% of orginal charge	100% of remaining charge	2
Fire suppression/extinguishing systems[d]				
Portable (mobile) systems	-	4	5	18
Total flooding (fixed) systems	-	2	5	18
Miscellaneous[d]	-	50% of orginal charge	100% of remaining charge	2
Other (specify)[d]	-	50% of orginal charge	100% of remaining charge	2

Notes:
a. Percentage of losses of the HFC charged into new equipement
b. Release percentage of HFC bank (by application) during operation
c. Release percentage of HFC bank (by application) during disposal
d. IPCC (2006)
e. Environment Canada (2015)

Table A6.2–12 **PFC as ODS Substitute – Assembly, In-Service and End-of-Life Emission Factors (%)**

Application/Sub-Application	Assembly[a]	In-Service[b]	End-of-Life[c]	Life Time (years)
Air Conditioning				
Mobile A/C	0.35	15	100	12
Residential and Commercial A/C, including Heat Pumps	0.6	5.5	100	15
Foam Blowing Agents				
Closed-Cell Foam	10% of original charge	4.5% of original charge	-	20
Refrigeration				
Industrial Refrigeration including Food Processing and Cold Storage	1.75	16	100	15
Medium and Large Commercial Refrigeration	1.75	22.5	100	15
Solvents	0	50% of original charge	100% of remaining charge	2

Notes:
a. Percentage of losses of the PFC charged into new equipment
b. Annual release percentage of PFC bank (by application) during operation
c. Release percentage of PFC bank (by application) during disposal
Source – IPCC (2006)

A6.3. Other Product Manufacture and Use

The uses of N_2O as an anaesthetic and as a propellant result in N_2O emissions. The emission factors used are shown in Table A6.3–1.

The use of perfluorocarbons (PFC) in contained applications (such as use in power transformers, as an electronic insulator, as a dielectric coolant, and as a heat transfer medium) results in PFC emissions. The emission factors used are shown in Table A6.3–2.

The use of urea-based diesel exhaust fluid (DEF) in diesel vehicles equipped with selective catalytic reduction (SCR) systems results in CO_2 emissions, the rate of which is dependent on the purity factor of urea in DEF as well as the dosing rate of urea to diesel consumption as per Table A6.3–3.

Table A6.3–1 **Emission Factors for N_2O Usage (Medical and Propellant)**

Product	Application	N_2O Emission Rate (%)
N_2O Use	Anaesthetic Usage	100
	Propellant Usage	100

Note: Source – IPCC (2006)

Table A6.3–2 **Emission Factor for PFC Emissions from Other Contained Product Uses**

Process	PFC Emissions from Other Contained Sources
Assembly	1% of charge
Annual Leakage Rate	2% of stock
Disposal	100% of remaining stock
Product Lifespan	15 years

Note: Source – IPCC (2000)

Table A6.3–3 **Emission Factors for Use of Urea in SCR Vehicles**

Product	DEF Purity	Dosing Rate
Urea use in SCR Vehicles	32.50%	2% of diesel consumption

Note: Source – IPCC (2006)

A6.4. Agriculture

The sources of agricultural GHGs are enteric fermentation, manure management, field burning of crop residues, agricultural soils (including nitrous oxide emissions from mineralization/immobilization associated with loss/gain of soil organic matter), and agricultural use of lime, urea and other-carbon containing fertilizers. The most significant sources use country-specific Tier 2 methodologies. Carbon dioxide emissions from liming, urea application and other carbon-containing fertilizers are calculated based on the total quantity of carbon (C) contained in these products. Ammonia emissions from synthetic nitrogen (N) application are estimated using a country specific modelling method as noted in Annex 3.4. Finally, indirect emissions from ammonia volatilization and nitrogen leaching are calculated based on the IPCC default emission factors provided in Table A6.4–27.

Those emission factors for agriculture calculated based on country-specific methodologies are described in detail in Annex 3.4. In certain cases, implied emission factors for these methologies are included below for reference. For enteric fermentation emissions from cattle, weighted national emission factors and the methodology for generating emission factors are detailed in section A3.4.2.1. In the case of manure management CH_4, the methodology for generating emission factors is described in A3.4.3, and weighted national emission factors are presented in A3.4.3.5. For manure management N_2O emissions, the methodologies for calculating direct and indirect N_2O emissions are described in sections A3.4.4.1 and A3.4.4.2, respectively. Finally, the methodologies for generating N_2O emission factors for direct emissions from agricuiltural soils and pasture, range and paddock (PRP), are described in A3.4.5.1. Cattle are described using an approach consistent with common reporting format (CRF) tables.[3] For enteric fermentation, Dairy Cattle includes only dairy cows, while for manure management and PRP, Dairy Cattle includes dairy cows and dairy heifers.

A compilation of emission factors for agriculture are provided here in Table A6.4–1 to Table A6.4–29.

3 Canada's 2021 CRF tables are available online at: https://unfccc.int/ghg-inventories-annex-i-parties/2021

A6.4.1. Enteric Fermentation

Table A6.4–1 **CH_4 Emission Factors (EF) for Enteric Fermentation for Cattle from 1990 to 2019**

Year	$EF_{(EF)T}$ – (kg CH_4/head/year)[a]							
	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	115.4	79.4	108.0	105.9	82.5	44.7	41.4	43.8
1995	119.1	78.6	117.2	112.1	85.9	48.8	43.6	43.8
2000	125.4	78.0	121.0	117.5	89.4	53.0	47.8	43.8
2005	125.0	77.2	119.9	114.4	87.0	52.8	46.0	43.6
2010	128.6	76.8	128.5	115.2	87.8	52.8	47.0	43.7
2011	129.2	76.8	127.6	115.0	87.5	52.7	47.4	43.7
2012	129.6	76.8	129.8	115.6	87.6	53.8	48.0	43.7
2013	134.0	76.8	117.1	115.3	87.5	53.7	48.0	43.8
2014	134.1	76.7	121.1	116.3	88.1	53.2	48.1	43.8
2015	135.2	76.7	127.5	120.0	90.7	53.8	48.8	43.8
2016	137.5	76.7	128.0	121.3	91.6	53.9	48.8	43.8
2017	138.1	76.7	130.1	120.8	91.3	53.6	48.4	43.8
2018	139.6	76.7	125.3	120.5	91.2	53.7	48.5	43.8
2019	142.2	76.6	124.0	120.3	91.0	53.9	49.0	43.7

Notes:

a. Enteric emission factors are derived from Boadi et al. (2004), modified to take into account trends in milk production in dairy cows and carcass weights for several beef cattle categories.

b. Reported as kg/head/yr; however, emissions are calculated based on time to slaughter.

Table A6.4–2 **Methane Emission Factors (EF) for Enteric Fermentation for Non-Cattle Animals**

Non-Cattle Animal Category	Enteric Fermentation EF[a] ($kg\ CH_4$/head/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
Bison	55
Llamas & Alpacas	8
Elk & Deer	20
Wild Boars	1.5
Fox	N/A
Mink	N/A
Rabbits	N/A
Mules and Asses	10
Poultry	
Chickens	N/A
Hens	N/A
Turkeys	N/A

Notes:

N/A = Not available

a. Data source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.10)

A6.4.2. Manure Management

Table A6.4–3 **Maximum Methane-Producing Potential (B_0) by Animal Category**

Animal Category	Maximum CH_4-Producing Potential (B_0) (m^3/kg VS)
Dairy Cattlea	0.24
Non-dairy Cattleb	0.19
Sheep	0.19
Goats	0.18
Horses	0.3
Swine	0.48
Hens	0.39
Broilers	0.36
Turkeys	0.36

Notes:

VS = Volatile solids

a. Dairy cattle include dairy cows and dairy heifers.

b. The non-dairy cattle value is also used for bison.

Data source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9)

Table A6.4–4 **Methane Conversion Factors (MCFs) by Animal Category and Manure Management System**

Animal Categories	Liquid Systems (MCF_L)	Solid Storage and Drylot (MCF_{SSD})	Pasture, Range and Paddock (MCF_{PRP})	Other Systems (MCF_O)
Non-dairy Cattle[a]	0.2	0.02	0.01	0.01
Poultry	0.2	0.015	0.015	0.015
Horses	NA	0.01	0.01	0.01
Goats	NA	0.01	0.01	NA
Sheep	0.2	0.01	0.01	0.01
Lambs	0.2	0.01	0.01	0.01

Notes:

NA = Not applicable

a. Non-dairy cattle values are also used for bison.

Source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9 – cool climate, average annual temperature 12°C)

Table A6.4–5 **Methane Conversion Factors (MCF) for Dairy Cattle and Swine**

Manure Management System	Manure Management Subsystem	Crust Formation	MCF
Liquid	Earthen Basin	No crust	0.2
	Earthen Basin	Crust	0.13
	Tank	No crust	0.2
	Tank	Crust	0.13
	Slatted floor	N/A	0.2
Solid	Exercise Yard	N/A	0.01
	Pack	N/A	0.01
	Pile	N/A	0.02
Compost		N/A	0.005
Pasture Range Paddock		N/A	0.01
		N/A	0.01

Notes:
N/A = Not available
Source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.17 – cool climate, average annual temperature 12°C)

Table A6.4–6 **Emission Factors (EF) to Estimate CH_4 Emissions from Manure Management for Cattle Subcategories from 1990 to 2019**

Year	$EF_{(MM)T}$ (kg CH_4/head/year)							
	Dairy Cows	Dairy Heifers[a]	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[b]	Steers[b]	Calves
1990	13	8	4.5	4.1	3.2	1.9	1.8	2.2
1995	15	9	4.7	4.3	3.2	2.0	1.9	2.1
2000	20	11	4.7	4.5	3.3	2.1	1.9	2.3
2005	26	12	4.6	4.3	3.1	2.1	1.9	2.4
2010	33	15	5.0	4.4	3.1	2.1	2.0	2.8
2011	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2012	35	16	5.0	4.4	3.1	2.1	2.0	2.9
2013	36	16	4.5	4.3	3.1	2.1	2.0	2.8
2014	36	17	4.7	4.4	3.1	2.1	2.0	2.9
2015	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2016	37	17	4.9	4.5	3.2	2.2	2.0	2.9
2017	38	17	5.0	4.5	3.2	2.1	2.0	2.9
2018	38	17	4.8	4.5	3.2	2.2	2.0	3.0
2019	39	17	4.8	4.5	3.2	2.2	2.0	3.0

Notes:
a. For dairy heifers, emission factors were estimated using B_0, MCF and manure management systems for dairy cows.
b. Reported as kg/head/year, but emissions are calculated based on time to slaughter.

Table A6.4–7 Emission Factors (EF) to Estimate CH_4 Emissions from Manure Management for Swine Subcategories from 1990 to 2019

Year	$EF_{(MM)T}$ (kg CH_4/head/year)				
	Boars	Sows	Pigs (< 20 kg)	Pigs (20-60 kg)	Pigs (> 60 kg)
1990	7.0	7.3	2.1	4.5	8.2
1995	7.0	7.2	2.1	4.5	8.3
2000	7.0	7.2	2.1	4.4	8.5
2005	7.0	7.1	2.1	4.4	8.5
2010	7.0	7.0	2.1	4.3	8.6
2011	7.0	7.0	2.1	4.3	8.7
2012	7.0	7.0	2.1	4.3	8.8
2013	7.0	7.0	2.1	4.3	8.8
2014	7.0	7.0	2.1	4.3	8.9
2015	7.0	7.0	2.1	4.3	8.9
2016	7.0	7.0	2.1	4.3	9.0
2017	7.0	7.0	2.1	4.2	9.0
2018	7.0	7.0	2.1	4.2	9.0
2019	7.0	7.0	2.1	4.2	9.2

Table A6.4–8 2019 CH_4 Emission Factors (EF) for Manure Management for Other Livestock

Non-Cattle Animal Categories	Manure Management Emission Factors $EF_{(MM)}$ (kg CH_4/head/year)
Other Livestock	
Sheep	0.33
Lambs	0.22
Goats	0.32
Horses	2.6
Bison	2.1
Elk and Deer	0.22
Wild Boars[a]	0.56
Foxes	0.68
Mink	0.68
Rabbits	0.08
Mules and Asses	0.76
Poultry	
Chickens	0.03
Hens	0.12
Turkeys	0.10

Note:
a. Emission factor based on swine volatile solids, assuming 100% solid manure.

Table A6.4–9 Dairy Cattle and Swine Emission Factors for Manure Nitrogen (N) Lost as N_2O-N by Animal Waste Management Systems

Manure Management System	Manure Management Subsystem	Crust Formation	Emission Factor
Liquid	Earthen Basin	No crust	0
	Earthen Basin	Crust	0.005
	Tank	No crust	0
	Tank	Crust	0.005
	Slatted floor	NA	0.002
Solid	Exercise Yard	NA	0.02
	Pack	NA	0.02
	Pile	NA	0.005
Other	Compost	NA	0.01

Notes:
NA = Not applicable
Source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.21)

Table A6.4–10 Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O-N by Animal Category and Animal Waste Management Systems

	Liquid Systems (EF_L)	Solid Storage and Drylot (EF_{SSD})	Other Systems (EF_O)
Non-dairy Cattle	0.001	0.02	0.005
Poultry	0.001	0.02	0.005
Sheep and Lambs	0.001	0.02	0.005
Goats	0.001	0.02	0.005
Horses	0.001	0.02	0.005
Mules and Asses	0.001	0.02	0.005
Buffalo	0.001	0.02	0.005

Note: Source – IPCC (2006) (Vol. 4: Agriculture, Forestry and Other Land Uses, Table 10.21)

Table A6.4–11 Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O During Storage of Cattle and Swine Manure

Year	EF (g N_2O head^{-1} year^{-1})				
	1990	2005	2010	2015	2019
Cattle					
Dairy Cows[a]	1 268	1 128	956	930	920
Beef Cows	862	999	1 016	1 093	1 099
Bulls	1 305	1 495	1 665	1 641	1 576
Dairy Heifersa	938	906	775	745	740
Beef Heifers	680	769	784	838	841
Heifers for Slaughter	320	425	435	458	463
Steers	336	426	439	468	477
Calves	382	383	382	382	379
Swine[b]					
Sows	74	29	25	24	24
Boars	95	58	53	58	59
Pigs (<20 kg)	7	3	3	2	2
Pigs (20–60 kg)	32	15	13	12	12
Pigs (>60 kg)	66	32	29	28	28

Notes:

Emission factors are derived from information in Boadi et al. (2004), Marinier et al. (2004) and (2005), and default factors in the 2006 IPCC Guidelines. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

a. For dairy cows and heifers, nitrogen excretion rates are derived from feed intake information from Lactanet (2020), and manure storage practices are taken from farm management surveys, as described in NIR Annex 3.4.

b. For swine, nitrogen excretion rates are calculated using default IPCC parameters and country-specific animal mass time series, and manure storage practices are taken from farm management surveys, as described in NIR Annex 3.4.

Table A6.4–12 2019 Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O During Storage of Non-Cattle and Non-Swine Manure

Livestock Category	Emission Factors (EF)[a] (g N_2O head^{-1} year^{-1})
Poultry	
Turkey	54
Hens	12
Pullets	6
Broiler	11
Other Livestock	
Sheep	45
Goat	139
Buffalo	991
Horse	485
Llama and alpacas	150
Lamb	44
Deer	219
Elk	219
Wild boars	350
Rabbit	149
Mink	95
Fox	250
Mules and Asses	259

Note:

a. Emission factors are derived from information in Marinier et al. (2004) and (2005), and default factors in the 2006 IPCC Guidelines. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

Table A6.4–13 Emission Factors (EF) for Cattle and Swine Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching During Storage

	EF (g N_2O head^{-1} year^{-1})				
	1990	2005	2010	2015	2019
Volatilization[a]					
Dairy Cow	207	209	186	175	174
Beef Cow	140	161	164	176	177
Bull	213	241	269	264	253
Dairy heifer	155	150	136	128	127
Beef heifer-bred	111	124	127	135	136
Beef heifer-slaughter	52	70	72	75	76
Steer	55	70	72	77	78
Calf	61	61	61	61	60
Sow	58	58	52	51	51
Boar	58	56	50	50	50
Pig (<20 kg)	6	6	5	5	5
Pig (20–60 kg)	25	25	22	21	21
Pig (>60 kg)	50	51	47	48	49
Leaching[b]					
Dairy Cow	23	15	11	10	9
Beef Cow	0	0	0	0	0
Bull	0	0	0	0	0
Dairy heifer	16	12	10	9	9
Beef heifer-bred	0	0	0	0	0
Beef heifer-slaughter	0	0	0	0	0
Steer	0	0	0	0	0
Calf	0	0	0	0	0
Sow	1.2	0.2	0.1	0.1	0.1
Boar	1.6	0.7	0.6	0.7	0.8
Pig (<20 kg)	0.13	0.03	0.02	0.02	0.02
Pig (20–60 kg)	0.6	0.2	0.1	0.1	0.1
Pig (>60 kg)	1.2	0.4	0.3	0.2	0.2

Notes:

a. Indirect N_2O emission factors are taken from default parameters in the 2006 IPCC Guidelines. Volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016). Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

b. A tier 2 method for the calculation of swine and dairy cattle leaching is based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016). Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

Table A6.4–14 **Annual Emission Factors (EF) for Cattle and Swine Manure Nitrogen (N) Lost as NH_3 Due to Volatilization During Storage**

	EF (kg NH_3 head^{-1} year^{-1})				
	1990	2005	2010	2015	2019
Cattle					
Dairy Cow	16	16	14	14	13
Beef Cow	11	12	13	14	14
Bull	16	19	21	20	20
Dairy heifer	12	12	11	10	10
Beef heifer-bred	8.6	10	10	10	10
Beef heifer-slaughter	4.0	5.4	5.5	5.8	5.9
Steer	4.2	5.4	5.6	5.9	6.1
Calf	4.7	4.7	4.7	4.7	4.6
Swine					
Sow	4.5	4.5	4.0	3.9	3.9
Boar	4.4	4.3	3.9	3.8	3.8
Pig (<20 kg)	0.5	0.5	0.4	0.4	0.4
Pig (20–60 kg)	1.9	1.9	1.7	1.6	1.6
Pig (>60 kg)	3.9	4.0	3.7	3.7	3.8

Note: Volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016). Derivation of the emission factors is explained in NIR Annex 3.4.

Table A6.4–15 **2019 Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching During Storage**

Livestock Category	Volatilization Emission Factor (EF)[a] (g N_2O head^{-1} year^{-1})	Leaching Emission Factor (EF)[b] (g N_2O head^{-1} year^{-1})
Poultry		
Turkey	13	0
Hens	4	0
Pullets	2	0
Broiler	3	0
Other Livestock		
Sheep	3	0
Goat	8	0
Buffalo	159	0
Horse	31	0
Llama and alpacas	9	0
Lamb	3	0
Deer	33	0
Elk	33	0
Wild boars	52	0
Rabbit	22	0
Mink	6	0
Fox	15	0
Mules and Asses	17	0

Notes:

a. Volatilization and indirect N_2O emission factors are taken from default parameters in the 2006 IPCC Guidelines. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

b. Leaching is not calculated as there are no tier 1 leaching factors available in the 2006 IPCC Guidelines.

Table A6.4–16 **2019 Emission Factors (EF) for Manure Nitrogen (N) Lost as NH_3 Due to Volatilization During Storage**

Livestock Category	Emission Factor (EF) (kg NH_3 head^{-1} year^{-1})
Poultry	
Turkey	1.0
Hens	0.3
Pullets	0.1
Broiler	0.2
Other Livestock	
Sheep	0.2
Goat	0.6
Buffalo	12
Horse	2.4
Llama and alpacas	0.7
Lamb	0.2
Deer	2.6
Elk	2.6
Wild boars	4.1
Rabbit	1.7
Mink	0.4
Fox	1.2
Mules and Asses	1.3

Note: Volatilization factors are taken from default parameters in the 2006 IPCC Guidelines. Derivation of the emission factors is explained in NIR Annex 3.4.

Table A6.4–17 Emission Factors (EF) for Manure Nitrogen (N) Lost as N_2O From Deposition of Cattle Manure on Pasture, Range and Paddock

Year	EF (g N_2O kg-N^{-1} $year^{-1}$)[a, b, c, d]									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.68	0.68	0.68	8.8	9.4	8.8	9.7	7.5	9.5	0.68
2005	0.68	0.68	0.68	8.8	9.5	8.8	9.6	7.5	9.4	0.68
2010	0.68	0.68	0.68	8.8	9.6	8.8	9.6	7.5	9.4	0.68
2019	0.68	0.68	0.68	8.8	9.5	8.8	9.6	7.5	9.4	0.68

Notes:

a. Emission factors are derived from Rochette et al. (2014) for eastern Canada, and Lemke et al. (2012) for western Canada.

b. The proportion of excreted manure deposited on pasture is taken from Marinier et al. (2005), for all livestock except dairy cows and heifers.

c. The proportion of excreted manure deposited on pasture by dairy cows and heifers is based on a farm size relationship derived from Sheppard et al. (2011a), as described in NIR Annex 3.4.

d. Derivation of the Tier 2 emission factors is explained in NIR Annex 3.4.

Table A6.4–18 Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching of Manure Deposited on Pasture, Range and Paddock

Year	EF (g N_2O kg-N^{-1} $year^{-1}$)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
Volatilization[a]										
1990	2.4	2.0	2.6	2.5	3.2	2.5	2.5	2.7	3.0	2.3
2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	2.2	2.8	2.0	2.3	1.7	2.5	2.3	2.3	1.6	1.9
2019	3.2	2.7	3.2	2.0	1.2	2.0	2.3	1.8	1.7	3.2
Leaching[b]										
1990	1.9	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2005	1.8	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2010	1.8	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.6
2019	1.8	1.8	2.1	3.5	3.5	3.5	3.1	3.5	3.4	1.5

Notes:

a. For dairy cattle, volatilization is calculated based on Sheppard et al. (2011b) and Chai et al. (2016), and the IPCC default indirect N_2O emission factor is used. For all other livestock the IPCC Tier 1 methodology is used to estimate indirect N_2O emission factors from volatilization. Default parameters are used from the 2006 IPCC Guidelines as described in NIR Annex 3.4.

b. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in NIR Annex 3.4.

Table A6.4–19 Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as NH_3 Due to Volatilization of Manure Deposited on Pasture, Range and Paddock

Year	EF (kg NH_3 kg N^{-1} $year^{-1}$)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.19	0.17	0.18	0.13	0.10	0.13	0.13	0.12	0.10	0.19
2005	0.20	0.18	0.19	0.14	0.09	0.14	0.15	0.13	0.12	0.20
2010	0.20	0.18	0.19	0.13	0.08	0.13	0.15	0.12	0.12	0.20
2019	0.20	0.18	0.19	0.13	0.09	0.13	0.14	0.12	0.11	0.20

Note:

For dairy cattle, volatilization is calculated based on Sheppard et al. (2011b) and Chai et al. (2016). For all livestock except dairy cattle, the IPCC Tier 1 methodology is used to estimate volatilization. Further detail can be found in NIR Annex 3.4.

Table A6.4–20 **Emission Factors (EF) for Crop Residue, Organic and Inorganic Fertilizer Nitrogen (N) Lost as N_2O Following Application to Agricultural Soils**

Year	EF (g N_2O kg^{-1} N $year^{-1}$)[a]									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	14	16	14	25	26	24	23	21	26	12
2005	13	16	15	25	26	24	23	21	26	11
2010	13	16	14	25	26	24	23	21	26	11
2019	13	16	14	25	26	24	23	21	26	12

Note:
a. Country-specific Tier 1 soil N_2O emission factors are calculated as described in NIR Annex 3.4.

Table A6.4–21 **Emission Factors (EF) for Manure Nitrogen (N) Lost as NH_3 from Agricultural Soils**

Year	EF (g NH_3 kg^{-1} N $year^{-1}$)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	225	209	219	291	262	290	250	291	267	229
2005	225	198	187	261	249	253	237	275	256	224
2010	224	193	181	249	245	241	234	264	252	225
2019	223	191	172	246	245	240	233	261	254	224

Notes:
For dairy cattle and swine, volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016).
For all other livestock the IPCC Tier 1 methodology is used to estimate volatilization. Further detail can be found in NIR Annex 3.4.

Table A6.4–22 **Emission Factors (EF) for Manure Nitrogen (N) Lost Indirectly as N_2O Due to Volatilization and Leaching of Manure Applied to Agricultural Soils**

	EF (g N_2O kg^{-1} N applied $year^{-1}$)									
Volatilization[a]	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	2.9	2.7	2.8	3.8	3.4	3.8	3.2	3.8	3.5	3.0
2005	2.9	2.6	2.4	3.4	3.2	3.3	3.1	3.6	3.3	2.9
2010	2.9	2.5	2.3	3.2	3.2	3.1	3.0	3.4	3.3	2.9
2019	2.9	2.5	2.2	3.2	3.2	3.1	3.0	3.4	3.3	2.9
Leaching[b]	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	1.9	2.4	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6
2005	1.8	2.3	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6
2010	1.8	2.4	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6
2019	1.8	2.5	2.1	3.5	3.5	3.5	3.1	3.5	3.5	1.6

Notes:
a. For dairy cattle and swine, volatilization is calculated based on Sheppard et al. (2010), Sheppard et al. (2011b) and Chai et al. (2016) and the IPCC default indirect N_2O emission factor is used. For all other livestock the IPCC Tier 1 methodology is used to estimate volatilization. Default parameters are used from the 2006 IPCC Guidelines as described in NIR Annex 3.4.
b. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in NIR Annex 3.4.

Table A6.4–23 **Fraction of N Volatilized ($FRAC_{GASM}$) as Ammonia Resulting from the Application of Biosolid N to Agricultural Soils**

IPCC default emission factor, $FRAC_{GASM}$	0.2 kg NH_3-N volatilized / kg N applied

Note: Source – IPCC (2006)

Table A6.4–24 **N_2O Emission Factor for Mid-latitude Cultivation of Organic Soils**

IPCC default emission factor for mid-latitude cultivation of organic soils	8.0 kg N_2O-N/ha-year

Note: Source – IPCC (2006)

Table A6.4–25 **Emission Factors (EF) for Biosolid Nitrogen (N) Lost Indirectly as N_2O Due to Leaching of Biosolids Applied to Agricultural Soils**

	EF (g N_2O kg^{-1} N applied $year^{-1}$)									
Leaching[a]	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	2.0	2.0	2.1	3.5	N/A	3.5	3.1	3.5	3.4	1.5
2005	2.0	2.1	2.1	3.5	N/A	3.5	3.0	3.5	3.4	1.5
2010	2.0	2.1	2.1	3.5	N/A	3.5	3.0	3.5	3.4	1.5
2019	2.0	2.0	2.1	3.5	N/A	3.5	3.0	3.5	3.4	1.5

Notes:
N/A = not available
a. A modified IPCC Tier 1 methodology is used to estimate N_2O emissions from leaching in agricultural soils, as described in NIR Annex 3.4.

Table A6.4–26 **Fractions of N Volatilized ($FRAC_{GASF}$) as Ammonia Resulting from the Application of Inorganic N Fertilizer, from Select Years, 1990–2019, at a Provincial Scale**

Year	Implied EF (kg NH_3-N volatilized/kg inorganic fertilizer N applied)									
	AB	BC	MB	NB	NL	NS	ON	PE	QC	SK
1990	0.06	0.09	0.06	0.07	0.00	0.08	0.08	0.06	0.09	0.05
1995	0.06	0.09	0.07	0.07	0.08	0.08	0.08	0.06	0.08	0.06
2000	0.06	0.10	0.07	0.06	0.00	0.07	0.08	0.05	0.08	0.06
2005	0.06	0.10	0.07	0.06	0.07	0.07	0.08	0.06	0.07	0.06
2010	0.06	0.09	0.07	0.05	0.07	0.06	0.08	0.05	0.07	0.06
2015	0.06	0.09	0.07	0.06	0.07	0.07	0.07	0.05	0.07	0.06
2019	0.06	0.08	0.07	0.06	0.07	0.08	0.07	0.05	0.07	0.06

Table A6.4–27 **Indirect N_2O Emissions from Agricultural Soils**

Emission factor due to volatilization and redeposition of Nitrogen	0.01 kg N_2O-N/kg N
Emission factor due to leaching/runoff	0.0075 kg N_2O-N/kg N

Note: Source – IPCC (2006)

A6.4.5. Other Sources

Table A6.4–28 **CH_4 and N_2O Emissions from Field Burning of Agricultural Residues**

CH_4 emission factor	2.7 g CH_4 kg^{-1} dry matter burnt
N_2O emission factor	0.07 g N_2O kg^{-1} dry matter burnt

Note: Source – IPCC (2006)

Table A6.4–29 **CO_2 Emissions from Liming and Urea Fertilization**

Dolomite emission factor	0.13 Mg C / Mg dolomite applied
Limestone emission factor	0.12 Mg C / Mg limestone applied
Urea emission factor	0.20 Mg C / Mg urea

Note: Source – IPCC (2006)

A6.5. Land Use, Land-Use Change and Forestry

The IPCC Tier 2 and Tier 3 methods and country-specific parameters are used for generating estimates for most of the LULUCF sector. The CBM-CFS3 model is used for estimating growth, litter fall, tree mortality and decomposition, as well as the effects of natural disturbances for Forest Land and the emissions due to forest conversion to other land uses. For Cropland, a process model (CENTURY) is used for estimating CO_2 emissions and removals as influenced by management activities, based on the National Soil Database of the Canadian Soil Information System.[4] More details on methods, emission factors and parameters for Forest Land, forest conversion and Cropland is provided in Annex 3.5 of this report, specifically in sections A3.5.2 and A3.5.4.

4 Available online at: https://sis.agr.gc.ca/cansis/nsdb/index.html

A country-specific model (NFCMARS-HWP) is used to estimate the emissions from the use and disposal of wood products reported under the Harvested Wood Products (HWP) category. For details on the methods and parameters used in the model, see section A3.5.3.

Emissions due to the conversion and management of peatlands for peat extraction, the creation of flooded lands (reservoirs) on areas with no evidence of forest clearing and from the conversion of grasslands to Settlements, are estimated using IPCC Tier 2 methods and country-specific parameters (see sections A3.5.6.1, A3.5.6.2 and A3.5.7.3). Net CO_2 removals from the growth of urban trees are estimated using an IPCC Tier 2A approach (see section A3.5.7.1). In addition, emissions due to the occasional burning of grassland are estimated using an IPCC Tier 1 method and default emissions factors (see section A3.5.5.1).

A compilation of the spatial framework and parameters used to develop and report the LULUCF estimates is provided in this annex (see figures A6.5–1 to A6.5–6 and tables A6.5–1 to A6.5–6).

A6.5.1. Reporting Zones

Figure A6.5–1 **Reporting Zones for LULUCF estimates**

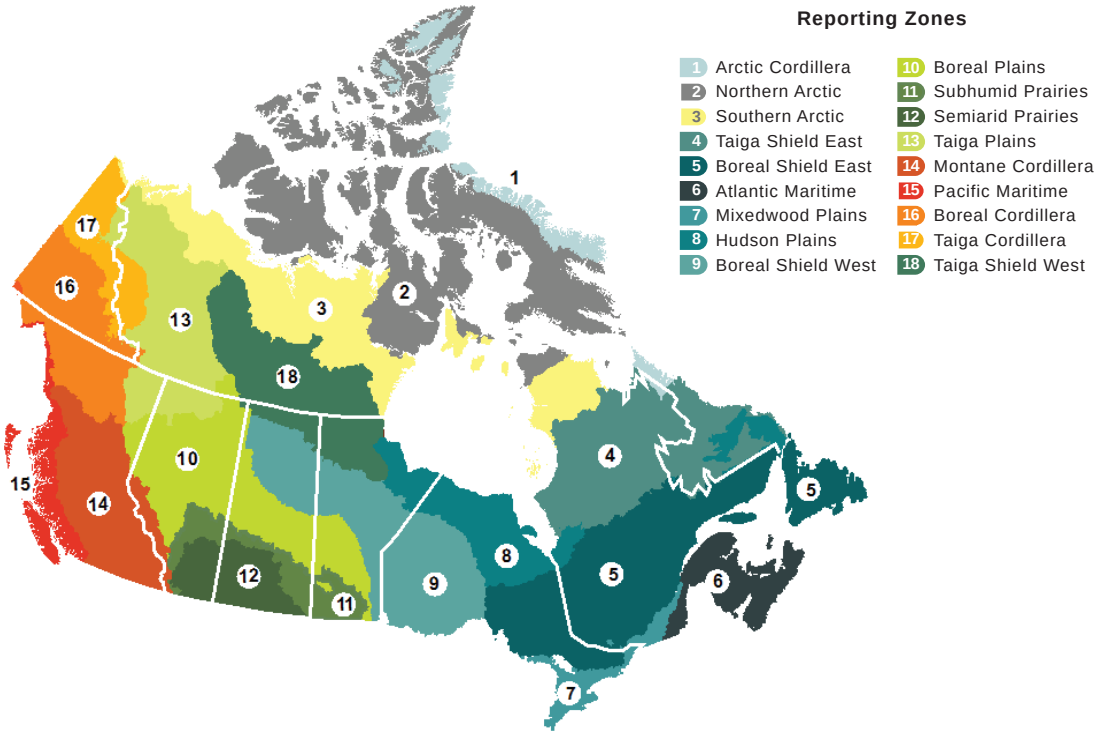
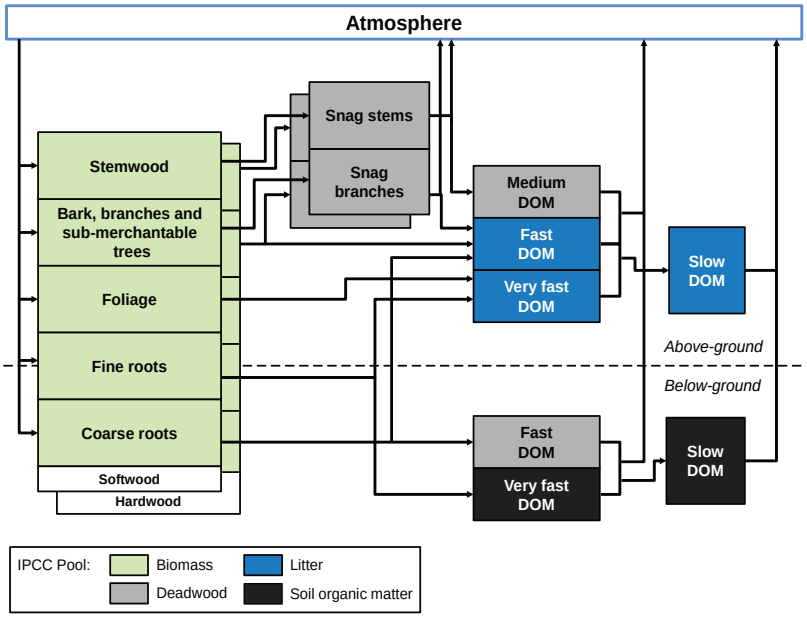


Figure A6.5–2 Carbon Transfers Between Forest Pools



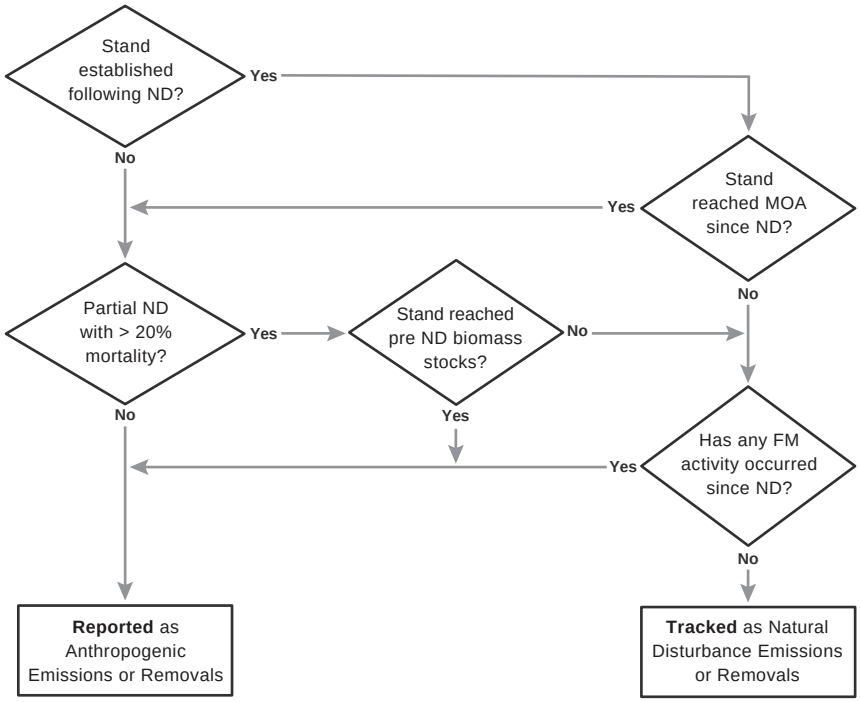
Note: Source – White et al. (2008), updated

Figure A6.5–3 Disturbance Matrix Parameters for Carbon Modelling (Selected Examples)

Disturbance Matrix Simulating the Carbon Transfers Associated with Clear-Cut Harvesting and Salvage Logging Applicable in all Ecozones Except Those in Alberta and Quebec

	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-merchantable			1							
5. Softwood coarse roots			0.5	0.5						
6. Softwood fine roots	0.5	0.5								
7. Hardwood merchantable					0.15					0.85
8. Hardwood foliage	1									
9. Hardwood other			1							
10. Hardwood sub-merchantable			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	

Figure A6.5–4 **Decision Tree for Managed Forest**



Notes:
ND = Natural disturbance
MOA = Minimum operable age
FM = Forest management

A6.5.3. Harvested Wood Products

Table A6.5–1 **Default Parameter Values Used in HWP Analysis**

Description	Units	Value	Source
Bark expansion factor, Softwoods	dimensionless	1.11	IPCC, 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Hardwoods	dimensionless	1.15	IPCC, 2006 (Vol. 4, Table 12.5)
Bark expansion factor, Mixedwoods	dimensionless	1.13	IPCC, 2006 (Vol. 4, Table 12.5)
C content of wood	tonnes C/od tonne [a]	0.5	IPCC, 2006 (Vol. 4, Table 12.4)

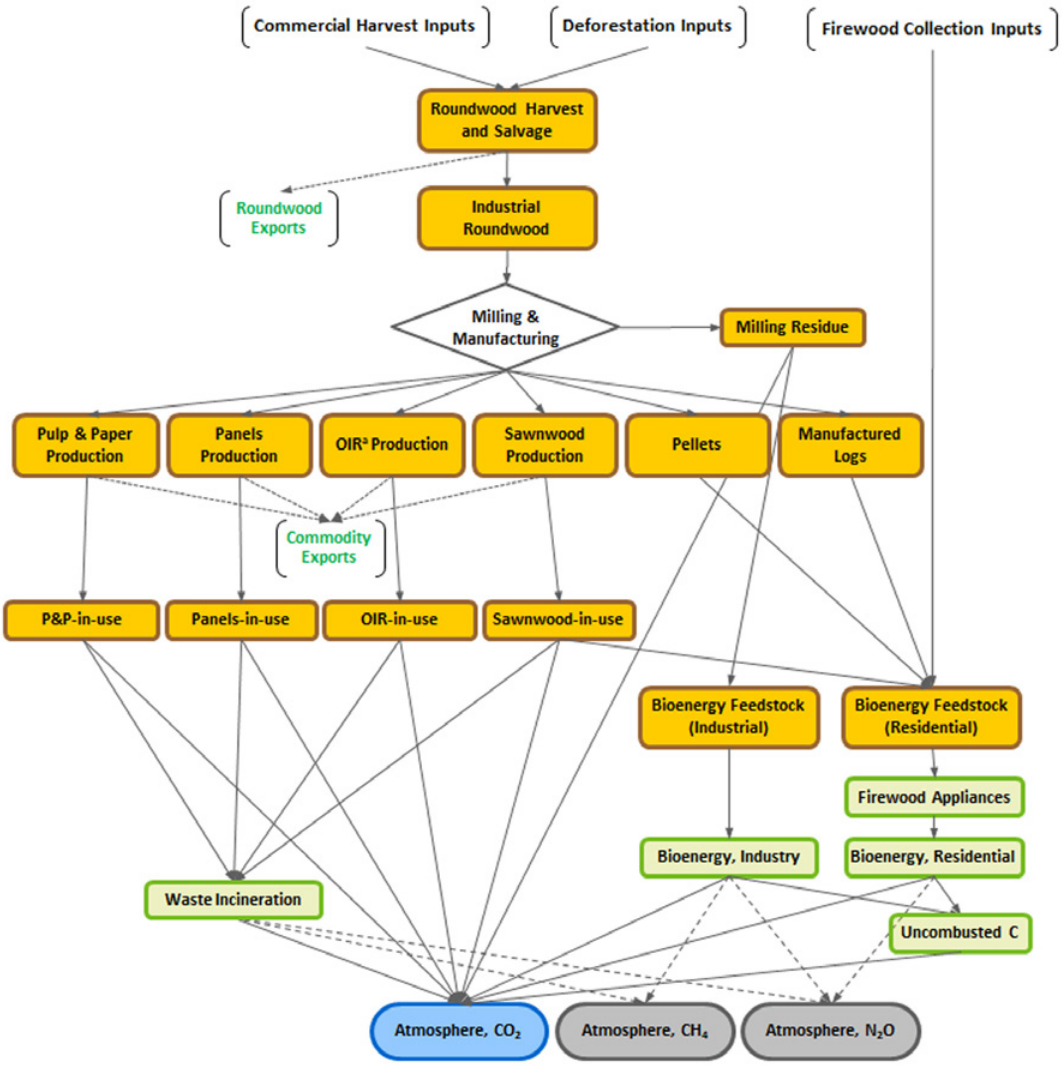
Note:
a. Tonnes carbon per oven dry tonne of wood material.

Table A6.5–2 **Wood Densities of Commodities**

Country/Countries	Description	Units	Value	Source
Canada	Species-weighted average density, Roundwood	od tonne/m³	0.386	Derived
Canada	Species-weighted average density, Sawnwood	od tonne/m³	0.481	Derived
Canada	Species-weighted average density, Other industrial roundwood	od tonne/m³	0.583	Derived
Canada	Species-weighted average density, Panels	od tonne/m³	0.643	Derived
Canada	Species-weighted average density, Bioenergy	od tonne/m³	0.523	Derived
U.S.	Coniferous (C) roundwood	od tonne/green m³	0.455	FAO, 2010
U.S.	Nonconiferous (NC) roundwood	od tonne/green m³	0.527	FAO, 2010
U.S.	C+NC roundwood	od tonne/green m³	0.465	FAO, 2010
U.S.	Hardwood (HW) plywood & veneer	tonnes C/m³	0.28	Skog, 2008
U.S.	Softwood (SW) lumber	tonnes C/m³	0.22	Skog, 2008
U.S.	HW lumber	tonnes C/m³	0.26	Skog, 2008
U.S.	Particle board	tonnes C/m³	0.29	Skog, 2008
U.S.	Hardboard	tonnes C/m³	0.42	Skog, 2008
U.S.	Medium density fibreboard	tonnes C/m³	0.32	Skog, 2008
U.S.	Fibreboard, compressed	tonnes C/m³	0.37	Derived
U.S.	Pulp, paper & board	tonnes C/ad tonne	0.42	Skog, 2008
U.S.	Insulating board	tonnes C/m³	0.45	Skog, 2008
All	Sawnwood – C	od tonne/m³	0.45	IPCC, 2006 (Vol. 4, Table 12.4)
All	Sawnwood – NC	od tonne/m³	0.45	IPCC, 2006 (Vol. 4, Table 12.4)
All	Panels, structural	od tonne/m³	0.628	IPCC, 2006 (Vol. 4, Table 12.4)
All	Panels, non-structural	od tonne/m³	0.628	IPCC, 2006 (Vol. 4, Table 12.4)
All	Paper	od tonne/ad tonne	0.9	IPCC, 2006 (Vol. 4, Table 12.4)
All	Wood pulp	od tonne/ad tonne	0.9	IPCC, 2006 (Vol. 4, Table 12.4)

Notes:
od tonne = oven dry tonne of wood material
ad tonne = air dry tonne of product

Figure A6.5–5 **Carbon Flows in Harvested Wood Products**



Note:
OIR = Other Industrial Roundwood

Table A6.5–3 **Half-Life Parameters (Years) of Harvested Wood Products In-Use**

Country/Countries	Description [a]	Value	Source
Canada	Sawnwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Wood panels	25	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Pulp and paper	2	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Canada	Other industrial roundwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Sawnwood	40	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Wood panels	27	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Pulp and paper	3	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
U.S.	Other industrial roundwood	40	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Sawnwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Wood panels	25	Derived from IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Pulp and paper	2	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)
Rest of world	Other industrial roundwood	35	IPCC, 2003 (Appendix 3a.1, Table 3a.1.3)

Note:

a. Firewood and mill residue assumed to be burned for the former, or disposed of for the latter, in the year of harvest.

A6.5.4. Cropland

Table A6.5–4 **Effective Linear Coefficients of Soil Organic Carbon for Land Management Change (LMC)**

Zone [a]	LMC [b,c]	k/year	ΔCLMCmax (Mg/ha)	Final Year of Effect after LMC [d]	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:

Effective Linear Coefficients of Soil Organic Carbon were generated using $F_{LMC(t)} = \Delta C_{LMCmax} \times [1 - \exp(-k \times t)]$.

a. Area-weighted summary: East Atlantic is the Atlantic Maritime reporting zone plus the Boreal Shield reporting zone in NL; East Central is the Mixedwood Plains reporting zone plus the Boreal Shield East reporting zone in ON and QC; 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.

b. For LMCs in the opposite direction to that listed, the FLMCmax will be the negative of the value listed.

c. IT = intensive tillage, RT = reduced tillage, NT = no-till

d. No further C changes once the absolute value of the rate of change is less than 25 kg C/ha per year.

Table A6.5–5 **Parameters and Emission Factors for Estimating Emissions from Peat Extraction**

Emission Factor/Parameter	Unit	EF Value	Sources
Biomass Clearing			
Forest land biomass cleared	t C ha^{-1}	19.2	Hayne and Verbicki, 2011
Other land biomass cleared	t C ha^{-1}	2.8	Hayne and Verbicki, 2011
Drainage			
CO_2 from drained areas	t CO_2 ha^{-1} yr^{-1}	11.4	Moore et al., 2002, as cited in Cleary, 2003; Glatzel et al., 2003; Waddington et al., 2010; Strack and Zuback, 2013; Strack et al., 2014
CO_2 -DOC from drained areas	t CO_2 ha^{-1} yr^{-1}	0.60	Waddington et al., 2008; Strack and Zuback, 2013
CH_4 from drained fields	t CH_4 ha^{-1} yr^{-1}	0.008	Moore et al., 2002 as cited in Cleary, 2003; Waddington and Day, 2007; Strack and Zuback, 2013; Strack et al., 2014
CH_4 from drainage ditches	t CH_4 ha^{-1} yr^{-1}	0.15	Waddington and Day, 2007
N_2O from drained areas	t N_2O ha^{-1} yr^{-1}	0.00047	IPCC, 2014 (Table 2.5, Default value for Boreal & Temperate climate zone)
CO_2 from abandoned block-cut areas	t CO_2 ha^{-1} yr^{-1}	8.6	Waddington and Price, 2000; Waddington and Warner, 2001; Waddington et al., 2002; McNeil and Waddington, 2003
CH_4 from abandoned block-cut areas	t CH_4 ha^{-1} yr^{-1}	0.012	Waddington and Price, 2000
CO_2 tree plantation biomass uptake	t CO_2 ha^{-1} yr^{-1}	-0.32	Garcia Bravo, 2015
Peat Stockpiling and Product Production			
Amount of stockpiled peat	t C ha^{-1}	50	Cleary, 2003
Exponential decay constant, stockpiled peat		0.05	Cleary, 2003
Carbon fraction of peat products	t C t air-dry peat-1	0.26	Hayne et al., 2014
Rewetting and Restoration			
CO_2 from restored areas	t CO_2 ha^{-1} yr^{-1}	7.60	Moore et al., 2002 as cited in Cleary, 2003; Petrone et al., 2001; Petrone et al., 2003; Waddington et al., 2010; Strack and Zuback, 2013; Strack et al., 2014
CO_2-DOC from restored areas	t CO_2 ha^{-1} yr^{-1}	0.13	Waddington et al., 2008; Strack and Zuback, 2013
CH_4 from restored fields	t CH_4 ha^{-1} yr^{-1}	0.03	Moore et al., 2002 as cited in Cleary, 2003; Waddington and Day, 2007; Strack and Zuback, 2013; Strack et al., 2014
CH_4 from restored ditches	t CH_4 ha^{-1} yr^{-1}	0.28	Waddington and Day, 2007; Strack and Zuback, 2013
N_2O from restored areas	t N_2O ha^{-1} yr^{-1}	N/A	IPCC, 2014, Default assumption of no N_2O emissions from rewetted/ restored areas

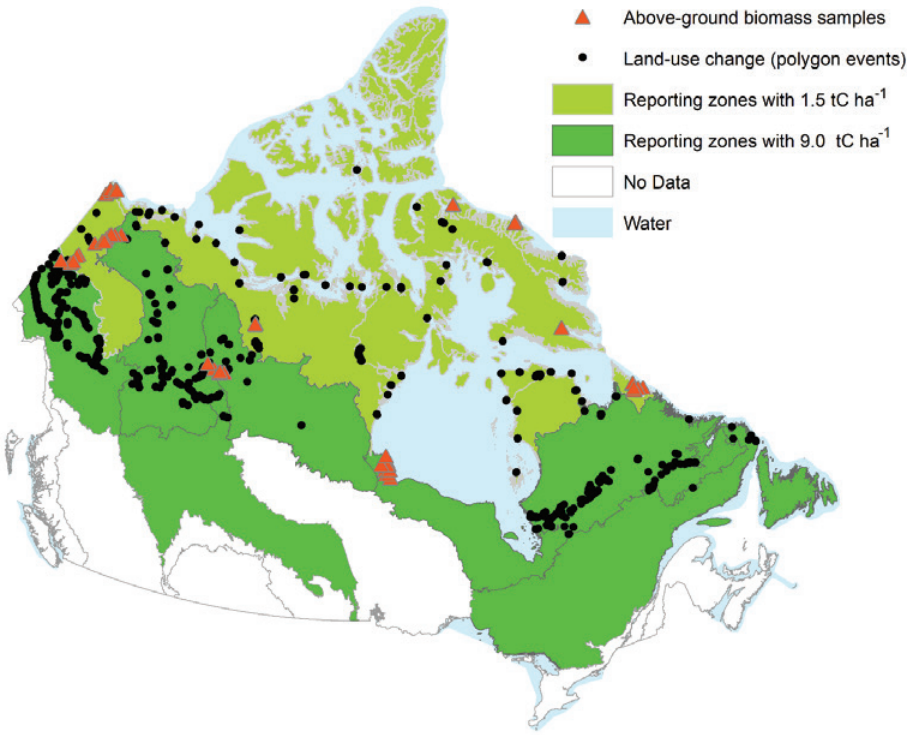
Note: All units where the greenhouse gas (GHG) is specified use units of the relevant GHG (CO_2, CH_4 or N_2O) instead of C and N.

Table A6.5–6 **Carbon Storage and Sequestration in Urban Trees**

Reconcilliation Unit (RU)	Carbon Storage (t C ha^{-1} yr^{-1})	Carbon Sequestration (t C ha^{-1} yr^{-1})
1 NF – Boreal Shield East	40	3.0
5 NS – Atlantic Maritime	62	3.4
6 PE – Atlantic Maritime	62	3.4
7 NB – Atlantic Maritime	62	3.4
11 QC – Atlantic Maritime	62	3.4
12 QC – Mixedwood Plains	58	2.4
15 QC – Boreal Shield East	40	3.0
16 ON – Boreal Shield West	40	3.0
17 ON – Mixedwood Plains	58	2.4
19 ON – Boreal Shield East	40	3.0
24 MB – Subhumid Prairies	55	2.9
28 SK – Boreal Plains	40	3.0
30 SK – Semiarid Prairies	55	2.9
34 AB – Boreal Plains	40	3.0
35 AB – Subhumid Prairies	55	2.9
37 AB – Semiarid Prairies	55	2.9
41 BC – Pacific Maritime	97	6.9
42 BC – Montane Cordillera	23	1.4

Note: Source – Steenberg et al., 2021

Figure A6.5–6 **Map of Sample Points and Land-Use Change Events in Canada's North**



Note: More southerly reporting zones are attributed to the 9 tC ha^{-1} biomass class, as some sites border on the northernmost boundary of these reporting zones.

A6.5.7. Forest Conversion

Table A6.5–7 **Soil Organic Carbon in Forest and Agricultural Land (0- to 30-cm soil depth)**

Soil Texture	Soil Organic Carbon (Mg C/ha)		Difference (%)
	Forested Land[a]	Cropland[a]	
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:
a. Standard deviation in parentheses.

A6. Biomass Combustion

A6.6.1. 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. Emissions from prescribed burning and from the combustion of biomass for energy use are estimated and reported in the Land Use, Land-use Change and Forestry (LULUCF) sector, in common reporting format (CRF) Tables 4(V) and 4.G respectively. Forest wildfires are considered uncontrollable natural disturbances in the modelling and reporting approach used in the LULUCF sector by which these emissions and subsequent removals are estimated and tracked separately from emissions/removals resulting from commercially managed forest stands, more details on his approach can be found in Annex A3.5.2.4.

The emissions related to energy use are reported as memo items in the CRF tables of the Energy sector, as required by the United Nations Framework Convention on Climate Change (UNFCCC).

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The CO_2 emission factor (Table A6.6–1) for industrial wood waste has been developed from facility source sampling data collected

Table A6.6–1 **Emission Factors for Biomass**

Source[a]	Description	Emission Factor (g/kg fuel)		
		CO_2	CH_4	N_2O
Wood Fuel / Wood Waste	Industrial Combustion	1 715[b]	0.1[c]	0.07[c]
Forest Wildfires	Open Combustion	NA	NA[d]	NA[e]
Controlled Burning	Open Combustion	NA	NA[d]	NA[e]
Spent Pulping Liquor	Industrial Combustion	1 250[f]	0.03[g]	0.005[g]
Stoves and Fireplaces	Residential Combustion			
Conventional Stoves		1 539[h]	12.9[h]	0.12[h]
Conventional Fireplaces and Inserts		1 539[h]	12.9[h]	0.12[h]
Stoves/Fireplaces with Advanced Technology		1 539[h]	5.9[h]	0.12[h]
or Catalytic Control				
Pellet Stove		1 652[b]	4.12[h]	0.059[h]
Other Wood-burning Equipment		1 539[h]	4.12[h]	0.059[h]

Notes:
NA = Not applicable

a. CO_2 emissions from biomass combusted for energy or agricultural purposes are not included in inventory totals, whereas CH_4 and N_2O emissions from these sources are inventoried under the Energy Sector. All greenhouse gas (GHG) emissions, including CO_2 emissions 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.
b. Adapted from U.S. EPA (2003).
c. Adapted from U.S. EPA (2003) and NCASI TB998 (2012).
d. Emission ratio for CH_4 is 1/90th CO_2. See NIR Annex 3.4.
e. Emission ratio for N_2O is 0.017% CO_2. See NIR Annex 3.4.
f. Adapted from NCASI (2011).
g. Adapted from NCASI (2012).
h. Adapted from IPCC (2006).

by the U.S. EPA in units of lb/MMBTU (one million British thermal units; U.S. EPA, 2003). The U.S. EPA data were converted to kg/tonne at 0% moisture content (m.c.) using a higher heating value (HHV) of 20.44 MJ/kg, 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 0% m.c. using a HHV of 13.7 MJ/kg (Tran, 2014).

CO_2 emission factor for residential combustion (Table A6.6–1) is based on the default 2006 IPCC guidelines. The IPCC data were converted to g/kg at 19% moisture content using a lower heating value (LHV) of 13.2 MJ/kg, which was calculated based on the assumption that LHV is 20% less than the HHV (FPL, 2004). The HHV was developed from an internal review of available moisture content and heating value data.

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 A3.5).

A6.6.2. CH_4

Emissions of CH_4 from residential combustion of firewood are technology-dependent. The CH_4 emission factors are based on the default 2006 IPCC guidelines. The IPCC values were converted to g/kg at 19% m.c. using the same method used for the CO_2 conversion.

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The emission factor (Table A6.6–1) 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 (U.S. EPA, 2003) and collected by the NCASI in units of kg/MMBTU and converted to kg/tonne at 0% m.c. as discussed in section A6.6.1. The emission factor for CH_4 from spent pulping liquor has been developed using source sampling data from NCASI in units of kg/MMBTU, converted to kg/tonne at 0% m.c. using a HHV of 13.7 MJ/kg as discussed in section A6.6.1.

Emission factors from landfill gas (Table A6.6–2) are adapted 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.

A6.6.3. N_2O

Emissions of N_2O from residential combustion of firewood are technology-dependent. The N_2O emission factors are based on the default 2006 IPCC guidelines. The IPCC values were converted to g/kg at 19% m.c. using the same method used for the CO_2 conversion.

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. Emission factors (Table A6.6–1) for industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA, 2003) and collected by the National Council for Air and Stream Improvements (NCASI) in units of kg/MMBTU and converted to kg/tonne at 0% m.c. as discussed in section A6.6.1. The emission factor for N_2O from spent pulping liquor has been developed using source sampling data from NCASI in units of kg/MMBTU, converted to kg/tonne at 0% m.c. using a HHV of 13.7 MJ/kg as discussed in section A6.6.1.

Emission factors for landfill gas (Table A6.6–2) are adapted 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 A3.5.2).

Table A6.6–2 **Emission Factors for Landfill Gas Combustion**

Source	Description	Emission Factor			Emissin Factor Units
		CO_2	CH_4	N_2O	
Landfill Gas	Industrial combustion (for energy)	2 752[a]	0.05[a]	0.05[a]	kg/t CH_4 utilized for energy
Landfill Gas	Flaring	NE	30[b]	NE	kg/t CH_4 flared

Notes:
NE = Not estimated
a. Adapted From IPCC (2006) (Vol. 2, Table 2.2)
b. U.S. EPA (1995)

A6.7. Waste

A6.7.1. Municipal Wastewater Handling

A6.7.1.1. CH_4

Emissions from municipal wastewater handling are dependent on the organic loading of the effluent stream (which is a function of population), and the type of wastewater treatment provided. Emission factors (EF) are the product of the methane correction factor (MCF), which is the technology-specific estimate of the fraction of biological oxygen demand (BOD) that will ultimately degrade anaerobically, and the maximum methane producing capacity (B_0), which is expressed in terms of kg CH_4/kg BOD removed. The IPCC default value of 0.6 kg CH_4/kg BOD for B_0 was not used. The AECOM (2011) study commissioned by Environment Canada confirmed that its derivation from the 0.25 kg CH_4/kg COD was erroneous, where COD is the chemical oxygen demand. A Canada specific value of 0.36 CH_4/kg BOD for B_0 was used (AECOM, 2011).

The MCF and EF values for CH_4 emissions from wastewater treatment and discharge, by treatment technology are shown in Table A6.7–1.

A6.7.1.2. N_2O

N_2O emissions from wastewater are a function of the nitrogen entering the wastewater stream, which is, in turn a function of protein consumption per capita, population, nitrogen content in protein, and adjustment factors for input of non-consumed nitrogen (e.g. from washing) and industrial inputs. The emission factor used is the IPCC 2006 Guideline default value of 0.005 kg N_2O-N/kg N (IPCC, 2006). The emission factor for N_2O from wastewater treatment and discharge is shown in Table A6.7–2.

Table A6.7–2 **Emission Factors for N_2O from Wastewater Treatment and Discharge**

N_2O Emission Factor	Units	Source
0.005	kg N_2ON/kg N	IPCC (2006) (Vol. 5, Chapter 6)

Table A6.7–1 **Methane Correction Factors (MCF) and Emission Factors (EF) for CH_4 from Wastewater Treatment and Discharge**

Treatment	MCF	EF	Source
No Treatment	0.1	0.036	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Primary	0.018	0.0036	IPCC (2019) Guideline Refinement
Aerobic Lagoon	0	0	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Anaerobic Lagoon	0.8	0.288	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Facultative Lagoon	0.2	0.072	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Other / Unspecified Lagoon	0.2	0.072[a]	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Secondary Anaerobic	0.8	0.288	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Secondary Activated Sludge	0.01	0.0036	IPCC (2019) Guideline Refinement
Trickling Filter	0.01	0.0036	IPCC (2019) Guideline Refinement
Trickling Filter – High Rate	0.01	0.0036	IPCC (2019) Guideline Refinement
Rotating Biological Contactor	0.01	0.0036	IPCC (2019) Guideline Refinement
Sequencing Batch Reactor	0.05	0.018	Taseli (2018). Point source pollution and climate change impact from Sequential Batch Reactor wastewater treatment plant
Secondary Biofiltration	0.018	0.0036	IPCC (2019) Guideline Refinement
Secondary with Biological Nutrient Removal	0.018	0.0036	IPCC (2019) Guideline Refinement
Septic	0.5	0.18	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Septic with Marine Outfall	0.5	0.18[b]	IPCC (2006) (Vol. 5, Chapter 6, Table 6.3)
Wetland	0.17	0.0612[d]	IPCC Supplement to 2006 Guidelines for Wetlands (2014). Chapter 6. Mean value of MCF's for three wetland types provided in document.
Other / Unknown	0.2	0.072[c]	Modeling as facultative lagoon

Notes:

a. Unspecified Lagoon types were assumed to be facultative.

b. Discharge to sea, river or lake.

c. Assuming facilities of unknown or other treatment type are either facultative lagoon or untreated discharge to sea. The median value of the MCF and EF of these technologies used.

d. Mean value of three possible wetland treatment types used.

A6.7.2. Waste Incineration

The emission factors for CO_2, CH_4, and N_2O for waste incineration are shown in Table A6.7–3.

A6.7.2.1. Sewage Sludge Incinerators

Emissions from sewage sludge incinerators are estimated from an emission factor obtained from the IPCC 2006 Guidelines (IPCC, 2006).

A6.7.2.2. Municipal Solid Waste Incinerators

The emission estimates from municipal solid waste incineration are calculated based on bach or continuous operations, and based on stoker or fluidized bed combustion technology. The emission factors used are from the IPCC 2006 Guidelines (IPCC, 2006). For CO_2 emissions, only the non-biogenic (fossil) portion of the waste is included when calculating emissions.

A6.7.2.3. Hazardous Waste Incinerators

The emission factors for hazardous waste incineration are taken from the IPCC 2006 Guidelines (IPCC, 2006). The CO_2 emission factor is based on a carbon content of 50% and fossil carbon content of 90% of the carbon content.

A6.7.2.4. Clinical Waste Incinerators

The emission factors for clinical waste incineration are taken from the IPCC 2006 Guidelines (IPCC, 2006). The CO_2 emission factor is based on a carbon content of 45%.

A6.7.3. Biological Treatment of Solid Waste

The emission factors for CO_2, CH_4, and N_2O for the biological treatment of solid waste are shown in Table A6.7–4.

Table A6.7–3 Emission Factors for Waste Incineration

Category	Emission Factors			Units
	CO_2	CH_4	N_2O	
Municipal Solid Waste Incineration – Continuous – Fluidized Bed	3666.67*	0.0002	0.00005	kg / tonne waste (for CH_4, N_2), *kg CO_2 / tonne fossil C in waste
Municipal Solid Waste Incineration – Continuous – Stoker		0	0.00005	
Municipal Solid Waste Incineration – Semi-Continuous – Fluidize Bed		0.006	0.00005	
Municipal Solid Waste Incineration – Semi-Continuous – Stoker		0.188	0.00005	
Municipal Solid Waste Incineration – Batch – Fluidized Bed		0.06	0.00006	
Municipal Solid Waste Incineration – Batch – Stoker		0.237	0.00006	
Sewage Sludge Incineration	1650.00	9.70	0.99	kg / tonne sewage sludge
Hazardous Waste Incineration	1650.00	0.20	0.10	kg / tonne waste
Clinical Waste Incineration – Continuous	1738.00	0.0002	0.05	kg / tonne wase
Clinical Waste Incineration – Batch	1738.00	0.06	0.06	kg / tonne waste

Note: Source – IPCC (2006)

Table A6.7–4 Emission Factors for the Biological Treatment of Solid Waste

Category	Waste of Facility Type	Emission Factors			Units	Source
		CO_2	CH_4	N_2O		
Anaerobic Digestion	Off-farm facilities	NA	2.10	NA	% of methane produced in biogas	ECCC (2020b)
Composting	Yard Waste	NA	1.72	0.25	g/kg Wet Waste	ECCC (2020c)
	Biosolids or Manure	NA	3.54	0.18	g/kg Wet Waste	ECCC (2020c)
	Mixture of Wastes	NA	1.09	0.11	g/kg Wet Waste	ECCC (2020c)
	Municipal Solid Waste	NA	1.51	0.18	g/kg Wet Waste	ECCC (2020c)

Note:
NA = Not applicable

OZONE AND AEROSOL PRECURSORS

The Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (FCCC/CP/2013/10/Add.3 – UNFCCC 2014) recommends that Parties provide information on indirect greenhouse gases (GHGs) such as carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SO_x) in the National Inventory Report.

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 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 GHG and quickly react to form GHGs, as in the case of CO reacting with a hydroxyl radical to form carbon dioxide (CO_2) in the atmosphere—hence the label "indirect greenhouse gases." Emissions from these precursors are produced by a number of sources, such as fossil fuel combustion in the energy and transportation sectors, industrial production and biomass combustion.

Information on ozone and aerosol precursor emissions in Canada, including CO, NO_x, NMVOC and SO_x is available in Canada's Air Pollutant Emissions Inventory Report.[1]

Canada also reports "indirect CO_2 emissions" that result from the atmospheric oxidation of CO emitted from biomass burned on site after forest harvest and from forest conversion activities. These emissions are reported in the Land Use, Land-use Change, and Forestry (LULUCF) sector within Table 6 of the Common Reporting Format[2] (CRF). National totals are presented in CRF Tables 10 and Summary 2 with and without these "indirect CO_2 emissions" in accordance with paragraph 29 of the UNFCCC Annex I inventory reporting guidelines (UNFCCC, 2014). Details on the source of these emissions can be found in Chapter 6 and Annex 3.5 of this report.

1 *Canada's Air Pollutant Emissions Inventory Report* can be found at www.canada.ca/APEI.

2 Canada's 2021 Common Reporting Format Tables can be found at https://unfccc.int/ghg-inventories-annex-i-parties/2021

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Annex 3.5, Methodology for Land Use, Land-Use Change and Forestry

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Annex 3.6, Methodology for Waste Sector

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