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1990–2012

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List of Acronyms, Abbreviations and Units

AAC	Aluminum Association of Canada
AAFC	Agriculture and Agri-Food Canada
AC	air conditioning
AER	Alberta Energy Regulator
AGEM	Aviation Greenhouse Gas Emission Model
AIA	Association de l'industrie d'aluminium du Québec
Al	aluminium
Al2O3	alumina
API	American Petroleum Institute
ASH	manure ash content
Asha	Ash content in baked anodes
Ashp	Ash content in pitch
ATV	all-terrain vehicle
AWMS	animal waste management system
BADA	Base of Aircraft Data
B_0	maximum methane production potential
BC	average binder content in paste
BOF	basic oxygen furnace
BOD_5	five-day biochemical oxygen demand
BSM	emissions of benzene-soluble matter
C	carbon
CAC	Criteria Air Contaminant
CaC_2	calcium carbide
$CaCO_3$	calcium carbonate; limestone
$CaMg(CO_3)_2$	dolomite (also $CaCO_3$•$MgCO_3$)
CanFI	Canada's National Forest Inventory
CANSIM	Statistics Canada's key socioeconomic database
CanSIS	Canadian Soil Information System
CanWEA	Canadian Wind Energy Association
CaO	lime; quicklime; calcined limestone
CAPP	Canadian Association of Petroleum Producers
CBM	Carbon Budget Model
CBM-CFS3	Carbon Budget Model for the Canadian Forest Sector, version 3
CC	baked anode consumption per tonne of aluminium
CEA	Canadian Electricity AssociationCEPA 1999 *Canadian Environmental Protection Act, 1999*
CESI	Canadian Environmental Sustainability Indicators
CF_4	carbon tetrafluoride
C_2F_6	carbon hexafluoride
CFC	chlorofluorocarbon
CFS	Canadian Forest Service
CGA	Canadian Gas Association
CH_3OH	methanol
CH_4	methane
C_2H_6	ethane
C_3H_8	propane
C_4H_{10}	butane
C_2H_4	ethylene
C_6H_6	benzene

$CHCL_3$	chloroform
CIEEDAC	Canadian Industrial Energy End-Use Data Analysis Centre
CKD	cement kiln dust
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO	carbon monoxide
CO_2	carbon dioxide
CO_2 eq	carbon dioxide equivalent
COD	chemical oxygen demand
CORINAIR	Core Inventory of Air Emissions in Europe
CPPI	Canadian Petroleum Products Institute
CRF	Common Reporting Format
CSPA	Canadian Steel Producers Association
CTS	crop and tillage system
CVS	Canadian Vehicle Survey
DE	digestible energy
DM	dry matter
DMI	dry matter intake
DOC	degradable organic carbon
DOCF	degradable organic carbon dissimilated
DOM	dead organic matter
EAF	electric arc furnace
EC	Environment Canada
EDC	ethylene dichloride
EF	emission factor
EF_{BASE}	basic emission factor
EMEP	European Monitoring and Evaluation Programme
EPA	Environmental Protection Agency (United States)
EPGTD	Electric Power Generation, Transmission and Distribution
eq	equivalent
ERCB	Energy Resources Conservation Board
ERT	Expert Review Team
EU	European Union
FAA	Federal Aviation Administration (United States)
FAACS	Feasibility Assessment of Afforestation for Carbon Sequestration
FCR	fuel consumption ratio
FGD	flue gas desulphurization
FLCL	forest land converted to cropland
FLWL	forest land converted to wetland
FOI	Swedish Defence Research Agency
FTILL	tillage ratio factor
GCD	great-circle distance
GCV	gross calorific value
GDP	gross domestic product
GE	gross energy
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
GIS	geographic information system
Gt	gigatonne
GRI	Gas Research Institute
GTIS	Global Trade Information Services
GVWR	gross vehicle weight rating

GWP	global warming potential
H_2	hydrogen
H_2O	water
H2S	hydrogen sulphide
HCFC	hydrochlorofluorocarbon
HCl	hydrochloric acid
HDD	heating degree-day
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
HE	harvest emissions
HF	hydrogen fluoride
HFC	hydrofluorocarbon
HHV	higher heating value
HNO_3	nitric acid
HQ	Hydro-Québec
HRAI	Heating, Refrigeration and Air Conditioning Institute of Canada
HSS	horizontal stud Søderberg
HWP	harvested wood product
HWP-C	carbon stored in harvested wood products
IAI	International Aluminium Institute
ICAO	International Civil Aviation Organization
IE	included elsewhere
IEA	International Energy Agency
IESO	Independent Electricity System Operator
I/M	inspection and maintenance
Impa	fluorine and other impurities
IPCC	Intergovernmental Panel on Climate Change
IT	intensive tillage
KAR	kilometre accumulation rate
K_2CO_3	potassium carbonate
kg	kilogram
kha	kilohectare
kt	kilotonne
kWh	kilowatt-hour
L_0	methane generation potential
LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LFG	landfill gas
LHV	lower heating value
LMC	land management change
LPG	liquefied petroleum gas
LTO	landing and takeoff
LULUCF	Land Use, Land-use Change and Forestry
m	metre
MARS	Monitoring, Accounting and Reporting System
MC	motorcycle
MCF	methane conversion factor (Agriculture)
MCF	methane correction factor (Waste)
Mg	magnesium; also megagram

$MgCO_3$	magnesite; magnesium carbonate
MGEM	Mobile Greenhouse Gas Emission Model
MgO	magnesia; dolomitic lime
Mha	megahectare, equivalent to a million hectares
MMIC	Motorcycle & Moped Industry Council
MODTF	Modeling and Database Task Force
mol	mole
MP	total aluminum production
MS	manure system distribution factor
MSW	municipal solid waste
Mt	megatonne
MTOW	maximum takeoff weight
MW	megawatt
N	nitrogen
N_2	nitrogen gas
Na_2CO_3	sodium carbonate; soda ash
Na_3AlF_6	cryolite
NA	not applicable
N/A	not available
NAICS	North American Industry Classification System
NCASI	National Council for Air and Stream Improvement
NCV	net calorific value
NE	not estimated
NEB	National Energy Board
NEU	non-energy use
NFR	nomenclature for reporting
NGL	natural gas liquid
NH_3	ammonia
NH_{4+}	ammonium
NH_4NO_3	ammonium nitrate
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound
N_2O	nitrous oxide
NO	nitric oxide; also used for not occurring
NO_2	nitrogen dioxide
NO_3	nitrate
NO_x	nitrogen oxides
NOC	Nitrous Oxide of Canada
NPRI	National Pollutant Release Inventory
NRCan	Natural Resources Canada
NSCR	non-selective catalytic reduction
NT	no tillage
O_2	oxygen
ODS	ozone-depleting substance
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
OS/HOU	oil sands and heavy oil upgrading
PC	paste consumption
PFC	perfluorocarbon
PJ	petajoule
POP	persistent organic pollutant

P/PE	precipitation/potential evapotranspiration
PTRC	Petroleum Technology Research Centre
QA	quality assurance
QC	quality control
RA	reference approach
RESD	*Report on Energy Supply and Demand in Canada*
RPP	refined petroleum product
RT	reduced tillage
RTI	Research Triangle Institute
SA	sectoral approach
Sa	sulphur content in baked anodes
SAGE	System for assessing Aviation's Global Emissions
SBR	styrene-butadiene
Sc	sulphur content in calcinated coke
SCR	selective catalytic reduction
SF_6	sulphur hexafluoride
SIC	Standard Industrial Classification
SiC	silicon carbide
SLC	Soil Landscapes of Canada
SMR	steam methane reforming
SO_2	sulphur dioxide
SO_x	sulphur oxides
SOC	soil organic carbon
Sp	sulphur content in pitch
SUV	sport utility vehicle
t	tonne
TWh	terrawatt-hour
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UPCIS	Use Patterns and Controls Implementation Section
UOG	upstream oil and gas
VCM	vinyl chloride monomer
VKT	vehicle kilometres travelled
VSS	vertical stud Søderberg
VS	volatile solids
WMO	World Meteorological Organization

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Annex 1

Key Categories

A1.1. Key Categories—Methodology

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

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

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

The IPCC Tier 1 quantitative approach is used to identify key categories from two perspectives: their contribution to the overall emissions, and to the emission trend. The level assessment analyzes the emission contribution that each category makes to the national total (with and without LULUCF). The trend assessment uses each category's relative contribution to the overall emissions, but assigns greater weights to the categories whose relative trend departs from the overall one (with and without LULUCF). In this assessment, trends are calculated as the absolute changes between the base and most recent inventory years.

The percent contributions to both levels and trends in emissions are calculated and sorted from greatest to least. A cumulative total is calculated for both approaches. A cumulative contribution threshold of 95% for both level and trend assessments is a reasonable approximation of 90% uncertainty for the Tier 1 method of determining key categories (IPCC 2000). This threshold has therefore been used in this analysis to define an upper boundary for key category identification. Hence, when source and/or sink contributions are sorted in decreasing order of importance, those largest ones that together contribute to 95% of the cumulative total are considered quantitatively to be key.

Level Assessment

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

Equation A1–1: for source category level assessment:

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

where:

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

Equation A1–2: for source/sink category level assessment:

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

where:

$L^*_{x,t}$	=	the level assessment for source or sink x in year t; the asterisk (*) indicates that contributions from all categories (including LULUCF) are entered as absolute values (i.e. negative values are always recorded as the equivalent positive values)
$E^*_{x,t}$	=	$\lvert E_{x,t} \rvert$, the absolute value of the emission or removal estimate (CO_2 eq) of source or sink category x in year t
E^*_t	=	$\sum_x \lvert E_{x,t} \rvert$, the sum of the absolute values of all emissions and removals (CO_2 eq) from all source or sink categories x in year t, kt CO_2 eq

A1

Trend Assessment

The trend contribution of each source is calculated according to Equation A1–3, which follows IPCC (2000) and Equation A1–4, which follows IPCC (2003). Note that the use of Equation A1–4 only applies to source categories where there are zero emissions in the current year. Equation A1–5 and Equation A1–6 for source and sink category trend assessment are used to calculate the trend contribution from both sources and sinks following IPCC (2003). Note that the use of Equation A1–6 only applies to source and sink categories where there are zero emissions in the current year.

Equation A1–3: for source category trend assessment:

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

where:

$T_{x,t}$	=	the contribution of the source category trend to the overall inventory trend (i.e. the trend assessment); the trend assessment is always recorded as an absolute value
$L_{x,t}$	=	the level assessment for source x in year t (derived in Equation A1–1)
$E_{x,t}$ and $E_{x,o}$	=	the emission estimates (CO_2 eq) of source category x in years t and 0, respectively
E_t and E_0	=	the total inventory estimates (CO_2 eq) in years t and 0, respectively

Equation A1–4: for source category trend assessment with zero current year emissions:

$$T_{x,t} = \left| \frac{E_{x,o}}{E_t} \right|$$

where:

$T_{x,t}$	=	the contribution of the source category trend to the overall inventory trend (i.e. the trend assessment); the trend assessment is always recorded as an absolute value
$E_{x,o}$	=	the emission estimates (CO_2 eq) of source category x in year 0
E_t	=	the total inventory estimates (CO_2 eq) in year t

Note that according to IPCC (2003), this equation is not shown in IPCC (2000); however, it is generally applicable to non-LULUCF categories.

Equation A1–5: for source and sink category trend assessment:

$$T^*_{x,t} = L^*_{x,t} \bullet \left| \left[\frac{(E_{x,t} - E_{x,o})}{E_{x,t}} \right] - \left[\frac{(E_t - E_0)}{E_t} \right] \right|$$

where:

$T^*_{x,t}$	=	the contribution of the source or sink category trend to the overall inventory trend (i.e. the trend assessment); the trend assessment is always recorded as an absolute value
$L^*_{x,t}$	=	the level assessment for source or sink category x in year t (derived in Equation A1–2)
$E_{x,t}$ and $E_{x,o}$	=	the emission estimates (CO_2 eq) of source or sink category x in years t and 0, respectively
E_t and E_0	=	$\sum_x E_{x,t}$ and $\sum_x E_{x,o}$, the sum of all emissions and removals from source and sink categories x (CO_2 eq) in years t and 0, respectively; E_t differs from E_t* in Equation A1–2 in that the removals are not entered as absolute values

Equation A1–6: for source and sink category trend assessment with zero current year emissions:

$$T^*_{x,t} = \left| \frac{E_{x,o}}{E_t} \right|$$

where:

$T^*_{x,t}$	=	the contribution of the source or sink category trend to the overall inventory trend (i.e. the trend assessment); the trend assessment is always recorded as an absolute value
$E_{x,o}$	=	the emission estimates (CO_2 eq) of source or sink category x in year 0
E_t	=	$\sum_x E_{x,t}$, the sum of all emissions and removals from source and sink categories x (CO_2 eq) in years t; E_t differs from E_t* in Equation A1–2 in that the removals are not entered as absolute values

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

keeping with the CRF. Within these major categories, the aggregation of subcategories occurs when estimates are made based on common assumptions with respect to emission factors and common activity data.

A1.1.1. Summary Assessment

Key categories were assessed for the 2012 inventory year using level and trend criteria and for the base year on the level criterion only.

There were 30 level key categories in 1990, while in 2012 there were 34 with all combined criteria. Results are shown in Table A1–1.

A1.2. Key Category Tables

A1.2.1. Level Assessment With and Without LULUCF

Table A1–2 shows the 1990 key categories generated from level assessment with and without LULUCF.

Table A1–3 shows the 2012 key categories generated from level assessment with and without LULUCF.

A1.2.2. Trend Assessment With and Without LULUCF

Table A1–4 and Table A1–5 show the key categories indicated from the trend assessment with LULUCF and without LULUCF, respectively. These tables also show the contribution of the key categories to the trend assessment.

In the level assessment presented in Section A1.2.1, the integration of the LULUCF Sector introduces additional key categories without much alteration of the relative categories' contributions. However, the integration of LULUCF to the trend assessment considerably alters the overall trend, which causes a rearrangement in the ranking of key categories. A single LULUCF category, Forest Land Remaining Forest Land (CO_2), contributes 39% to the overall trend.

The trend assessment without LULUCF identifies 20 key categories (down from 21 in 2011), while the same analysis with LULUCF results in 27 key categories (unchanged from 2011), including 7 categories from the LULUCF Sector.

Table A1–1 Key Category Analysis Summary, 2012 Inventory

Source Table	IPCC Category	Direct GHG	Key Category (1990/2012)	Criteria (1990/2012)
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	Yes/Yes	L/L,T
1-A*	Stationary Fuel Combustion - Solid Fuels	CH_4	No/No	
1-A*	Stationary Fuel Combustion - Solid Fuels	N_2O	No/No	
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	Yes/Yes	L/L,T
1-A*	Stationary Fuel Combustion - Liquid Fuels	CH_4	No/No	
1-A*	Stationary Fuel Combustion - Liquid Fuels	N_2O	No/No	
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	Yes/Yes	L/L,T
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CH_4	No/No	
1-A*	Stationary Fuel Combustion - Gaseous Fuels	N_2O	No/No	
1-A*	Stationary Fuel Combustion - Other Fuels	CO_2	No/No	
1-A*	Stationary Fuel Combustion - Other Fuels	CH_4	No/No	
1-A*	Stationary Fuel Combustion - Other Fuels	N_2O	No/No	
1-A*	Stationary Fuel Combustion - Fugitives	CO_2	No/No	
1-A*	Stationary Fuel Combustion - Fugitives	CH_4	No/No	
1-A*	Stationary Fuel Combustion - Fugitives	N_2O	No/No	
1-A*	Stationary Fuel Combustion - Biomass	CO_2	No/No	L/L,T
1-A*	Stationary Fuel Combustion - Biomass	CH_4	No/No	
1-A*	Stationary Fuel Combustion - Biomass	N_2O	No/No	
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	CO_2	Yes/Yes	L/L,T
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	CH_4	No/No	
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	N_2O	No/No	
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	Yes/Yes	L/L,T

Table A1-1: Key Category Analysis Summary, 2012 Inventory (cont'd)

Source Table	IPCC Category	Direct GHG	Key Category (1990/2012)	Criteria (1990/2012)
1-A-3-b	Fuel Combustion - Road Transportation	CH_4	No/No	
1-A-3-b	Fuel Combustion - Road Transportation	N_2O	Yes/No	L
1-A-3-c	Fuel Combustion - Railways	CO_2	Yes/Yes	L/L,T
1-A-3-c	Fuel Combustion - Railways	CH_4	No/No	
1-A-3-c	Fuel Combustion - Railways	N_2O	No/No	
1-A-3-d	Fuel Combustion - Navigation (Domestic Marine)	CO_2	Yes/Yes	L/L
1-A-3-d	Fuel Combustion - Navigation (Domestic Marine)	CH_4	No/No	
1-A-3-d	Fuel Combustion - Navigation (Domestic Marine)	N_2O	No/No	
1-A-3-e	Fuel Combustion - Other Transport (Off-road)	CO_2	Yes/Yes	L/L,T
1-A-3-e	Fuel Combustion - Other Transport (Off-road)	CH_4	No/No	
1-A-3-e	Fuel Combustion - Other Transport (Off-road)	N_2O	No/No	
1-A-3-e	Fuel Combustion - Pipeline Transport	CO_2	Yes/Yes	L/L,T
1-A-3-e	Fuel Combustion - Pipeline Transport	CH_4	No/No	
1-A-3-e	Fuel Combustion - Pipeline Transport	N_2O	No/No	
1-B-1-a	Fugitive Emissions - Coal Mining	CH_4	No/Yes	T
1-B-2-(a+c)	Fugitive Emissions - Oil	CO_2	Yes/Yes	L/L,T
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	Yes/Yes	L/L,T
1-B-2-(a+c)	Fugitive Emissions - Oil	N_2O	No/No	
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	Yes/Yes	L/L
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH_4	Yes/Yes	L/L,T
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	N_2O	No/No	
2-A-1	Industrial Processes - Cement Production	CO_2	Yes/Yes	L/L
2-A-2	Industrial Processes - Lime Production	CO_2	No/No	
2-A-3	Industrial Processes - Limestone and Dolomite Use	CO_2	No/No	
2-A-4	Industrial Processes - Soda Ash Production and Use	CO_2	No/No	
2-A-7-2	Industrial Processes - Magnesite Use	CO_2	No/No	
2-B-1	Industrial Processes - Ammonia Production	CO_2	Yes/Yes	L/L
2-B-2	Industrial Processes - Nitric Acid Production	N_2O	No/No	
2-B-3	Industrial Processes - Adipic Acid Production	N_2O	Yes/Yes	L/T
	Industrial Processes - Petrochemical Production	CH_4	No/No	
	Industrial Processes - Petrochemical Production	N_2O	No/No	
2-C-1	Industrial Processes - Iron and Steel Production	CO_2	Yes/Yes	L/L,T
2-C-3	Industrial Processes - Aluminium Production	CO_2	No/Yes	L,T
2-C-3	Industrial Processes - Aluminium Production	PFCs	Yes/Yes	L/ T
2-C-4-1	Industrial Processes - Aluminium Production	SF_6	No/No	
2-C-4-2	Industrial Processes - Magnesium Production	SF_6	No/Yes	T
2-C-5	Industrial Processes - Magnesium Casting	SF_6	No/No	
2-E	Industrial Processes - Production of Halocarbons	HFCs	No/No	
2-E	Industrial Processes - Production of Halocarbons	PFCs	No/No	
2-E	Industrial Processes - Production of SF_6	SF_6	No/No	
2-F	Industrial Processes - Consumption of Halocarbons	HFCs	No/Yes	L,,T
2-F	Industrial Processes - Consumption of Halocarbons	PFCs	No/No	
2-F-6	Industrial Processes - Consumption of SF_6 for Semiconductor Manufacture	SF_6	No/No	

Table A1-1: Key Category Analysis Summary, 2012 Inventory (cont'd)

Source Table	IPCC Category	Direct GHG	Key Category (1990/2012)	Criteria (1990/2012)
2-F-7	Industrial Processes - Consumption of SF_6 for Electrical Equipment	SF_6	No/No	
2-G	Industrial Processes - Other (Undifferentiated Processes)	CO_2	Yes/Yes	L/L,T
3-D	Solvent and Other Product Use	N_2O	No/No	
4-A	Agriculture - Enteric Fermentation	CH_4	Yes/Yes	L/L,T
4-B	Agriculture - Manure Management	CH_4	No/No	
4-B	Agriculture - Manure Management	N_2O	Yes/No	L
4-D-1	Agriculture - Direct Agricultural Soils	N_2O	Yes/Yes	L/L,T
4-D-2	Agriculture - Animal Manure on Pasture, Range and Paddock	N_2O	No/No	
4-D-3	Agriculture - Indirect Agricultural Soils	N_2O	Yes/Yes	L/L
	Agriculture - Field Burning of Agricultural Soils	CH_4	No/No	
	Agriculture - Field Burning of Agricultural Soils	N_2O	No/No	
5-A.1	LULUCF - Forest Land remaining Forest Land	CO_2	Yes/Yes	L/L,T
5-A.1	LULUCF - Forest Land remaining Forest Land	CH_4	Yes/Yes	L/L,T
5-A.1	LULUCF - Forest Land remaining Forest Land	N_2O	No/Yes	L,T
5-A.2	LULUCF - Land converted to Forest Land	CO_2	No/No	
5-B.1	LULUCF - Cropland remaining Cropland	CO_2	No/Yes	L,T
5-B.2	LULUCF - Land converted to Cropland	CO_2	Yes/Yes	L/L,T
5-B.2	LULUCF - Land converted to Cropland	CH_4	No/No	
5-B.2	LULUCF - Land converted to Cropland	N_2O	No/No	
5-D.1	LULUCF - Wetlands remaining Wetlands	CO_2	No/No	
5-D.2	LULUCF - Land converted to Wetlands	CO_2	Yes/Yes	L/T
5-D.2	LULUCF - Land converted to Wetlands	CH_4	No/No	
5-D.2	LULUCF - Land converted to Wetlands	N_2O	No/No	
5-E.2	LULUCF - Settlements remaining Settlements	CO_2	No/No	
5-E.2	LULUCF - Land converted to Settlements	CO_2	Yes/Yes	L/L,T
5-E.2	LULUCF - Land converted to Settlements	CH_4	No/No	
5-E.2	LULUCF - Land converted to Settlements	N_2O	No/No	
5.C.	LULUCF - Grasslands	CH_4	No/No	
5.C.	LULUCF - Grasslands	N_2O	No/No	
6-A	Waste - Solid Waste Disposal on Land	CH_4	Yes/Yes	L/L,T
6-B	Waste - Wastewater Handling	CH_4	No/No	
6-B	Waste - Wastewater Handling	N_2O	No/No	
6-C	Waste - Waste Incineration	CO_2	No/No	
6-C	Waste - Waste Incineration	N_2O	No/No	
6-C	Waste - Waste Incineration	CH_4	No/No	

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

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

Source Table	IPCC Source Category	Direct GHG	1990 (kt CO_2 e)	2012 (kt CO_2 e)	Level Assessment		Cumulative Total	
					without LULUCF	with LULUCF	without LULUCF	with LULUCF
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	119 870	184 395	0.203	0.165	0.20	0.16
5-A.1	LULUCF - Forest Land remaining Forest Land	CO_2	-101 538	18 102	NA	0.139	NA	0.30
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	93 212	129 444.18	0.158	0.128	0.36	0.43
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	85 870	68 155	0.145	0.118	0.51	0.55
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	68 516	49 684	0.116	0.094	0.62	0.64
1-A-3-e	Fuel Combustion - Other Transport (Off-road)	CO_2	21 758	33 884	0.037	0.030	0.66	0.67
6-A	Waste - Solid Waste Disposal on Land	CH_4	17 437	18 899	0.030	0.024	0.69	0.70
4-A	Agriculture - Enteric Fermentation	CH_4	16 111	17 568	0.027	0.022	0.72	0.72
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH_4	14 619	23 027	0.025	0.020	0.74	0.74
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	14 053	22 021	0.024	0.019	0.76	0.76
4-D-1	Agriculture - Direct Agricultural Soils	N_2O	13 882	17 173	0.023	0.019	0.79	0.78
5-B.2	LULUCF - Land converted to Cropland	CO_2	13 020	5 369	NA	0.018	NA	0.80
2-B-3	Industrial Processes - Adipic Acid Production	N_2O	10 718	0	0.018	0.015	0.81	0.81
2-C-1	Industrial Processes - Iron and Steel Production	CO_2	10 193	9 844	0.017	0.014	0.82	0.83
5-E.2	LULUCF - Land converted to Settlements	CO_2	9 001	9 756	NA	0.012	NA	0.84
4-D-3	Agriculture - Indirect Agricultural Soils	N_2O	8 704	11 662	0.015	0.012	0.84	0.85
2-G	Industrial Processes - Other (Undifferentiated Processes)	CO_2	7 360	16 790	0.012	0.010	0.85	0.86
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	CO_2	7 047	5 988	0.012	0.010	0.86	0.87
1-A-3-e	Fuel Combustion - Pipeline Transport	CO_2	6 652	5 534	0.011	0.009	0.87	0.88
2-C-3	Industrial Processes - Aluminium Production	PFCs	6 539	1 519	0.011	0.009	0.88	0.89
1-A-3-c	Fuel Combustion - Railways	CO_2	6 159	6 721	0.010	0.008	0.89	0.90
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	6 002	7 090	0.010	0.008	0.90	0.90
1-B-2-(a+c)	Fugitive Emissions - Oil	CO_2	5 459	7 924	0.009	0.007	0.91	0.91
2-A-1	Industrial Processes - Cement Production	CO_2	5 436	6 287	0.009	0.007	0.92	0.92
1-A-3-d	Fuel Combustion - Navigation (Domestic Marine)	CO_2	4 693	5 436	0.008	0.006	0.93	0.93
2-B-1	Industrial Processes - Ammonia Production	CO_2	4 510	5 772	0.008	0.006	0.94	0.93
5-D.2	LULUCF - Land converted to Wetlands	CO_2	3 977	655	NA	0.005	NA	0.94
1-A-3-b	Fuel Combustion - Road Transportation	N_2O	3 195	2 808	0.005	0.004	0.94	0.94
4-B	Agriculture - Manure Management	N_2O	3 159	3 640	0.005	0.004	0.95	0.95
5-A.1	LULUCF - Forest Land remaining Forest Land	CH_4	2 924	9 036	NA	0.004	NA	0.95

Note: NA = Not applicable

Table A1–3 2012 Key Categories by Level Assessment With and Without LULUCF

Source Table	IPCC Source Category	Direct GHG	1990 (kt CO_2 e)	2012 (kt CO_2 e)	Level Assessment without LULUCF	Level Assessment with LULUCF	Cumulative Total without LULUCF	Cumulative Total with LULUCF
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	119 870	184 395	0.264	0.242	0.26	0.24
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	93 212	129 444	0.185	0.170	0.45	0.41
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	85 870	68 155	0.098	0.089	0.55	0.50
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	68 516	49 684	0.071	0.065	0.62	0.57
1-A-3-e	Fuel Combustion - Other Transport (Off-road)	CO_2	21 758	33 884	0.049	0.044	0.67	0.61
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH_4	14 619	23 027	0.033	0.030	0.70	0.64
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	14 053	22 021	0.032	0.029	0.73	0.67
6-A	Waste - Solid Waste Disposal on Land	CH_4	17 437	18 899	0.027	0.025	0.76	0.69
5-A.1	LULUCF - Forest Land remaining Forest Land	CO_2	-101 538	18 102	NA	0.024	NA	0.72
4-A	Agriculture - Enteric Fermentation	CH_4	16 111	17 568	0.025	0.023	0.78	0.74
4-D-1	Agriculture - Direct Agricultural Soils	N_2O	13 882	17 173	0.025	0.023	0.81	0.76
2-G	Industrial Processes - Other (Undifferentiated Processes)	CO_2	7 360	16 790	0.024	0.022	0.83	0.79
4-D-3	Agriculture - Indirect Agricultural Soils	N_2O	8 704	11 662	0.017	0.015	0.85	0.80
5-B.1	LULUCF - Cropland remaining Cropland	CO_2	-1 482	-10 481	NA	0.014	NA	0.82
2-C-1	Industrial Processes - Iron and Steel Production	CO_2	10 193	9 844	0.014	0.013	0.86	0.83
5-E.2	LULUCF - Land converted to Settlements	CO_2	9 001	9 756	NA	0.013	NA	0.84
5-A.1	LULUCF - Forest Land remaining Forest Land	CH_4	2 924	9 036	NA	0.012	NA	0.85
1-B-2-(a+c)	Fugitive Emissions - Oil	CO_2	5 459	7 924	0.011	0.010	0.87	0.86
2-F	Industrial Processes - Consumption of Halocarbons	HFCs	0	7 783	0.011	0.010	0.88	0.87
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CO_2	6 002	7 090	0.010	0.009	0.90	0.88
1-A-3-c	Fuel Combustion - Railways	CO_2	6 159	6 721	0.010	0.009	0.90	0.89
2-A-1	Industrial Processes - Cement Production	CO_2	5 436	6 287	0.009	0.008	0.91	0.90
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	CO_2	7 047	5 988	0.009	0.008	0.92	0.91
2-B-1	Industrial Processes - Ammonia Production	CO_2	4 510	5 772	0.008	0.008	0.93	0.92
5-A.1	LULUCF - Forest Land remaining Forest Land	N_2O	1 807	5 611	NA	0.007	NA	0.92
1-A-3-e	Fuel Combustion - Pipeline Transport	CO_2	6 652	5 534	0.008	0.007	0.94	0.93
1-A-3-d	Fuel Combustion - Navigation (Domestic Marine)	CO_2	4 693	5 436	0.008	0.007	0.95	0.94
5-B.2	LULUCF - Land converted to Cropland	CO_2	13 020	5 369	NA	0.007	NA	0.94
2-C-3	Industrial Processes - Aluminium Production	CO_2	2 715	4 707	0.007	0.006	NA	0.95

Note: NA = Not applicable

Table A1–4 Key Categories by Trend Assessment with LULUCF

Source Table	IPCC Source Category	Direct GHG	1990 (kt CO_2 e)	2012 (kt CO_2 e)	Trend Assessment	Contribution to Trend	Cumulative Total
5-A.1	LULUCF - Forest Land remaining Forest Land	CO_2	-101 538	18 102	0.150	0.388	0.39
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	85 870	68 155	0.050	0.129	0.52
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	68 516	49 684	0.044	0.114	0.63
2-B-3	Industrial Processes - Adipic Acid Production	N_2O	10 718	0.21	0.014	0.036	0.67
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	119 870	184 395	0.013	0.033	0.70
5-B.2	LULUCF - Land converted to Cropland	CO_2	13 020	5 369	0.012	0.031	0.73
5-B.1	LULUCF - Cropland remaining Cropland	CO_2	-1 482	-10 481	0.008	0.020	0.75
2-F	Industrial Processes - Consumption of Halocarbons	HFCs	0	7 783	0.007	0.019	0.77
2-C-3	Industrial Processes - Aluminium Production	PFCs	6 539	1 519	0.007	0.019	0.79
2-G	Industrial Processes - Other (Undifferentiated Processes)	CO_2	7 360	16 790	0.006	0.015	0.80
6-A	Waste - Solid Waste Disposal on Land	CH_4	17 437	18 899	0.005	0.014	0.82
4-A	Agriculture - Enteric Fermentation	CH_4	16 111	17 568	0.005	0.013	0.83
5-D.2	LULUCF - Land converted to Wetlands	CO_2	3 977	655	0.005	0.012	0.84
5-A.1	LULUCF - Forest Land remaining Forest Land	CH_4	2 924	9 036	0.004	0.012	0.85
2-C-1	Industrial Processes - Iron and Steel Production	CO_2	10 193	9 844	0.004	0.011	0.87
2-C-4-2	Industrial Processes - Magnesium Production	SF_6	2 870	0	0.004	0.010	0.88
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	CO_2	7 047	5 988	0.004	0.010	0.89
1-A-3-e	Fuel Combustion - Pipeline Transport	CO_2	6 652	5 534	0.004	0.009	0.89
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	93 212	129 444	0.003	0.007	0.90
5-E.2	LULUCF - Land converted to Settlements	CO_2	9 001	9 756	0.003	0.007	0.91
5-A.1	LULUCF - Forest Land remaining Forest Land	N_2O	1 807	5 611	0.003	0.007	0.92
1-A-3-e	Fuel Combustion - Other Transport (Off-road)	CO_2	21 758	33 884	0.003	0.007	0.92
4-D-1	Agriculture - Direct Agricultural Soils	N_2O	13 882	17 173	0.002	0.006	0.93
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH_4	14 619	23 027	0.002	0.005	0.94
1-B-1-a	Fugitive Emissions - Coal Mining	CH_4	2 199	1 006	0.002	0.005	0.94
1-A-3-c	Fuel Combustion - Railways	CO_2	6 159	6 721	0.002	0.005	0.94
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	14 053	22 021	0.002	0.005	0.95

Table A1–5 Key Categories by Trend Assessment without LULUCF

Source Table	IPCC Source Category	Direct GHG	1990 (kt CO_2 e)	2012 (kt CO_2 e)	Trend Assessment	Contribution to Trend	Cumulative Total
1-A*	Stationary Fuel Combustion - Gaseous Fuels	CO_2	119 870	184 395	0.013	0.033	0.20
1-A*	Stationary Fuel Combustion - Solid Fuels	CO_2	85 870	68 155	0.050	0.129	0.36
1-A*	Stationary Fuel Combustion - Liquid Fuels	CO_2	68 516	49 684	0.044	0.114	0.51
1-A-3-b	Fuel Combustion - Road Transportation	CO_2	93 212	129 444	0.003	0.007	0.60
2-B-3	Industrial Processes - Adipic Acid Production	N_2O	10 718	0.21	0.014	0.036	0.66
1-A-3-e	Fuel Combustion - Other Transport (Off-road)	CO_2	21 758	33 884	0.003	0.007	0.70
2-G	Industrial Processes - Other (Undifferentiated Processes)	CO_2	7 360	16 790	0.006	0.015	0.74
2-F	Industrial Processes - Consumption of Halocarbons	HFCs	0	7 783	0.007	0.019	0.78
2-C-3	Industrial Processes - Aluminium Production	PFCs	6 539	1 519	0.007	0.019	0.81
1-B-2-(b+c)	Fugitive Emissions - Natural Gas	CH_4	14 619	23 027	0.002	0.005	0.83
1-B-2-(a+c)	Fugitive Emissions - Oil	CH_4	14 053	22 021	0.002	0.005	0.86
2-C-4-2	Industrial Processes - Magnesium Production	SF_6	2 870	0	0.004	0.010	0.88
1-A-3-a	Fuel Combustion - Civil Aviation (Domestic Aviation)	CO_2	7 047	5 988	0.004	0.010	0.89
1-A-3-e	Fuel Combustion - Pipeline Transport	CO_2	6 652	5 534	0.004	0.009	0.90
2-C-1	Industrial Processes - Iron and Steel Production	CO_2	10 193	9 844	0.004	0.011	0.91
6-A	Waste - Solid Waste Disposal on Land	CH_4	17 437	18 899	0.005	0.014	0.92
1-B-1-a	Fugitive Emissions - Coal Mining	CH_4	2 199	1 006	0.002	0.005	0.93
2-C-3	Industrial Processes - Aluminium Production	CO_2	2 715	4 707	0.001	0.002	0.93
4-A	Agriculture - Enteric Fermentation	CH_4	16 111	17 568	0.005	0.013	0.94
1-B-2-(a+c)	Fugitive Emissions - Oil	CO_2	5 459	7 924	0.000	0.000	0.95
4-A	Agriculture - Enteric Fermentation	CH_4	16 111	17 983	0.001	0.006	0.95

Annex 2

Methodology and Data for Estimating Emissions from Fossil Fuel Combustion

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

A2.1. Methodology

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

Equation A2–1: for general fuel combustion:

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

where:

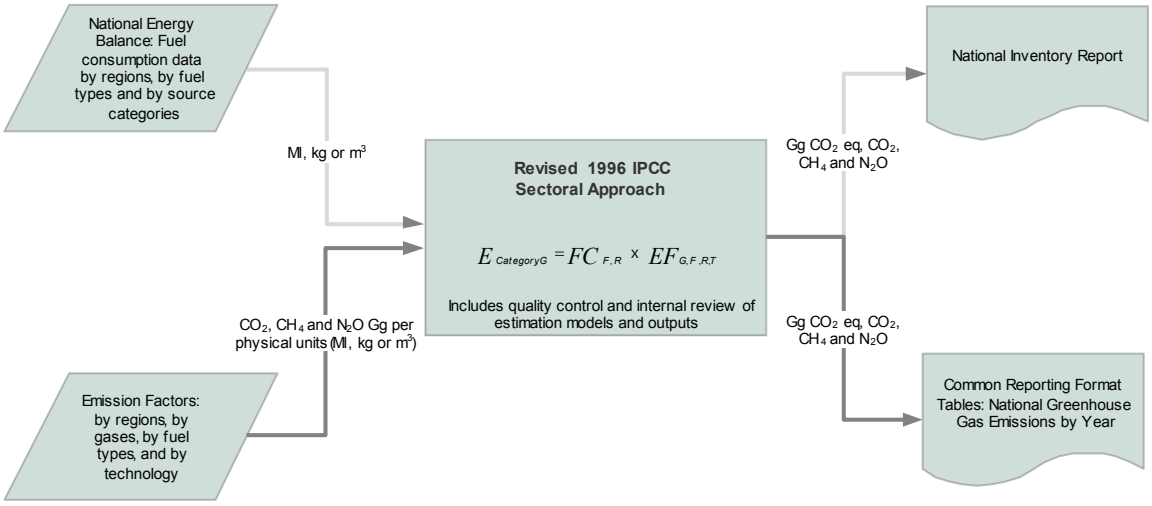
$E_{Category,G}$	=	GHG emissions by source category and by GHG (CO_2, CH_4 or N_2O)
$FC_{F,R}$	=	Quantity of fuel consumed (in physical units, such as kg, L, or m3) by fuel type (i.e. natural gas, sub-bituminous coal, kerosene, etc.) and by region
$EF_{G,F,R,T}$	=	Country-specific emission factor (in physical units) by GHG, by fuel type, by region (where available) and by technology (for non-CO_2 factors)

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

A2.2. Activity Data from Statistics Canada

The principal source of fuel and energy data used to estimate combustion emissions is the annual *Report on Energy Supply-Demand in Canada* (RESD) (Statistics Canada #57-003). The RESD uses a mix of 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 are divided into broad sectors based on the North American Industrial Classification System (NAICS). Currently, these sectoral industrial energy-use data do not include energy used to generate electricity or steam by industry (auto producers). This energy is captured in the RESD in two separate lines (one for electricity and one for steam); however, they are summary lines and are not divided by sector. Prior to 2003, these summary lines are fractionally allocated to

Figure A2–1 GHG Estimation Process Flow



the appropriate sector based on the quantities reported by sector in the *Industrial Consumption of Energy Survey* (ICE) (Statistics Canada 2013). After 2003, the electricity line (from auto producers) is reallocated directly to the appropriate sector based on the quantities reported by sector in the *Electric Power Thermal Generating Station Fuel Consumption Survey* (EPTGS) (Statistics Canada 2013). This change reflects a change in the Electricity by Industry line in the RESD, which from 2003 on was replaced directly with data from the EPTGS. This improvement activity was implemented by Statistics Canada to increase the transparency and accuracy of subsector information, since the fuel used to generate electricity is more complete and of higher quality. Statistics Canada is working closely with centres of excellence and other federal departments to develop an approach that will address the time series consistency concerns; it plans to have the dataset ready for use by the next inventory submission (refer to Section 3.2.1.5 on its progress). This new approach is not expected to have an impact on the national total unless data error corrections are needed. The steam line continues to be allocated using the fractional method and ICE data.

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

The combustion and transport models apply the quantity of fossil fuel consumed in physical units rather than in energy units, since this is how the information is reported to Statistics Canada by reporting facilities under the *Statistics Act*. The quantities of fossil fuel consumed are also available in gross calorific units; however, this is assumed to be less accurate, since Statistics Canada applies, in most cases, constant energy conversion factors (from 1990 to 1997 and from 1998 onward) to each fuel type. One exception involves waste fuels, for which the data are only available in energy units from the Cement Association of Canada.

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

A2.3. Fuel Combustion Emission Factors

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

Natural Gas: The emission factors for CO_2 vary depending on the source of natural gas and whether or not the product is marketable or non-marketable (raw natural gas for on-site consumption by natural gas producers). Therefore, emission factors are

assigned for different provinces based upon the origin and quality of the natural gas. The emission factors for CH_4 and N_2O vary with the combustion technology.

Refined Petroleum Products (RPP): The emission factors vary by fuel type and/or combustion technology (for CH_4 and N_2O).

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

A2.3.1. CO_2 Emission Factors

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

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

A2.3.2. Non-CO_2 Emission Factors

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

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

During the combustion of carbon-based fuels, a small portion of the fuel remains unoxidized as CH_4. Additional research is necessary to better establish CH_4 emission factors for many combustion processes. Overall factors are developed for sectors based on typical technology splits and available emission factors for the sector.

During combustion, some of the nitrogen in the fuel and air is converted to N_2O. The production of N_2O is dependent upon the combustion temperature and the emission control technology employed. Additional research is necessary to better establish N_2O emission factors for many combustion processes. Overall factors are developed for sectors based on typical technologies and available emission factors for the sector. Non-CO_2 emission factors in this inventory are listed in Annex 8.

A2.3.3. Biomass

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

A2.4. Methodology for Stationary Combustion and Transport

A2.4.1. Stationary Combustion

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

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

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

- Public Electricity and Heat Production;
- Fossil Fuel Industries;

- Manufacturing Industries and Construction;
- Other Sectors; and
- Pipelines.

Details on specific source categories are included in the notes section of Table A2–1. 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. Emission estimates are calculated using Equation A2–1 exclusively and are consistent with the IPCC Tier 2 approach.

Table A2–1 presents the methodology and emission factors according to fuel types as presented in Table A2–2. Most fossil fuels have been grouped based on their original production source, with the exception of propane and butane, which are still reported as gases. Data from the national statistical agency do not differentiate between propane and butane produced from gas industry sources or refinery sources. Since the majority of propane and butane is produced from the natural gas stream in Canada, all reporting for these two fuels has been left in the gaseous category.

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

CRF Source Category[1]	Fuels List (Table A2-2)	Activity Data Source[2]	Notes
1.A.1.a.i Electricity Generation – Utilities	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 10 – Transformed to Other Fuels: Electricity – By utilities	Provincial/territorial coal CO_2 emissions are calculated using regional emission factors and summed to a national total. Totals for petroleum coke and coke CO_2 emissions are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 10 – Transformed to Other Fuels: Electricity – By utilities	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 10 – Transformed to Other Fuels: Electricity – By utilities	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for the remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	NA	NA
1.A.1.a.ii Electricity Generation – Industry	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry	Line 11 is allocated to 1.A.1.b, 1.A.1.c and 1.A.2 based on either fractions developed from sector data reported in ICE (prior to 1998) or fractions developed from sector data reported in the EP-GTS (1998 onward) prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry	Line 11 is allocated to 1.A.1.b, 1.A.1.c and 1.A.2 based on either fractions developed from sector data reported in ICE (prior to 1998) or fractions developed from sector data reported in the EP-GTS (1998 onward), prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry	Line 11 is allocated to 1.A.1.b, 1.A.1.c and 1.A.2 based on either fractions developed from sector data reported in ICE (prior to 1998) or fractions developed from sector data reported in the EP-GTS (1998 onward), prior to calculating emissions.
	Biomass	NA	NA
1.A.1.a.iii Heat & Steam Generation	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 14 – Transformed to Other Fuels: Steam Generation	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. Line 14 is allocated to 1.A.1.b, 1.A.1.c and 1.A.2 based on fractions developed from sector data reported in ICE, prior to calculating emissions.

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

CRF Source Category[1]	Fuels List (Table A2-2)	Activity Data Source[2]	Notes
1.A.1.a.iii Heat & Steam Generation (cont'd)	*Liquid Fuels*	Table 3 – Refined Petroleum Products Line 14 – Transformed to Other Fuels: Steam Generation	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Gasoline, diesel and aviation fuel are not included in this subsector because there are no data reported in the table. Line 14 is allocated to 1.A.1.b, 1.A.1.c and 1.A.2 based on fractions developed from sector data reported in ICE, prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Line 14 – Transformed to Other Fuels: Steam Generation	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. Line 14 is allocated to 1.A.1.b, 1.A.1.c and 1.A.2 based on fractions developed from sector data reported in ICE, prior to calculating emissions.
	Biomass	Landfill gas utilization provided by the Waste Sector	Canada totals for CO_2, CH_4 and N_2O are based on the national total provided by the Waste Sector. CO_2 emissions are not included in national totals, but are reported as a memo item in the CRF table.
1.A.1.b. Petroleum Refining	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table 3 – Refined Petroleum Products Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 25 – Petroleum refining	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Table 11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD MINUS emissions related to flaring (which is included under category 1B Fugitive). The activity data reported in the RESD include the amount of fuel used to flare. CO_2, CH_4 and N_2O emissions from flaring activity are considered a fugitive source following the IPCC Guidelines; therefore, the fugitive emission and fuel value is subtracted from the estimated emissions and the RESD value to ensure that emissions are not double counted. Only flaring emissions from the petroleum refining fugitive model are subtracted. All other flaring emissions are subtracted from Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c). Petroleum coke – Refineries & Others and Still Gas – Refineries & Others emissions are based on the national total MINUS that used by crude bitumen upgraders reported in the RESD (which is included in 1.A.1.c). A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.

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

CRF Source Category[1]	Fuels List (Table A2-2)	Activity Data Source[2]	Notes
1.A.1.b. Petroleum Refining (cont'd)	*Gaseous Fuels*	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 25 – Petroleum Refining	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	NA	NA
1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 16 – Producer consumed Table 11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 16 – Producer consumed Table 11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 16 – Producer consumed	The activity data for natural gas reported in the RESD include the amount flared. Flared emissions are a fugitive source; therefore, the fugitive emissions and the quantity of fuel associated with flaring are subtracted, respectively, from estimated combustion emissions and RESD activity data to avoid double counting. Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	NA	NA
1.A.2.a. Iron and Steel	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 22 – Iron and steel	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. CO_2 emissions from coke are reported under Industrial Processes. CH_4 and N_2O emissions are reported here. The CO_2 is considered to be a product of the process (the reduction of iron), while the CH_4 and N_2O are by products of combustion. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 22 – Iron and steel	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.

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

CRF Source Category[1]	Fuels List (Table A2-2)	Activity Data Source[2]	Notes
1.A.2.a. Iron and Steel (cont'd)	*Gaseous Fuels*	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 22 – Iron and steel	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	NA	NA
1.A.2.b. Non-ferrous Metals	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 23 – Smelting and refining, non ferrous	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 23 – Smelting and refining, non ferrous	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 23 – Smelting and refining, non ferrous	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	NA	NA
1.A.2.c. Chemicals	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 26 – Chemicals	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 26 – Chemicals	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.

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

CRF Source Category[1]	Fuels List (Table A2-2)	Activity Data Source[2]	Notes
1.A.2.c. Chemicals (cont'd)	*Gaseous Fuels*	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 26 – Chemicals	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	NA	NA
1.A.2.d. Pulp, Paper and Print	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 21 – Pulp and paper	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 21 – Pulp and paper	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 21 – Pulp and paper	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	Table 10 – Solid Wood Waste and Spent Pulping Liquor, Total Consumption	Total biomass is the amount of solid wood waste and spent pulping liquors combusted. Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. Biomass CO_2 emissions are not included in the national totals, although CH_4 and N_2O emissions are. Instead, biomass CO_2 emissions are reported in the memo items section.
1.A.2.e. Food Processing, Beverages and Tobacco	*Solid Fuels*	Included elsewhere	Emissions for this subsector are included in 1.A.2.f.iv. – Other Manufacturing.
	Liquid Fuels	Included elsewhere	Emissions for this subsector are included in 1.A.2.f.iv. – Other Manufacturing.
	Gaseous Fuels	Included elsewhere	Emissions for this subsector are included in 1.A.2.f.iv. – Other Manufacturing.
	Biomass	Included elsewhere	Emissions for this subsector are included in 1.A.2.f.iv. – Other Manufacturing.

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

CRF Source Category[1]	Fuels List (Table A2-2)	Activity Data Source[2]	Notes
1.A.2.f.i. Cement	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 24 – Cement Waste fuel data from the Canadian Industrial Energy End-use Data Analysis Centre (CIEEDAC).	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke and waste fuel emissions, which are based on the national total. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 24 – Cement	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 24 – Cement	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	NA	NA
1.A.2.f.ii. Mining	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 20 – Total mining & oil & gas extraction	Canada total for CO_2 is the sum of all provinces'/territories' emissions calculated using regional emission factors EXCEPT for coke emissions, which are based on the national total reported in the RESD. Mining, according to the RESD, includes fuel consumed for mining and extraction of oil and gas as well as upgrading of crude bitumen. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 20 – Total mining & oil & gas extraction	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 20 – Total mining & oil & gas extraction	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.

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

CRF Source Category[1]	Fuels List (Table A2-2)	Activity Data Source[2]	Notes
1.A.2.f.ii. Mining (cont'd)	*Biomass*	NA	NA
1.A.2.f.iii. Construction	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 30 – Construction	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used EXCEPT for coke emissions, which are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 30 – Construction	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 30 – Construction	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	NA	NA
1.A.2.f.iv. Other Manufacturing	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 27 – Other manufacturing	A weighted emission factor is calculated for CH_4 and N_2O based on fuel consumption and applied on an annual basis. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 27 – Other manufacturing	A weighted emission factor is calculated for CH_4 and N_2O based on fuel consumption and applied on an annual basis. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 27 – Other manufacturing	A weighted emission factor is calculated for CH_4 and N_2O based on fuel consumption and applied on an annual basis. A weighted emission factor is calculated for CH_4 and N_2O and applied on an annual basis. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	NA	NA
1.A.3.e Pipelines (Transport)	*Solid Fuels* *Not Occurring (NO)*	NO	NO
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 39 – Pipelines	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD.

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

CRF Source Category[1]	Fuels List (Table A2-2)	Activity Data Source[2]	Notes
1.A.3.e Pipelines (Transport)	*Gaseous Fuels*	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 39 – Pipelines	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	NA	NA
1.A.4.a.i. Commercial and Other Institutional	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 46 – Commercial and Institutional	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 46 – Commercial and Institutional	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 46 – Commercial and Institutional	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	NA	NA
1.A.4.a.ii. Public Administration	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 45 – Public Administration	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 45 – Public Administration	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 45 – Public Administration	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	NA	NA
1.A.4.b. Residential	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 44 – Residential	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 44 – Residential	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD.

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

CRF Source Category[1]	Fuels List (Table A2-2)	Activity Data Source[2]	Notes
1.A.4.b. Residential	*Gaseous Fuels*	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 44 – Residential	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	Firewood consumption estimated using the residential firewood model.	Total biomass is the amount of residential firewood combusted and is based on Environment Canada's survey data. CO_2 emissions are not included in the national totals, but CH_4 and N_2O emissions are. CO_2 emissions from the use of biomass fuels are reported in the memo items section.
1.A.4.c.i. Forestry	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 29 – Forestry	Canada total for CO_2 is the sum of all provinces'/territories emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 29 – Forestry	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Gaseous Fuels	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 11 – Transformed to Other Fuels: Electricity – By industry Line 14 – Transformed to Other Fuels: Steam Generation Line 29 – Forestry	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD. A portion of Lines 11 and 14 is allocated to this source category prior to calculating emissions.
	Biomass	NA	NA
1.A.4.c.ii. Agriculture	*Solid Fuels*	Table 1 – Primary and Secondary Energy Table F – Coal Details Line 43 – Agriculture	Canada total for CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Liquid Fuels	Table 3 – Refined Petroleum Products Line 43 – Agriculture	Canada totals for CO_2, CH_4 and N_2O are based on the national total reported in the RESD. CO_2, CH_4 and N_2O associated with Transport fuels (i.e. gasoline and diesel) are included in the Transport subsector.

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

CRF Source Category[1]	Fuels List (Table A2-2)	Activity Data Source[2]	Notes
1.A.4.c.ii. Agriculture (cont'd)	*Gaseous Fuels*	Table 1 – Primary and Secondary Energy Table 6 – Details of Natural Gas Liquids Line 43 – Agriculture	Canada total for natural gas CO_2 is the sum of all provinces'/territories' emissions due to regional emission factors being used. Totals for remaining gaseous fuel CO_2 are based on the national total reported in the RESD. Canada totals for CH_4 and N_2O are based on the national total reported in the RESD.
	Biomass	NA	NA
1.A.5. Other Information (not included elsewhere)	*NA*	NA	Emissions from all other industrial sources are included in 1.A.2.f.iv. – Other Manufacturing.

Notes:
1. The CRF categories listed are the lowest-level subsectors for which emissions are estimated.
2. Activity data refer to the specific location of the data in the annual *Report on Energy Supply–Demand in Canada (RESD) (Statistics Canada* #57-003). Also refer to Table A2–3 for non-RESD data source references.
3. NA = Not applicable.
4. NO = Not occurring.

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

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

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

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

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

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

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

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

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

To determine the activity data associated with the Petroleum Refining subsector, some data reported in the RESD must be reallocated. All refined petroleum products (RPPs) that are reported as Producer-consumed are allocated to the Petroleum Refining subsector based on the assumption that they are consumed by the producers. Calculating the emissions associated with the fuels listed below involves summing the activity data reported under Petroleum Refining and Producer-consumed and applying Equation A2–1 to:

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

In addition, activity data, in the form of fuel used by industry (including Petroleum Refining) to generate electricity or steam, are currently aggregated to two summary lines in the RESD (Lines 11 – Electricity by Industries and 14 – Steam Generation). A portion of each of these lines needs to be reallocated to the

Table A2–3 Activity Data Model References

Statistics Canada – Manufacturing, Construction and Energy Division; annual Report on Energy Supply–Demand in Canada (RESD), #57-003-XPB.
Table 1 – Primary and Secondary Energy
Table 3 – Refined Petroleum Products
Table 5 – Non-energy Refined Petroleum Products
Table 6 – Details of Natural Gas Liquids
Table 10 – Solid Wood Waste and Spent Pulping Liquor
Table 11 – Estimated Additions to Still Gas, Diesel, Petroleum Coke and Crude Oil
Table F – Coal Details (as identified in the 1990 to 2001P RESD publications)
Waste fuel data - Based on CIEEDAC (2013). CIEEDAC Database on Energy, Production and Intensity Indicators for Canadian Industry. NAICS 327310 Cement Manufacturing. Canadian Industrial Energy End-use Data Analysis Centre. Also based on data collected by the Cement Assocation of Canada under WBCSD (2005). Cement Sustainability Initiative CO_2 Emissions Inventory Protocol. v.2.0.
Residential fuelwood consumption – Based on Environment Canada. (1999). 1995 Criteria Contaminants Emissions Inventory Guidebook, Version 1, Section 2.4. National Emissions Inventory and Projections Task Group, Criteria Air Contaminants Division, Environment Canada, March 1999.
Landfill Gas Utilization – See Annex 3, Additional Methodologies.

appropriate industry where the fuel is used. This is completed using one of two methods.

Since the Electricity – By Industry line (RESD Line 11) is populated with EPTGS survey data:

- 1998 to present: the reallocation was completed using fractions developed based on the quantities reported by the Petroleum Refining subsector in the EPTGS survey. 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.
- 1990 to 1997: the reallocation was completed using fractions developed based on the quantities reported by the Petroleum Refining subsector 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 ICE 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 Heat and Steam Generation line is populated by ICE data:

- 1990 to present: The procedure used to reallocate the RESD Line 11 values between 1990 and 1997 is also applied to the RESD Line 14 value using corresponding ICE data representing steam generation.

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

- gasoline; and
- diesel.

The IPCC default emission factors for N_2O are used to estimate emissions for petroleum coke and motor gasoline, and are based on the calorific value of the fuel. The gross calorific value (GCV) for petroleum coke is reported in the RESD and can change annually. As such, the emission factor for petroleum coke for both oil sands/crude bitumen production and refineries changes on an annual basis. The conversion between the GCV and the net calorific value (NCV), a necessary part of generating annual emission factors, is based on 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 Other Energy Industries subsector, activity data for the following fuels reported as Producer-consumed in the RESD are used in Equation A2–1:

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

The following fuels are reported as Producer-consumed in the oil sands/crude bitumen production industry in the RESD. The relevant quantities of petroleum coke, still gas and diesel fuel oil are subtracted from the Petroleum Refining subsector and included in the Manufacture of Solid Fuels and Other Energy Industries subsector. Consumption of all fuels is reported in a separate table in the RESD and allocated to mining/upgrading facilities:

- petroleum coke;
- still gas; and
- diesel.

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

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

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

The Manufacturing Industries and Construction subsector include a number of industrial categories. Activity data in the RESD are reported for the main economic and fuel-consuming industrial categories; however, this does not include fuel used to generate electricity or steam by industry. This energy is captured in the RESD in two separate lines (one for electricity and one for steam); however, they are summary lines and are not divided by industrial categories. In order to reallocate the fuel reported in the summary lines for electricity and steam in the RESD (Lines 11 and 14), one of two methods was used:

Since the Electricity – By Industry line (RESD Line 11) is populated with EPTGS survey data:

- 1998 to present: the allocation was completed using a fractional allocation method developed based on the quantities reported by subsector in the EPTGS survey. For each fuel and each province, the fueluse 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.
- 1990 to 1997: the allocation was completed using a fractional allocation method developed based on the quantities reported by subsector in the ICE survey, since EPTGS data are not available prior to 1998. For each fuel and each province, the fueluse data reported by industry in ICE for electricity generation are used to develop each industry's fraction of the total fuel use. The fractions are then used with Line 11 from the RESD to determine what portion of that line should be reallocated to a particular industry. Since ICE data did not exist prior to 1995, for years between 1990 and 1995, the 1995 fractions were used.

For the allocation of the Heat and Steam Generation line:

Since RESD Line 14 is populated with ICE data:

- 1990 to present: the procedure used to reallocate the RESD Line 11 values between 1990 and 1997 is also applied to the RESD Line 14 value using corresponding ICE data representing steam generation.

Emissions are calculated for the following categories:

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

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

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

CO_2 emissions associated with biomass combustion in the Pulp, Paper and Print subsector are reported but not included in the national totals; however, CH_4 and N_2O emissions are included in the totals. Industrial consumption of biomass and spent pulping liquors is reported in the RESD; however, some of the data are limited. The RESD data for 1990 and 1991 were combined for the Atlantic provinces, as were the data for the Prairie provinces. Individual provincial data were delineated by employing a data comparison with the 1992 RESD data. For 1992, the data for Newfoundland and Nova Scotia were also combined, and there were no comparable data to allow separation of these provinces. Emissions are listed under Nova Scotia. In 2010, Environment Canada conducted a review of available wood waste moisture content data and concluded that for the purposes of the NIR, solid wood waste activity data are reported on a wet-weight basis and that the average moisture content is 50%.

CO_2 emissions from the combustion of waste fuels in the cement industry are calculated based on data provided by the Cement Association of Canada and reported by CIEEDAC (2013) on an energy basis.

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

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

The activity data used in the calculation of GHG emissions from the combustion of residential firewood are based on estimated fuel use. Fuel-use data are based on the criteria air contaminant inventory (Environment Canada 1999). Residential fuel-use data from Statistics Canada and Natural Resources Canada (NRCan) were not used since they appear to greatly underestimate firewood consumption (as a significant portion of firewood consumed in Canada is not from commercial sources).

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

1. Conventional stoves
   - non-airtight
   - airtight, non-advanced technology
   - masonry heaters
2. Stove/fireplace inserts with advanced technology or catalyst control
   - advanced-technology fireplaces
   - advanced-technology stoves

- catalytic fireplaces
- catalytic stoves

3. Conventional fireplaces
   - without glass doors
   - with non-airtight glass doors
   - with airtight glass doors
4. Furnaces
   - wood-burning furnaces
5. Other equipment
   - other wood-burning equipment

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

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

The Commercial 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; however, CH_4 and N_2O emissions are included.

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

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

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

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

Emission estimates are developed at the provincial/territorial level and aggregated to the national level. Fuel combustion emissions associated with the Transport subsector are calculated using various adaptations of Equation A2–1.

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

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

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

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

Step 1: Activity Data – Vehicle Populations, Technology Penetration, Catalyst Survival Rate, Fuel Consumption Ratios and Kilometre Accumulation Rates

Vehicle Populations

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

Two distinct data sets are used to develop a complete vehicle population profile. Light-duty vehicle and truck populations for 1990–2002 were obtained from the *Canadian Vehicles in Operation Census*, which is maintained by DesRosiers Automotive Consultants Inc. Light-duty vehicle and truck populations for 2003–2012 were derived from Statistics Canada's *Canadian Vehicle Survey* (CVS). Heavy-duty vehicle populations were obtained from R.L. Polk & Co. for 1994–2002. Heavy-duty vehicle populations for 2003–2012 were derived from Statistics Canada's *Canadian Vehicle Survey*, while populations for 1990–1993 were estimated based on historical population trends. Light-duty vehicles (cars) and light-duty trucks (pickups, minivans, SUVs, etc.) are those with a GVWR of less than or equal to 3900 kg, whereas heavy duty classes have a GVWR above 3900 kg.

Motorcycle populations for 2012 were extrapolated based upon

data obtained from the Motorcycle & Moped Industry Council for the 2012 Submission (MMIC 2010).

Technology Penetration

To account for the effects that emission control technologies have on emissions of CH_4 and N_2O, estimates of the number of vehicles on the road equipped with catalytic converters and other control technologies were developed. Figure A2–2 illustrates the varying penetration percentages of evolving technologies into new light-duty gasoline vehicles (LDGVs) and light-duty gasoline trucks (LDGTs) in successive model years. Technology penetration for heavy-duty gasoline vehicles (HDGVs), heavy-duty diesel vehicles (HDDVs), light-duty diesel vehicles (LDDVs), light-duty diesel trucks (LDDTs) and motorcycles (MCs) are detailed in Table A2–4 (U.S. EPA 2013).

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 (I/M) 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 Ratios

Average provincial fuel consumption ratios (FCRs) by vehicle class and model year (based on provincial vehicle sales) are available for LDGVs, LDGTs, LDDVs and LDDTs (NRCan 2010). FCRs for HDGVs are based on a vehicle class and model year average (IPCC/OECD/IEA 1997). HDDV and motorcycle FCRs are based on a yearly fleet average (NRCan 2010). All class-specific FCRs representing the 2012 model year contribution to the Canadian fleet were extrapolated based upon the previously existing time series.

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

Kilometre Accumulation Rates

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

Step 2: On-road Fuel Calculation

On-road gasoline and diesel fuel consumption is estimated using Equation A2–2; this calculation represents the initial "bottom-up" fuel calculation ("C") for consideration in the fuel normalization process described below.

Equation A2–2:

$$Fuel\ Consumption = Population * KAR * FCR$$

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

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

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

Step 3: Normalization

In an effort to improve the allocation of fuel between on- and off-road applications, a balancing algorithm has been incorporated into MGEM. It operates between two top-down fuel availability estimates and one bottom-up fuel consumption estimate. Below, the algorithm's logic is outlined.

There are two different sources of top-down fuel availability data to be considered against the bottom-up fuel consumption estimate calculated by MGEM:

- The RESD (Statistics Canada #57-003) compiles data from refineries, industry and import/export records to generate the national energy balance for gasoline and diesel. The RESD is believed to provide an all encompassing picture of national fuel availability on a gross fuel-consumed level.

A2

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

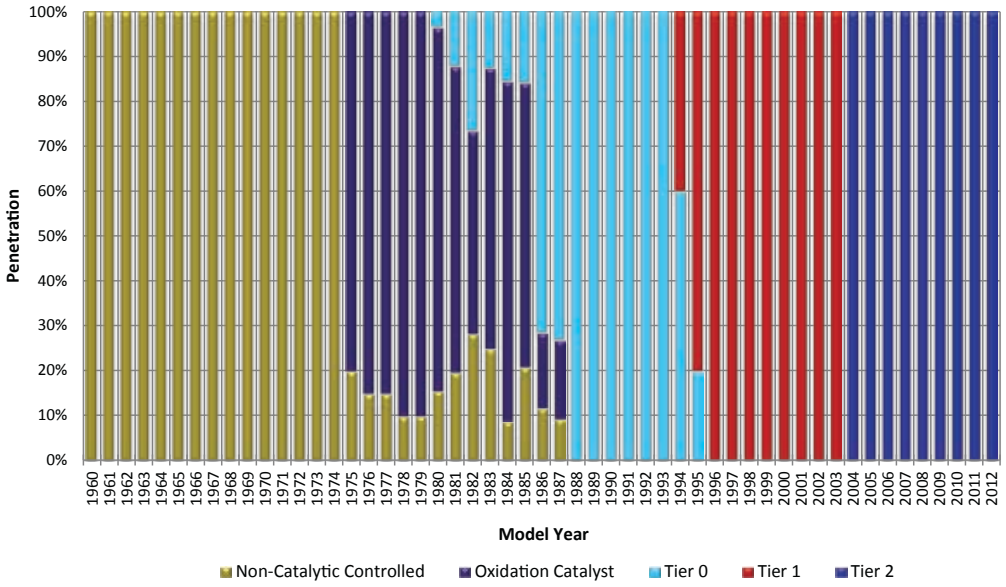


Table A2–4 Technology Penetration for HDGVs, HDDVs, LDDVs, LDDTs and MCs

Control Technology	Model Years
Heavy-duty Gasoline Vehicles (HDGVs)	
Uncontrolled	1960–1984
Non-catalytic Controlled	1985–1995
Three-way Catalyst	1996–2012
Heavy-duty Diesel Vehicles (HDDVs)	
Uncontrolled	1960–1982
Moderate Controls	1983–1995
Advanced Controls	1996–2012
Light-duty Diesel Vehicles and Trucks (LDDVs and LDDTs)	
Uncontrolled	1960–1982
Moderate Controls	1983–1995
Advanced Controls	1996–2003
Tier 2	2004–2012
Motorcycles (MCs)	
Uncontrolled	1960–1995
Non-catalytic Controlled	1996–2012

- Statistics Canada's Road Motor Vehicles, Fuel Sales, Annual (CANSIM, Table 405-0002) compiles reported provincial/territorial fuel sales data in the form of taxed and non-taxed fuel sales. This source is used for its ratio between taxed and non-taxed fuel consumption, where taxed fuel consumption represents on-road use and non-taxed use represents off-road use.

The RESD and Fuel Sales survey do not typically reconcile in terms of total fuel consumed. The balancing algorithm in MGEM ensures that total fuel consumed equals that reported in the RESD, and consults the Fuel Sales survey to help distinguish between on-road (taxed) and off-road (untaxed) use.

Given that Statistics Canada has stated that the volumes of gasoline reported in the RESD include ethanol, the estimates of ethanol are removed from the volumes of gasoline reported. Therefore, 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, the opposite is true: given that the RESD does not report biodiesel, diesel volumes in the CRF will equate to the diesel volumes in the CRF.

Gasoline

This section references Figure A2-3.

The preliminary gasoline on-road fuel consumption estimate is represented as C and is calculated in step 2 (above). It represents a bottom-up estimate based on vehicle population, FCRs and KARs.

The preliminary off-road estimate is represented by R and is the difference between the RESD total fuel consumed (represented by Q) and C.

The next process reconciles the two top-down reported fuel quantities at a total fuel level. The total sum (G) of taxed fuel (T) and non-taxed fuel (NT) is scaled to equal the RESD total fuel available (Q). This provides G_{max}, T_{max} and NT_{max} and a scaling factor A. These new values are illustrated in Phase 2 of Figure A2–3. The two top-down reported fuel quantities now equal each other, but the Fuel Sales survey has the additional information of a taxed versus non-taxed fuel use ratio, which will be used to help normalize MGEM's bottom-up on-road estimate.

To calculate the final normalized on-road estimate, represented by "On-Road" in Phase 2 of Figure A_2–3, the following logic is applied:

- when C is less than T_{max}, "On-Road" is the average of C and Tmax (midpoint between C and T_{max})
- when C is greater than Tmax, "On-Road" is set to T_{max}

The final process is to scale C so that it equals "On-Road." This is accomplished by adjusting the initial KARs until the new bottom-up consumption equals the "On-Road" fuel volume.

"Off-Road" (as represented in Phase 2 of Figure A2–3) is now represented by the difference between Gmax (which is equivalent to Q) and "On-Road."

Therefore, all fuel available in the RESD (Q) is accounted for, while the Fuel Sales survey aided in differentiating on-road from off-road fuel use.

At a provincial level, top-down and bottom-up gasoline consumption estimates differ slightly; however, at a national level, there is a high degree of correlation between the two estimates. Please refer to Table A2–5 for the national normalization factors for On-Road. The normalization factor is represented by the ratio of On-Road to C. Table A2–5 also includes the national values for the various coefficients found in Figure A2–3.

Diesel Oil

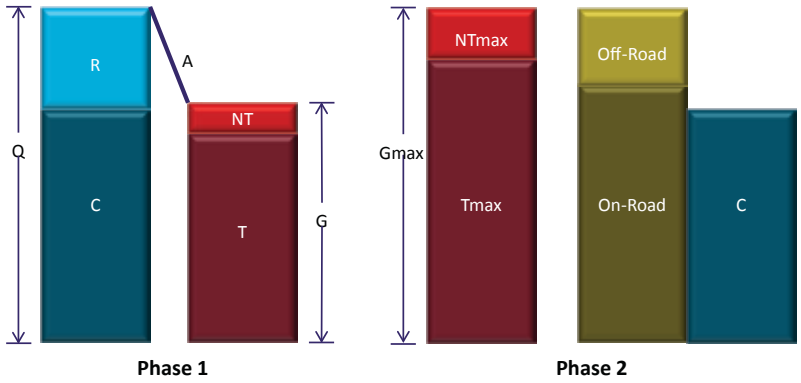
This section references Figure A2–4

The preliminary diesel on-road fuel consumption estimate is represented as C and is calculated in step 2 (above). It represents a bottom-up estimate based on vehicle population, FCRs and KARs.

The preliminary off-road estimate is represented by R and is the difference between the RESD total fuel consumed (represented by Q) and C.

The two top-down reported fuel quantities for diesel differ from that of gasoline in that there is no gross fuel amount (Taxed + Non-Taxed) provided in the Fuel Sales survey for diesel, only Taxed (T). Subsequently, the reconciling of the two top-down sources is quite different: if taxed fuel sales (represented by T) exceeds that of the total fuel consumed in the RESD (represented

Figure A2–3 On-Road Gasoline Normalization Procedure for MGEM



Q – Total gasoline fuel available in Canada from RESD
C – Preliminary bottom-up On-Road fuel consumption estimate (vehicle population x kilometre accumulation rate x fuel consumption rate)
R – First Off-Road estimate represented by Q-C
G – Gross gasoline fuel sales from Fuel Sales survey
T – Taxed gasoline fuel sales from Fuel Sales survey
NT – Non-Taxed gasoline fuel sales from Fuel Sales survey
A – Factor used to scale G to match Q: A = Q/G (range from 0.99 to 1.05)
Gmax – Scale G to match Q: Gmax = G x A = Q
Tmax – Scale T to preserve original gross to taxed fuel sales ratio from Fuel Sales survey: Tmax = T x A
NTmax – Scale NT to preserve original gross to taxed fuel sales ratio from Fuel Sales survey: NTmax = NT x A
On-Road – When C is less than or equal to Tmax then On-Road = (C + Tmax)/2; When C is greater than Tmax then On-Road = Tmax
Off-Road – The difference between Q (same as Gmax) and On-Road: Off-Road = Q - On-Road

Table A2–5 Diesel Normalization Values, Selected Years

		1990	2000	2005	2008	2009	2010	2011	2012
Phase 1	C - Bottom-up On-Road Vehicle Calc. (ML)	30 238	32 729	35 636	37 216	37 702	38 182	38 377	38 587
	Q - RESD's Total Gasoline Fuel Available (ML)	33 943	38 268	40 810	41 687	42 217	43 347	42 905	42 988
	T - Taxed Gasoline Fuel Sales (ML)	31 842	36 375	38 484	39 149	39 708	40 101	40 412	40 444
	G - Gross Gasoline Fuel Sales (ML)	33 721	38 177	39 846	40 496	41 028	41 453	42 076	42 033
	A - Scaling Factor	1.01	1.00	1.02	1.03	1.03	1.05	1.02	1.02
Phase 2	Tmax - Scaled Taxed Gasoline Fuel Sales (ML)	32 052	36 462	39 415	40 300	40 859	41 933	41 208	41 363
	On-Road - Final On-Road Gasoline Fuel Estimate (ML)	31 145	34 595	37 526	38 758	39 281	40 058	39 793	39 975
	Off-Road - Final Off-Road Gasoline Fuel Estimate (ML)	2 798	3 672	3 284	2 929	2 936	3 289	3 113	3 012
	On-Road + Off-Road (ML)	33 943	38 268	40 810	41 687	42 217	43 347	42 905	42 988
	On-Road Gasoline Normalization Factor	1.03	1.06	1.05	1.04	1.04	1.05	1.04	1.04

Note: Values may not add up due to rounding.

by Q), T is forced to equal Q; otherwise, T is not adjusted.

At the national level, T is always less than Q. The result of the above reconciliation is that, at a national level, Tmax equals T.

To calculate the final normalized on-road estimate, represented by On-Road in Figure A2–4, the following logic is used:

- When the average of C and Tmax is greater than Q, On-Road equals Q; otherwise,
- On-Road is equal to the average of C and Tmax.

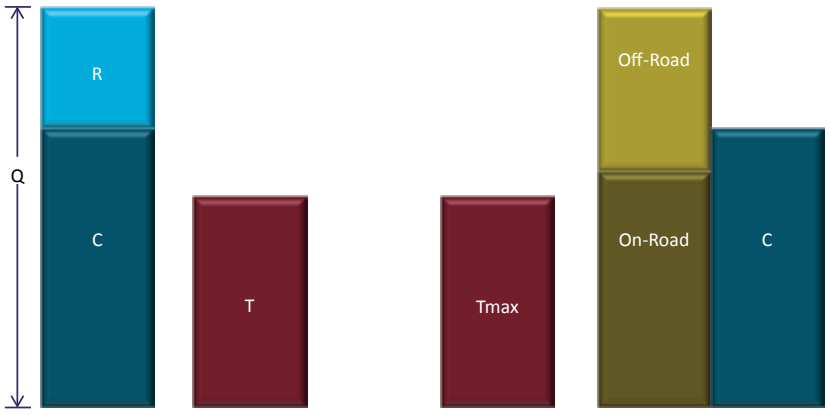
The final process is to scale C so that it equals "On-Road." This is accomplished by adjusting the initial KARs until the new bottom-up consumption equals the "On-Road" fuel volume.

"Off-Road" (as represented in Phase 2 of Figure A2–4) is now represented by the difference between Q and "On Road."

Therefore, all fuel available in the RESD (Q) is accounted for while the Fuel Sales survey aided in differentiating on-road from off-road fuel use.

At a provincial level, top-down and bottom-up diesel consumption estimates differ slightly; however, at a national level, there is a high degree of correlation between the two estimates. Please refer to Table A2–6 for the national normalization factors for On-Road. The normalization factor is represented by the ratio of On-Road to C. Table A2–6 also includes the national values for the various coefficients found in Figure A2–4.

Figure A2–4 On-Road Diesel Normalization Procedure for MGEM



Q – Total diesel fuel available in Canada from RESD
C – Preliminary bottom-up On-Road fuel consumption estimate (vehicle population x kilometre accumulation rate x fuel consumption rate)
R – First Off-Road estimate represented by Q-C
T – Taxed diesel fuel sales from Fuel Sales survey
Tmax – When T is greater than or equal to Q then Tmax = Q; When T is less than Q then Tmax = T
On-Road – When (C + Tmax)/2 is greater than Q than On-Road = Q; Otherwise On-Road = (C + Tmax)/2
Off-Road – The difference between Q and On-Road: Off-Road = Q - On-Road

Table A2–6 Technology Penetration for HDGVs, HDDVs, LDDVs, LDDTs and MCs

		1990	2000	2005	2008	2009	2010	2011	2012
Phase 1	C - Bottom-up On-Road Vehicle Calc. (ML)	7 181	11 116	13 405	14 316	14 644	14 974	15 216	15 461
	Q - RESD's Total Diesel Fuel Available (ML)	13 076	19 588	22 411	24 084	22 982	25 176	26 397	25 809
	T - Taxed Diesel Fuel Sales (ML)	8 543	13 275	16 216	16 555	16 188	16 779	17 798	17 436
Phase 2	Tmax - Scaled Taxed Diesel Fuel Sales (ML)	8 543	13 275	16 216	16 555	16 188	16 779	17 798	17 436
	On-Road - Final On-Road Diesel Fuel Estimate (ML)	7 862	12 196	14 811	15 436	15 416	15 876	16 507	16 448
	Off-Road - Final Off-Road Diesel Fuel Estimate (ML)	5 214	7 392	7 600	8 649	7 566	9 300	9 890	9 361
	On-Road + Off-Road (ML)	13 076	19 588	22 411	24 084	22 982	25 176	26 397	25 809
	On-Road Diesel Normalization Factor	1.10	1.10	1.11	1.08	1.05	1.06	1.09	1.07

Note: Values may not add up due to rounding.

Step 4: On-road Emission Calculation

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

Emissions are calculated using Equation A2–1.

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

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

Step 1: Off-road Fuel Calculation

Off-road fuel is calculated using Equation A2–3

Equation A2–3:

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

Step 2: Off-road Emission Calculation

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

Emissions are calculated using Equation A2–1.

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

The methodology used to estimate GHG emissions from Civil Aviation employs a modified IPCC Tier 1 approach for aviation gasoline and a modified IPCC Tier 3 approach for aviation turbo fuel. The Aviation model has been named AGEM as an acronym for Aviation Greenhouse Gas Emission Model.

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

Emission estimates for aviation gasoline are calculated using the quantity of aircraft fuel apparently consumed (IPCC/OECD/IEA 1997) and the fuel-specific emission factor. Aircraft fuel sales are reported in the RESD (Statistics Canada #57-003) representing that sold to Canadian airlines, foreign airlines, public administration and commercial/institutional sectors. All aviation gasoline use is designated domestic, other than that reported under foreign airlines.

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 (broken down 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 deemed

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.

Tier 3 Methodology

A2

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 2013) 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 Transport Canada before November 1996. Both data streams are processed by Statistics Canada and redistributed to NAV Canada and Transport Canada. Environment Canada receives the information directly from Statistics Canada, including small airport movements that Statistics Canada collects directly and appends to the tower data from NAV Canada.

The data 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 them as well as validation of airports, aircraft types, and various data fields that are not crucial to modelling fuel use.

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

Flight Path Length

The flight path length is the true distance travelled between two airports. The movement data used for modelling are not radar data and thus do not track the exact path travelled by each individual movement. AGEM estimates the flight path length based on additional information obtained from the Federal Aviation Administration (FAA). The FAA operates an aviation model titled SAGE that is based on true radar data. The FAA provided Environment Canada with an extract from their model for calendar year 2005 involving Canadian airports and included the statistical measures (maximum, minimum, average, standard deviation) for the radar distance travelled between any Canadian origin and final destination for a given 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[1]) is used when the average radar distance is unknown. A factor applied to the GCD was developed by comparing GCD to radar distance for a given origin/destination/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, elevation, etc. were compiled from various sources including Transport Canada (Cadieux 2006), the Canada Flight Supplement (NAV Canada 2009), SAGE (Fleming 2008b), the Modeling and Database Task Force (MODTF) (Fleming 2008c), the FAA (FAA 2009) and previous departmental work (Manning 2007). The main information required is the geographical coordinates so that a GCD can be calculated and used to determine the flight path length.

Aircraft Fuel Use Characteristics

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

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 2009; IPCC 2006; ICAO 2008; EMEP/CORINAIR 2006) and matching aircraft characteristics (MTOW,[2] number of engines, engine type, etc.) when there was no published mapping for a given aircraft.

1 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.

2 Maximum takeoff weight.

Aircraft Emission Performance

In an attempt to better estimate CH_4 emissions, aircraft-specific emission factors are used within AGEM for the LTO cycle. The factors are taken from table 3.6.9 in the 2006 IPCC Guidelines (IPCC 2006), in the form of total emissions per LTO cycle. These factors are then adjusted by a ratio based on the total LTO fuel difference between that published in the table and that calculated in AGEM. It is recognized that a one to one adjustment of CH_4 emissions based on fuel ratio differences may not be entirely correct; however, lacking any additional information, this modification was made recognizing that the default values from table 3.6.9 do not truthfully reflect AGEM's methodology. For the cruise portion, CH_4 emissions are assumed to be zero (Wiesen et al. 1994). For ease of use by the general public, the published CH_4 emission factor will be a fleet average across the entire time series and based on total fuel consumed (LTO and cruise).

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

Step2: Aircraft Fuel Calculation

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

Equation A2–4:

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

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

The cruise phase of flight (above 3000 ft) is calculated based on 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 apparently consumed in Canada is reported in the RESD (Statistics Canada #57-003). The fuel consumed, as estimated by the bottom-up approach of AGEM, is adjusted to match that of the RESD at a national level. The adjustment to LTO and cruise fuel estimates takes place at the individual movement level, across all movements.

Step 4: Emission Calculation

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

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

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

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

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

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

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

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

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

The volumes of biofuels used for transportation purposes for 1990–1996 were obtained from a 2011 report examining biofuel production and consumption in Canada (TFIS Inc. 2011). National consumption values for 1997–2010 were obtained from the Office of Energy Efficiency (OEE) within NRCan.[3] For 2012 biofuel data, provincial biofuel-use estimates (which also contained revised 2011 estimates) were obtained from NRCan.[4]

Often, these biofuel volumes are reported directly to NRCan from the provinces. If not, and a given province has a regional mandate, that mandated percentage is applied to the volumes of fossil-based fuels available in that region in order to estimate the volume of biofuel available. Where no provincial mandate existed, the federal mandate percentage was applied.

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

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

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

Combustion-related GHG emissions associated with this equipment are calculated by applying Equation A2–1 to activity data and emission factors for specific fuels on a provincial (for natural gas) and national basis.

3 Appleby J. 2011. Personal communications (emails sent to S. McKibbon July 22, 2011, and August 11, 2011). Pollution Inventories and Reporting Division.

4 Lam H. 2013. Personal communications (email sent to S. McKibbon Dec. 13, 2013). Pollution Inventories and Reporting Division.

Annex 3

Additional Methodologies

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

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

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

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

A3.1.1. Solid Fuels

A3.1.1.1. Coal Mining

Fugitive emission estimates are based on the study *Management of Methane Emissions from Coal Mines: Environmental, Engineering, Economic and Institutional Implications of Options*, prepared by B. King in 1994 for Neill and Gunter Ltd (King 1994). In the study, emission factors were calculated for all types of coal and coal mines. There are two types of coal mines in Canada: underground mines and surface mines. The method used by King (1994) to estimate emission rates from coal was based on a modified procedure from the Coal Industry Advisory Board. It consists of a hybrid of IPCC Tier 3- and Tier 2-type methodologies, depending on the availability of mine-specific data. Gross production, before cleaning and prep work, is used to calculate fugitive emissions for all mine types. For commercial purposes, mines typically report post-cleaning and prep work volumes. Underground mining activity emissions and surface mining activity emissions are separated, with both including post-mining activity emissions. The methodologies used to estimate the emissions from both types are explained below.

Underground Mines

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

Equation A3–1:

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

where:

Y	=	emissions of CH_4 per 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 gas content of the mined coal was not known, then it was assumed that the CH_4 content was 1.5 m^3/t (the global average for coals). Emissions from post-mining activities are included in the coal production emission factors.

Surface Mines

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

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

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

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

Equation A3–2:

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

where:

$EF_{i,j,k,l}$	=	the emission factor from the King (1994) study for province i, coal type j, mine k and coal field l
$Coal_{i,j,k,l}$	=	the gross production data of coal mined 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.

A3.1.1.2. Activity Data

The activity data required are the gross mine output data for each type of coal mined in each province from Statistics Canada's *Coal and Coke Statistics* publication (#45-002, Table 2). However, the *Coal and Coke Statistics* publication was cancelled in 2002 by Statistics Canada and this information is now provided directly to Environment Canada through a memorandum of understanding.

A3.1.1.3. Emission Factors

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

The weighted emission factors, by mine and coal type, developed using the King (1994) methodology, are listed in Table A3–1.

A3.1.2. Oil and Natural Gas

A3.1.2.1. Upstream Oil and Natural Gas Production

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

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

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

The methodology, emission factors and activity data used to estimate the emissions for 1990–1999 and from 2001 onwards were developed by Clearstone Engineering Ltd. and are presented in the following subsections. Consult the UOG study (CAPP 2005a) and the UOG model (CAPP 2005b) for additional details.

Table A3–1 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	0.60	t CH_4/kt coal mined
Alberta	Bituminous	Underground	1.69	t CH_4/kt coal mined
Alberta	Sub-bituminous	Surface	0.18	t CH_4/kt coal mined
British Columbia	Bituminous	Surface	0.65	t CH_4/kt coal mined
British Columbia	Bituminous	Underground	2.78	t CH_4/kt coal mined

Source: Adapted from King (1994).

Methodology for the 2000 Estimates

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

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

The resulting emissions were then aggregated to determine overall emissions by facility type, activity type and geographic

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

Sector	Source	CRF Fugitive Category
Accidents and Equipment Failures	Surface Casing Vent Flow / Gas Migration	2.B.iii Natural Gas—Other Leakage at Industrial Plants and Power Stations
Accidents and Equipment Failures	Spills / Pipeline Ruptures	2.B.iii Natural Gas—Other Leakage at Industrial Plants and Power Stations
Conventional Oil Production	Glycol Dehydrator Off-gas	2.C.i Venting—Oil
Conventional Oil Production	Flaring	2.C.i Flaring—Oil
Conventional Oil Production	Fugitive Equipment Leaks	2.A.ii Oil—Production
Conventional Oil Production	Loading/Unloading	2.A.ii Oil—Production
Conventional Oil Production	Reported Venting	2.C.i Venting—Oil
Conventional Oil Production	Storage Losses	2.A.ii Oil—Production
Conventional Oil Production	Unreported Venting	2.C.i Venting—Oil
Oil and Gas Well Drilling	Reported Venting	2.C.ii Venting—Combined
Natural Gas Production	Glycol Dehydrator Off-gas	2.C.ii Venting—Natural Gas
Natural Gas Production	Flaring	2.C.ii Flaring—Natural Gas
Natural Gas Production	Fugitive Equipment Leaks	2.B.i Natural Gas—Production/Processing
Natural Gas Production	Reported Venting	2.C.ii Venting—Natural Gas
Natural Gas Production	Storage Losses	2.B.i Natural Gas—Production/Processing
Natural Gas Production	Unreported Venting	2.C.ii Venting—Natural Gas
Natural Gas Processing	Glycol Dehydrator Off-gas	2.C.ii Venting—Natural Gas
Natural Gas Processing	Flaring	2.C.ii Flaring—Natural Gas
Natural Gas Processing	Fugitive Equipment Leaks	2.B.i Natural Gas—Production/Processing
Natural Gas Processing	Loading/Unloading	2.B.i Natural Gas—Production/Processing
Natural Gas Processing	Formation CO_2	2.C.ii Venting—Natural Gas
Natural Gas Processing	Storage Losses	2.B.i Natural Gas—Production/Processing
Natural Gas Processing	Unreported Venting	2.C.ii Venting—Natural Gas
Heavy Oil / Cold Bitumen Production	Glycol Dehydrator Off-gas	2.C.i Venting—Oil
Heavy Oil / Cold Bitumen Production	Flaring	2.C.i Flaring—Oil
Heavy Oil / Cold Bitumen Production	Fugitive Equipment Leaks	2.A.ii Oil—Production
Heavy Oil / Cold Bitumen Production	Loading/Unloading	2.A.ii Oil—Production
Heavy Oil / Cold Bitumen Production	Reported Venting	2.C.i Venting—Oil
Heavy Oil / Cold Bitumen Production	Storage Losses	2.A.ii Oil—Production
Heavy Oil / Cold Bitumen Production	Unreported Venting	2.C.i Venting—Oil
Thermal Operations	Flaring	2.C.i Flaring—Oil
Thermal Operations	Fugitive Equipment Leaks	2.A.ii Oil—Production
Thermal Operations	Loading/Unloading	2.A.ii Oil—Production
Thermal Operations	Reported Venting	2.C.i Venting—Oil
Thermal Operations	Storage Losses	2.A.ii Oil—Production
Thermal Operations	Unreported Venting	2.C.i Venting—Oil
Liquid Product Transportation	Flaring	2.C.i Flaring—Oil
Liquid Product Transportation	Fugitive Equipment Leaks	2.A.iii Oil—Transport
Liquid Product Transportation	Storage Losses	2.A.iii Oil—Transport
Liquid Product Transportation	Reported Venting	2.C.i Venting—Oil
Well Testing	Flaring	2.C.iii Flaring—Combined
Well Testing	Reported Venting	2.C.iii Venting—Combined

area. The basic methods used to estimate GHG emissions are the following:

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

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

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

Other required data included the following:

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

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

Methodology for the 1990–1999 Estimates

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

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

Methodology for 2001 Onwards

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

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

Equation A3-3 was used for pro-rating:

Equation A3–3:

$$ER_{i,j}^{k} = ER_{i,j}^{2000} \times \left(\frac{AF_{j}^{k}}{AF_{j}^{2000}} \right)$$

where:

$ER_{i,j}^{k}$	=	emission rate of compound i, source j, and year k, t/year
$ER_{i,j}^{2000}$	=	base year (2000) emission rate for compound i and source j, t/year
AF_{j}^{k}	=	activity factor for source j and year k
AF_{j}^{2000}	=	base year activity factor for source j

The activity data listed in Table A3–3 are used to calculate the 12 activity parameters given above, which are used in the estimation of the emissions from 2001 onwards. These data are input into the model, and the outputs are the UOG fugitive emission estimates for the specified year.

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

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

Publisher	Publication	Activity Data
Statistics Canada	CANSIM Table 131-0001 Supply and disposition of natural gas, monthly (Statistics Canada 2013a)	Less field flared and waste Field disposition and usage Gathering system disposal and use Plant uses Shrinkage
	CANSIM Table 126-0001 Supply and disposition of crude oil and equivalent, monthly (Statistics Canada 2013b)	Gross new production Heavy crude oil Light and medium crude oil Synthetic crude oil Crude bitumen
Saskatchewan Ministry of Energy and Resources	2012 Crude Oil Volume and Value Summary (Saskatchewan Ministry of Economy 2013a)	Light and medium crude oil production Heavy crude oil production
	2012–2013 Annual Report (Saskatchewan Ministry of Economy 2013b)	Total capable wells
Canadian Association of Petroleum Producers (CAPP)	*Statistical Handbook for Canada's Upstream Petroleum Industry* (CAPP 2013)	Total wells drilled (including dry and service)
Alberta Energy Regulator (AER)	ST-57 Field Surveillance and Operations Branch - Field Operations Provincial Summary 2012 (AER 2013a)	Sum of blowouts (drilling, servicing and other), kicks and pipeline ruptures
	ST-59 Alberta Drilling Activity, Monthly Statistics, December 2012 (AER 2013b)	December capable oil and gas wells
British Columbia Ministry of Energy, Mines and Petroleum Resources	Oil and Gas Production and Activity in British Columbia 2012[1]	Sum of producing oil wells and producing gas wells
Manitoba Innovation, Energy and Mines	Manitoba Petroleum Statistics (Manitoba Innovation, Energy and Mines 2013)	Wells capable of producing (Dec)
Canada–Newfoundland and Labrador Offshore Petroleum Board (CNLOPB)	Development Wells – Hibernia (CNLOPB 2013a) Development Wells – Terra Nova (CNLOPB 2013b) Development Wells – White Rose (CNLOPB 2013c) Development Wells – North Amethyst (CNLOPB 2013d)	Sum of all oil producers and gas injectors Sum of all oil producers and gas injectors Sum of all oil producers and gas injectors Sum of all oil producers and gas injectors

1. Mou C. 2013. Personal Communication (email from Mou C to Smyth S, Project Engineer, Pollutant Inventories and Reporting Division, dated 28 Oct 2013). British Columbia Ministry of Energy, Mines and Petroleum Resources.

A3.1.2.2. Natural Gas Transmission

Methodology

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

Fugitive emissions for natural gas transmission are based on two documents. The first, *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 Brian Ross from Clearstone Engineering Ltd. that describe the CO_2 emissions. There are no N_2O fugitive emissions from natural gas transmission. The CO_2 and CH_4 emissions for 1990–1996 are taken directly from the two sources. The CO_2 and CH_4 emissions for 1997 onwards are estimated using specific provincial emission factors.

Equation A3–4 is used to estimate the emissions:

Equation A3–4:

$$Emissions(kt) = TransmissionPipelineLength(km) \times EmissionFactor\ (leakage\ rate, kt/km)$$

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

Emission Factors

Provincial emission factors from 1997 onward (Table A3–5) were developed based on the 1996 emissions and lengths of pipeline from CAPP (1999). No fugitive emissions were present up to and including 1998 in Nova Scotia, New Brunswick or the Northwest

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

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

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

Territories, since natural gas transmission pipelines were not operating in these regions until 1999.

Activity Data

The activity data required to estimate the fugitive emissions for 1997 onwards are the length of the natural gas pipeline used for natural gas transmission for each year. These data were published annually in *Natural Gas Transportation and Distribution* (Statistics Canada #57-205). Statistics Canada has discontinued this publication. Updated pipeline lengths for 2010 and 2011 were provided by Statistics Canada, while pipeline lengths for 2012 were estimated. For the provinces of Quebec, Ontario, Manitoba, Saskatchewan, Alberta and British Columbia, as well as for the Northwest Territories, the 2012 pipeline lengths were estimated based on the average annual change in length between 2000 and 2011. The 2012 values were assumed to be the same as 2011 for New Brunswick and Nova Scotia since the natural gas transmission pipeline lengths have not changed since 2003 and 2002, respectively. Improvements to the model are being investigated. Refer to Chapter 3 for more details.

A3.1.2.3. Petroleum Refining

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

There are three sections in the refinery methodology: fugitive (unintentional releases), process venting and flaring methods. The combustion methodology for petroleum refining is discussed in Annex 2 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 emission factors are used to estimate the fugitive emissions for the years not included in the study: 1991–1993 and 2003 onwards.

The fugitive emissions are generated using Equation A3–5:

Equation A3–5:

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

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

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

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

The emission factors are:

CO_2: 2.78 kg CO_2/TJ

CH_4: 11.89 kg CH_4/TJ

The refinery study has listed fugitive N_2O emissions for 1990 and 1994–2002 as a constant 0.1 kt N_2O/year; however, there were not enough data to develop an emission factor for them. The N_2O emissions were kept constant at 0.1 kt N_2O/year for the years 1991–1993 and 2003 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

Table A3–6 Required Refinery Activity Data and Their Source

Publisher	Publication	Activity Data
Statistics Canada	*Report on Energy Supply–Demand in Canada* (RESD) (Statistics Canada #57-003-XIB)	Refinery and producer consumption (by refineries) annual energy consumption. 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

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 are listed in Table A3–6.

A3.1.2.4. Natural Gas Distribution

Methodology

Fugitive emissions from natural gas distribution are based on the Canadian Gas Association (CGA) report, *1995 Air Inventory of the Canadian Natural Gas Industry (CGA 1997) and Vented Emissions from Maintenance at Natural Gas Distribution Stations in Canada* (GRI 2000). The GRI (2000) report is an update to the CGA (1997) study with more accurate and better substantiated data for station vents. The emissions are estimated using activity data from Statistics Canada and the leakage rate developed from CGA (1997) and GRI (2000). Only fugitive emissions of CH_4 occur in the distribution of natural gas. The relationship between the data and emission factors is as follows:

Equation A3–6:

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

The fugitive emissions for natural gas distribution are estimated for each province and then summed to get 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.

Emission Factors

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

Activity Data

The activity data required are the length of natural gas distribution pipeline per province. These data were published annually in *Natural Gas Transportation and Distribution* (Statistics Canada #57-205) but have since been discontinued. Updated pipeline lengths for 2010 and 2011 were provided by Statistics Canada. Lengths for 2012 for all provinces were estimated based on the change in length between 2010 and 2011.

For New Brunswick and Nova Scotia, distribution lengths for 2000–2006 were provided by Enbridge Gas New Brunswick[1] and Heritage Gas,[2] respectively. In the Northwest Territories, the Ikhil Pipeline began providing Inuvik with natural gas in 1999 (Quenneville 2009). Distribution lengths for 1999–2006 were backcast based on the change in distribution length between 2007 and 2008.

Finally, the 2007 length for British Columbia provided by Statistics Canada was twice as large as the 2006 value. Statistics Canada confirmed that the data for 2006 and previous years were incorrect but 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. Improvements to the model are being investigated. Refer to Chapter 3 for more details.

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

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

A3.1.2.5. Oil Sands and Heavy Oil Upgrading Industry

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

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

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

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

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

- process emissions from the steam reforming of natural gas to produce hydrogen for upgraders;
- CH_4 present in the oil sands deposits that is released during mining, mine dewatering and ore handling activities;
- volatilization of hydrocarbons from the exposed oil sands and during transport and handling of the oil sands;
- biogenic gas formation (primarily CH_4) in some tailings ponds;
- volatilization and decomposition of residual bitumen and diluent, which carry through to the tailings ponds;
- fugitive equipment leaks, venting, flaring and storage losses at ore preparation, extraction and upgrader plants and their associated utility and cogeneration plants;
- spills and accidental releases; and
- secondary sources, such as sewage treatment facilities, landfills, onsite construction and fabrication activities, motor vehicle fleets, corporate aircraft, and boats and dredges used on the tailings ponds.

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

Bitumen Report: 1990–2003 Emission Estimates

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

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

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

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

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

The following sources were used to estimate emissions:

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

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

Bitumen Model: 2004 Onwards

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

In 2006, the Petro-Canada Fort Hills oil sands operations started reporting to the AER. It has yet to produce any product. In 2008 the CNRL Horizon mining, extraction and upgrading operation and OPTI-Nexen upgrader came online. Emissions from the CNRL Horizon mining, extraction and upgrading operations were estimated using various emission factors from Suncor, Syncrude and Albian's Muskeg River operations. Emissions from the OPTI-Nexen upgrader were estimated using emission factors from the Shell Scotford upgrader, except for CO_2 flaring. These approximations are problematic in that each facility has different processes with different emissions, especially when comparing the Nexen and Scotford upgraders. The Nexen upgrader is the only facility to employ gasification technology that transforms waste product (asphaltenes) into syngas used to create steam for *in-situ* extraction and hydrogen for upgrading (AER 2013c). For CO_2 emissions from flaring, the emission factor was estimated using data reported to the Greenhouse Gas Reporting Program by OPTI-Nexen and publicly available activity data from the AER. This was done because use of the Scotford flaring emission factor resulted in hugely overestimated flaring emissions. All of these approximations will be addressed when a new bitumen study is conducted in the future. Refer directly to the report on the bitumen model (Environment Canada 2007) for specific methodological discussions.

In 2010, the Shell Jackpine oil sands mine started reporting to the AER. Emissions from the Jackpine mine were estimated using emissions factors for the Albian Sand's Muskeg River operation.

Estimation Methodology

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

Equation A3–7:

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

where:

ER_i	=	emissions of substance i
EF_i	=	emission factor for substance i
A_1, A_2	=	activity values applicable to the emission factor

Emission Factors

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

Activity Data

Two activity data sources are used to extrapolate emissions. Alberta facilities data are extracted from ST 39: *Alberta Mineable Oil Sands Plant Statistics, Monthly Supplement December 2012* (AER 2013d). Data for Saskatchewan are taken from the National Energy Board's (NEB) *2012 Estimated Production of Canadian Crude Oil and Equivalent* (NEB 2013) table. The required data are listed in Table A3–8.

Table A3–8 Activity Data Required for the Bitumen Model

Required data from the ERCB ST-43 Report for Alberta emission estimates		
Albian Sands	Muskeg River	Bitumen Production
		Oil Sands Mined
Petro-Canada UTS	Fort Hills	Bitumen Production
		Oil Sands Mined
Shell	Scotford Upgrader	Process Gas Flared/Wasted
		Synthetic Crude Production
		Synthetic Crude Deliveries
Shell	Jackpine	Bitumen Production
		Oil Sands Mined
Suncor	Tar Island	Diluent Naphtha Flared/Wasted
		Diluent Naphtha Further Processed
		Diluent Naphtha Production
		Sulphur Flared/Wasted
		Synthetic Crude Fuel/Used
		Synthetic Crude Production
		Oil Sands Mined
Syncrude	Mildred Lake	Bitumen Production
		Intermediate Hydrocarbon Production
		Oil Sands Mined
		Synthetic Crude Fuel/Used
		Synthetic Crude Production
	Aurora	Bitumen Production
		Oil Sands Mined
		Synthetic Crude Fuel/Used
CNRL	Horizon	Bitumen Production
		Oil Sands Mined
		Synthetic Crude Production
		Diluent Naphtha Further Processed
		Diluent Naphtha Production
		Sulphur Flared/Wasted
OPTI Canada Inc.	OPTI-Nexen Upgrader	Synthetic Crude Production
		Synthetic Crude Deliveries
		Process Gas Flared/Wasted
Williams Energy, Inc.	Tar Island - Williams Energy	Process Gas Flared/Wasted
		Diluent Naphtha Production
Aux Sable Canada Ltd.	Aux Sable Heartland Offgas Plant	Process Gas Flared/Wasted
Required data from the NEB for Saskatchewan emission estimates		
Crude Type	**Crude Subcategory**	**Province**
Heavy Crude	SK CONV	Saskatchewan

A3

A3.2. Methodology for Industrial Processes

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

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

A3.2.1. CO_2 Emissions from Ammonia Production

A3.2.1.1. Methodology

Steam Methane Reforming (SMR), which generates hydrogen—the essential feed to the Haber-Bosch production process for 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 for 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 only estimates CO_2 emissions from the feedstock use of natural gas in the SMR process. The 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.

The facility-specific data on the feedstock use of natural gas and the annual ammonia production were obtained as part of Environment Canada's (EC) voluntary data collection for the years 2005 to 2009. These data were then used to develop the facility-specific ammonia-to-feed fuel (conversion) factors. Considering that these facility-specific ammonia-to-feed fuel factors can be used to reveal the performance of a specific facility, they are not published and they are kept confidential. The ammonia-to-feed fuel factor for some facilities could not be determined either because they were not part of EC's voluntary data request or they did not respond to the data request. For these facilities the average ammonia-to-feed fuel factors, based on the average of the other known facilities, is used. The average ammonia-to-feed fuel factor is 671 m^3 of natural gas/tonne of NH_3 produced.

The facility-specific annual ammonia production data are then multiplied by the facility-specific ammonia to-feed fuel factor to determine the amount of natural gas used for each facility. The facility specific feedstock uses of natural gas are then aggregated according to the province of Canada in which these facilities are situated; see Equation A3–8.

Equation A3–8:

$$\text{Feedstock use of natural gas}_p = \sum_{i=1}^{n} \text{annual } NH_3 \text{ production}_i \times \text{ammonia-to-feed fuel factor}_i$$

where:

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

The aggregates of the feedstock use natural gas, according to province, are then multiplied by the respective provincial natural gas carbon content found in Table A8-1 to determine the total carbon used. It is expected that all the carbon present in the feedstock gets transformed to CO_2 (IPCC 2006). Based on these factors, the process CO_2 emissions from ammonia production are calculated; see Equation A3–9.

Equation A3–9:

$$\text{Process } CO_2 = \sum_{p=1}^{m} \text{Feedstock use of natural gas}_p \times \text{carbon content}_p \times \frac{44}{12}$$

where:

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

It should be noted that the quantity of feedstock natural gas used in the SMR process should be subtracted from 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. Please refer to the discussions in Section A3.2.2 Other and Undifferentiated Production, for details.

The annual facility-specific ammonia production data for the years 1990 to 2011 were obtained from the following sources: 1990 to 2004 from the Cheminfo Services (2006) study; 2005 to 2009 from Environment Canada's voluntary data collection; and

2008 to 2011 from the micro data of Statistics Canada's *Industrial Chemicals and Synthetic Resins* Survey (Statistics Canada #46-002-X).

A3.2.2. CO_2 Emissions from Other and Undifferentiated Production

A3.2.2.1. Methodology

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

Gaseous Fuels

The only gaseous fuel considered in this category is natural gas. 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. The CO_2 from ammonia production is estimated and reported in the source category 2.B.1 and explained in Section A3.2.1 above. The feedstock use of natural gas in ammonia manufacturing is included in the overall non-energy use of natural gas, as reported by Statistics Canada in the *Report on Energy Supply–Demand in Canada* (RESD; Statistics Canada 57-003-XIB). To avoid double counting of emissions, the non-energy natural gas attributed to ammonia manufacturers—estimated in the calculation of CO_2 emissions from the source category 2.B.1 Ammonia Production—is subtracted from the RESD's overall non energy natural gas. This will determine the remaining (residual) non-energy natural gas, which represents the use made by other industries (excluding the ammonia industry).

The Cheminfo Services (2005) study determined the CO_2 emission factor for the overall non-energy use of natural gas. It used detailed natural gas consumption data for the fertilizer, methanol and carbon black industries to determine the overall non-energy natural gas emission factor of 1522 g CO_2 /m^3.

To determine CO_2 emissions from non-energy use of natural gas—excluding ammonia production—natural gas use data for non-ammonia production were used to develop a new non-energy (residual) natural gas emission factor of 38 g CO_2/m^3.

The residual non-energy natural gas values were then multiplied by the new non-energy emission factor to determine CO_2 emissions from the residual non-energy use of gaseous fuels. The non-energy gaseous fuel emissions are determined at the provincial level because the RESD data are available at the provincial level. The provincial level CO_2 emissions are then summed to obtain the national level CO_2 estimates. It should be noted 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 Other and Undifferentiated Production category are the non-energy use of

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

To determine, by province, the CO_2 emissions coming from these solid fuels, the fuel-, province- and year- specific emission factors shown in Table A8-5, Table A8-7, and Table A8-16 of Annex 8 for petroleum coke, coal and metallurgical coke, respectively, are applied to the consumption quantities reported as non-energy use. The national emission estimate for non-energy use of solid fuels is the total of all provincial/territorial emissions.

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

The CO_2 emissions resulting from the consumption of electrodes in the aluminium industry are included in the source category of 2.C.3 Aluminium Production. A key fuel used to make electrodes for the aluminium industry is petroleum coke. The overall non-energy use of petroleum coke, found in the RESD, includes the petroleum coke used to make electrodes for the aluminium industry. To avoid double counting of emissions, the non-energy petroleum coke is subtracted from the RESD's overall non-energy petroleum coke. The remaining (residual) non energy petroleum coke quantities represent the other industries' (excluding the aluminium producers) use of non-energy petroleum coke. The residual petroleum coke non energy CO_2 emissions are calculated by use of the factor provided in Table A8-5.

The non-energy fuels used to make electrodes to be used in electric arc furnaces (EAFs) in the iron and steel industry, for which emissions have been allocated to category 2.C.1 Iron and Steel Production, are expected to be included in the non-energy fuels reported in Statistics Canada's *Report on Energy Supply–Demand in Canada* (RESD; Statistics Canada #57-003). For this reason, and to avoid double counting, the CO_2 emissions resulting from electrode consumption in the EAF are removed from the provincial CO_2 estimates of the non-energy use of solid fuels.

Liquid Fuels

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

To estimate these emissions at provincial/territorial levels, the quantity of non-energy use of fuel is multiplied by the corresponding emission factor, as shown in Table A3–9 and Table A3–10 for liquid fuels. The summation of the provincial/territorial estimates gives the national emission estimate.

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

In the case of non-energy use of NGLs, the potential emission factors that occur when all the carbon is oxidized are provided in the McCann (2000) study. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) show a default value for the fraction of carbon stored in products when propane, butane or ethane are used as feedstock. The McCann (2000) potential emission factors are then multiplied by (1 - IPCC default fraction of carbon stored of 0.8) to give the non energy use emission factors of the three NGLs as shown in Table A3–9.

The non-energy use of petroleum products coming out of the oil refineries (i.e. petrochemical feedstocks, naphthas, lubricants, greases and other petroleum products) also results in CO_2 emissions, and is accounted for in the Other and Undifferentiated Production category. Their carbon factors (mass of carbon emitted per unit of fuel used) come from Jaques (1992). These factors are then multiplied by the molecular weight ratio of CO_2 to carbon, which is 44/12, and by (1 - fraction of carbon stored) to give the CO_2 emission factors used to estimate emissions. The default values of the fraction of carbon stored are also provided in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). Derivations of the non-energy use emission factors are shown in Table A3–10. To estimate emissions at national and provincial/territorial levels, the volume of non-energy product used is multiplied by its corresponding emission factor.

The CO_2 emissions resulting from the non-energy uses of gaseous, solid and liquid fuels are summed together, for each province and territory, to obtain the provincial and territorial CO_2 estimates for the Other and Undifferentiated Production category. The sum of the provincial and territorial CO_2 estimates represent the national CO_2 estimates, and only the national level CO_2 estimates are published in order to satisfy the confidentiality requirements of the non-energy fuels data.

Table A3–9 CO_2 Emission Factors for Natural Gas Liquids

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

Table A3–10 CO_2 Emission Factors for Non-Energy Petroleum Products

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

A3.2.2.2. Data Sources

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

A3.2.3. SF_6 Emissions from Electrical Equipment

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

To quantify SF_6 emissions (for 2006–2010), the Canadian electricity industry uses a method derived from the basic tier 3 IPCC life cycle equation below.

Equation A3–10:

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

The sections below explain in detail how the country- specific quantification method is derived from Equation A3–10.

A3.2.3.1.1. Equipment Manufacturing Emissions

Since Canadian electric utilities do not manufacture their transmission and distribution equipment, they are not responsible for the SF_6 released during the manufacturing stage. In fact, according to some utilities, electrical equipment purchased by the Canadian electricity industry is manufactured in the United States, Europe or Asia, and hence, emissions associated with manufacturing would have occurred mainly outside of Canada. As such, emissions from equipment manufacturing (i.e. the first term of Equation A3–10) are assumed to be not applicable to the electricity industry.

A3.2.3.1.2. Equipment Installation Emissions

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

A3.2.3.1.3. Equipment Use Emissions

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

Due to the SF_6 leakage that occurs during the above circumstances, utilities are required to "top up" their equipment to keep their equipment properly charged and operational. By topping up equipment with SF_6 gas, utilities are able to replace the amount of gas that has escaped.

A3.2.3.1.4. Equipment Decommissioning and Failure Emissions

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

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

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

A3.2.3.1.5. Emissions from SF_6 Recycling

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

Given the reasoning above, the Canadian electricity industry will use a modified Tier 3 IPCC approach (which is country-specific) to estimate SF_6 releases. Equation A3–10 is simplified to include only emissions from equipment use and decommissioning, as

shown in Equation A3–11.

Equation A3–11:

$$\begin{aligned} &Total\ Utility\ SF_6\ Emissions \\ &= \sum Equipment\ Use\ Emissions \\ &+ \sum Equipment\ Decommissioning\ and\ Failure\ Emissions \end{aligned}$$

A3.2.3.2. Methodology – Quantifying Equipment Use Emissions

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

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

Hence, an accurate estimate of the amount of SF_6 released is the amount used by utilities to top up their equipment during the equipment use stage, as shown in Equation A3–12.

Equation A3–12:

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

A3.2.3.2.1. Options for Tracking SF_6 Consumed for Top-ups

Based on Equation A3–12, utilities are able to estimate SF_6 releases from equipment use by tracking the amount of SF_6 used to top up their equipment. The following is a list of options for Canadian electric utilities to track the amount of SF_6 that is used for top-up purposes in order to quantify emissions of SF_6 from the equipment use phase. These options are listed in order of most accurate to least accurate. The most accurate method involves directly measuring the amount of gas transferred during top-ups, and the less accurate methods involve utilities relying on inventory records or purchase receipts to obtain an estimate. Each utility will have discretion over which method to use.

For all of the tracking options discussed below, it is assumed that the quantities of the SF_6 gas tracked do not include the gas used to pressurize the new switchgear to its full capacity at time of installation. Quantities of gas used for this pressurization are typically provided by the switchgear vendor at time of installation and hence do not come out of the utility inventory (please see also A3.2.3.1.2, Equipment Installation Emissions).

Option 1: Mass Flow Meters

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

Option 2: Weigh Scales

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

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

Under this approach, a utility weighs each individual cylinder before and after it is used to top up or refill equipment. The difference in weight then represents the amount that was used to top up the equipment. This procedure can be represented by Equation A3–13 below.

Equation A3–13:

$$\begin{aligned} &SF_6\ Used\ to\ top\ up\ equipment \\ &= \sum \begin{pmatrix} Weight\ of\ Individual\ SF_6\ Cylinders\ before\ Top\ Up \\ -Weight\ of\ Individual\ SF_6\ Cylinders\ after\ Top\ Up \end{pmatrix} \end{aligned}$$

Option 2b: Weighing SF_6 Cylinders on an Inventory Basis

With this approach, utilities weigh all SF_6 cylinders that are placed in their maintenance inventory at the beginning of the year and the end of the year. They must also account for any purchases or additions to the inventory, weight of SF_6 cylinders returned to suppliers and the quantity of SF_6 sent off-site for recycling or destruction during the year. This method can be represented by Equation A3–14.

Equation A3–14:

$$SF_6\ Used\ to\ top\ up\ equipment = Weight\ of\ SF_6\ Cylinders\ in\ Maintenance\ Inventory_{Beginning\ of\ Year} - Weight\ of\ SF_6\ Cylinder\ in\ Maintenance\ Inventory_{End\ of\ Year} + Weight\ of\ SF_6\ Cylinders\ Purchased\ /Acquired - Weight\ of\ SF_6\ Cylinders\ Returned\ to\ Suppliers - Weight\ of SF_6\ sent\ off-site\ for\ recycling\ or\ destructions$$

Option 3: Cylinder Count

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

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

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

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

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

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

When relying on inventory or purchase records, it is important to take into consideration the amount of residual gas left in the cylinders after it is used for top-ups. According to information supplied by two major SF_6 gas distributors, approximately 12% of gas is left in cylinders after they are used. This amount should be subtracted from the total amount of SF_6 found in inventory records. Equation A3–15 represents the SF_6 tracking method based on the central purchasing or inventory records.

Equation A3–15:

$$SF_6\ Used\ for\ Top-Up = \sum_{i=1}^{n}\left[\begin{matrix}number\ of\ cylinder\ i\ purchased\ and\ placed\ in\ inventory \\ *\ SF_6\ weight\ in\ cylinder\ i\ *\ (1-y)\end{matrix}\right]$$

where:

i	=	different types of cylinders
y	=	% of gas left in cylinders when returned to suppliers *(Note: utilities may choose to directly weigh the residual gas in cylinders and calculate the residual gas in % as y, or may use a default value of 12% for y.)*

Option 3b: Tracking Cylinder Inventory Count Throughout the Year

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

Since utilities are not weighing their cylinders, an estimate of the amount of residual gas left in the cylinders when returned to suppliers must be estimated. Utilities may choose to weigh this amount or use the suggested 12% explained above. This methodology is represented by Equation A3–16.

Equation A3–16:

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

where:

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

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

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

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

Equation A3–17:

$$\begin{aligned} &Equipment\ decommisioning\ emissions \\ &= Nameplate\ capacity\ of\ retired\ equipment \\ &- SF_6\ amount\ recovered\ from\ retired\ equipment \end{aligned}$$

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

When equipment failures or damages occur to the point where they cannot be repaired, the nameplate capacity of the equipment can provide a reasonable estimate of emissions that have taken place as a result of equipment failures (see Equation A3–18).

Equation A3–18:

$$\begin{aligned} &Emissions\ from\ damaged\ equipment \\ &= Nameplate\ capacity\ of\ damaged\ equipment \end{aligned}$$

The information provided in this section (A3.2.3) is extracted from the SF_6 Emission Estimation and Reporting Protocol for Electric Utilities (Environment Canada and Canadian Electricity Association 2008), available upon request at http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=5926D759-36A6-467C-AE05-077C5E6C12A2. For further details on data uncertainty, data quality control, data verification by third party, transfer of information and data to the GHG Division, documentation and archiving, new information or data updates, and protocol reviews and amendments, please refer to the Protocol.

A3.2.3.4. Data Sources

The SF_6 emission estimates by province for 2006–2011 were provided by the Canadian Electricity Association (CEA)—which represents electricity companies across Canada, except for the province of Quebec—and Hydro Quebec (HQ).

A3.2.4. CO_2 Emissions from Iron and Steel Production

A3.2.4.1. Methodology

In addition to the methodology descriptions provided in Chapter 4, Section 4.16, information is provided here that focuses on production plants in Canada and their process technologies.

Canadian Iron and Steel Manufacturing Facilities

As of 1998, the Canadian steel sector consisted of 17 facilities. These facilities comprise five integrated mills and 12 non-integrated mills (10 mini-mills and two specialty steel mills). Nine of these facilities, including four integrated mills, are located in Ontario. There are four mills in Quebec and one each in Alberta, Saskatchewan, Manitoba and Nova Scotia. All 17 are listed in Table A3–11, which also indicates the manufacturing processes involved (Environment Canada 1998).

Canadian Iron and Steel Process Technologies

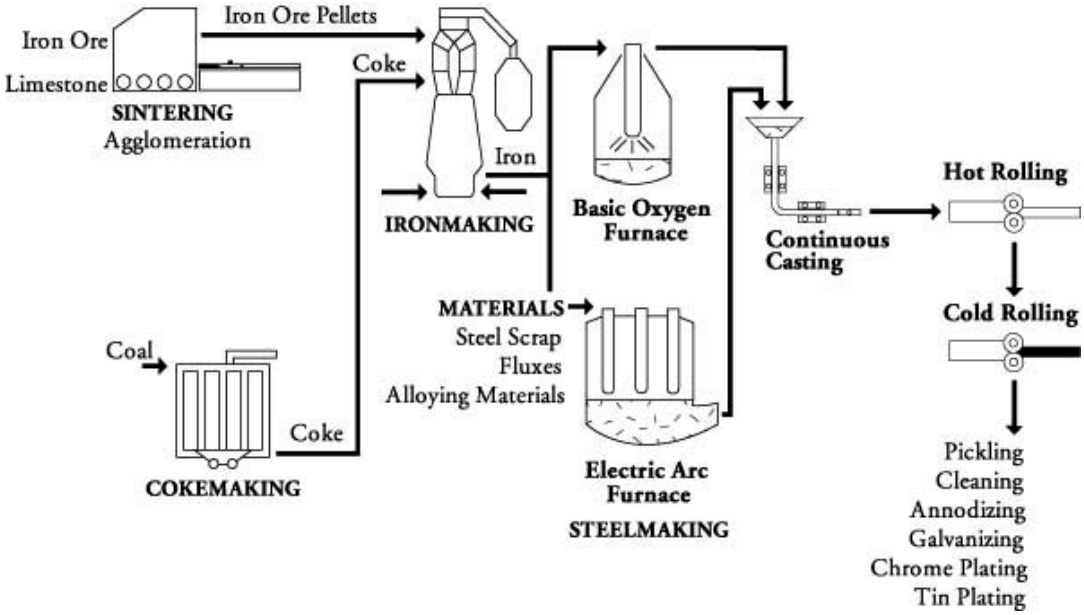
Steel is produced in Canada by two main steelmaking processes (see Figure A3-1): basic oxygen furnaces (58.5% in 1998) and electric arc furnaces (41.5% in 1998) (Environment Canada 1998). The basic oxygen furnace is used in integrated mills in conjunction with cokemaking, sintering, and blast furnace ironmaking operations. The 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 (DRI) to produce a wide product range of carbon and alloy steels. Dofasco Inc. operates the only integrated steel plant in Canada that produces part of its steel by the electric arc furnace process. Ispat Sidbec Inc. operates the only Canadian steel mill that produces and uses DRI as part of its raw material feed. Ancillary or secondary steelmaking processes that are common to both integrated and non-integrated steelmaking include ladle metallurgy, continuous casting, hot forming, cold forming and finishing.

Table A3–11 Canadian Iron and Steel Manufacturing Facilities and Processes

Plant Company/Name	Location	Manufacturing Process
AltaSteel Ltd.	Edmonton, AB	MM
IPSCO Inc.	Regina, SK	MM
Gerdau MRM Steel Inc.	Selkirk, MB	MM
Algoma Steel Inc.	Sault Ste. Marie, ON	IM
Dofasco Inc.	Hamilton, ON	IEM
Stelco Inc., Hilton Works	Hamilton, ON	IM
Lake Erie Steel Co. (Stelco)	Nanticoke, ON	IM
Slater Steels, Specialty Bar Division	Hamilton, ON	MM
Gerdau Courtice Steel Inc.	Cambridge, ON	MM
Atlas Specialty Steels	Welland, ON	SS
Co-Steel Lasco	Whitby, ON	MM
Ivaco Inc.	L'Orignal, ON	MM
Ispat Sidbec Inc.	Contrecoeur, QC	DRM
Stelco-McMaster Ltée	Contrecoeur, QC	MM
Atlas Stainless Steels	Tracy, QC	SS
QIT-Fer et Titane Inc.	Sorel, QC	IM
Sydney Steel Corporation	Sydney, NS	MM

Legend:
IM = Integrated Mills
IEM = Integrated and Electric Arc Furnace Mill
MM = Mini-Mill
DRM = Direct Reduction Mini-Mill
SS = Specialty Steel Mill

Figure A3–1 Canadian Steelmaking Processes



A3.3. Methodology for the Agriculture Sector

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

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

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

A3.3.1. Animal Population Data Sources

Annual livestock population data at a provincial level were used to develop emission estimates. Livestock and poultry populations, by animal subcategory, and by province, were obtained from Statistics Canada (Table A3–12).

Annual animal populations of cattle, sheep and swine are presented as the simple mean of semi annual or quarterly surveys. Surveys are corrected by Statistics Canada to the *Census of Agriculture*, conducted every 5 years. The populations of horses, goats, buffalo,[3] llamas, alpacas and poultry are taken from the *Census of Agriculture* exclusively. Annual populations are developed by linear interpolation in order to avoid large changes in census years. Buffalo populations were not collected in 1986; thus, the buffalo population was set constant for 1990 at the 1991 level.

For beef and dairy cattle, the IPCC Tier 2 approach (IPCC 2000) was adopted to estimate CH_4 emission factors from enteric fermentation and manure management. The subcategories of provincial cattle populations collected by Statistics Canada were further disaggregated into subannual production stages to

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

Table A3–12 Animal Categories and Sources of Population Data

Category	Sources/Notes
Cattle	Statistics Canada. Table 003-0032 - Number of cattle, by class and farm type, annual (head), CANSIM (database). http://www5.statcan.gc.ca/cansim/a05?lang=eng&id=0030032&pattern=0030032&searchTypeByValue=1&p2=35 (accessed September 24, 2013)
—Dairy Cattle	All cattle used in the production of milk and milk products
—Non-dairy Cattle	All other cattle
Buffalo, Goats, Horses, Llamas and Alpacas	Statistics Canada. 2008. Alternative Livestock on Canadian Farms: Census years 1981, 1986, 1991, 1996, 2001, and 2006 (Catalogue # 23-502-X), 2011 Census: Statistics Canada. Table 95-640-XWE - 2011 Farm and farm operator data (database). http://www29.statcan.gc.ca/ceag-web/eng/data-type-selection-type-donnees?geoId=0 —linear interpolation between census years, remains constant after last census
Mules and Asses	Not compiled by Statistics Canada.
Sheep and Lambs	Statistics Canada. Table 003-0031 - Number of sheep and lambs on farms, annual (head), CANSIM (database). http://www5.statcan.gc.ca/cansim/a05?lang=eng&id=0030031&pattern=0030031&searchTypeByValue=1&p2=35 (accessed September 24, 2013)
Swine	Statistics Canada. Table 003-0004 - Number of hogs on farms at end of quarter, quarterly (head), CANSIM (database). http://www5.statcan.gc.ca/cansim/a26;jsessionid=59B3777642DC730198B7D13BA6029B86?lang=eng&retrLang=eng&id=0030004&tabMode=dataTable&srchLan=-1&p1=-1&p2=35 (accessed September 24, 2013) Subcategories: Boars, Sows, Growers under 20 kg, 20 to 60 kg, and over 60 kg
Poultry	Farm data and farm operator data tables (section 6.5 of publication #95-629) (Statistics Canada [2007a]) Selected historical data from the Census of Agriculture, Canada and provinces: census years 1976 to 2006 (Table 2.16 and section 4.6 of Statistics Canada catalogue #95-632). (Statistics Canada [2007b]) 2011 Census: Statistics Canada. Table 95-640-XWE - 2011 Farm and farm operator data (database). http://www29.statcan.gc.ca/ceag-web/eng/data-type-selection-type-donnees?geoId=0 (Accessed December 20, 2012) —linear interpolation between census years, remains constant after last census

Table A3–13 Cattle Stage Production Model

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

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

isolate and quantify the effect of specific production practices on gross energy intake and as a consequence, CH_4 emission. Data to describe the production environment and associated performance of classes of animals were collected from a combination of production and management practices published in scientific journals, a survey of dairy and beef production practices conducted and administered to regional and provincial beef and dairy cattle specialists across the country, and consultation with scientists at universities and federal research institutions, as well as from provincial/national associations and provincial/regional performance-recording organizations (Boadi et al. 2004b).

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 non dairy cattle and 9 for dairy cattle, observed throughout the different provinces of Canada (Table A3–13). The model characterizes cattle by physiological status, diet, age, sex, weight, growth rate, activity level and production environment.

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

A3.3.1.1. Dairy Cattle

Production and Performance

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

Table A3–14 provides an example of production performance data collected for Canadian dairy cattle, originally used as a quality assurance (QA) verification of the data incorporated in the Tier 2 model.

Currently, it is assumed that all production characteristics of the Canadian dairy herd have remained constant over the 1990–2012 time period, including the live weight of dairy cows, as data from Holstein Ontario do not indicate increases in weight over this period. As a result, dairy cows' and dairy heifers' live weights are set constant to the 2001 weight, estimated in Boadi et al. (2004b).

Milk Yield and Fat Data

Milk productivity has increased in all Canadian provinces (Table A3–15), as documented by the CanWest Dairy Herd Improvement (DHI) Services, representing more than two thirds of the Canadian dairy cow population for the period of 1999–2012. These data are the best estimate of actual milk production per 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 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 and the management data from 1999 to 2007. A 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 animals that were dry during the summer months were on pasture; animals that were dry during the remainder of the year were in confinement. Replacement heifers were assumed to calve at 24 months.

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

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

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

Table A3–15 Average Milk Production from 1990 to 2012 at a Provincial Level

	Average Milk Production (kg/head/day)[1]									
Year	N.L.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
1990	21.0	20.9	21.0	20.8	20.3	21.7	22.1	22.2	23.2	24.3
1991	21.3	21.2	21.3	21.1	20.6	21.7	22.4	22.5	23.6	24.7
1992	22.1	22.0	22.1	21.9	21.5	22.6	23.3	23.4	24.5	25.6
1993	22.6	22.5	22.6	22.5	21.7	23.2	23.8	23.9	25.1	26.2
1994	23.5	23.4	23.5	23.3	22.4	23.6	24.8	24.8	26.0	27.3
1995	23.1	23.1	23.2	23.0	22.2	24.0	24.2	24.2	25.5	26.8
1996	23.7	23.6	23.7	23.5	23.0	24.7	25.2	25.4	26.5	27.5
1997	24.0	24.0	24.1	23.9	23.2	24.8	25.4	25.8	26.7	27.2
1998	24.4	24.4	24.5	24.3	24.1	25.3	25.7	26.6	27.3	27.9
1999	25.6	25.5	26.4	26.1	25.1	26.4	26.0	26.4	27.1	28.8
2000	27.4	26.1	26.8	26.4	25.5	26.5	27.9	27.7	29.0	30.0
2001	28.3	26.4	27.1	27.2	25.7	26.3	28.0	28.1	29.4	30.4
2002	28.2	26.4	26.9	27.2	26.2	26.7	28.3	29.4	30.4	31.2
2003	28.7	26.2	26.9	26.4	26.0	26.5	28.3	29.1	29.8	31.1
2004	26.1	26.3	26.8	26.3	26.1	26.1	28.1	29.1	29.2	30.7
2005	27.0	27.1	26.9	26.4	25.9	26.7	27.4	29.3	29.3	30.4
2006	27.3	27.3	26.8	26.4	26.3	27.3	27.7	29.3	29.7	30.5
2007	26.5	26.4	26.5	26.7	26.6	27.4	27.9	29.7	29.8	30.5
2008	26.7	26.9	26.9	26.4	26.7	27.3	28.1	29.8	29.8	30.2
2009	26.6	26.7	27.3	26.3	26.6	27.3	28.6	30.7	30.3	30.2
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

1. Data source: VALACTA Dairy Services/CanWest DHI.

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. (2004b) 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 Digestible Energy

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

A3.3.1.2. Non-Dairy Cattle

Production Practices and Performance

Production practices for non-dairy cattle also vary across the country due to climate, land prices and differences in traditional farming practices. The study conducted by Boadi et al. (2004b) characterized the predominant practices in 2001, for each province according to animal type, physiological status, age, gender, growth rate, activity level and production environment. The values presented in Table A3–16 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. (2004b) for the specific animal subcategories presented in Table A3–17. Carcass weight data are collected by the Canadian Beef Grading Agency (CBGA) and published by Agriculture and Agri-Food Canada (AAFC 1990–2012). Carcass weights increased from 1990 to 2003 for beef cows, heifers for slaughter, steers and bulls (Figure A3–2). Since 2003, beef cow carcass weights have remained more or less stable, but slaughter animal weights have continued to increase.

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

Animal Category	Production Characteristics[2]	Data Sources[3]
Beef Cows		
Average weight, kg	603 (36)	Kopp et al. (2004)
Mature weight, kg	619 (52)	AAFRD (2001)
Milk, kg/day	7.3 (1.2)	Kopp et al. (2004)
Milk fat, %	3.6 (0.6)	Kopp et al. (2004)
Conception rate, %	93.7 (1.3)	Manitoba Agriculture and Food (2000); AAFRD (2001)
Replacement Heifers		
Average weight, kg	478 (34)	
Mature weight, kg	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)	

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

In 2003, the Canadian cattle meat industry was affected by bovine spongiform encephalopathy (BSE) disease, which shut down beef exports to the United States. After 2003 the slaughtered carcass weight of bulls had evidently increased due to the culling of older bulls. To provide an estimate more representative of the on-farm herd, the average live weights of bulls was retained at their 2002 value; however, since 2009, the slaughter weight of bulls was, once again, used in the time series; however, due to the identification of anomalous values for bulls in the published data, the 2011 weight of bulls was retained in 2012, awaiting a complete review of data published on the AAFC website.

Duration of Time in a Production Environment

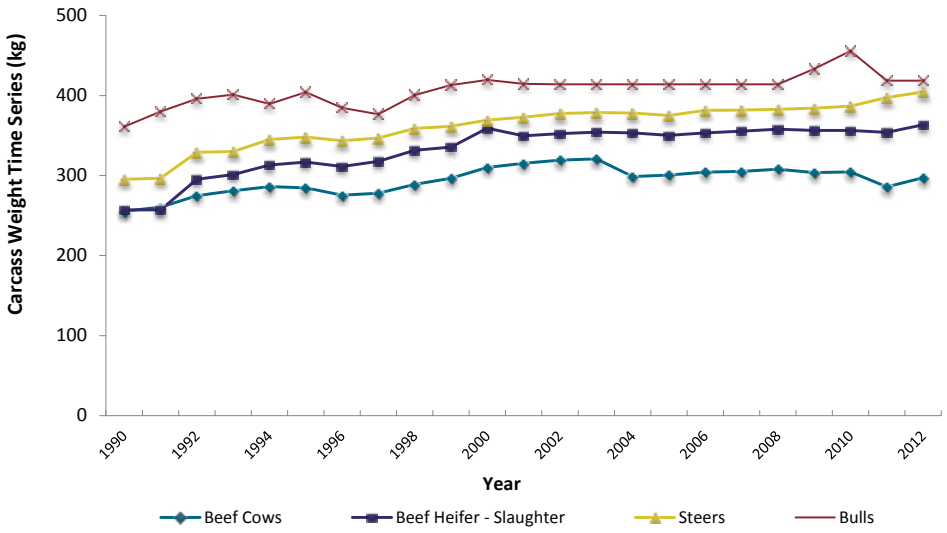
Replacement heifers over 15 months of age are assumed to be bred or pregnant. All replacement stock (breeding bulls, young and replacement heifers over 12 months of age) are assumed to enter the breeding herd (mature breeding bulls, and beef cows) at 24 months of age. Slaughter heifers and steers at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

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

Cattle Subcategory	Trend in Live Weight Applied
Beef cows	Trends in beef cow carcass weight used as an indicator of live weight.
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; 2009–2011 uses carcass weight trend again; 2012 values were kept constant.
Calves	No change
Dairy heifers[1]	No change

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

Figure A3–2 Non-dairy Cattle Carcass Weight, Based on Data Collected by CBGA and Published by AAFC



typically backgrounded for 6 months before being sent to feedlots where they are finished after 2 to 4 months.

Ration Digestible Energy (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 AAFRD and the University of Alberta (2003) were used for Alberta, whereas NRC (2001) values were used to estimate the DE of rations for British Columbia and the eastern provinces. Overall, DE ranged from 60 to 84%, depending on rations and feeding regimes.

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

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A3.3.2. CH_4 Emissions from Enteric Fermentation

The release of CH_4 from enteric fermentation from all categories of livestock in Canada is calculated using Equation A3–19. CH_4 emissions from enteric fermentation for cattle are estimated using the country-specific emission factors derived from IPCC (2000) Tier 2 equations (Table A3–18). For the other animal categories, the IPCC Tier 1 methodology and default emission factors are applied (see Annex 8).

Equation A3–19:

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

where:

CH_{4EF}	=	CH_4 emissions from 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 A3–18 for cattle; for other animal categories, see Annex 8).

A3.3.2.1. Enteric CH_4 Emission Factors for Cattle

Emission factors were derived at the provincial level using IPCC (2000) Tier 2 equations for different subcategories of cattle (dairy cows, dairy heifers, beef cows, beef heifers, bulls, calves, heifer replacement, heifers > 1 year and steers > 1 year) based on stages of production. Tier 2 enteric fermentation estimates require an approximation of gross energy consumed (GE) calculated according to Equation A3–20.

Equation A3–20:

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

where:

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_{mob}	=	net energy mobilized by weight loss during lactation, MJ/day
NE_p	=	net energy required for pregnancy, MJ/day
NE_m/DE	=	ratio of net energy available in a diet for growth to digestible energy
NE_g	=	net energy required for growth, MJ/day
NE_g/DE	=	ratio of net energy available in a diet for growth to digestible energy
DE	=	digestible energy of the ration, %

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

The total duration of time an animal spends in a production stage can also be variable; a weighted average emission factor was calculated. Criteria used in the weighting included duration of time spent in the production category and relative percentage of the population in each stage of production. Furthermore, some net energy calculations may be modified based on a factor that takes into account the time that the energy is supplied within a production stage. For example, weight loss during lactation in dairy cattle only occurs within the first 70 days of lactation; therefore NE_{mob} is modified by a ratio of the days of weight loss over the total lactation period. For each province an emission factor ($EF_{(EF)}$) is calculated according to Equation A3–21. Provincial emission factors were weighted on the basis of the proportion of the provincial animal population relative to the national population to calculate a national emission factor for each subcategory, for each year in the time series (Table A3–18).

Equation A3–21:

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

where:

$EF_{(EF)T}$	=	annual emission factor for defined animal population T, kg/head/year
GE_T	=	gross energy, MJ/day within the defined population T, kg/day
Y_{mT}	=	methane conversion rate at which the fraction of gross energy is converted to methane by an animal within defined population T, m^3/kg
TP_T	=	time (days/year) of a stage of production with defined population T

A3.3.2.2. 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 enteric fermentation was carried out.

Research measuring enteric fermentation 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 outside of feedlots, 3.2% (±1.9) GE on feedlots and 6.2% (±2.4) for dairy cattle (McCaughey et al. 1997, 1999; Boadi and Wittenberg 2002; Boadi et al. 2002, 2004a; McGinn et al. 2004, 2008, 2009; Beauchemin and McGinn 2005, 2006; Chaves et al. 2006; Kebreab

Table A3–18 CH_4 Emission Factors for Enteric Fermentation for Cattle from 1990 to 2012

	$EF_{(EF)T}$ - (kg CH_4/head/year)[1]							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter[2]	Steers[2]	Calves
1990	109.4	72.2	79.7	81.6	69.2	52.7	48.6	39.8
1991	110.1	72.2	82.5	82.4	69.8	52.9	48.9	39.8
1992	112.6	72.3	84.8	84.6	70.7	55.5	50.9	39.7
1993	113.8	72.2	85.5	85.6	71.1	56.6	50.5	39.7
1994	114.1	72.2	83.9	86.5	71.6	57.2	51.7	39.7
1995	114.3	72.1	86.1	86.1	71.5	57.1	51.2	39.7
1996	116.9	72.1	83.3	84.5	70.5	57.4	51.4	39.6
1997	116.7	72.1	82.2	85.0	71.3	58.3	52.2	39.7
1998	118.4	72.2	85.7	86.6	72.3	59.4	53.4	39.7
1999	120.6	72.2	87.6	87.8	73.1	60.3	54.2	39.6
2000	122.0	72.3	88.4	89.8	74.1	61.7	54.8	39.7
2001	122.3	72.3	87.8	90.4	74.6	61.2	54.7	39.8
2002	123.7	72.4	87.7	90.9	75.2	61.3	54.7	39.7
2003	123.3	72.4	87.6	91.0	75.0	60.8	54.2	39.5
2004	122.8	72.4	87.6	87.4	72.4	60.7	53.5	39.5
2005	123.3	72.4	87.6	87.5	72.1	60.8	53.5	39.5
2006	124.6	72.3	87.5	88.0	72.4	61.0	54.2	39.5
2007	125.0	72.3	87.6	88.1	72.5	61.1	54.4	39.5
2008	125.4	72.4	87.5	88.6	73.0	61.1	54.2	39.5
2009	125.7	72.4	90.1	87.9	72.5	60.9	54.4	39.6
2010	127.2	72.3	93.3	88.1	72.6	60.8	54.5	39.6
2011	127.6	72.4	88.1	85.0	70.2	60.6	55.3	39.6
2012	128.1	72.4	88.1	86.7	71.2	61.2	55.7	39.6

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

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). These values tend to agree with the values published in *the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). From the same compilation of research, the emission factor for non-dairy cattle is observed to be 57 (±22) kg/head/yr outside of feedlots and 56 (±24) kg/head/yr in feedlots, and the average measured dairy cattle emission factors are 130 kg/head/yr (±34).

Caution must be used in interpreting these values, as the majority of studies focus on yearling heifers and steers, and the average value does not take into account the relative importance of different cattle subcategories on the average emission factor. Nonetheless, the emission factor values do agree, in general, with the emission factors used by Canada: non-dairy emission factors from 60 to 65 kg/head/yr and dairy emission factors from 109 to 127 kg/head/yr. In the Canadian cattle model, a Y_m of 6% GE for non-dairy cattle outside of feedlots and dairy cattle and 4% GE for non-dairy cattle in feedlots is used, taken from the IPCC Good Practice Guidance (IPCC 2000).

As it currently stands, no evident bias could be identified from the review of Canadian literature results. It appears that any bias that is introduced through the use of the Y_m values from the 2000 Good Practice Guidance is compensated for by the estimate of GE for specific animal subcategories. Improvements to the cattle emission model require the development of direct links between the Ym and animal production, including nutrition, creating consistency with the estimated GE and emission factors.

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

This literature analysis suggests that it would be difficult to improve Canadian estimates by updates of single parameters. Improving on the current model would require the development and introduction of a country-specific Tier 3 calculation methodology.

A3.3.2.3. 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 8).

A3.3.2.4. Uncertainty

A comprehensive uncertainty analysis was carried out on all methodology used in the calculation of methane from livestock for 2010. For this submission, the uncertainty ranges (percentages) of means were rerun for 2012. 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 upon a recent study (Karimi-Zindashty et al. 2012); however, the Environment Canada stochastic model (ECSM) built in Mathematica© (i) used the exact parameters and equations used in the Canadian inventory methodology based on the 2000 GPG, but also (ii) included uncertainty associated with populations and duration of production stages that impacts subcategory emission factors (Table A3–33), and (iii) used the provincial distribution of manure management systems with improved estimates of probability distributions (Table A3–19). The ECSM was run for the years 1990, 2005, 2010 and 2012. A new trend analysis was carried out to establish the uncertainty in the estimate of the differences in emissions from 1990 to 2012.

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, cattle, swine and sheep, were supplied directly from Statistics Canada based on biannual and quarterly survey statistics. For small provinces with few animals in certain categories, sample variance is large, 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 non-dairy cattle populations 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 function was developed that increased uncertainty as a function of time from the census. A linear regression was run through census year population estimates from 1991, 1995, 2001 and 2006. 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 times 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 in the 2010/2011 uncertainties, similar to those animals from which populations are taken from biannual and quarterly surveys, though this had little impact on total uncertainty. The national population uncertainties for these 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: (i) those associated with cattle production and performance (see Section A3.3.2 for detailed descriptions of parameters), and (ii) those that are specific to the IPCC Tier 2 equations (see section A3.3.3 for details). For the most part, the uncertainty assigned to parameters associated with cattle production and performance are 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 took the probability distributions either from Monni et al. (2007) or from the IPCC (2006). Two differences are notable: (i) digestible energy probability distributions became available from Valacta Dairy Services after the published study

was completed, allowing the calculation of typical distributions of different types of feed; and (ii) Karimi-Zindashty et al. (2012) used the IPCC 2006 methodology and therefore did not include the effects of weight loss on gross energy. Therefore, a uniform distribution was incorporated 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 7 in Table A3–19). The parameters in 1990 and 2012 are considered to be 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 analysis were animal populations, milk production and fat content in dairy cattle, and body weights in cattle.

The summary results of the uncertainty analysis for emissions from enteric fermentation are reported in Chapter 6, Section 6.2.3. Briefly, the uncertainty range for enteric fermentation emissions is 39% (-17% to +22% of the mean) (Table 6-3). Most uncertainty in the estimate is associated with the Tier 2 emission factors for cattle that lie within an uncertainty range of -19% to +22% of the mean non-dairy emission factor and -16% and +21% of the mean dairy cattle emission factor. In the case of other animals that use Tier 1 IPCC (2003) 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 dairy cattle and non-dairy cattle 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 also the uniform distribution of the factor that defines energy released from weight loss during lactation in dairy cattle.

The overall uncertainty for each estimate of each individual year used as activity data has changed very little over time. The uncertainty range for emissions in 1990 and 2012 is 39~40%. Based on the trend analysis, over the long term, emissions of methane increased between the 1990 base year and 2012 by between 9–19%, with a most likely value (MLV) of 15% (trend uncertainty 10%). Most of the increase in emissions is associated with enteric fermentation, which increased by 11–22% with an MLV of 16%. To estimate the trend uncertainty reported in Table 6-3, the percentage difference between confidence intervals and the MLV was applied to the mean change in emissions between 1990 and 2012, resulting in a range of +8% to +16% around the mean calculated change in emissions of +12%.

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 among the two different national emission estimation methodologies. Monni et al. (2007) estimated the national-scale uncertainty for Finnish agriculture enteric fermentation of different cattle subcategories ranging from –22 to +29% of the mean to –29 to +39% of the mean. Rypdal & Winiwarter (2001) reported uncertainty for some European countries from ±20% of the mean in the United Kingdom to ±50% of the mean in Austria, but these were mainly Tier 1 estimation methodologies. We did not find comparable publications for trend uncertainty analyses within the domain of Agriculture.

The results for 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 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 estimates towards higher emission estimates. The sensitivity analysis carried out by Karimi-Zindashty et al. (2012) indicated that the large majority of uncertainty in emission estimates 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 (C_{fi}) 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.

Uncertainty analyses will be completely updated only when changes are made to the emission model or source of activity data.

Table A3–19 Uncertainties in Inputs, Sources of Uncertainty and the Spatial and Animal Category at which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Enteric Fermentationn

Parameter Category	Coefficient/ Parameter Source	Distribution Type	Uncertainty Range[1]	Uncertainty Distribution Estimate Source and Notes	Spatial Allocation/ Animal Category Allocation
Population Data[7]					
Cattle biannual surveys					
Dairy	Statistics Canada (Table 003-0032)	normal	±6% – ±42%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]	Provincial/subcategory
Non-dairy	Statistics Canada (Table 003-0032)	normal	±5% – ±73%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]	Provincial/subcategory
Other survey-based populations					
Swine	Statistics Canada (Tables 003-0004 and 003-0031)	normal	±8% – ±89%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]	Provincial/subcategory
Sheep	Statistics Canada (Tables 003-0004 and 003-0031)	normal	±14% – ±80%	Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]	Provincial/subcategory
Census of Agriculture					
Goats	Census of Agriculture (Statistics Canada 2012a)	normal	±9% – ±21%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	Provincial/subcategory
Poultry	Census of Agriculture (Statistics Canada 2012a)	normal	±5% – ±12%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	Provincial/subcategory
Bison	Census of Agriculture (Statistics Canada 2012a)	normal	±18% – ±85%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	Provincial/subcategory
Llamas and Alpacas	Census of Agriculture (Statistics Canada 2012a)	normal	±16% – ±42%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	Provincial/subcategory
Horses	Census of Agriculture (Statistics Canada 2012a)	normal	±5% – ±16%	Statistics Canada, *Census of Agriculture* plus uncertainty associated with linear extrapolation, function of time from census	Provincial/subcategory
Cattle Production Parameters and Performance					
Milk production[7]	Valacta/Canwest DHI	normal	±8%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Fat content[7]	Valacta/Canwest DHI	normal	±8%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Dairy herd efficiency[7]	Valacta/Canwest DHI	normal	±8%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Pregnancy coefficient	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Average daily gain (ADG)	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Pregnancy period	Boadi et al. (2004b)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Production stage duration	Boadi et al. (2004b)	normal except slaughter animals, triangular, non-symetric	±5%, Slaughter animals: MLV[5] 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[6]
Production stage population fraction	Boadi et al. (2004b)	normal	±5% – ±30%	Expert opinion, Boadi et al. (2004b)	Provincial/production stage subcategory, internal correlation[6]
Cattle Weight Estimates[7]					
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)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/production stage subcategory
Carcass weight	CBGA[2] and published AAFC[3] (1990–2010)	normal	±5%	Karimi-Zindashty et al. (2012) – from expert opinion	National/subcategory
Emissions Factors for Cattle (IPCC Tier 2 Equations)					
Methane conversion rate (Ym)		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 A3–2					
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

Table A3-18: Uncertainties in Inputs, Sources of Uncertainty and the Spatial and Animal Category at which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Enteric Fermentation (cont`d)

Parameter Category	Coefficient/ Parameter Source	Distribution Type	Uncertainty Range[1]	Uncertainty Distribution Estimate Source and Notes	Spatial Allocation/ Animal Category Allocation
Gross Energy for Cattle Calculation IPCC Tier 2 Equation A3–2 (cont'd)					
Net Energy for Cattle Tier 2 Equations 4.1 to 4.10, IPCC Good Practice Guidance (2000)					
Animal activity coefficient (Ca)	IPCC (2000)	normal	±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
Gender coefficient (C)	IPCC (2000)	normal	±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
Maintenance coefficient Cfi	IPCC (2000)		±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
Lactation coefficient	IPCC (2000)		±30%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/cattle
Weight loss rate	IPCC (2000)	normal	5%	Karimi-Zindashty et al. (2012) – from expert opinion	Provincial/subcategory
Weight loss duration	IPCC (2000)	normal	LB: 0 UB: 20% of lactation period.	Interpretation of differences between 2000 and 2006 IPCC guidelines.	Provincial/subcategory
Non-cattle Emission Factors					
Swine	IPCC (2000)	normal	±37%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/category
Other animals	IPCC (2000)	normal	±50%	Karimi-Zandashty et al. (2012) – Monni et al. (2007)	National/category

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

A3.3.3. CH_4 Emissions from Manure Management

The IPCC Tier 2 methodology is used to estimate CH_4 emission factors from manure management systems (IPCC 2000). Equation A3–22 is used to calculate CH_4 emissions from manure management for all categories of livestock in Canada. Sources of animal population data are the same as those used in the enteric fermentation estimates and are listed in Table A3–12.

Equation A3–22:

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

where:

CH_{4MM}	=	emissions for all animal categories
N_T	=	animal population for the 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 A3–23)

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

Equation A3–23:

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

where:

$EF_{(MM)T}$	=	annual emission factor for defined animal population T, kg/head-year
VS_T	=	daily volatile solids excreted for an animal within the defined population T, kg/day
B_{oT}	=	maximum CH_4 producing potential for manure produced by an animal within defined population T, m^3/kg VS
MCFij	=	CH_4 conversion factor for each manure management system i in climate region j
$AWMS_{Tjj}$	=	system distribution factor, defined as the fraction of animal category T's manure that is handled using manure system i in climate region j (IPCC 2000, Equation 4.17, p. 4.34), often referred to in IPCC documents as management system (MS)

The following sections outline the sources of input values for Equation A3–23: VS, DE, ASH, B_0, MCF and AWMS.

A3.3.3.1. 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 IPCC methodology based on the digestible energy (DE) of dietary intake, manure ash content and gross energy (GE) consumed by a given animal subcategory, according to Equation A3–24 (IPCC 2006).

For cattle subcategories, the GE depends on the cattle production model defined for enteric fermentation (Boadi et al. 2004b), as shown in Equation A3–20. Estimates of VS were derived for each cattle subcategory at the provincial level based on regional and seasonal stages of production. Increases in milk production in dairy cattle and carcass weight in beef cattle have increased VS and, as a result, CH_4 emission factors over the time series.

Equation A3–24:

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

where:

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

Non-Cattle (VS)

Volatile solids for animal categories other than cattle were calculated by Marinier et al. (2004) using a stochastic approach, taking into account the variability in the values of DMI, DE and ASH derived from expert opinion surveys. The values for DMI, DE and ASH taken from that survey were used to calculate VS for non-cattle livestock categories for each individual province. A Monte Carlo simulation of Equation A3–25 was performed using Crystal Ball® (Decisioneering 2000), resulting in a mean value of VS and a probability distribution based on the variance in expert opinion and scientific literature (Table A3–20).

Equation A3–25:

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

where:

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

Table A3–20 Mean Volatile Solids in Manure of Non-cattle Animal Categories and Associated 95% Confidence Interval, Expressed as a Percentage of the Mean

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

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

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

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

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

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

Generally, rations for grazing livestock consist of roughage and grains. Diet digestibility will vary, with grains having a higher digestibility than roughage. The distribution of grain-based and roughage-based diets was estimated for sheep and horses in each province. A weighted estimate of DE was calculated using the known approximate DE for grains and roughage for each animal type and the distribution of grain and roughage usage by province (Table A3–21). This method does not, however, account for additives that may increase or decrease digestibility. The DMI for non-cattle was determined through consultation with experts and published values (Table A3–22).

Table A3–21 Approximate Digestible Energy (DE) for Selected Livestock Subcategories and Data Sources

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

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

Table A3–22 Dry Matter Intake for Selected Livestock

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

Note:
1. Calculated as 3.5% of body weight.
2. Data sources: Expert consultations (Marinier et al. 2004).

Manure Ash Content (ASH)

The ash content in the manure is the inorganic portion of the manure. Table A3–23 contains the values used in this inventory for ash content in volatile solid calculations and their sources.

A3.3.3.2. 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

Table A3–23 Manure Ash Content for Selected Livestock and Data Sources

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

and is expressed in m_3/kg VS loaded. The values published in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) were used for all animals. For buffalo, non-dairy cattle values were used.

A3.3.3.3. Methane Conversion Factor (MCF)

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

A3.3.3.4. 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 information published on the distribution of manure management systems in Canada. A survey of experts in manure management and animal production was conducted in 2003–2004 as part of the Tier 2 study by Marinier et al. (2004); national averages of results are summarized in Table A3–24. Briefly, among the dominant animal production categories across the country, swine manure is mainly handled as liquid manure, while poultry manure is stored as solid manure. On average, dairy cattle manure storage is evenly distributed among solid and liquid forms, with roughly 20% being deposited on pastures; however in certain provinces, the proportion of dairy manure handled as liquid can be as high as 89% (British Columbia) or as low as 20% (Manitoba and Prince Edward Island). Beef cattle manure is equally distributed between solid storage and deposition on pastures, with the exception of British Columbia and Manitoba, where the majority of manure is deposited in pastures.

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

A3.3.3.5. Cattle Manure Management CH_4 Emission Factors

Cattle emission factors developed to calculate CH_4 emissions from manure management vary by animal subcategory and

Table A3–24 Percentage of Manure Handled by Animal Waste Management Systems (AWMS) for Canada (Marinier et al. 2004), Presented as National Averages

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

Notes:
1. Assumes that manure handled by AWMS is the same for llamas and alpacas as for sheep and lambs.

over time (Table A3–25). As VS was calculated based on the GE derived from the enteric fermentation cattle production model, an emission factor time series was derived for cattle to reflect i) the increase in milk productivity of dairy cows, and ii) the change in live weight of non-dairy cattle as explained in sections A3.3.2.1 and A3.3.2.2, respectively. Emission factors are highest from dairy cattle, reflecting their high rates of confinement, high proportions of liquid manure management systems and high dietary intake for sustained milk production. Beef cattle emission factors are lower, reflecting their lower rates of confinement, lower GE and the fact that the majority of manure is managed in a solid form with a low MCF.

A3.3.3.6. Non-Cattle Manure Management CH_4 Emission Factors

Manure management emission factors for non-cattle animals vary by animal subcategory but are constant over time (Table A3–26). For the largest non-cattle animal categories—swine, sheep and poultry—growth stages for animals are taken into account. The emission factor calculations use VS derived from Marinier et al. (2004). However, emission factors were recalculated to incorporate the latest scientific information available on B_0 and MCF taken from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). The largest emission factors are from swine, varying between 1.8 and 7.9 kg/head/year depending on growth stage, due to the high percentage of manure that is stored in liquid form. Emission factors for other minor categories tend to be low due to the large portion of manure that is either deposited on pasture, range or paddock or in solid form in pens and holding yards. Buffalo manure management emission factors are equal to the non-dairy emission factors for each individual province.

A3.3.3.7. 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.

Table A3–25 Emission Factors to Estimate CH_4 Emissions from Manure Management for Cattle Subcategories from 1990 to 2012[1]

	$EF_{(MM)T}$ (kg CH_4/head/year)							
Year	Dairy Cows	Dairy Heifers[1]	Bulls	Beef	Beef Heifers	Heifers for Slaughter[2]	Steers[2]	Calves
1990	23.1	18.2	3.2	3.1	2.6	1.6	1.5	1.5
1991	23.3	18.3	3.3	3.2	2.6	1.6	1.5	1.5
1992	23.9	18.4	3.4	3.2	2.6	1.7	1.5	1.5
1993	24.3	18.4	3.4	3.3	2.7	1.7	1.5	1.5
1994	24.4	18.4	3.3	3.3	2.6	1.7	1.6	1.5
1995	24.5	18.3	3.4	3.3	2.6	1.7	1.5	1.5
1996	25.1	18.3	3.3	3.2	2.6	1.7	1.5	1.5
1997	25.0	18.2	3.2	3.2	2.6	1.7	1.6	1.5
1998	25.3	18.3	3.3	3.3	2.6	1.7	1.6	1.5
1999	25.6	18.6	3.4	3.3	2.6	1.7	1.6	1.5
2000	26.1	18.8	3.4	3.4	2.7	1.8	1.6	1.5
2001	26.3	18.8	3.3	3.4	2.7	1.8	1.6	1.5
2002	26.7	18.8	3.3	3.4	2.7	1.8	1.6	1.5
2003	26.7	18.9	3.3	3.4	2.7	1.8	1.6	1.5
2004	26.6	18.8	3.3	3.3	2.6	1.8	1.6	1.5
2005	26.7	18.7	3.3	3.3	2.5	1.8	1.6	1.5
2006	26.9	18.6	3.3	3.3	2.5	1.8	1.6	1.5
2007	27.0	18.8	3.3	3.3	2.5	1.8	1.6	1.5
2008	27.1	18.9	3.3	3.3	2.6	1.8	1.6	1.5
2009	27.3	19.0	3.4	3.3	2.6	1.8	1.6	1.5
2010	27.6	19.0	3.5	3.3	2.5	1.8	1.6	1.5
2011	27.7	19.0	3.3	3.2	2.4	1.8	1.6	1.5
2012	27.8	19.1	3.3	3.2	2.4	1.8	1.6	1.5

Note:

1. For dairy heifers, emission factors were estimated using B_0, MCF and manure management systems for dairy cows.
2. Reported as kg/hd/yr; however, emissions are calculated based on time to slaughter.

Table A3–26 CH_4 Emission Factors for Manure Management for Non-Cattle

Non-cattle Animal Categories	Manure Management Emission Factors $EF_{(MM)}$ (kg CH_4/head/year)
Pigs	
Boars	6.4
Sows	6.3
Pigs < 20 kg	1.8
Pigs 20–60 kg	5.1
Pigs > 60 kg	7.9
Other Livestock	
Sheep	0.3
Lambs	0.2
Goats	0.3
Horses	2.3
Buffalo	2.3–3.2
Poultry	
Chickens	0.03
Hens	0.11
Turkeys	0.08

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 varies 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 make comparisons to IPCC parameters difficult.

A recent article with a small sample from eastern Canadian farms suggested that the B_0 values for swine, beef and dairy cattle were 0.47–0.42, 0.21–0.19 and 0.35–0.30, respectively (Godbout et al. 2010). The values for beef cattle and swine are consistent with IPCC default values, though dairy manure is the exception and observed B_0 was 50% higher than the default value. As this was a single measurement, 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; therefore, the variability observed in studies is likely linked to a combination of differences in measurement methodology, variability in manure characteristics (B_0) and in a number of physical and biochemical factors for each experimental situation that are not taken into account in the IPCC Tier 2 model. These factors include temperature, manure composition, storage dimension, storage duration and storage cleaning procedures—all of which may influence emissions from manure storage (Pattey et al. 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 manure management results, as there is no clear standard to evaluate whether IPCC parameters are appropriate for estimating emissions from manure management systems.

A3.3.3.8. Uncertainty in manure management CH_4 emissions

Methane emissions from manure management were included in the comprehensive uncertainty analysis discussed in Section A3.3.4.8. As was the case with enteric fermentation, the analysis built on the recent study by Karimi-Zindashty et al. (2012) and has applied a precautionary principle such that for parameters with very little information, probability distributions were intentionally conservative (Table A3–27). 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.

Population uncertainty for major animal categories was identical to that discussed in Section A3.3.2.3, and the distributions used to define uncertainties can be found in Table A3–19.

The parameters used in the calculation of Tier 2 manure management emission factors for all animals can be divided into two categories: those associated with volatile solid calculation, and those used 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 due to the fact that parameters such as DMI and DE are values that producers are very familiar with and can provide with 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%).

Table A3–27 Uncertainties in Inputs, Sources of Uncertainty and the Spatial and Animal Category at which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Manure Management.

Parameter Category	Parameter/ Animal Category or Subcategory	Distribution Type	Uncertainty Range[1]		Spatial Allocation/ Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[1]		
Volatile Solid Calculations (Equation A3–24 and Equation A3–25)						
Dry Matter Intake (DMI)		Triangular				
	-Swine					
	Boars		1.2–3.4	2.28	National/Subcategory	Marinier et al. (2004)
	Sows		2.0–2.5	2.25	National/Subcategory	Marinier et al. (2004)
	Pigs < 20 kg		0.55–0.72	0.68	National/Subcategory	Marinier et al. (2004)
	Pigs 20–60 kg		0.63–2.1	1.75	National/Subcategory	Marinier et al. (2004)
	Pigs > 60 kg		2.1–3.3	2.7	National/Subcategory	Marinier et al. (2004)
	-Poultry					
	Laying hens		7.4–9.9	9.85	National/Subcategory	Marinier et al. (2004)
	Broilers		0.085–0.088	0.086	National/Subcategory	Marinier et al. (2004)
	Turkeys		0.23–0.53	0.27	National/Subcategory	Marinier et al. (2004)
	-Other livestock					
	Sheep		1.2–3.0	2	National/Subcategory	Marinier et al. (2004)
	Lambs		1.2–1.6	1.35	National/Subcategory	Marinier et al. (2004)
	Goats		1.4–2.3	1.75	National/Subcategory	Marinier et al. (2004)
	Horses		7.4–9.9	9.85	National/Subcategory	Marinier et al. (2004)
	Buffalo		6.8–10.1	8.43	National/Subcategory	Marinier et al. (2004)
Ash		Triangular				
	-Cattle		3.9–11	8	National/Category	Marinier et al. (2004)
	-Swine		3.9–11	4.8–5.1	National/Category[2]	Marinier et al. (2004)
	-Poultry					
	Laying hens		3.9–11	10	National/Category	Marinier et al. (2004)
	Broilers		3.9–11	7	National/Category	Marinier et al. (2004)
	Turkeys		3.9–11	5	National/Category	Marinier et al. (2004)
	-Other livestock					
	Sheep		3.9–11	8	National/Category	Marinier et al. (2004)
	Lambs		3.9–11	8	National/Category	Marinier et al. (2004)
	Goats		3.9–11	8	National/Category	Marinier et al. (2004)
	Horses		3.9–11	4	National/Category	Marinier et al. (2004)
	Buffalo		3.9–11	8		
Digestible Energy (DE)		Normal				
	-Cattle		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	Derived from raw data supplied by Valacta Dairy Services
	-Poultry					
	Laying hens		±5.5%		National/Subcategory	Derived from raw data supplied by Valacta Dairy Services
	Broilers		±5.5%		National/Subcategory	Derived from raw data supplied by Valacta Dairy Services
	Turkeys		±5.5%		National/Subcategory	Derived from raw data supplied by Valacta Dairy Services
	-Other livestock					
	Sheep		±9%		Provincial/Category	Derived from raw data supplied by Valacta Dairy Services
	Lambs		±9%		Provincial/Category	Derived from raw data supplied by Valacta Dairy Services
	Goats		±9%		Provincial/Category	Derived from raw data supplied by Valacta Dairy Services
	Horses		±9%		Provincial/Category	Derived from raw data supplied by Valacta Dairy Services
	Buffalo		±9%		Provincial/Category	Derived from raw data supplied by Valacta Dairy Services
Emission Factor Calculation (Equation A3–23)						
Methane Conversion Factor (MCF)		Normal				
	All Animals		±45%		National	Karimi-Zindashty et al. (2012) – expert opinion
Maximum Methane Producing Potential (B_0)		Triangular				
	Dairy cattle		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	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
	Swine		0.32–0.48	0.48	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)

Table A3-27: Uncertainties in Inputs, Sources of Uncertainty and the Spatial and Animal Category at which Uncertainty is Assigned, for Parameters Used for Estimating Methane Emissions from Manure Management (cont'd)

Parameter Category	Parameter/Animal Category or Subcategory	Distribution Type	Uncertainty Range[1]		Spatial Allocation/ Animal Category Allocation	Uncertainty Distribution Estimate Source and Notes
			Range	Most Likely Value[1]		
Emission Factor Calculation (Equation A3–23) (cont'd)						
Maximum Methane Producing Potential (B_0) (cont'd)		Triangular				
	Poultry		0.24–0.39	0.32	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
	Sheep and Lamb		0.19–0.36	0.19	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
	Goats		0.15–0.19	0.18	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
	Horses		0.30–0.36	0.3	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
	Buffalo		0.19–0.33	0.19	National/Category	Karimi-Zindashty et al. (2012) – IPCC (2006)/Marinier et al. (2004)
Manure Management System (MS)[5]						
	Dairy cattle	Triangular	LB: MLV-10% UB: MLV+25%	MLV[4] from Marinier et al. (2005)	Provincial/Category	Expert opinion, bounds based on interpretation of multiple data sources Internally correlated variable[3] Liquid systems allowed to vary to non-symmetric triangular distributions
	Swine	Triangular	LB: MLV-10% UB: 100%	MLV from Marinier et al. (2005)	Provincial/Category	Expert opinion, bounds based on interpretation of multiple data sources Internally correlated variable[3] Liquid systems allowed to vary to non-symmetric triangular distributions
	Non-dairy cattle	Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]
	Poultry	Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]
	Sheep and Lamb	Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]
	Goats	Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]
	Horses	Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]
	Buffalo	Normal	±17%		Provincial/Category	Marinier et al. (2005). Internally correlated variable[3]

Notes:
1. Most likely value when triangular distribution, normal distributions given as simple ±%.
2. Ash for swine varies among some provinces.
3. Internal correlation indicates values that vary in terms of a fraction of the whole, i.e., a fraction of a total equalling 100%.
4. MLV – most likely value; LB – lower bound; UB – upper bound
5. Values that vary independently during trend analysis

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 IPCC (2006). The uncertainty for B_0 was taken from Marinier et al. (2004), but no reliable source was available for the estimate of 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. Therefore, the actual value of the total uncertainty estimate for manure management must 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, 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 Marinier et al. survey (2005). In the case of swine, 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. As was the case for enteric fermentation, for the long-term trend, emissions for 1990 and 2012 were calculated simultaneously, allowing only time-dependent parameters to vary independently in the estimates. More detailed description of the trend analysis is found in Section A3.3.2.3. The parameters allowed to vary independently for the manure management trend analysis were animal populations, milk production and fat content in dairy cattle, body weights in cattle, and AWMS (noted by a superscript 7 in Table A3–19 and superscript 5 in Table A3–27. 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 Marinier et al. survey (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.

The summary of results of the uncertainty analysis on emissions from manure management is reported in Chapter 6, Section 6.3.1.3. Briefly, the uncertainty range for manure management CH_4 emissions is 60% (-32% to +27% of the mean). As was the case with enteric fermentation, emission factors account for the majority of uncertainty. Emission factors lie within an uncertainty range of -34% to +62% for non-dairy cattle and a range of -60% to +50% for dairy cattle. The emission factors for swine, 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: 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, mean emissions for both dairy cattle and non dairy cattle 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 -8% to a 10% increase, though it is most likely that there has been an increase in emissions of roughly 7.5%. The assumption that liquid manure storage and other manure storages have increased over time affects the trend. For example, for dairy cattle 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, also 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 for 2012 was slightly smaller than for 2010 (2%), likely due to a combination of lower uncertainty for census animals populations, and due to the 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 those 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.

A3.3.4. N_2O Emissions from Manure Management

Emissions of N_2O from manure management systems result from mineralization of organic materials, nitrification and denitrification of mineral nitrogen. Three factors are required to estimate N_2O emissions from manure management systems using the IPCC Tier 1 methodology: 1) N excretion rates for various animal categories and subcategories; 2) types of AWMS; and 3) emission factors associated with manure management systems (Equation A3–26).

Equation A3–26:

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

where:

N_2O_{AWMS}	=	emissions for all AWMS and provinces, excluding emissions from manure N excreted on pasture, range and paddock, kg N_2O/yr
N_T	=	population for the Tth animal category or subcategory in province i (see Section A3.3)
N_{AWMS}	=	percentage of N handled by each AWMS in province i, fraction (see Table A3–24)
$N_{EX,T}$	=	N excretion rate for the Tth animal category or subcategory (see Table A3–29 for non cattle and Table A3–28 for cattle), kg N/head/year
EF_{AWMS}	=	N_2O emission factors from manure management for each specific AWMS (see Annex 8), kg N_2O-N/kg N
44/28	=	coefficient converting N_2O-N to N_2O

Table A3–24 summarizes the distribution of manure management systems in Canada by animal category. Emissions of N_2O from manure on pasture, range and paddock systems are not included under Manure Management, as they are reported under the category of Agricultural Soils, Section A3.3.5.2. Animal population data are detailed in Section A3.3.1.

A3.3.4.1. Nitrogen Excretion Rates for Various Domestic Animals

Manure N excretion from cattle varies by animal subcategory, and also over the time series, due to the increase in animal weight. Annual live weights (see Section A_3.3.1.2) were multiplied by the IPCC default N excretion rate (IPCC 2006) to produce a time series of manure N excretion rates (Table A3–28). Annual manure N excretion rates from non-cattle domestic animals, according to IPCC Tier 1 default values (IPCC 2006), vary by livestock category. Poultry have high excretion rates (Table A3–29), while horses and buffalo have the lowest excretion rates; however, on a per-head basis, buffalo are the largest N excretors in the non cattle category. In the case of cattle, dairy cows have very high excretion factors due to the protein requirements of sustained milk production.

A3.3.4.2. Emission Factors Associated with AWMS

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

A3.3.5. N_2O Emissions from Agricultural Soils

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

A3.3.5.1. Direct N_2O Emissions from Soils

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

The approach involves determining base emission factors "EF_{BASE}" for each of 449 ecodistricts,[4] using long-term precipitation and potential evapotranspiration. The EF_{BASE} is subsequently modified to reflect site-specific practices and conditions. Data on long-term climate normals and topographic characteristics are used to develop an EF_{BASE} (Equation A3–27).

4 "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.

Table A3–28 Time Series of Manure N Excretion Rates for Cattle (kg N/head/year)[1]

	(kg N/head/year)							
Year	Dairy Cows	Dairy Heifers	Bulls	Beef Cows	Beef Heifers	Heifers for Slaughter	Steers	Calves
1990	102.4	53.7	88.0	57.2	44.5	45.1	48.4	26.6
1991	102.4	53.7	92.6	58.3	45.4	45.1	48.7	26.5
1992	102.4	53.7	96.8	61.6	47.6	51.6	53.9	26.5
1993	102.5	53.6	98.0	62.9	48.4	52.5	54.1	26.5
1994	102.5	53.6	95.2	64.1	49.4	54.6	56.5	26.5
1995	102.5	53.6	98.8	63.7	49.2	55.2	56.9	26.5
1996	102.5	53.6	94.2	61.7	47.5	54.1	56.2	26.5
1997	102.5	53.6	92.2	62.3	48.2	55.3	56.8	26.5
1998	102.5	53.7	98.1	64.7	50.0	57.7	58.7	26.5
1999	102.4	53.6	101.3	66.4	51.3	58.6	59.1	26.5
2000	102.4	53.6	102.9	69.4	53.4	62.7	60.4	26.5
2001	102.4	53.7	101.7	70.5	54.3	61.1	61.0	26.5
2002	102.4	53.7	101.6	71.4	55.0	61.5	61.6	26.5
2003	102.5	53.8	101.9	71.7	55.1	61.7	61.9	26.5
2004	102.5	53.7	101.9	66.9	51.2	61.5	61.7	26.5
2005	102.5	53.7	101.9	67.2	51.4	60.9	61.2	26.5
2006	102.4	53.7	102.0	68.0	51.9	61.6	62.2	26.5
2007	102.4	53.6	101.9	68.2	52.1	61.9	62.3	26.5
2008	102.5	53.6	101.9	68.8	52.6	62.3	62.4	26.5
2009	102.5	53.6	106.5	67.8	51.9	62.0	62.7	26.5
2010	102.5	53.6	111.9	68.1	52.0	62.0	63.1	26.5
2011	102.5	53.6	102.9	63.9	48.8	61.6	64.8	26.5
2012	102.5	53.6	102.9	66.3	50.6	63.2	66.0	26.5

Note:

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

Table A3–29 Manure N Excretion Rates for Non-cattle

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

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

Equation A3–27:

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

where:

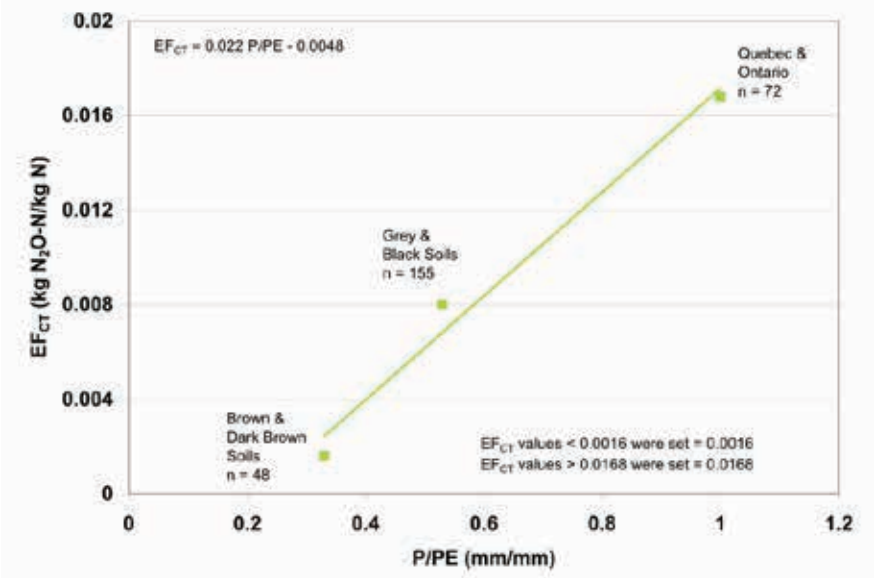
EF_{CT}	=	emission factor, estimated at actual P/PE accounting for moisture regime and topography in an ecodistrict, kg N_2O-N/kg N (see Figure A3–4)
$EF_{CT, P/PE}$	=	emission factor of 0.017 estimated at P/PE = 1, kg N_2O-N/kg N applied
F_{TOPO}	=	fraction of the ecodistrict area in the lower section of the toposequence See Rochette et al. (2008)
P	=	long-term mean growing season precipitation from May to October in an ecodistrict, mm
PE	=	long-term mean potential evapotranspiration from May to October, mm

Base N_2O Emission Factor (EF_{BASE})

Nitrous oxide is mostly produced during denitrification and, therefore, is greatly influenced by soil oxygen status. Accordingly, in moisture-limited conditions, N_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 A3–3). 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/kg N) (Gregorich et al. 2005) and fit (r^2 = 0.43) as the IPCC Tier 1 default emission factor derived by Bouwman (1996) using global data. In the Prairie region, low and variable N_2O emissions were measured across the range of N fertilizer rates (Brown and Dark Brown soils = 0.0016 kg N_2O-N/kg N; Grey and Black soils = 0.008 kg N_2O-N/kg N). These observations suggest that soil N_2O production in the Prairie 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 Prairie 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/kg N applied (EF_{BASE} at P/PE = 1) was used for the lower sections of the landscapes. The fraction of the landscape to which this condition was applied differs among landscape types. Landscape segmentation data were incorporated into the calculation of the national N_2O emission estimates, based upon the observations that N_2O emissions are greater in lower sections of the landscape, where intermittently saturated soil conditions

Figure A3–3 EF_{CT} as a Function of Long-term Ratio of Precipitation over Potential Evapotranspiration (P/PE) from 1971 to 2000



are favourable to denitrification (Corre et al. 1996, 1999; Pennock and Corre 2001; Izaurralde et al. 2004). The fraction of the landscape occupied by such lower sections (F_{TOPO}) was applied to concave portions of the landscape (i.e. lower and depressional landscape positions) where soils are likely to be saturated for significant periods of time on a regular basis and soils are imperfectly and poorly drained with mottles[5] 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 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).

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 Thurtel 1998). The intensity of soil freezing was also found to influence spring thaw emissions (Wagner-Riddle et al. 2007). Limiting emission estimates to the snow-free period therefore underestimates total annual 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 included in the relationship between EF_{CT} and P/PE shown in Figure A3–3.

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.[6] These stations (80°00'N–41°55'N, 139°08'W–52°40'W) 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. Canadian weather data were provided by the Meteorological Service of Canada, Environment Canada.

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

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

Soil Texture and N_2O Emissions

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

The impact of soil texture on N_2O emissions from agricultural soils was incorporated in the emission factor using a ratio factor ($RF_{TEXTURE}$) defined as the ratio of N_2O emissions on soils of a given textural class to the mean emissions from soils of all textures (Equation A3–28). A value of 0.8 was assigned to the $RF_{TEXTURE-COARSE}$ and $RF_{TEXTURE-MEDIUM}$ and 1.2 for $RF_{TEXTURE-FINE}$ (Rochette et al. 2008). $RF_{TEXTURE}$ could not be estimated in regions other than Quebec, Ontario and the Atlantic provinces. Assuming a low influence of soil texture on N_2O emissions ($RF_{TEXTURE}$ =1) is likely justified under dry climates such as in the Prairie region, where low soil water content results in low N_2O emissions, regardless of the soil texture.

Equation A3–28:

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

where:

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

Manure Applied as Fertilizer

Emissions of N_2O from manure N applied as fertilizers include N_2O produced from the application of manure from drylot and solid storage, liquid and other waste management systems on agricultural soils. A country-specific Tier 2 methodology is used for estimating N_2O emissions from manure N applied as fertilizers. The methodology is based on the quantity of manure

N produced by domestic animals (see Section A3.3.4.8) and country-specific EF_{BASE} taking into account moisture regime and topographic conditions at the ecodistrict level. Estimates of N_2O emissions from this source are calculated using Equation A3–29.

Equation A3–29:

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

where:

N_2O_{MAN}	=	emissions from manure N applied to cropland as fertilizers, kg N_2O/year
$EF_{BASE,i}$	=	a weighted average emission factor for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N-year
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict i
44/28	=	coefficient converting N_2O-N to N_2O

The amount of animal manure applied as fertilizer at an ecodistrict level was calculated using Equation A3–30. It was assumed that all manure, excluding that deposited on pasture, range and paddock, is applied to cropland soils.

Equation A3–30:

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

where:

$N_{MAN-CROPS,i}$	=	animal manure applied as N fertilizers on cropland in ecodistrict i, kg N/year
N_T	=	population for animal category or subcategory T, heads
$N_{EX,T}$	=	N excretion rate for animal category or subcategory (Table A3–28 and Table A3–29), kg N/head/year
$N_{PRP,T}$	=	fraction of manure N on pasture, range and paddock for each animal category or subcategory T in ecodistrict i (see Table A3–24)
$FRAC_{(LossMS,T)}$	=	fraction of manure N losses (volatilization, leaching, etc.) for each animal category or subcategory T excluding pasture, range and paddock in ecodistrict i (Table A3–30)

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

Table A3–30 Total N, NH_3-N and NO_x-N Losses Associated with Various Livestock and Manure Management Systems[1]

Animal Categories	Manure Management Systems	$FRAC_{(LossMS)}$ (%)[1]	NH_3-N and NO_x-N Loss (%)[1, 2] ($FRAC_{GASM}$)
Dairy Cow	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	35 (10–55)	25 (10–40)
	Pasture and Range		20 (5–50)
Non-dairy Cattle	Liquid	40 (15–45)	40 (15–45)
	Solid Storage	40 (20–50)	30 (20–50)
	Pasture and Range		20 (5–50)
Swine	Liquid	48 (15–60)	48 (15–60)
	Solid Storage	50 (20–70)	45 (10–65)
Sheep, Lamb, Llamas and Alpacas	Solid Storage	15 (5–20)	12 (5–20)
	Pasture and Range		20 (5–50)
Goat and Horse	Solid Storage	15 (5–20)	12 (5–20)
	Pasture and Range		20 (5–50)
Poultry	Liquid	50	50
	Solid Storage	53 (20–80)	48 (10–60)
	Pasture and Range		20 (5–50)

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

Synthetic Nitrogen Fertilizers

The method for estimating N_2O emissions from synthetic N fertilizer application on agricultural soils takes into account moisture regimes and topographic conditions. Equation A3–31 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 A3–31:

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

where:

N_2O_{SFN}	=	emissions from synthetic N fertilizers, kg N_2O/year
$N_{FERT,i}$	=	total synthetic fertilizer consumption in ecodistrict i, kg N/year; N_{FERT} at an ecodistrict level is estimated using Equation A3–34
$EF_{BASE,i}$	=	a weighted average of emission factors at ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N-year
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict i
44/28	=	coefficient converting N_2O-N to N_2O

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

Equation A3–32:

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

where:

$N_{APPLDP,i}$	=	total N fertilizer potentially applied in ecodistrict i, kg N/year
$N_{RCMD,i}$	=	recommended fertilizer application in ecodistrict i, kg N/year
$N_{MAN\text{-}AV,CROPS,i}$	=	available N from manure applied to crops in ecodistrict i, kg N/year

Based on the work of Yang et al. (2007), 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 A3–33:

$$N_{RCMD,i} = \sum_{ij} \left(CROPA_{ij} \times N_{RECRT,i}\right)$$

where:

$CROPA_{ij}$	=	area of crop type j in ecodistrict i, ha
$N_{RECRTij}$	=	recommended annual N application rate for crop type j in ecodistrict i, kg N/ha-year

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

Equation A3–34:

$$N_{MAN-AV,CROPS,i} = N_{MAN,CROPS,i} \times (1 - UNAV)$$

where:

$N_{MAN,CROPS,i}$	=	total amount of manure N applied as fertilizers to cropland in ecodistrict i, kg N/year
UNAV	=	fraction of manure N that is either in organic form or unavailable for crops: 0.35 (Yang et al. 2007)

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

Equation A3–35:

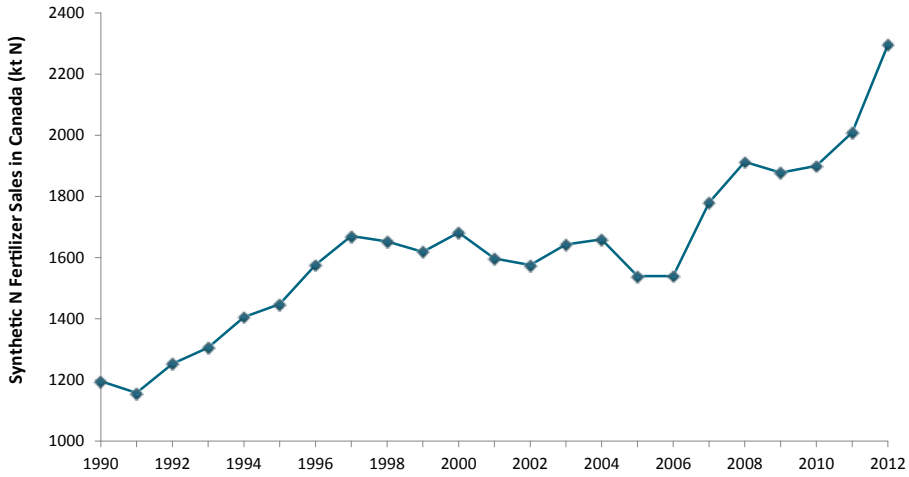
$$N_{FERT,i} = N_{APPLDi} \times \left[\frac{\sum_i^p N_{APPLDi}}{N_{SALESp}}\right]$$

where:

$N_{FERT,i}$	=	total fertilizer N actually applied to all crops in ecodistrict i, kg
N_{APPLDi}	=	total fertilizer N potentially applied to all crops in ecodistrict i, kg
N_{SALESp}	=	total amount of fertilizer N sold in province p, kg

For years between census years (census years are 1991, 1996, 2001 and 2006), N_{RCMD} was linearly interpolated to successively estimate annual values of N_{APPLD} and N_{FERT} at the ecodistrict level. The consumption of synthetic N fertilizers in Canada has significantly increased, from 1.2 Mt to 2.3 Mt N, since 1990 mainly because of the intensification of cropping systems (Figure A3–4).

Figure A3–4 Synthetic Nitrogen Fertilizer Sales in Canada from 1990 to 2012



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.[7] Since 2007, Statistics Canada has collected and published fertilizer sales data annually (Statistics Canada 2012b).

Biological Nitrogen Fixation

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

Crop Residue Decomposition

The transformations (nitrification and denitrification) of the N released during the decomposition of crop residues result in N_2O emissions into the atmosphere. A country-specific Tier 2 methodology similar to that for synthetic N fertilizers and manure applied as fertilizers is used to estimate N_2O emissions from crop residues, based on Equation A3–36, Equation A3–37 and Equation A3–38. The amount of N contained in the above-ground crop residues subjected to field burning at the provincial level is removed from the emission estimate to avoid double counting (see Section A3.3.7).

Equation A3–36:

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

where:

N_2O_{RES}	=	emissions from crop residue decomposition, kg N_2O/year
$EF_{BASE,i}$	=	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes and topographic conditions, kg N_2O-N/kg N/year
44/28	=	coefficient converting N_2O-N to N_2O
$N_{RES,i}$	=	total amount of crop residue N that is returned to the cropland for ecodistrict i, exluding N losses due to residue burning, kg N/year (see Equation A3–37)
$RF_{TEXTURE,i}$	=	soil texture N_2O ratio factor for ecodistrict, i

Equation A3–37:

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

where:

$FRAC_{RENEW,T,i}$	=	fraction of total area under crop T that is renewed annually in ecodistrict i
$R_{AG,T}$	=	ratio of above-ground residues to harvested yield for crop T, kg dry matter (DM)/kg
$N_{AG,T}$	=	N content of above-ground residues for crop T, kg N/kg DM
$R_{BG,T}$	=	ratio of below-ground residues to harvested yield for crop T, kg DM/kg
$N_{BG,T}$	=	N content of below-ground residues for crop T, kg N/kg DM
$P_{T,i}$	=	total production of the T^{th} crop type that is renewed annually in ecodistrict i, kg DM/year (Equation A3–38).

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

Equation A3–38:

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

where:

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

Statistics Canada collects and publishes annual field crop production data by province (Statistics Canada 2013; CANSIM, Table 001-0010). Crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, sugar beets, tame hay, dry peas, soybean, dry white beans, coloured beans, chick peas and lentils. The area seeded and the yield of each crop are reported at the census agricultural region and provincial levels, and yields have been allocated to Soil Landscapes of Canada (SLC) polygons through area overlays by Agriculture and Agri-Food Canada. Specific parameters for each crop type are listed in Janzen et al. (2003).

Cultivation of Organic Soils (Histosols)

Cultivation of organic soil (histosols) for annual crop production produces N_2O. The IPCC Tier 1 methodology is used to estimate N_2O emissions from cultivated organic soils (Equation A3–39).

Equation A3–39:

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

where:

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

Areas of cultivated histosols at a provincial level are not collected as part of the *Census of Agriculture*. Consultations with numerous soil and crop specialists across Canada indicate that the total area of cultivated organic soils from 1990 to 2012 in Canada was 16 kha (Liang et al. 2004).

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

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

Field studies in Quebec and Ontario showed that NT practices increased N_2O emissions, whereas on the Prairies the opposite was observed (Gregorich et al. 2005). To quantify the impact of tillage practices on N_2O, a tillage ratio factor (F_{TILL}) defined as the ratio of mean N_2O fluxes on NT or RT to mean N_2O fluxes on IT (N_2O_{NT}/N_2O_{IT}), is used as follows (Rochette et al. 2008):

Equation A3–40:

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

where:

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

The fraction of cropland under NT and RT ($FRAC_{NT-RT}$) for each ecodistrict was derived from the *Census of Agriculture* and is identical to that used in the LULUCF Cropland Remaining Cropland category for NT and RT practices (see Section 3 – Cropland in Annex 3.4). These data are published at the census agricultural region, census division and provincial and national levels. Annual $FRAC_{NT-RT}$ between two consecutive census years is interpolated.

N_2O Emissions Resulting from Summerfallow

Summerfallowing is a farming practice typically used in the Prairie region to conserve soil moisture by leaving the soil unseeded for an entire growing season in a crop rotation. During the fallow year, no fertilizer or manure is applied. Several factors may stimulate N_2O emissions relative to a cropped situation, such as higher soil water content, temperature and available carbon and N. Field studies have shown that N_2O emissions in fallow fields are similar to emissions from continuously cropped fields (Rochette et al. 2008). In order to account for these emissions not captured by the default IPCC input-driven approach, the following country-specific method is used to estimate the effect of summerfallow on N_2O emissions. During a crop year, direct N_2O emissions from a given field are summarized as follows:

Equation A3–41:

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

where:

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

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

Equation A3–42:

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

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

Equation A3–43:

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

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

Equation A3–44:

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

where:

N_2O_{FALLOW}	=	emissions due to the effect of summerfallow, kg N_2O/year
$N_2O_{SFN,i}$	=	emissions from synthetic N fertilization 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 animal manure applied as fertilizers to cropland 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 synthetic N fertilizers, manure N applied as fertilizers and crop residue N. The fraction, $FRAC_{FALLOW}$, is derived from the *Census of Agriculture* for each ecodistrict and is identical to that used in the LULUCF Cropland Remaining Cropland category for the summerfallow practice (see Section 3 – Cropland in Annex 3.4). Annual $FRAC_{FALLOW}$ between two consecutive census years is adjusted through interpolation.

N_2O Emissions from Irrigation

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

Equation A3–45:

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

where:

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

The fraction, $FRAC_{IRRI}$, is derived from the *Census of Agriculture* for each ecodistrict (see Section 3 – Cropland in Annex 3.4). Annual $FRAC_{IRRI}$ between two consecutive census years is adjusted through interpolation.

A3.3.5.2. Manure on Pasture, Range and Paddock from Grazing Animals

The IPCC Tier 1 methodology is used to estimate N_2O emissions from manure on pasture, range and paddock. The IPCC methodology is based on the quantity of manure N produced by domestic animals on pasture, range and paddock. N_2O emissions are calculated using Equation A3–46

Equation A3–46:

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

where:

N_2O_{PRP}	=	emissions from manure on pasture, range and paddock from grazing animals, kg N_2O/year
N_T	=	animal population of category or subcategory T in a province, heads
$N_{EX,T}$	=	annual N excretion rate for animal category or subcategory T, kg N/head-year (Table A3–28 and Table A3–29)
$N_{PRP,T}$	=	fraction of manure N excreted on pasture, range and paddock by animal category or subcategory T (Table A3–24)
$EF_{PRP,T}$	=	emission factor for manure N deposited by animals on pasture, range and paddock (IPCC 2006) (Annex 8)
44/28	=	coefficient converting N_2O-N to N_2O

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

A3.3.5.3. Indirect N_2O Emissions from Soils

Volatilization and Redeposition of Nitrogen

The IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from volatilization and redeposition of fertilizer and manure N. The emission calculation is shown in Equation A3–47:

Equation A3–47:

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

where:

N_2O_{VD}	=	emissions from volatilization and redeposition of N, kg N_2O/year
$N_{FERT,i}$	=	synthetic N fertilizer consumption in ecodistrict i, kg N/year
$FRAC_{GASF}$	=	fraction of synthetic fertilizer N applied to soils that volatilizes as NH_3- and NO_x-N: 0.1 kg (NH_3-N + NO_x-N)/kg N (IPCC/OECD/IEA 1997)
$N_{MAN-CROPS,i}$	=	animal manure applied as N fertilizers on cropland in ecodistrict i, kg N/year (see Equation A3–30)
$FRAC_{GASM}$	=	fraction of volatilized manure N applied as fertilizer to cropland in ecodistrict i: 0.2 kg (NH_3-N + NO_x-N)/kg N (IPCC/ OECD/IEA 1997)
EF_{VD}	=	emission factor due to volatilization and redeposition: 0.01 kg N_2O-N/kg N (IPCC/ OECD/IEA 1997)
44/28	=	coefficient converting N_2O-N to N_2O
$N_{MAN-VOLAT,i}$	=	total manure N lost as NH_3-N and NO_x-N from livestock excretion in ecodistrict i, kg N (Equation A3–48)

Equation A3–48:

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

where:

N_T	=	animal population for animal category or subcategory T, heads
$N_{EX,T}$	=	N excretion from animal category or subcategory T, kg N/year (Table A3–28 and Table A3–29)
$AWMS_{m,T}$	=	fraction of manure N from animal category or subcategory T under manure management system m (Table A3–24)
$FRAC_{GASMm,T}$	=	fraction of manure N excreted by animal category or subcategory T under manure management system m that volatilizes as NH_3-N and NO_x-N (Table A3–30)

Data sources for estimating N_{FERT} and $N_{MAN\text{-}VOLAT}$ at an ecodistrict level are provided in the previous sections (Section A3.5.7.1 and Equation A3–40).

Leaching and Runoff

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

Equation A3–49:

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

where:

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

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

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

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

For ecodistricts with a P/PE value for the growing season (May through October) greater than or equal to 1, the maximum $FRAC_{LEACH}$ value recommended by the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) of 0.3 was assigned. For ecodistricts with the lowest P/PE value (0.23), a minimum $FRAC_{LEACH}$ value of 0.05 was assigned. For ecodistricts with a P/PE value that ranged between 0.23 and 1, $FRAC_{LEACH}$ was estimated by the linear function that joins the two-end points (P/PE, $FRAC_{LEACH}$) = (1,0.3; 0.23,0.05) (Figure A3–5).

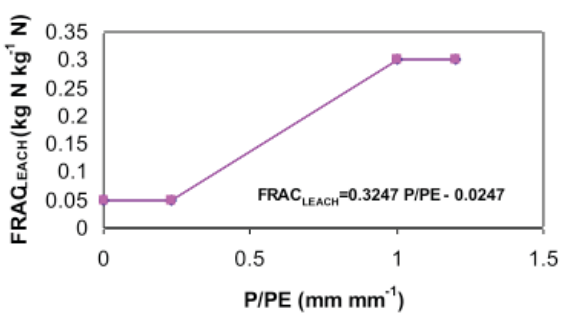
Data sources for N_{FERT} (Section A3.5.7.1), $N_{MAN,CROPS}$ (Section A3.5.7.1), N_{PRP} (Section A3.5.7.2) and N_{RES} (Section A3.5.7.1) at an ecodistrict level are provided in the previous sections.

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

A3.3.6. Uncertainty Estimates of N_2O Emissions

A comprehensive uncertainty analysis was completed for all methodology used in the calculation of N_2O from livestock and

Figure A3–5 Determination of the Ecodistrict FRACLEACH Values



agricultural soils for 2010 (Karimi-Zindashty et al., in preparation). The analysis has not yet been published in a refereed journal, 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 principle emission source categories. For this submission, the uncertainty ranges (percentages) developed for 2010 means were applied to means for 2012. In the analysis, a stochastic reproduction of the complete N_2O emission model was built in Analytica© at the scale of ecodistricts, and a Monte Carlo simulation (MCS) was run according to the methodology proposed in the IPCC Good Practice Guidance (IPCC 2000). A sensitivity analysis was carried out to identify the parameters that contributed the greatest amount to different emission source categories.

The parameters used in the calculation of N_2O emissions can be divided into three categories: those associated with information at the ecodistrict scale; provincial-scale data; and IPCC / national-scale parameters (Table A3–31). The majority of national-scale parameters are taken directly from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) or from the original country-specific methodological development work carried out by Rochette et al. (2008), either derived analytically 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 Section A3.3.3.3 and Section A3.3.4.8; the distributions used to define uncertainties can be found in Table A3–19 and Table A3–27. 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 summary of results of the uncertainty analysis on emissions of N_2O is reported in Chapter 6. The uncertainty range for N_2O emissions from agricultural sources is 88% (-36% to +52% 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 165% (-66% to +99% 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 lower 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 62% (28% to +34% 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 between -50% and +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 (UK), 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.

Sensitivity analysis indicated that indirect EF uncertainty was the largest contributor 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.

A3.3.7. CH_4 and N_2O Emissions from Field Burning of Agricultural Residues

Crop residues are sometimes burned in Canada, as a matter of convenience and disease control through residue removals, even though 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:

Table A3–31 Uncertainty Parameters Used in the Calculation of Agricultural N_2O Emissions.

Parameter	Coefficient/ Parameter Source	Distribution Type	Uncertainty Range	Most Likely Value[1]	Uncertainty Distribution Estimate Source and Notes
IPCC and National Scale Parameters					
Animal populations and characterization data					Karimi-Zindashty et al. (2012) from Statistics Canada, personal communication[4]
N excretion	IPCC, 2006 Guidelines[3]	Normal	±50%	IPCC default	
FRACGAS/FRACLOSSMS	IPCC, 2006 Guidelines[3]	Triangular	IPCC default	IPCC default	See Table 10.22/10.23 IPCC, 2006 Guidelines
AWMS emission factor	IPCC, 2006 Guidelines[3]	Triangular	Liquid 0.0005–0.002 PRP -0.007–0.06	Minimum liquid 0.001 Maximum PRP -0.02	IPCC, 2006 Guidelines,[4] variable depending on the manure storage type
Crop characteristics					
H_2O content	Rochette et al. 2008, factors are drawn from common usage in AAFC[2] literature and modelling studies.	Normal	±15%		Expert Opinion
Relative DM allocation of residue (product, above ground and below ground)	Rochette et al. 2008, factors are drawn from common usage in AAFC[2] literature and modelling studies.	Normal	±15%		Expert Opinion
$FRAC_{Renew}$ (duration)	Rochette et al. 2008, factors are drawn from common usage in AAFC[2] literature and modelling studies.	Normal	±15%		Expert Opinion
N concentration in residue (aboveground and belowground)	Rochette et al. 2008, factors are drawn from common usage in AAFC[2] literature and modelling studies.	Normal	±15%		Expert Opinion
Direct and indirect emission factors/modifiers					
P/PE regression parameters	Rochette et al. 2008	Normal	Intercept +/- 54% Slope +/- 21%		Analysis of raw research data, consultation with study authors
$FRAC_{LEACH}$ calculation parameters	Rochette et al. 2008	Normal	Intercept +/- 54% Slope +/- 21%		Analysis of raw research data, consultation with study authors
F_{TILL}	Rochette et al. 2008	Normal	±100%		Analysis of raw research data, consultation with study authors
$RF_{TEXTURE}$	Rochette et al. 2008	Normal	±30%		Analysis of raw research data, consultation with study authors
EF_{LEACH}	IPCC, 2006 Guidelines[3]	Triangular	0.002–0.12	0.025	IPCC, 2006 Guidelines
EF_{VD}	IPCC, 2006 Guidelines[3]	Triangular	0.002–0.05	0.01	IPCC, 2006 Guidelines
EF_{HIST}	IPCC, 2006 Guidelines[3]	Triangular	2–24	8	IPCC, 2006 Guidelines
Provincial–Scale Parameters					
Fertilizer application rate (kg/ha)	Factors are drawn from common usage in AAFC[3] literature and modelling studies.	Normal	±15%		Expert Opinion
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[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	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	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	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.
Animal population distribution to ecodistrict	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	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.
F_{TOPO} (proportion of lowland soils in ecodistrict)	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	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.
Extent of organic soils	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	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.
Irrigated soil area	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	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.
Soil texture	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	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.

Table A3-32 Uncertainty Parameters Used in the Calculation of Agricultural N_2O Emissions (cont'd)

Parameter	Coefficient/ Parameter Source	Distribution Type	Uncertainty Range	Most Likely Value[2]	Uncertainty Distribution Estimate Source and Notes
Ecodistrict–Scale Parameters (cont'd)					
Perennial soil texture	AAFC[3], Geographically referenced soil landscape agricultural database, derived from Census of Agriculture, 1991-2011	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.

Uncertainty associated with most livestock parameters can be found in Section A3.3.3.3 and Section A3.3.4.8, and the distributions used to define uncertainties can be found in Table A3-8 and Table A3–27.

1. Reported where applicable when using a triangular distribution.
2. Agriculture and Agri-Food Canada.
3. IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006).

Equation A3–50:

$$Q_{BURN} = \sum_{T} (PRODUCTION_T \times (1 - MOISTURE_T) \times RatioAR/P_T \times PCB_T \times RATIO_{SCALE})$$

where:

Q_{BURN} = quantity of crop residue burned from crop T for each province, Mg dry matter/year

$PRODUCTION_T$ = total production of crop T, Mg dry matter/year

$MOISTURE_T$ = moisture content of the product from crop T, fraction

$RatioAR/P_T$ = Ratio of above-ground crop residue to the crop product for crop T , unitless

PCB_T = 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 in 2001 and 2006 by Statistics Canada collected through its Farm Environmental Management Survey (FEMS)[8] 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 A3–32. 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, the crop that was subject to field burning in 2006 was also assumed for the entire time series.

The intensity of the crop residue burning in each province for 1991, 1996 and 2001 was adjusted as a ratio based on the average burning for 2006. Basic characteristics of crops, such as moisture content of crop product and ratio of above-ground crop residue to crop product, are reported by Janzen et al. (2003). Annual production of each crop subject to residue burning is available (Statistics Canada 2011; Catalogue #22-002). Other parameters such as fraction of biomass actually burned and emission factors required for emission estimates were obtained from the Good Practice Guidance (IPCC 2000).

Emissions of N_2O and CH_4 from crop residue burning are estimated using Equation A3–51:

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

Table A3–32 Burning Of Crop Residues by Crop Types In 2006

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

Table A3–33 Crop Residue Burning by Province in Canada for 1991, 1996, 2001 and 2006

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

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

Equation A3–51:

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

where:

$EMISSION_{BURN}$ = emissions of N_2O or CH_4 from the burning of crop residues for Canada (kt N_2O or CH_4)

Q_{BURNi} = quantity of crop residue burned from province i, Mg, dry matter/year

C_F = fuel efficiency [IPCC 2000], unitless

G_{EF} = emission factor [IPCC 2000], g N_2O or CH_4 kg^{-1} of dry matter burned

1000 = converting Mg to kt

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

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

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

A general description of the approach to estimate the delayed carbon emissions due to long-term carbon storage in harvested wood products is described in Section A3.4.7.

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

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

At the finest level of spatial resolution are analysis units, which are specific to each estimation system. In managed forests, the analysis units are the geographic intersection of reporting zones (Chapter 7, Figure 7-1) and provincial/territorial forest management units. For the purpose of this assessment, managed forests were classified into 635 analysis units across 12 provinces and territories (Table A3–34). Changes in the number of spatial analy-

Table A3–34 Spatial Analysis Units of Managed Forests

Province/Territory	Number of Analysis Units
Newfoundland and Labrador	25
Nova Scotia	1
Prince Edward Island	1
New Brunswick	1
Quebec	129
Ontario	52
Manitoba	70
Saskatchewan	40
Alberta	181
British Columbia	92
Yukon	13
Northwest Territories	30
Canada	**635**

sis units may occur from one submission to the next and reflect refinements in the integration of multiple spatial layers. For example, the modifications of administrative boundaries, timber areas and parks can result in units that do not meet the criteria for separate analysis; these units are therefore regrouped.

The most suitable spatial framework for GHG monitoring of agricultural lands (Cropland category) is the National Soil Database of the Canadian Soil Information System[9] and its underlying Soil Landscapes of Canada (SLC). The full array of attributes that describe a distinct type of soil and its associated landscapes, such as surface form, slope, typical soil carbon content under native and dominant agricultural land use, and water table depth, is called a soil landscape. Soil landscapes are spatially associated with SLC polygons (the analysis units), that may contain one or more distinct soil landscape components. The SLC polygons are in the order of 1000 to 1 000 000 hectares (ha) in area and are appropriate for mapping at the scale of 1:1 million.

SLC polygons are also the basic units of Canada's National Ecological Framework, a hierarchical, spatially consistent national context within which ecosystems at various levels of generalization can be described, monitored and reported on (Marshall and Schut 1999). The 12 353 SLC polygons are nested in the next level of generalization (1021 ecodistricts), which are further grouped into 218 ecoregions and 15 ecozones.

Analysis units for estimating the areas of forest converted to other uses are the result of the spatial intersection of forest conversion strata (see Figure A3–10) with ecological and administrative boundaries. Forest conversion strata were developed on the basis of expected conversion rates and characteristics. The sampling approach used to monitor forest conversion requires that analysis units be (i) as consistent as possible with respect to the patterns of forest conversion and (ii) large enough to provide an acceptable sample size given the predetermined sampling rate.

The LULUCF Sector of the GHG inventory reports information in 18 reporting zones (Chapter 7, Figure 7-1). These reporting zones are essentially the same as the ecozones of the National Ecological Framework, with three exceptions: the Boreal Shield and Taiga Shield ecozones are split into their east and west components to form four reporting zones; and the Prairies ecozone is divided into a semi-arid and a subhumid component. These subdivisions do not alter the hierarchical nature of the spatial framework. Table A3–35 provides the land and water areas of each reporting zone, as well as the estimated area of managed forest and cropland for the 2012 inventory year. Methods and data sources used for developing this information are described in McGovern (2008).

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

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

A3.4.2.1. Carbon Modelling

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

The ecosystem processes (or "annual processes") modelled by the CBM-CFS3 to generate the estimates submitted in this report are growth, litter fall, non-disturbance tree mortality and decomposition. The CBM CFS3 also models events, such as management

9 Available online at http://sis.agr.gc.ca/cansis.

Table A3–35 Estimates of Land, Water, Managed Forest and Cropland Areas in 2012

Reporting Zone Number	Reporting Zone Name	Total Area (kha)	Total Land Area (kha)	Total Fresh Water Area (kha)	Managed Forest Area (kha)	Cropland Area (kha)
1	Arctic Cordillera	24 278	23 992	286		
2	Northern Arctic	151 023	142 416	8 606		
3	Southern Arctic	84 636	74 609	10 027		
4	Taiga Shield East	74 834	65 669	9 166	1 103	
5	Boreal Shield East	111 057	99 129	11 928	55 647	656
6	Atlantic Maritime	20 939	19 737	1 202	15 443	1 022
7	Mixedwood Plains	16 781	11 015	5 766	2 675	5 749
8	Hudson Plains	37 371	36 394	977	302	
9	Boreal Shield West	83 951	71 112	12 839	28 775	192
10	Boreal Plains	73 612	67 186	6 426	37 848	10 352
11	Subhumid Prairies	22 341	21 599	742	1 789	15 204
12	Semiarid Prairies	23 966	23 494	473	40	12 354
13	Taiga Plains	65 804	58 219	7 585	20 544	6
14	Montane Cordillera	48 471	47 226	1 244	35 528	1 132
15	Pacific Maritime	20 810	20 488	322	13 204	124
16	Boreal Cordillera	46 785	45 842	944	16 618	
17	Taiga Cordillera	26 530	26 374	157	412	
18	Taiga Shield West	63 168	52 178	10 990	1 827	

activities, forest conversion and natural disturbances. Management activities represented are commercial thinning, clear-cutting, partial cutting, salvage cutting[10] and the burning of harvest residues during site preparation or for fire risk management. Different practices of forest conversion are also simulated, including controlled burning.

The forest carbon pools represented in the CBM-CFS3 can be matched to the Intergovernmental Panel on Climate Change (IPCC) forest carbon pools (Table A3–36). Although not shown here, living biomass pools are further subdivided into two sets, for each of hardwood and softwood tree species.

Annual processes and events trigger arrays of carbon transfers between pools as shown in Figure A3–6.

Annual ecosystem processes comprise growth, litter fall, mortality and decomposition and are simulated as carbon transfers executed at each time step (annually) in every inventory record. During annual processes, carbon is taken up in the biomass pool and some biomass carbon is transferred to dead organic matter (DOM) pools. The decay of DOM carbon results in its transfer to another DOM pool (e.g. stem snags to medium deadwood pool), to a slow soil pool or to the atmosphere. More information on pool structure and decay rates is provided in Kurz et al. (2009). Rates of carbon transfer are defined for each pool, based on pool-specific turnover rates (for biomass pools) or decay rates (DOM and soil pools). Turnover rates can be very high (e.g. 95% for hardwood foliage) or very low (e.g. < 1% for stemwood). Annual decay rates are defined for a reference mean annual temperature of 10°C and exhibit temperature sensitivity according to defined Q10 relationships; the decay rates vary between 50% (very fast DOM pools, such as dead fine roots) and 0.0032% (slow soil pool).

Growth is simulated as an annual process. Every record in the forest inventory used in each of the 635 analysis units is associated with a yield curve that defines the dynamics of merchantable volume over time. Assignment of an inventory record to the appropriate curve is based on a classifier set that includes province, ecological stratum, leading species, site productivity class and several other classifiers that differ between provinces and territories. Curve libraries for each province and territory in Canada are derived from permanent or temporary sample plots or from forest inventory information.

Conversion of merchantable volume curves to above-ground biomass curves is performed with a set of equations developed for Canada's National Forest Inventory (Boudewyn et al. 2007). These equations derive the above-ground biomass of each stand component from merchantable stemwood volume (per ha), for each province/territory, ecozone, leading species or forest type. Finally, below-ground biomass pools are estimated using regression equations (Li et al. 2003). Mean annual increments are not used in this derivation.

Disturbances trigger different combinations of carbon transfers, based on the disturbance type and severity, the forest ecosystem affected and the ecological region. For modelling purposes, different practices of forest conversion are also implemented as

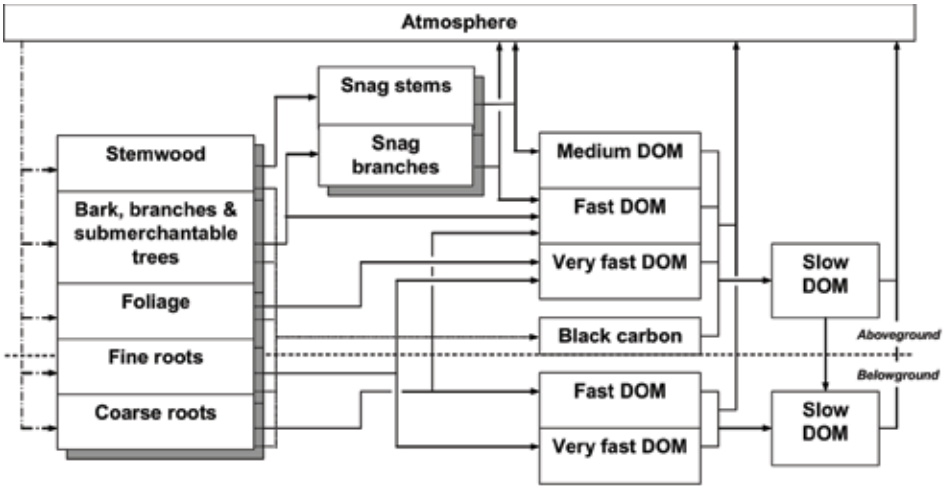
10 Salvage cutting (or "salvage logging") is the removal of merchantable timber left after a natural disturbance. Whenever possible, salvage logging is distinguished from conventional harvesting operations.

Table A3–36 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)	Dead wood	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[1] Below-ground slow Black carbon[2] Peat[2]

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

Figure A3–6 Carbon Pools and Transfers Simulated by the CBM-CFS3. Source: White et al. (2008)



disturbances. The impact of a disturbance is defined in a disturbance matrix, which specifies for one or more disturbance types the proportion of carbon in each ecosystem pool that is transferred to other pools, released to the atmosphere (in different GHGs) or transferred to harvested wood products. Figure A3–7 illustrates one such matrix, simulating clear-cut harvesting and salvage logging, which is applicable in all ecozones except those in Alberta and Quebec. In the 2014 submission, the simulation uses a total of 119 disturbance matrices to simulate the impact of disturbances. The number of different disturbance matrices is dependent on the availability of activity data (e.g. the spatial and temporal resolution of data sources used to document disturbances) and on the knowledge required to parameterize the matrices for more distinct regions or intensities of disturbance in place of more generically developed parameter sets.

The proportion of CO_2-C emitted from each pool, 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 carbon emitted in each carbon containing GHG (CO_2, CO, and CH_4) due to fire is constant: 90% of carbon is emitted as CO_2, 9% as CO and 1% as CH_4 (Cofer et al. 1998; Kasischke and Bruhwiler 2003).

Figure A3–7 Disturbance Matrix Simulating the Carbon Transfers Associated with Clearcut Harvesting and Salvage Logging

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

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

A3.4.2.2. Data Sources

Managed Forest Land

The Canadian provincial and territorial governments, whose jurisdiction includes natural resource management, provided essential information—notably detailed forest inventory data and, when available, details on forest management activities and practices, disturbances and disturbance prevention or control, regional yield tables (volume/age curve) for dominant tree species, and site indices—as well as regional expertise (Table A3–37). The forest inventory data in Canada's National Forest Inventory (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. Considerable efforts were necessary to harmonize, format and compile the detailed inventory information into input data for the CBM-CFS3. A series of "methods papers" describe the compilation process for each provincial and territorial forest inventory. Since forest inventory data were not collected in the same years, additional steps were necessary to synchronize the inventory data to the year 1990 (Stinson et al. 2006a).

Conceptually, forests are classified as "managed" or "un-managed" based on the occurrence of management activities for timber or non-timber, and on the level of protection against disturbances (Figure A3–8). 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. (2006b). Figure A3–9 illustrates the location of lands with managed and un-managed forests in Canada, for the purpose of GHG estimation and reporting. In 2012, the total area of managed forests was 231 755 kilohectares (kha), of which 68% lie in four reporting zones: Boreal Shield East, Montane Cordillera, Boreal Plains and Boreal Shield West (see Table A3–35). The managed forest area represents 67% of the total forest area in Canada.

Forest management activities are documented in the National Forestry Database;[11] additional information on specific activities is obtained directly from provincial and territorial forest management agencies.

Historical data on areas disturbed by wildfires were extracted from the Canadian National Fire Database for the years 1990 to

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

Table A3–37 Main Sources of Information and Data, Managed Forests

Description	Source	Spatial Resolution	Temporal Coverage	Reference
Fire data	National Burned Area Composite	Spatially explicit	2004–2012	http://www.nrcan.gc.ca/node/13159
	Canadian National Fire Database	Spatially referenced	1959–2003	http://www.nrcan.gc.ca/node/13159
Forest inventories & merchantable volume data[1]	Canada's National Forest Inventory (CanFI)	CanFI grid cell	1949–2004	https://nfi.nfis.org/index.php
	Alberta[2]	Analysis units	1949–1999	Provincial experts
	British Columbia	Analysis units	1995–2000	Provincial experts
	Newfoundland	Analysis units	1991–2006	Provincial experts
	Nova Scotia	Analysis units	2006	Provincial experts
	Ontario	Analysis units	2000	Provincial experts
	Prince Edward Island	Analysis units	2000	Provincial experts
	Quebec	Analysis units	2000	Provincial experts
Harvest data[3]	National Forestry Database	Provincial boundaries	1990–2012	http://nfdp.ccfm.org/
	Alberta	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	British Columbia	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	Newfoundland and Labrador	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	Manitoba	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	New Brunswick	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	Northwest Territories	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	Nova Scotia	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	Ontario	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	Prince Edward Island	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	Quebec	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	Saskatchewan	Analysis units	1990–2012	National Forestry Database http://nfdp.ccfm.org/
	Yukon	Analysis units	1990–2002	National Forestry Database http://nfdp.ccfm.org/
Insect data	Forest Insect and Disease Survey	Spatially explicit	1990–2009	Atlantic Forestry Centre and Pacific Forestry Centre
	Alberta	Spatially explicit	1990–2012	Provincial experts
	British Columbia	Spatially explicit	1990–2012	Provincial experts
	Saskatchewan	Spatially explicit	1998–2001	Provincial experts
	Manitoba	Spatially explicit	1990–1998	Provincial experts
	Newfoundland	Spatially explicit	2000–2003	Provincial experts
	Yukon	Spatially explicit	1994–2005	Provincial experts
Climate data	CFS	Analysis units	1961–1990 normals	McKenney (2005)

Note:
1. Forest inventory and merchantable wood volume yield data were obtained from Canada's National Forest Inventory and/or obtained from provincial experts where specified.
2. Alberta's forest inventory database is comporised of provincial forest inventory for the province's Forest Management Areas, and CanFI inventory for the remainder of the managed forest landbase.
3. Given the absence of complete harvest data for the most recent reporting year for all provinces and territories besides Quebec, 2012 harvest data are estimated by assuming them to be equal to 2011 values.

Figure A3–8 Decision Tree for the Determination of Managed Forest Area

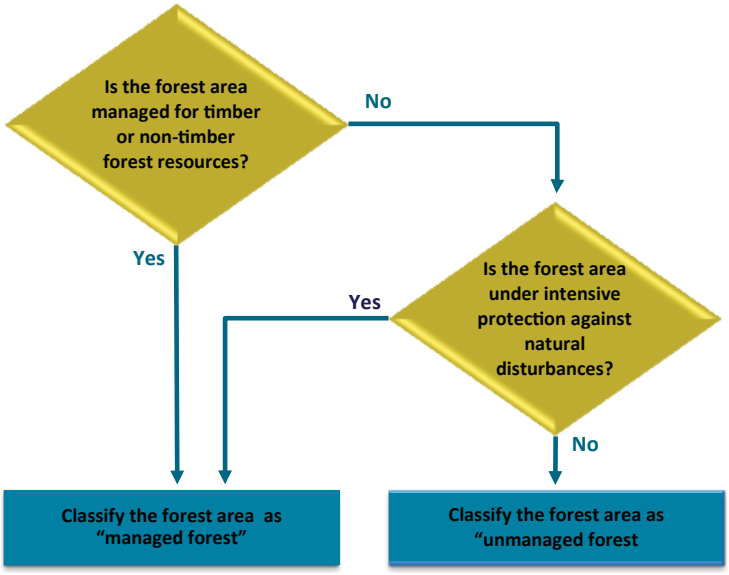
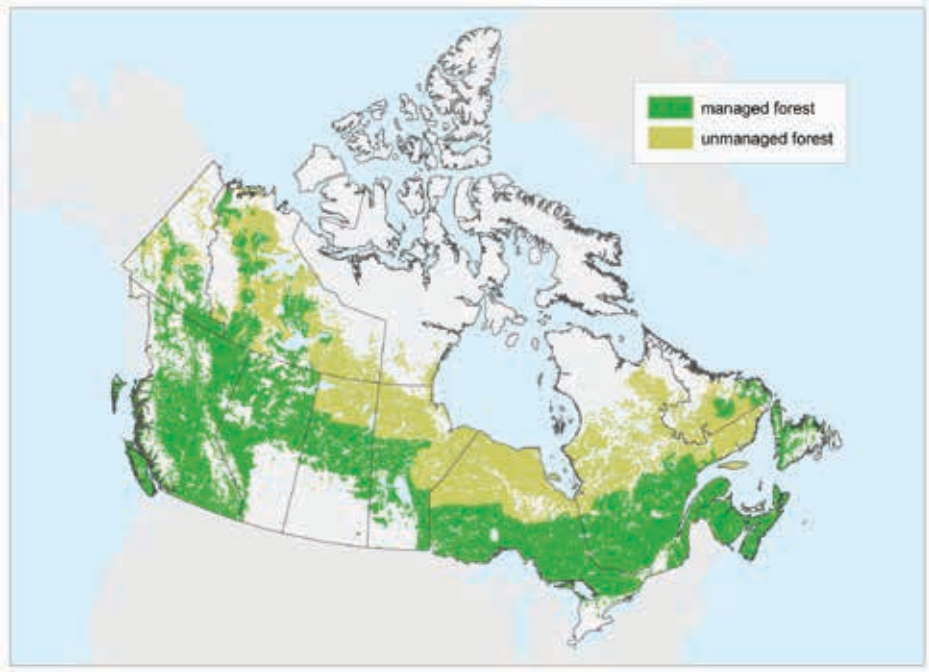


Figure A3–9 Lands with Managed and Un-managed Forests in Canada



2003 and from the Canadian Wildland Fire Information System's National Burn Area Composite (NBAC) product for the years 2004 to 2012 (Table A3–37). The NBAC is a composite of low- and medium-resolution remote sensing data and fire mapping data, provided by resource management agencies from across Canada, that provides complete mapping of wildfires using the best available data sources. Medium-resolution remote sensing data are used where these are available; data from resource management agencies are given second priority; and low resolution remote sensing data are only used where no other fire mapping data are available.

Insect disturbances are monitored by aerial surveys (Table A3–37), 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 the severity of the

impact is reflected in the parameters of the disturbance matrix applied (Kurz et al. 2009).

Forest Conversion

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

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

Change imagery is interpreted and analyzed; each forest conversion event larger than 1 ha is manually delineated. The broad forest type prior to forest conversion is interpreted,[12] and the post-deforestation land use recorded ("post-class"). Confidence ratings on the land use at the initial time and a later time period are used in subsequent quality control and field validation procedures.

Monitoring of forest conversion activity covers all forest areas of Canada, and is not limited to the managed forest. The entire forested area of Canada is broadly stratified into regions of expected forest conversion level and dominant cause, which dictate the target sampling intensity. Depending on the expected spatial patterns and rates of forest conversion, sampling approaches ranged from complete mapping, to systematic sampling over the entire analysis unit of interest, to a representative selection of sample cells within a systematic grid. For example, in populated areas of southern Quebec and in the Prairie fringe, a 12% sampling rate was generally achieved, with 3.5 × 3.5-km sample cells at the nodes of a 10-km grid (Figure A3–11). In practice, resource constraints limit the size of the remote sensing sample; wherever possible, a target sampling rate of 12% or 6% was achieved. It is also important to note that different sampling rates may be applied for each time period, in an effort to track differing activity rates between time periods. The total areas, either fully mapped or sampled, cover approximately 346 million hectares (Mha), of which over 16 Mha were mapped for 1975–1990, 40 Mha were mapped for 1990–2000, and 21 Mha were mapped for 2000–2008. Figure A3–10 provides an overview of sampling and mapping for the forest conversion stratification.

Representative samples are used in areas of moderate expected rates of forest conversion (e.g. eastern woodlots in the Maritimes, the Eastern Townships in Quebec, the Lower Mainland of British Columbia, and the south agricultural zone of the Prairies). The forest activity region comprises a large area of Canada with a low population density; the main economic activities consist of forestry and other resource extraction. Again, a representative sampling approach is used, augmented with additional samples (e.g. pilot studies) in Quebec, Ontario and British Columbia. Special cases of known, localized and large forest conversion activities were also identified, such as hydroelectric reservoirs and oil sands development in Alberta. In such cases, the entire areas are handled as single events ("Hot Spot" in Figure A3–10), with spatially complete mapping.

Records were gathered when available. They consist mostly of information on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs (Leckie et al. 2006). The temporal coverage, availability and applicability of these records are assessed to determine the most appropriate information sources (records or imagery). Records data are sometimes used to aid in the validation of estimates made through image interpretation. In particular for British Columbia, records data are used to provide estimates of conversion activity for power lines and oil and gas activity. In northern Quebec, a mix of remote sensing image interpretation and records data are used to assess the areas of forest converted as a result of hydroelectric development. If the extent of forests affected by land submersion cannot be determined through official records or image interpretation, it is estimated by multiplying the area of land flooded by the proportion of forest cover in the region surrounding the reservoir, as determined by a Landsat image classification forest cover map (Wulder et al. 2004).

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

Expert opinion is only called upon when remote sensing sampling is insufficient and records data are unavailable or of poor

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

Figure A3–10 Forest Conversion Strata and Areas Sampled for the 2014 Submission

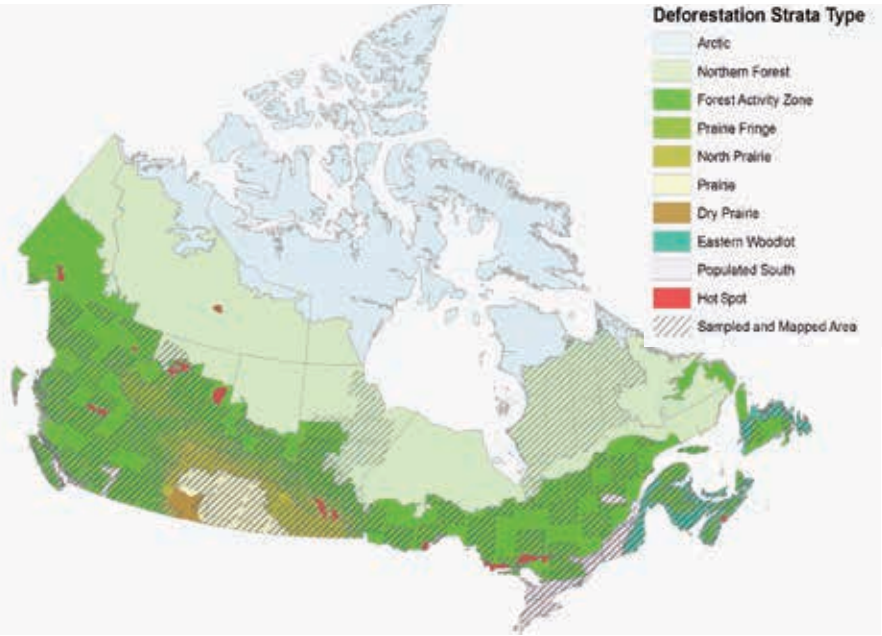
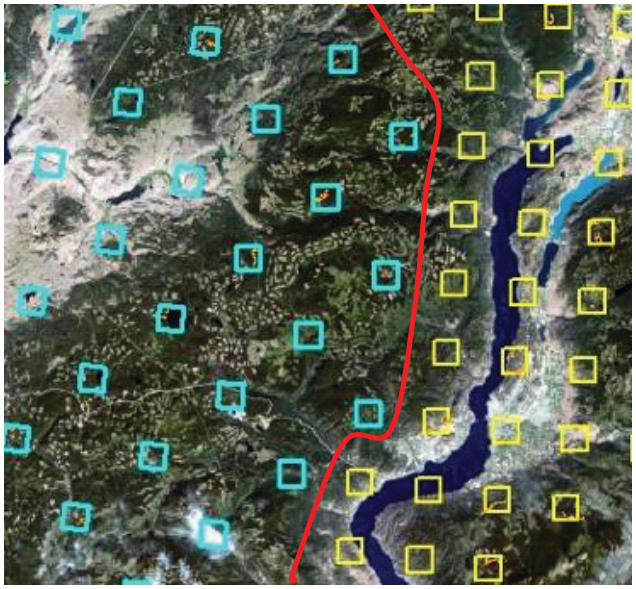


Figure A3–11 Sampling Grids Over Satellite Imagery for Forest Conversion Mapping. Background Imagery: Area Near Kelowna, British Columbia, Landsat TM, Summer 2000. Denser grid cells at right represent a 12% sampling density; lighter grid on the left is 6% intensity.



quality. Expert judgement is also used to reconcile differences between records and remote sensing information and to resolve large discrepancies in the 1975–1990, 1990–2000 and 2000–2008 area estimates. In such cases, available expert opinion and data sources are brought together, remote sensing and records data are reviewed, and decisions are made (Leckie 2006b; Leckie et al. 2010b; Dyk et al 2012b). For most estimates, certainly those where the land-use change categories had the largest impacts, estimates are derived directly from remote sensing samples.

The activity data are compiled and summarized initially by analysis unit. All conversion events are assembled into a database. A compilation is made to summarize events for detailed post-conversion classes for each reconciliation unit. This compilation process also involves insertion of records data and expert judgement. In the course of these procedures, each event is compiled to yield a local forest conversion rate (ha/year) based on the time interval between the images. Since the available imagery was not necessarily dated 1975, 1990, 2000 or 2008, the rates cover

different time periods. At the data compilation phase, forest conversion events are assigned to one of three time periods (1975–1990, 1990–2000, 2000–2008), and the corresponding rate of forest conversion is assigned to that period. For example, a 7.0-ha event encountered on imagery from the period 1975–1989 would yield a 0.5 ha/year rate (7.0 ha/14 years) and then would be assigned to the period 1975–1990. The total area interpreted in an analysis unit for that time period is then used to determine a relative rate of forest conversion ([ha/year]/km^2 interpreted) for all events of the same type. Relative rates are scaled up for each analysis unit. Data are finally grouped by end use (e.g. the change rate for agricultural crop or rural residential) and in turn, are summarized by broader categories when recompiled by reconciliation unit.

The remote sensing data are derived using the imagery from circa 1975, 1990, 2000 and 2008, whereas records data are annual or summarized over time periods. As explained above, the remote sensing core method provides three distinct average rates of forest conversion for 1975–1990, 1990–2000 and 2000–2008 but no annual estimates of these rates. The preparation of annual forest conversion rates for 1970–2010 requires the simultaneous application of two procedures: 1) extrapolation of annual rates prior to 1975 and beyond 2008; and 2) interpolation between the 1975–1990, 1990–2000 and 2000–2008 data (Figure A3–12). In the absence of documented and tested procedures, the simplest approach is to assign the 1975–1990 rate to each year from 1970 to 1983, the 1990–2000 rate to each year from 1983 to 1995, and the 2000–2008 rate to each year from 1995 to 2004. A constant forest conversion rate is assumed for the post-2004 period. Information for an additional period will be used to update the process.

A linear interpolation is applied between the three temporal anchor points (1983, 1995 and 2004), which results in an estimate of the annual rate of forest conversion for each intervening year. The procedure is illustrated in Figure A3–12. Noted exceptions to this procedure do occur, and reflect individual large events for which actual disturbance information is known either from records information or detailed mapping activity. One example of this would be the case of hydroelectric reservoirs.

Figure A3–13 displays the annual rates of forest conversion by selected end uses: forest land to cropland (FLCL) and forest land to wetlands (FLWL [reservoir flooding]). The figure helps illustrate the different approaches implemented in developing annual estimates. The conversion to cropland estimate is based on the approach illustrated in Figure A3–12. The estimate of forest conversion to wetlands (reservoir flooding) reflects the use of records and detailed mapping information to account for large unique events. Note that these figures differ from the ones reported in the common reporting format (CRF) tables, which are cumulative areas in the "Land converted to" categories.

QA/QC of Forest Conversion Data

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

The remote sensing interpretation follows defined procedures (Leckie et al. 2010a; Dyk et al. 2012b), although it is conducted by a variety of organizations, including provincial government

Figure A3–12 Procedure for Developing a Consistent Time Series of Rates of Forest Conversion

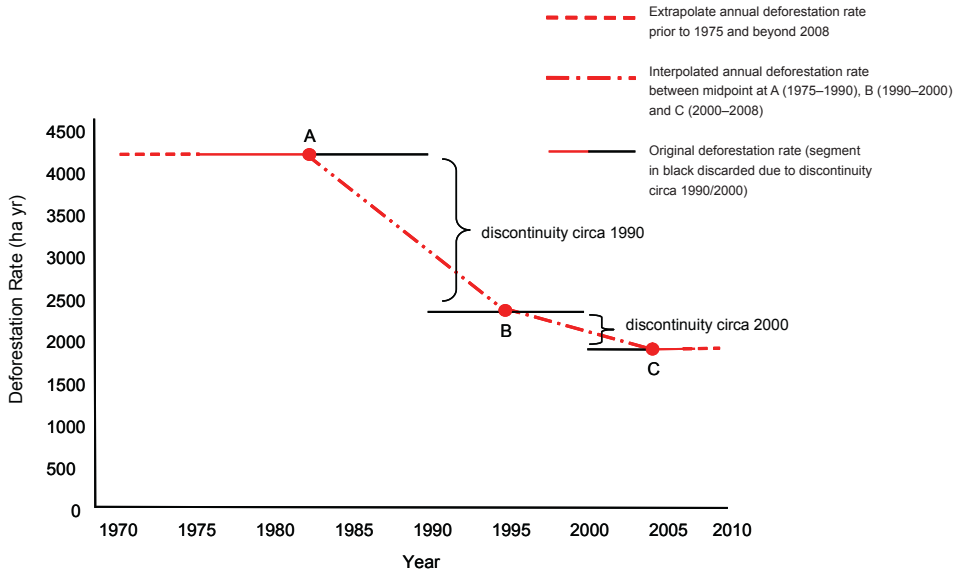
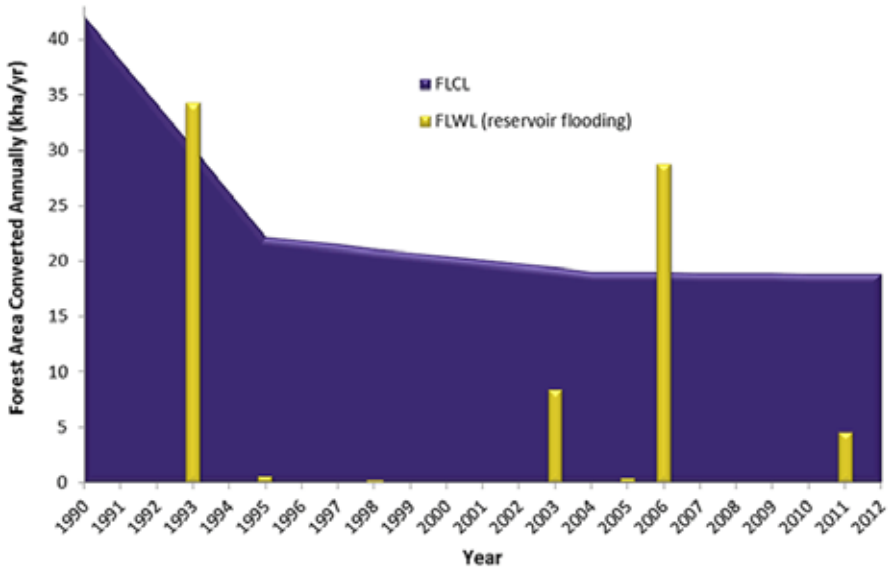


Figure A3–13 Annual Rates of Forest Conversion to Cropland (FLCL) and Forest Conversion to Wetland (FLWL [reservoir flooding])



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. 2011).

Records of decision as to data used and expert judgement applied, as well as decisions on the resolution of contradictory data, are documented within the overall processing database (Leckie 2006b) and updated for each new submission (Dyk et al. 2012a, 2012b). Data sources and limitations are recorded, and remote sensing data and interpretations archived.

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. 2012a, 2012b). 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. 2012b). Specific improvements include the following:

1. Expanded data sets with additional earth observation data, Landsat (MSSS/TM/ETM/Winter), SPOT-5, aerial photography, and high resolution satellite imagery.
2. Expansion of the sampled area for targeted and other areas.
3. Analysis and validation of records data with high-resolution imagery (for example, co-disturbance of pipelines and access roads).
4. Extending the temporal coverage to the 2000–2008 period, which provides a longer time period to confirm the nature of historical events. This results in greater confidence and the reduction of commission and omission [13] errors.
5. Greater knowledge resulting from increased experience and expertise gained through QC review and validation activity.

These improvements result in enhanced detection, delineation and determination of event size and cause, as well as a more accurate estimate of timing of conversion events.

Two approaches were considered to estimate uncertainties: an empirical approach and an analytical approach. The resulting estimate is based on consideration of these approaches and provides an estimate of uncertainty associated with activity area estimates. The additional sources of uncertainty related to forest type being removed, post-conversion land category and event timing are not considered.

13 Omission errors are the result of missing true conversion events, and commission errors are the result of including non conversion disturbances (e.g. forest harvest, burns, beaver flooding).

The empirical estimate was developed by making estimates of extreme low, low, high and extreme high forest conversion rates for each reconciliation unit and end-use class. These estimates were based on expert knowledge of activity and practices at a regional scale. All of these estimates were then compiled on a national basis. Comparisons between extreme and non extreme estimates provided some insight into the possible range for which conversion activity could occur. Based on this exercise, an estimate for overall uncertainty for forest conversion was determined to be in the range of ± 20% to ± 30%.

The analytical approach breaks the uncertainty down into subcomponents and then combines these through simple error propagation. The components considered are omission and commission, sampling, and boundary delineation errors.

Omission and commission errors are influenced by a number of factors, but in particular are dependent on the date and quality of pre and post imagery. Throughout the time series there is a tendency for omitted events to be smaller in size, whereas commission errors are usually from a misinterpretation rather than an oversight, and thus are less size-dependent. Commission and omission errors tend to offset each other. For the 2000–2008 time period, commission errors are likely to be greater than omission errors, particularly because of insufficient time lapse to enable post-disturbance conditions to be confirmed.

Uncertainty associated with boundary delineation errors considers the errors resulting from the displacement of the event boundary from the actual or true boundary of the event. Both underestimation and overestimation of area can result. This source of uncertainty is greatly influenced by the quality and resolution of imagery used in the delineation process; improvements made in resolution and image quality reduce this source of uncertainty.

Estimates of sampling uncertainty take into account the uncertainty associated with the sampling process and the scaling of estimates to large regions (strata/reconciliation units). The sampling process is a mixture of wall-to-wall mapping and systematic sampling. In some areas, the sample coverage and design differed between 1975–1990, 1990–2000 and 2000–2008. The sample error depends on the amount of activity in each region within each time period sampled. In addition, it is dependent on the conversion event size and spatial distribution (Paradine et al. 2004). Uncertainty due to sampling and scaling activity is therefore regionally variable, and, because conversion activity causes may vary by region, the uncertainty is variable.

The results of this analytical approach are consistent with those made based on an empirical approach. Based on these efforts, a conservative estimate is taken, which sets the uncertainty at the higher range of ± 30%. Further work will help improve the current understanding of the various sources of uncertainty, their interaction, and approaches used to combine these components.

This ± 30% uncertainty about the estimate of the total forest area converted annually in Canada places, with 95% confidence, the true value of this area for 2012 as being between 35 and 66 kha. This 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).

Planned Improvements in Forest Conversion

Planned improvements will be incremental, with an emphasis on reducing uncertainties and improving specific estimates. Improvement strategies combine a greater sample coverage, expanded records compilation, improved information processing and system documentation, and additional field verification. Initial image collection and compilation as well as record gathering are underway, to enable extending of estimates for the post-2008 period.

Land Converted to Forest Land

Records of land conversion to forest land in Canada were available for 1990–2002 from the Feasibility of Afforestation for Carbon Sequestration (FAACS) 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 during 2000–2008. Each event, regardless of date, source, type or location, was converted to an inventory record for the purposes of carbon modelling. All events were compiled in a single data set of afforestation activity in Canada from 1970 to 2008. No new afforestation activity data were identified for the 2009–2012 inventory years. Renewed efforts are underway to obtain additional data on recent afforestation activities in Canada.

For 1990–2008, the area planted was stratified by ecozone, province and species. Total area planted by province and ecozone, in conjunction with the proportion of species planted for each province, was used to calculate area planted by species, resulting in estimates of the area converted to forest, by species, for each reconciliation unit.

Yield curves are not always available for some plantation species or growing conditions (stocking level or site history); those used to estimate growth increments were taken from a variety of sources, most often directly from provincial experts. Where species do not have their own yield curve, they are given the yield curve of another species with similar growth characteris-

tics or the species most likely to have been present in that area. Changes in soil carbon stocks are highly uncertain because of difficulties in locating data about the carbon stocks prior to plantation. It was assumed that the ecosystem would generally accumulate soil carbon at a slow rate; the limited time frame of this analysis and the scale of the activity relative to other land use and land-use change activities suggest that the impact of this uncertainty, if any, is minimal.

A3.4.2.3. Estimation of Carbon Stock Changes, Emissions and Removals

At the beginning of each annual time step 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 applies the sets of carbon transfers associated with annual processes to all records (managed forest, land converted to forest and land converted from forest), including both stocked and non-stocked stands. As explained above, annual processes combine growth, turnover and decay processes, applied to the entire area of managed forests. The outputs consist of the net GHG balance of managed forests, including growth; immediate emissions due to disturbances (carbon stock changes, carbon losses to the atmosphere and to forest products); and decay of both DOM and soil organic matter, including on stands affected by disturbances. During this stage, inventory records that have been in a "Land converted to" category for 20 years are converted into the "Land remaining" category and the simulation of C dynamics—usually decay—continues in this new category.

The same data output is available on converted forest lands (except tree growth), but is reported in the new land category—e.g., the Land converted to cropland (CRF Table 5.B Row 2), Land converted to wetlands (CRF Table 5.D Row 2), and Land converted to settlements (CRF Table 5.E Row 2) categories. Exceptions consist of estimates of soil organic matter emissions on forest land converted to cropland and peatlands, which are developed separately; methods are described in sections A3.4.3.3 and A3.4.5.1. Likewise, estimation methods for emissions (as opposed to carbon stock changes) from forest land converted to flooded lands are described in Section A3.4.5.2.

Note that the immediate effect of disturbances is identifiable in the output data sets for the year of the disturbance. In subsequent years, post-disturbance emissions and removals in forests are simulated as annual processes. The CBM-CFS3 does not distinguish post-disturbance processes from other processes affecting forest ecosystem C; hence, the long-term impact of disturbances in the managed forests cannot be fully identified.

Table A3–38 gives 2012 estimates of the broad components of the GHG emissions and removals in managed forests generated by the CBM-CFS3. The largest fluxes are carbon uptake by biomass and its release by DOM decay (from heterotrophic respiration). The first is largely influenced by the age-class distribution of the managed forests; organic matter decay is controlled by input from litter fall, mortality and post-disturbance decay. Insect disturbances cause very limited immediate emissions; however, depending on the severity of infestations and insect damage, they may result in 1) reductions in C uptake through growth reductions, 2) large carbon transfers from biomass to DOM and 3) alterations in the long-term trend of organic matter decay (Kurz et al. 2008a).

A3.4.2.4. Uncertainties

Good practice recommends the use of numerical methods for assessing uncertainties within complex modelling frameworks with multiple interactions between data and parameters. These methods are data-intensive; computational requirements can

Table A3–38 GHG Fluxes To and From Managed Forests, 2012

Process/Event	GHG Balance (Gg CO_2 eq)[1]				
	Biomass	DOM	Soil	N_2O[3]	Ecosystem Net Balance
Annual processes	-2 950 343	2 108 424	616 999	0	- 224 920
Harvesting	117 391	16 235	0	344	133 970
Wildfires	22 083	96 341	0	5 267	123 692
Insects[2]	8	0	0	0	8
Total	-2 810 861	2 221 000	616 999	5 611	32 749

Notes:
1. On a C pool basis, exchanges of GHG with the atmosphere are not equal to C stock changes.
2. "0" emissions indicate that events do not cause emissions to, or removals from, the atmosphere. Rather, they kill biomass that is transferred to DOM.
3. Carbon in CH_4 and CO emissions is included in each pool's assessment, but N_2O emissions are computed separately from total CO_2 emissions (see Annex 8).

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 dead organic matter 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 Monte Carlo run outputs. The following paragraphs provide details on the characterization of uncertainty sources.

The forest inventory data used in model simulations are developed for planning and operational purposes. Methods, standards, definitions and quality differ by jurisdiction, depending on their objectives. Although documentation on the different inventory techniques and procedures used across the country is usually available, it seldom contains any quantitative assessment of uncertainty. While it is currently impossible to quantify uncertainties about, for example, managed forest areas, the influence of this uncertainty source can be indirectly built into the uncertainty about the biomass increment simulated by the model. For the purpose of this assessment, a 50% uncertainty about biomass increment 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 the forest carbon dynamics as a whole. Disturbances affect emissions and removals of C in the short term, and in the long term through residual decay and age-class distribution. Uncertainties of 10% and 25% are assumed on the areas of managed forests subject annually to wildfires and insect infestations, respectively.

The uncertainties about the carbon removed in harvested material are regionally specific, and incorporate error ranges in harvested volume (± 1%), and standard deviations about roundwood specific gravity and bark adjustment factor (Table A3–39). No error was assumed for the carbon proportion of biomass. The annual coefficient of variation was multiplied by 2 to approximate a normal distribution with a triangular one.

The assessment also provides uncertainties about emissions due to forest conversion; here a 30% uncertainty about areas converted annually is used. The "Forest Conversion" section of this annex describes the derivation of this value.

Soil and other slow-decaying DOM pools contain a considerable amount of carbon. Previous work had shown that the initial DOM

Table A3–39 Uncertainty Ranges for Harvested Carbon, by Canadian Province and Territory Source: Metsaranta et al. (2014)

Province/Territory	Minimum Multiplier	Maximum Multiplier
Alberta	0.9	1.1
British Columbia	0.92	1.08
Newfoundland	0.96	1.04
Manitoba	0.86	1.14
New Brunswick	0.92	1.08
Northwest Territories	0.74	1.26
Nova Scotia	0.88	1.12
Ontario	0.92	1.08
Prince Edward Island	0.88	1.12
Quebec	0.86	1.14
Saskatchewan	0.92	1.08
Yukon	0.84	1.16

C stocks, at the beginning of a complete run, are sensitive to historical disturbance rates. In this assessment, initial C stocks in the soil and DOM pools were allowed to vary by modifying the historical (pre-1990) fire return intervals. Even though the rates of soil organic matter decay modelled by the annual processes are very low, they do, by virtue of the pool size and forest areas, strongly influence emissions from annual processes. A sensitivity analysis of carbon emissions from the dead organic matter and soil pools revealed that the most influential model parameters included decay rates for soil organic matter, and the decay and release to the atmosphere of carbon from very-fast cycling pools, such as dead fine roots and litter (White et al. 2008).

For the purpose of this analysis, 28 model parameters 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).

Significant uncertainty in the modelling framework results 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 the pre-conversion standing carbon stocks, the parameters of the disturbance matrices that re-allocate carbon among pools or "release" it to the atmosphere, and the post-conversion decay rates. Hence, uncertainties about estimates cannot be obtained from a simple combination of "activity data" and "emission factor" uncertainties.

Uncertainty bounds about annual estimates were numerically calculated over the 1990–2012 period. Resulting uncertainty ranges were provided in Chapter 7, and are illustrated below for net CO_2 fluxes in Forest Land remaining Forest Land (FLFL) (Figure A3–14).

Not all uncertainty sources have been captured: importantly, the analysis did not consider the impact of processes that are currently not simulated. Hence, the results should not be used to assess potential bias (or accuracy) of estimates. Additional considerations may be warranted to identify the direct human-induced effects, and their uncertainties, on forest carbon dynamics. Improvements are expected to occur over coming years, due to better knowledge, refined procedures and access to more computing capacity.

A3.4.3. Cropland

The methodologies described in this section apply to carbon stock changes in mineral soils subject to cropland management and to the conversion of land in the Forest and Grassland categories to the Cropland category; CO_2 emissions from liming; CO_2 emissions from the cultivation of histosols; changes in the biomass of woody perennial crops; and N_2O emissions from soil disturbance upon conversion to cropland. The estimation methodologies for carbon stock changes and GHG emissions from the biomass and DOM pools upon conversion of forest land to cropland are provided in Section A3.4.2.3.

A3.4.3.1. Cropland Remaining Cropland

A detailed description of the methodologies used for this category can be found in McConkey et al. (2007a).

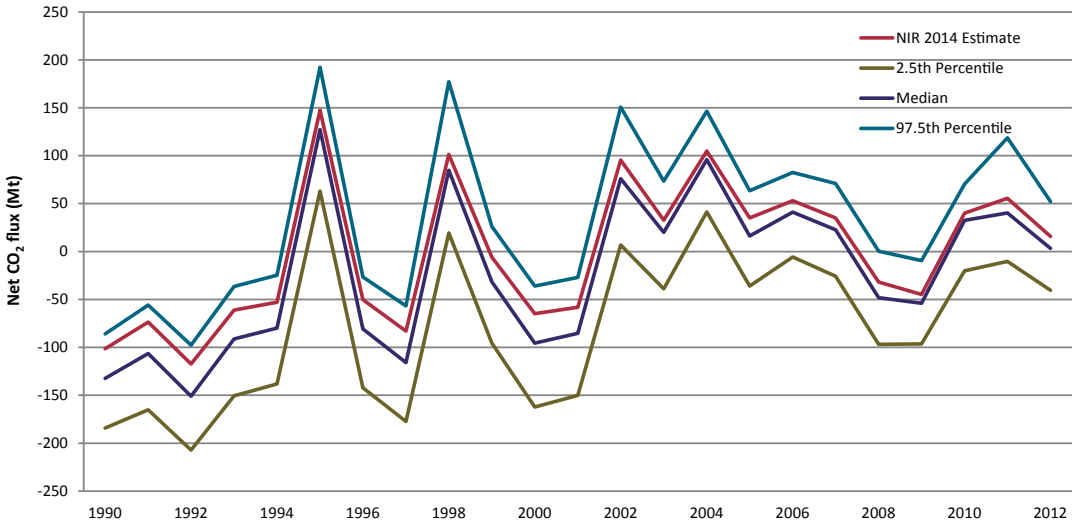
Change in Carbon Stocks in Mineral Soils

Changing Management Practices

The amount of organic carbon retained in soil represents the balance between the rates of input from crop residues and losses through soil organic carbon (SOC) decomposition. How the soil is managed determines whether the amount of SOC stored in a soil is increasing or decreasing. The IPCC (2003) approach, which guided the development of the CO_2 estimate methodology, is based on the premise that, on long-existing cropland, changes in soil C stocks over time occur following changes in soil management that influence the rates of either C additions to, or C losses from, the soil. If no change in management practices occurs, the C stocks are assumed to be at equilibrium, and hence the change in C stocks is deemed zero.

A number of management practices are generally known to increase SOC in cultivated cropland, such as reduction in tillage intensity, intensification of cropping systems, adoption of yield-

Figure A3–14 Uncertainty Range of Net FLFL CO_2 Flux (Full Thin Lines), the Median Value of the 100 Monte Carlo Runs (Dashed Line), and the Estimates of the 2014 Submission (Full Thick Line) for Each Inventory Year in the 1990–2012 Time Series. Source: Metsaranta et al. (2014)



promoting practices and re-establishment of perennial vegetation (Janzen et al. 1997; Bruce et al. 1999). Adoption of reduced tillage (RT) or no-till (NT) can result in significant accumulation of SOC compared with intensive tillage (IT) (Campbell et al. 1995, 1996a, 1996b; Janzen et al. 1998; McConkey et al. 2003). Many cropping systems can be intensified by increasing the duration of photosynthetic activity through a reduction of summerfallow (Campbell et al. 2000, 2005; McConkey et al. 2003) and greater use of perennial forage (Biederbeck et al. 1984; Bremer et al. 1994; Campbell et al. 1998). Intensification of cropping systems not only increases the amount of C entering the soil, but may also reduce decomposition rates by cooling the soil through shading and by drying the soil. Conversely, switching from conservative to conventional tillage or from intensive to extensive cropping systems will generally reduce C input and increase organic matter decomposition, thereby reducing SOC.

VandenBygaart et al. (2003) compiled published data from long-term studies in Canada to assess the effect of agricultural management practices on SOC. This compendium, as well as the availability of activity data from the *Census of Agriculture*, provided the basis for identifying key management practices and management changes used to estimate changes in soil C stocks. Emissions and removals of CO_2 from mineral soils are estimated for the following land management changes (LMCs):

1. Change in mixture of crop type
   a) Increase in perennial crops
   b) Increase in annual crops
2. Change in tillage practices
   a) IT to RT
   b) IT to NT
   c) RT to IT
   d) RT to NT
   e) NT to IT
   f) NT to RT
3. Change in area of summerfallow
   a) Increase in area of summerfallow
   b) Decrease in area of summerfallow

Where nutrients are greatly limiting, proper fertilization can increase SOC; in such conditions, however, fertilizer or other nutrient-enhancing practices are generally applied. Irrigation in semi-arid areas can affect SOC, but the impact is unclear, and the area of irrigated land has been relatively constant in Canada. Therefore, it is assumed that the selected LMCs represent the most important and consistent influences on SOC in mineral soils.

Carbon Stock Change Factor

To estimate C emissions or removals, an SOC stock change factor specific to each combination of Soil Landscapes of Canada (SLC) polygon 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 A3–52:

$$\Delta C = F \times A$$

where:

ΔC	=	change in SOC stock for inventory year, Mg C
F	=	average annual change in SOC subject to LMC, Mg C/ha/year
A	=	LMC area, ha

Areas of LMC such as changes in tillage, crop type and fallow are obtained from the *Census of Agriculture*. Census data provides information on the net change in area over five-year census periods. In practice, land probably both enters and leaves a land management practice, and combinations of management changes occur. However, because only net change data are available, two assumptions are made: additivity and reversibility of SOC factors. Reversibility assumes that the factor associated with an LMC from A to B is the opposite of that associated with the LMC from B to A. Additivity assumes that the C changes from each individual LMC occurring on the same piece of land are independent and therefore additive. This assumption is supported by the findings of McConkey et al. (2003), who reported that the impact of tillage and crop rotations on SOC is generally additive.

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 general method for developing C factors is outlined in Figure A3–15 and Figure A3–16. The starting points were the SOC values in the SLC polygon attribute database (CanSIS). These database SOC values were derived from measurements made for soil surveys and land resource studies (Tarnocai 1997) and were assumed to represent average SOC on cropland in 1985. Initial SOC in 1910 was estimated as 1.25 times the SOC in the SLC

Figure A3–15 Method for Deriving Carbon Factors for a Land Management Change of Interest

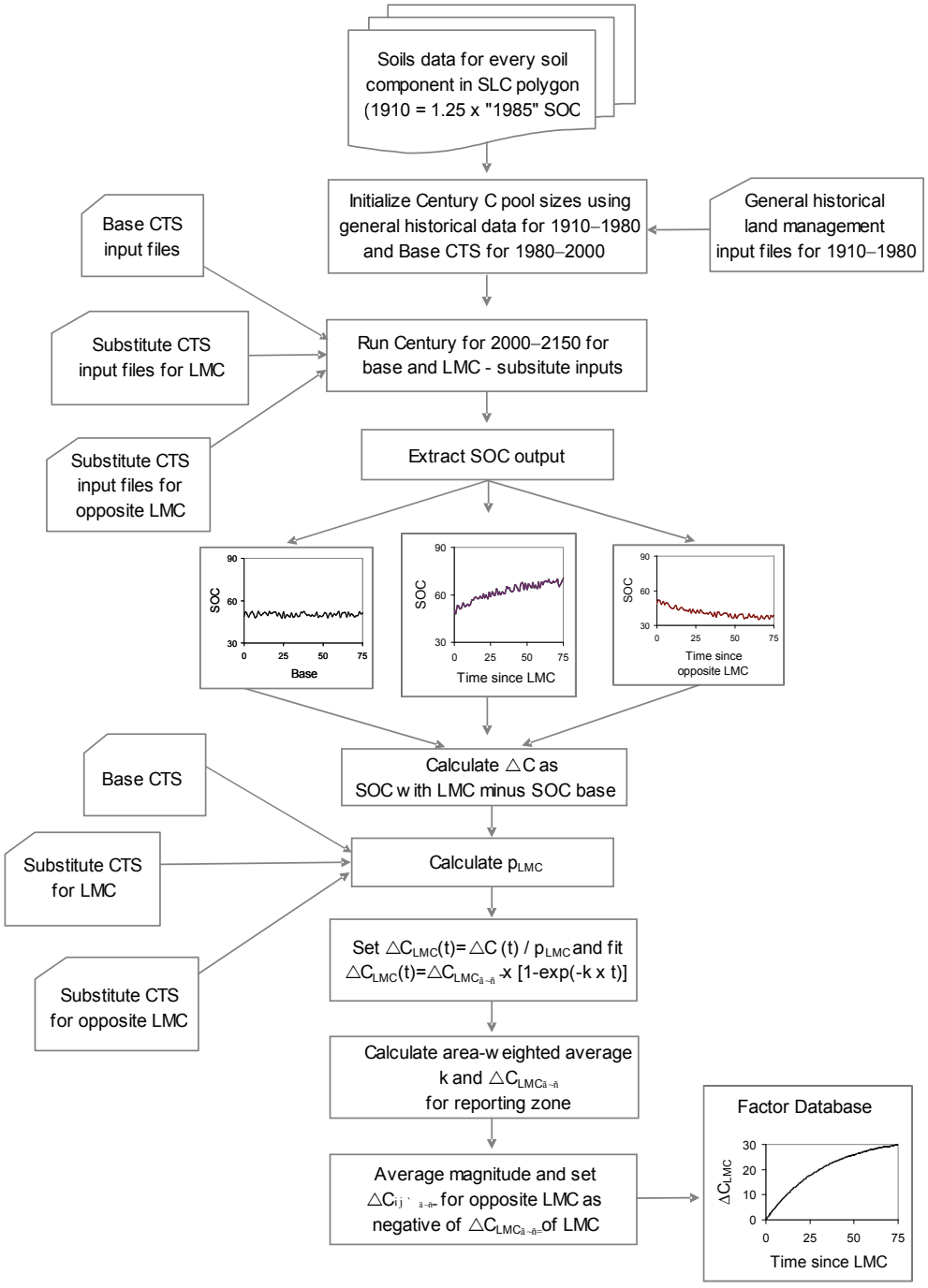
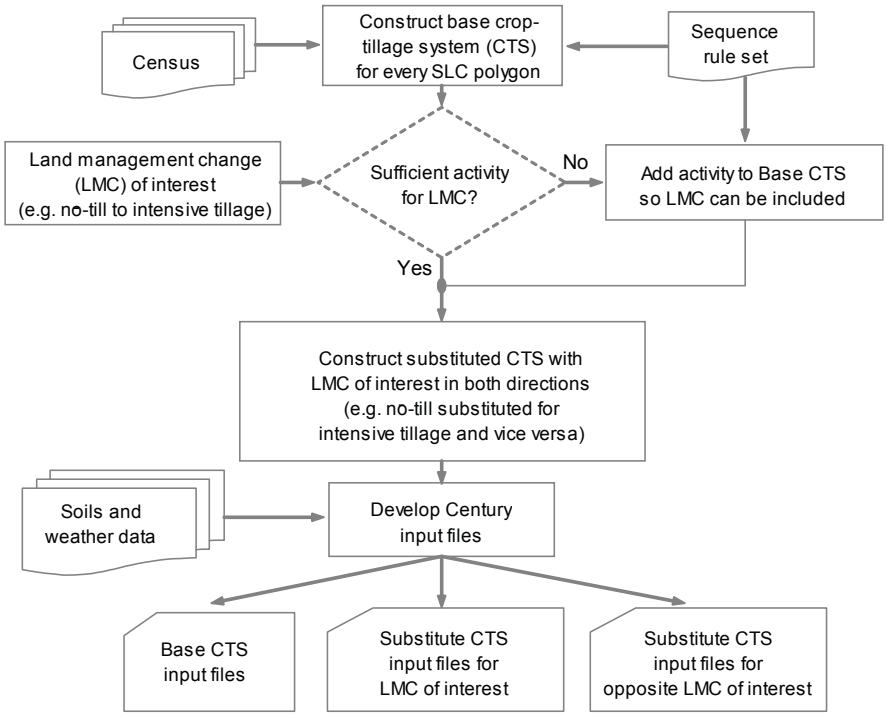


Figure A3–16 Method for Deriving Land Management Input Files to Use with Century Model to Estimate the Carbon Factor for a Land Management Change of Interest



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 A3–53:

$$\Delta C_{LMC}(t) = \frac{\Delta C}{P_{LMC}}$$

where:

$\Delta C_{LMC}(t)$	=	the difference in SOC between land management systems from year to year (Mg SOC/ha)
P_{LMC}	=	the proportion of the land area under a given land management system subject to the LMC

This proportion (P_{LMC}) can be derived as the proportion of the particular LM in the base system less the amount of the LM in the new system after the LMC. That is,

Equation A3–54:

$$P_{LMC} = P_{LMbase} - P_{LMnew}$$

where:

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 Semi-arid Prairies reporting zone. A base model run was made using a 10-year base mix of crops based on the *1996 Census of Agriculture* and weather data covering the years 1951–2001. Century simulations of SOC were made by substituting perennial crops for the seven annual crops out of ten in the base mixture. As a separate exercise, NT was substituted for IT four years out of ten in the base mixture (Figure A3–17). 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 A3–53). Finally, the $\Delta C_{LMC}(t)$ was calculated as the proportion of area of farming system divided by the P_{LMC} (Equation A3–54). Figure A3–18 illustrates the time series of ΔC_{LMC}. In this particular case 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.

SOC dynamics are believed to be governed by first-order kinetics, and thus C change can be expressed as

Equation A3–55:

$$\Delta C_{LMC}(t) = \Delta C_{LMCmax} \times \left[1 - exp^{(-k \times t)}\right]$$

where:

ΔC_{LMCmax}	=	the maximum SOC change induced by the LMC
k	=	the rate constant
t	=	year

In practice, the exponential equations are fit statistically using standard statistical analysis software by methods of least squares.

The slope of the exponential equation has units of Mg C/ha per year and is the instantaneous factor value. Since the estimation is based on annual changes, the equation used for estimating the factor for annual change from the previous year (i.e. from year t–1 to year t) is

Equation A3–56:

$$F_{LMC}(t) = \Delta C_{LMCmax} \times \left[exp^{(-k \times [t-1])} - exp^{(-k \times t)}\right]$$

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 A3–19).

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 A3–40). The geometric mean was used for k, since its distribution was positively skewed. These means were calculated by three general soil texture classes (sandy, loamy and clayey) and applied to each soil component based on its textural class. Occasionally, k values less than 0 or greater than 0.15 resulted from the fit to ΔC_{LMC}; the k and ΔC_{LMCmax} from these fits were excluded from the reporting zone means.

Figure A3–17 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

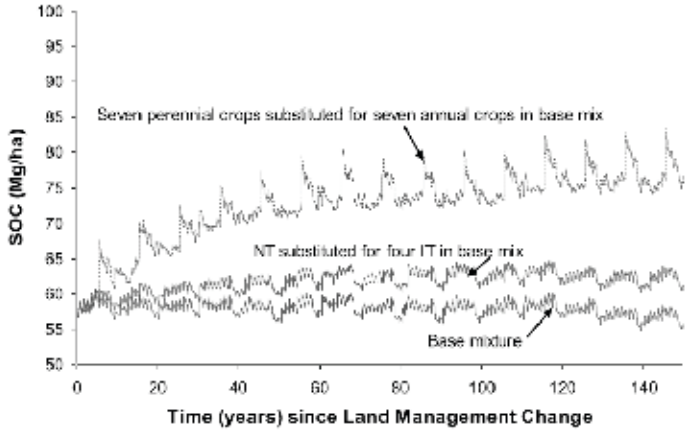


Figure A3–18 Change in SOC for Simulations with Substitutions Relative to Simulations with Base Crop Mix

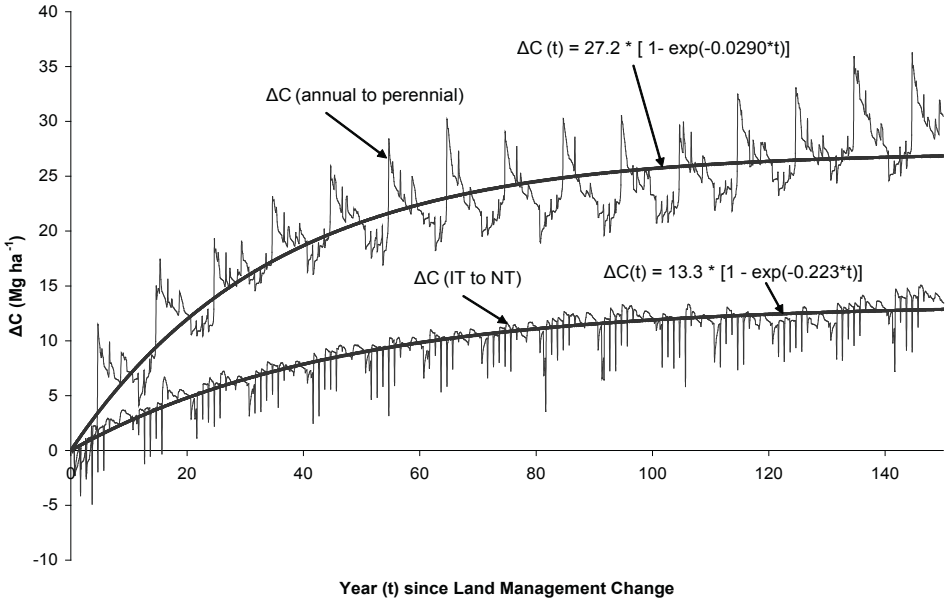
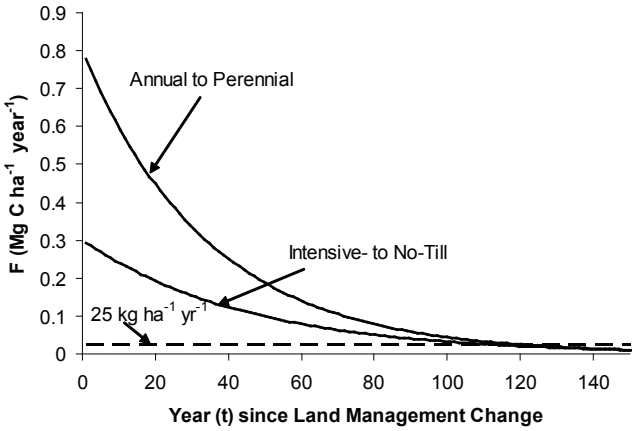


Figure A3–19 Carbon Factors as a Function of Time



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 may be expected to be greater upon an LMC than rates of SOC gain upon the reverse LMC. However, this effect depends greatly on the relative SOC amount at the time of the LMC. Documenting SOC at the time of all LMCs is currently impossible; hence for transparency and simplicity the reversibility assumption was imposed, which requires that the SOC effect of an LMC in one direction is exactly the negative of the SOC effect of the practice change in the opposite direction.

Soil Carbon Factor Validation

SOC change factors for LMCs used in the inventory were compared with empirical coefficients in VandenBygaart et al. (2008). They showed that empirical data comparing SOC change between IT and NT were highly variable, particularly for eastern Canada. Nonetheless, the modelled factors were still within the range derived from the empirical data. The mean IT-NT factor for experiments in the Subhumid Prairies reporting zone was over four times that of the Semi-arid Prairies reporting zone. The mean Century model–derived factor for the Semi-arid Prairies reporting zone was similar to the factor derived from the field experiments.

Table A3–40 Generalized Values of Parameters for $F_{LMC}(t) = \Delta C_{LMCmax} \times [1 - \exp^{(-k \times t)}]$ to Predict Change from Land Management Change (LMC) and Effective Linear Coefficients of SOC Change

Zone[1]	LMC[2]	k/year	ΔC_{LMCmax} (Mg/ha)	Final Year of Effect after LMC[3]	Mean Annual Linear Coefficient over Duration of Effect of LMC (Mg/ha per year)	Mean Annual Linear Coefficient over First 20 years after LMC (Mg/ha per year)
East Atlantic	IT to NT	0.0216	3.5	52	0.05	0.06
	IT to RT	0.0251	2.4	36	0.04	0.05
	RT to NT	0.0233	1.1	1	0.03	0
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0217	43.4	167	0.25	0.77
East Central	IT to NT	0.025	5	65	0.06	0.1
	IT to RT	0.0261	1.9	25	0.04	0.04
	RT to NT	0.0255	3.2	46	0.05	0.06
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0247	38.2	147	0.25	0.74
Parkland	IT to NT	0.0286	6.5	70	0.08	0.14
	IT to RT	0.0242	2.8	41	0.04	0.05
	RT to NT	0.0263	3.7	51	0.05	0.07
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0233	29.4	142	0.2	0.55
Semi-arid Prairies	IT to NT	0.0261	4.9	63	0.06	0.1
	IT to RT	0.0188	2.3	30	0.03	0.04
	RT to NT	0.0222	2.5	37	0.04	0.05
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0281	26.1	120	0.21	0.56
West	IT to NT	0.0122	4.8	69	0.04	0.05
	IT to RT	0.0116	0.8	0	0	0
	RT to NT	0.0119	3.9	53	0.03	0.04
	Decrease fallow	0.0305	13.1	91	0.14	0.3
	Increase perennial	0.0155	34.4	198	0.17	0.46

Notes:

1. Area-weighted summary: East Atlantic is the Atlantic Maritime reporting zone plus the Boreal Shield reporting zone in Newfoundland and Labrador; East Central is the Mixedwood Plains reporting zone plus the Boreal Shield East reporting zone in Ontario and Quebec; Parkland is the Subhumid Prairies, Boreal Shield West and Boreal Plains reporting zones plus those parts of the Montane Cordillera reporting zone with agricultural activity contiguous to agricultural activity within the rest of the Parkland zone; and West is the Pacific Maritime reporting zone plus the Montane Cordillera reporting zone excepting that portion of the latter that is included in the Parkland zone as described above.
2. For LMCs in the opposite direction to that listed, the FLMCmax will be the negative of the value listed.
3. No further C change once the absolute value of the rate of change is less than 25 kg C/ha per year.

However, the Century-derived IT-NT factor for the Subhumid Prairies reporting zone was about 30% lower than the factor derived from the field experiments.

When considering the switch from annual to perennial cropping, the mean empirical factor was 0.59 Mg C/ha per year, and this compared favourably with the range of 0.46–0.56 Mg SOC/ha per year in the modelled factors in the Parkland, Semi-arid Prairies and West reporting zones (Table A3–40). In eastern Canada, only two empirical change factors were available in the East Central reporting zone, but they appeared to be in line with the modelled values (0.60–1.07 Mg SOC/ha per year empirical versus 0.74–0.77 Mg C/ha per year modelled).

For conversion of crop fallow to continuous cropping, the rate of C storage was more than double the average rate of 0.15 ± 0.06 Mg/ha per year derived from two independent assessments of the literature. This difference led to the decision to use empirically based factors for changes in summerfallow in the inventory.

Estimates of Change in Soil Carbon Stocks

SOC changes as a result of LMC were reported for 1990–2012. Because the effect of LMCs declines over time, a vintage or time when change was deemed to have occurred is maintained for each LMC. The C change factor was multiplied by the area of LMC and summed across soil components to produce an estimate of SOC change for the SLC polygon. This is the smallest georeferenced unit of SOC stocks and SOC stock changes, with accounting using an IPCC Tier 2 approach as follows:

Equation A3–57:

$$\Delta C_{LMC} = \sum_{1951-2012} \sum_{ALLSLC} (\Delta C_{TILL} + \Delta C_{SF} + \Delta C_{CROPPING})$$

where:

ΔC_{LMC} = change in SOC stocks due to LMC for a specific year since 1951

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 A3–20 provides a schematic of the method for C accounting.

Data Sources

Carbon stock change estimates rely on C factors and a time series of land management data in the *Census of Agriculture*. There are two types of data used for either deriving C factors (modelling) or computing the actual estimates of C stock change. The data mainly used for modelling C factors include SLC, crop-tillage systems derived from the *Census of Agriculture*, and crop yields, climate data and activity data from other surveys and databases. The land management practices from the *Census of Agriculture* are mainly used for estimating annual C stock changes.

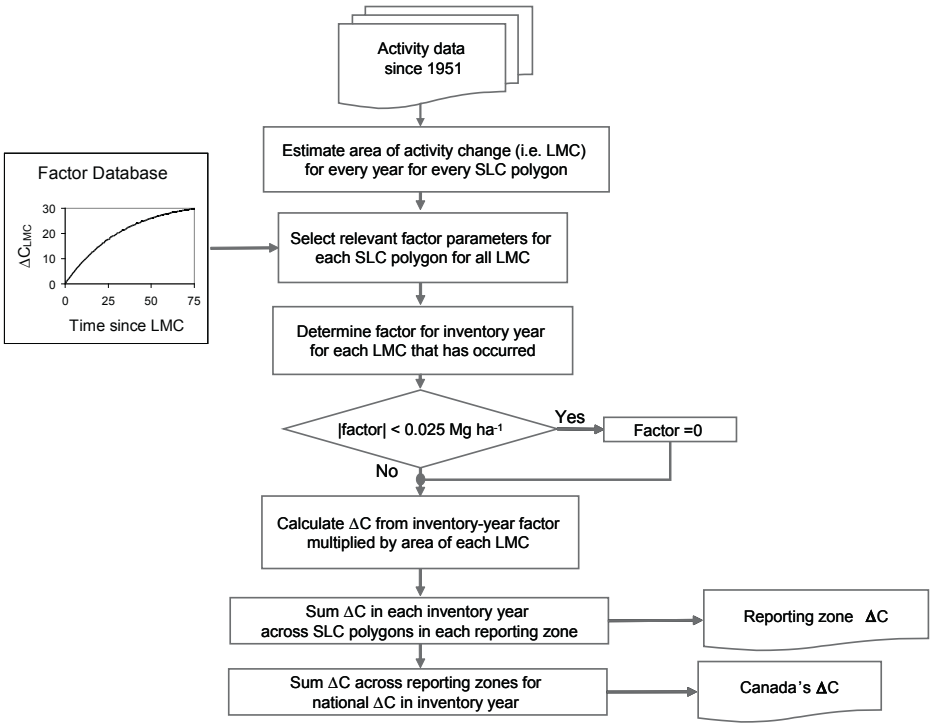
Land Information and Activity

The SLC is a national-scale spatial database describing the types of soils associated with landforms, displayed as polygons at an intended scale of representation of 1:1 million.[14] The SLC Version 3.0 was chosen for the LULUCF inventory because of its national scope and standardized structure that ensure that all areas of the country are treated in a consistent manner with regard to inventory assessment procedures. In addition, 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 for modelling C factors with Century. The SLC polygon provides the spatial basis for allocating land management practices such as tillage practices and cropping systems from the *Census of Agriculture* and Cropland converted from Forest and Grassland to modelled C factors.

14 Available online at http://sis.agr.gc.ca/cansis/nsdb/slc/v1/intro.html

Figure A3–20 Method of Using Factors for Land Management Change to Estimate Carbon Change over Large Areas



Analysis Units

There are 3264 SLC polygons that have agricultural activities. Since the SLC polygons have several soil landscape components, the finest spatial resolution for analysis of agricultural activities is 11 530 unique combinations of soil landscape components within SLC polygons. These unique combinations represent the basic analysis units. The location of land management and soil components is not spatially explicit but rather spatially referenced to SLC polygons.

A procedure was developed to assign agricultural activities to the SLC based on the suitability of each component of a soil polygon. The soil components have different inherent properties that make them more or less likely to have different types of agricultural activities. Each soil component within the SLC attribute file has a suitability rating of high, moderate or low in terms of its likelihood of being under annual crop production. Annual crop production is linked to those components with a high rating. If there was insufficient area with high likelihood of being under annual cropland for area of annual crops, the remaining annual crop production was linked to components with moderate likelihood of being under annual crop production and, if required, to low-ranked components. After linking the annual crop production area, perennial forages and seeded pasture area were linked to the remaining components in the same manner, starting with components with the highest likelihood of being in annual crops and ending with components with the lowest likelihood of being cropped.

Crop Yields

Crop yields at an ecodistrict level were developed from Statistics Canada surveys. Statistics Canada conducts annual surveys of up to 31 000 farmers, stratified by region, to compile estimates of the area, yield, production and stocks of the principal field crops grown in Canada. Eight publications are released at strategic points in the crop year; the first area report contains the planting intentions of producers, whereas the June estimates are made after most of the seeding has been completed. Yields and levels of production by province are estimated twice, based on expectations to the end of harvest, whereas the November estimate is released after the harvest. The data are released at the Census Agricultural Region level, providing crop yields for approximately 70 spatial units in the country. Census Agricultural Region boundaries were overlaid on SLC boundaries in a GIS, and a yield value for each crop in each soil polygon was assigned based on majority proportion. Data used for accounting included 1975–2004 yield data for wheat, barley, oats, corn, soybeans, potatoes and canola. These yields were used to calibrate the Century crop growth submodel.

Climatic Data

There are 958 weather stations in the weather database archived by Agriculture and Agri-Food Canada (AAFC). Long-term normals of monthly maximum and minimum temperatures (°C) and precipitation (mm) from 1951 to 2001 for all ecodistricts were used for modelling C factors. AAFC-archived weather data were provided by the Meteorological Service of Canada, Environment Canada.

Census of Agriculture

Activity data for accounting in cropland remaining cropland rely mainly on data from the Census of Agriculture. The smallest area for which Statistics Canada will release data externally for confidentiality reasons is the Dissemination/Enumeration Area level (approximately 52 000 in Canada). Agriculture and Agri-Food Canada has reconfigured census data for 1981, 1986, 1991, 1996, 2001, 2006 and 2011 from Dissemination Area units to SLC polygons and higher-level ecostratification units using a procedure involving geographic overlays of the relevant boundary files.

Data on tillage practices were taken from the census according to the following categories: 1) IT—tillage that incorporates most of the crop residue into the soil, 2) RT—tillage that retains most of the crop residue on the surface, and 3) NT—no-till seeding or zero-till seeding. For summerfallow, the following tillage categories were used: 1) NT—the area on which chemicals only were used for weed control, 2) IT—the area on which tillage only was used, and 3) RT—the area on which a combination of tillage and chemicals was used. There are two limitations of the census data pertaining to tillage practices that resulted in uncertainties: 1) Statistics Canada and expert opinion indicate that the conservation tillage tends to be underestimated, and 2) tillage distributions as reported for a region must be applied equally to all crops within that region.

Uncertainty

The derivation of uncertainties about estimates of CO_2 emissions or removals requires estimates of uncertainties for LMC areas and C factors of management changes for fallow, tillage and annual/perennial crops (McConkey et al. 2007b).

The uncertainty of area of change was determined for ecodistricts (one level of spatial aggregation above SLC). The average area of agricultural land within an ecodistrict is about 140 kha, i.e., sufficiently large that the areas of different management practice were considered independent of those in others, including adjacent ecodistricts. Errors in the areas of management practices in each ecodistrict were assumed to represent inherent uncertainty that was unaffected by the uncertainty of those in other ecodistricts. Further, the ecodistrict area is sufficiently large that a null report of an activity can be assumed to mean that activity is not occurring within the ecodistrict. Therefore, area

uncertainty can be more reliable considered in relative terms for an ecodistrict than for an SLC polygon.

The uncertainty of the area in a management practice at any time for an average ecodistrict was based on the relative proportion of the area of that management practice in that ecodistrict. The relative uncertainty of the area of management practice expressed as standard deviation of an assumed normal population decreased from 10% of the area to 1.25% of the area as the relative area of that practice increased.[15]

The uncertainties associated with C change factors for fallow, tillage and annual/perennial crops were assumed to arise from two main influences: 1) process uncertainty in C change due to inaccuracies in predicting C change even if the situation of the management practice were to be defined perfectly, and 2) situational uncertainty in C change due to variation in the situation of the management practice.

Process uncertainty includes the effect of uncertainty in the model. This includes the uncertainty in the model predictions from uncertain model parameters and from inaccurate and/or incomplete representation of all relevant processes by the model. Where empirical data are used, process uncertainty includes inadequacies in measurement techniques, analysis error, poor representativeness of measurements, and/or components of C change not measured. To estimate the process error, the variation from measured C change for controlled experiments was used. It was assumed that this represents the inherent uncertainty even when the situation is accurately described. Process uncertainty scaling coefficients for tillage and fallow were derived for Canada from VandenBygaart et al. (2003).

Situational uncertainty derives from the inability to accurately describe each situation. This includes the effect of interactions with past or concurrent changes to land use or land management, variability in the weather or soil properties, variability in crop management, and/or continuity of LMCs. The situational uncertainty scaling coefficients for fallow change, tillage change and annual-perennial crop change were estimated from the observed variability of Century-simulated C change for all the soil component-management-climate combinations within the reconciliation unit. There were many combinations of management within which C change was calculated. There was also a range of historical ecodistrict weather that was included in the Century simulations. The situational uncertainty also includes the additional variability of the regional factors introduced by the imposition of reversibility of C change. Average situational uncertainty scaling coefficients were derived for Canada (McConkey et al. 2007b).

Although process and situational uncertainty are expected to interact, given the complexity of the large number of possible interactions between deviations due to process uncertainty and those due to situation uncertainty, it is infeasible to describe their relationship. Hence, it was assumed that the total deviation in total C change was the sum of the deviation from process and situational uncertainty. Details of uncertainty estimate development are provided in McConkey et al. (2007b). Results are provided in Chapter 7.

CO_2 Emissions from Agricultural Lime Application

Limestone (C_aCO_3) and dolomite ($CaMg(CO_3)_2$) are often used to neutralize acidic soils; increase the availability of soil nutrients, in particular phosphorus; reduce the toxicity of heavy metals; and improve the crop growth environment. During this neutralization process, CO_2 is released in bicarbonate equilibrium reactions that take place in the soil.

The rate of release varies with soil conditions and the types of compounds applied. In most cases lime is applied repeatedly. Thus, for the purposes of the inventory, it is assumed that the annual rate of lime is in near equilibrium with the consumption of lime in previous years. Emissions associated with lime application are calculated from the amount and composition of the lime applied annually.

The amount of C released as a result of limestone application is calculated using the default IPCC Tier 1 approach (IPCC 2003):

Equation A3–58:

$$C = \sum (A_i \times 12/100)$$

where:

A_i	=	annual limestone consumption in province i, Mg/year
12/100	=	ratio of molecular weight of C to molecular weight of limestone

Similarly, the amount of C released as a result of dolomite application is calculated as

Equation A3–59:

$$C = \sum (A_i \times 24/184.3)$$

where:

Ai	=	annual consumption of dolomitic lime in province i, Mg/year
24/184.3	=	ratio of molecular weight of 2C to molecular weight of dolomite

15 Huffman T. (Agriculture and Agri-Food Canada). 2006. Personal communication to B.G. McConkey (Agriculture and Agri-Food Canada)

There is no single source of data for lime application on agricultural soils. The quantity of lime used for agricultural purposes is not collected by Statistics Canada. Lime usage data were retrieved from western Canada, Atlantic, Ontario and Quebec fertilizer associations.

Uncertainty

The 95% confidence limits associated with annual lime consumption data were estimated to be ±50%.[16] This uncertainty was assumed to include the uncertainty of lime sales, uncertainty in proportion of dolomite to calcite, uncertainty of when lime sold is actually applied, and uncertainty in the timing of emissions from applied lime. The uncertainty in the emission factor was not considered because the chemical conversion is deemed complete, and the maximum value of the emission factor was used.

CO_2 Emissions and Removals from Woody Biomass

Vineyards, fruit orchards and Christmas tree farms are intensively managed for sustained yields. Vineyards are pruned each year, leaving only the trunk and one-year-old stems. Similarly, fruit trees are pruned annually to maintain the desired canopy shape and size. Old plants are replaced on a rotating basis for disease prevention, stock improvement or introduction of new varieties. Typically, Christmas trees are harvested at about 10 years of age. For all three crops, it was assumed that, because of these rotating practices and the requirements for sustained yield, a uniform age-class distribution is generally found on production farms. Hence, there would be no net increase or decrease in biomass C within existing farms, as C lost from harvest or replacement would be balanced by gains due to new plant growth. The approach was therefore limited to detecting changes in areas under vineyards, fruit orchards and Christmas tree plantations and estimating the corresponding C stock changes in total biomass.

There are no Canadian studies on the above-ground or below-ground C dynamics of vineyards or fruit trees. However, results from other studies are considered valid inasmuch as varieties, field production techniques and even root stocks are often the same. Canadian literature on Christmas tree plantations is used whenever suitable.

On average, vines are replaced at 28 years of age; the average vine is therefore 14 years old (Mailvaganam 2002). Because of intensive pruning, the biomass of shoots and leaves is set at the constant value of 4 Mg/ha, whereas linear rates of above ground and below-ground biomass accumulation in trunks and roots were 0.4 and 0.3 Mg/ha per year, respectively (Nendel and Kersebaum 2004). These were converted to C values using a 50% C content in biomass. Upon a decrease in vineyard areas, an instantaneous loss of 6.9 Mg C/ha is assumed, equal to the average standing biomass for 14-year-old vines (McConkey et al. 2007a).

Because of different standard planting densities, the 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 12-year growth period at 1.6 Mg C/ha per year. The same rate, multiplied by a root: shoot ratio of 0.40 (Bartelink 1998), was used to estimate C sequestration in below-ground biomass. It was assumed that, on new orchard areas, trees accumulate biomass at a linear rate for 10 years (the average tree age on a plantation). Instantaneous C loss upon a decrease of orchards was equal to 50% of the total biomass of a 10-year-old tree (22.4 Mg C/ha).

Christmas trees are marketed at about 10 years of age (McConkey et al. 2007a). Wood accounts for approximately 70% of Christmas tree biomass, and fresh wood has a moisture content of 60~80%. With typical spacing and an expected market mass of 10 kg per tree, a plantation of marketable trees is estimated to have an above-ground biomass density of 17.1 Mg/ha. With a root: shoot ratio of 0.3 (Bartelink 1998; Litton et al. 2003; Xiao and Ceulemans 2004), the total C biomass of a marketable tree plantation is estimated at 11.1 Mg C/ha. Carbon sequestration in biomass of new Christmas tree plantations is calculated for five years at rates of 0.85 and 0.26 Mg C/ha for above-ground and below-ground biomass, respectively. A decrease of plantation area would result in the immediate loss of 5.6 Mg C/ha.

Uncertainty

Poorly growing plants are regularly removed and replaced. Frequently, fruit trees and vineyards are irrigated to maintain desired growth during dry periods. Consequently, the variability in C stock changes should be less than that for other agricultural activities.

For loss of area, all C in woody biomass is assumed to be immediately released. There are no Canadian-specific data on this uncertainty. Therefore, the default uncertainty of ±75% for woody biomass on Cropland from the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003) was used. If the loss in area of fruit trees, vineyards or Christmas trees is estimated to have gone to annual crops, there is also a deemed perennial to annual crop conversion with associated C change uncertainty that contributes to C change uncertainty for a reporting zone.

Cultivation of Organic Soils

Cultivation of histosols for annual crop production usually involves drainage, tillage and fertilization. All these practices

16 McConkey BG. (Agriculture and Agri-Food Canada). 2007. Personal communication to Chang Liang (Environment Canada).

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 A3–60:

$$C = \sum (A_i \times EF)$$

where:

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% (Hutchinson et al. 2007). The 95% confidence limits of the emission factor provided in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) is ±90%.

A3.4.3.2. Grassland Converted to Cropland

Conversion of native grassland to cropland generally results in losses of SOC and soil organic nitrogen (SON) and in turn leads to emissions of CO_2 and N_2O to the atmosphere. Carbon changes from the above-ground or below-ground biomass or dead organic matter upon conversion are generally insignificant based on findings from a recent work by Bailey and Liang (2013) on burning of managed grassland in Canada: they 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 these results are summarized by McConkey et al. (2007a).

Losses of Soil Organic Carbon

The average loss of SOC based on field observations was 22% (McConkey et al. 2007a). Many of the studies involved comparisons within 30 years of breaking, whereas others were 70 or more years from breaking. Since many of these studies did not specify the period since breaking, it is assumed that the 22% SOC loss would refer to about 50–60 years after breaking.

The SOC dynamics from breaking of grassland to cropland for the Brown and Dark Brown Chernozemic soils (Figure A3–21) 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:

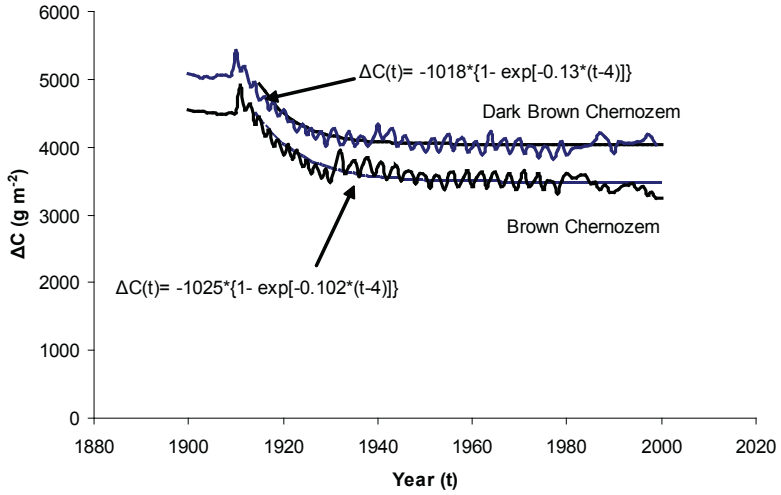
Equation A3–61:

$$\Delta C(t) = \Delta C_{Bmax} \times \left[1 - exp^{(-k[t - t_{lag}])}\right]$$

where:

$\Delta C(t)$	=	change in SOC for the t^{th} 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
t	=	time since breaking of grassland, years
t_{lag}	=	time lag before ΔC becomes negative, years

Figure A3–21 Century-simulated SOC Dynamics after Breaking of Grassland to Cropland for the Brown and Dark Brown Chernozemic Soils



Assuming that the 22% loss at about 50–60 years after initial breaking represents the total loss, the ΔSOC_{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 A3–62:

$$\Delta C(t) = 0.28 \times SOC_{agric} \times \left[1 - exp^{(-0.12 \times t)}\right]$$

where:

ΔC(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 A3–63:

$$\Delta C_{GLCL} = \sum_{1951-2012} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{GLCL})$$

where:

ΔC_{GLCL}	=	losses of SOC in 2012 due to conversion of grassland to cropland since 1951, Mg C
ALL SLC	=	all soil polygons that contain grassland
t	=	time after grassland conversion, years
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 A3–64:

$$N_2O_{GLCL} = \sum_{1951-2012} \sum_{ALLSLC} \sum_{t} (\Delta C_{GLCL} \times AREA_{GLCL}) \times 0.06 \times EF_{BASE} \times \frac{44}{28}$$

where:

N_2O_{GLCL}	=	emissions of N_2O in 2012 due to the conversion of grassland to cropland since 1951, kt
ALL SLC	=	all soil polygons that contain grassland
t	=	time after grassland conversion, years
ΔC_{GLCL}	=	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
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 A3.3.6)
0.06	=	ratio of ON to OC losses
44/28	=	coefficient converting N_2O-N to N_2O

Data Sources

The area of Grassland remaining Grassland (GLGL) in 2000 was estimated using Land Cover (Circa 2000),[17] and grassland areas for the entire time series are reconciled with area estimates of Grassland converted to Cropland (GLCL) back to 1990 and onward.

Within an SLC, GLGL was allocated to soil components identified as "low" for "likelihood of being cropped." Once allocated to SLC polygons, area totals for GLGL were aggregated to an ecodistrict or reconciliation unit level as required in each year from 1990.

Uncertainty

The conversion from the agricultural Grassland category to the Cropland category occurs, but the conversion in the other direction 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).

17 Land Cover (Circa 2000): http://www.geobase.ca/geobase/en/data/landcover/csc2000v/description.html;jsessionid=035AD079A457BC69D3022E02DDCACBE0

A3.4.3.3. Forest Converted to Cropland

CO_2 and N_2O Emissions from Soils

Clearing forest to increase agricultural land is a declining but still significant practice in Canada. This section describes the methodology for estimating CO_2 and N_2O emissions associated with the soil disturbance. The method for estimating emissions from biomass upon conversion is presented in Section A3.4.2.3. For SOC change, there is a need to differentiate between the eastern and the western parts of the country.

Eastern Canada

There are many observations that compare SOC for land under forest with adjacent land under agriculture in eastern Canada. The mean loss of C was 20.3% for a depth of approximately 30 cm (McConkey et al. 2007a). This value is comparable with the soil database in CanSIS (Table A3–41), indicating that, on average, SOC for the uppermost 30 cm of soil under agriculture was 20.5% less than under forest.

Although the SOC for forested land in Table A3–41 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, and Figure A3–22 shows an example of such dynamics. In the first years after the conversion, there is an increase in soil organic matter, as litter and aboveground and below-ground DOM become part of SOC. After a few years, SOC declines below the amount of SOC that existed before forest conversion. The rate of SOC decline gradually decreases with time.

The following equation was fit to the Century results in Figure A3–19, neglecting the initial SOC increase:

Equation A3–65:

$$\Delta C(t) = \Delta C_{Dmax} \times \left[1 - exp^{(-k \times [t - t_{lag}])}\right]$$

where:

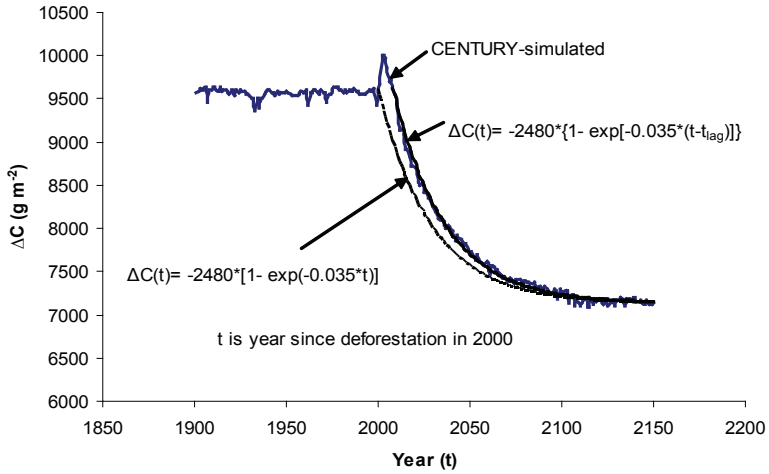
$\Delta C(t)$	=	change in SOC for the t^{th} year after conversion, Mg C/ha
ΔC_{Dmax}	=	ultimate change in SOC from forest conversion to agriculture, Mg C/ha
k	=	rate constant for describing the decomposition /$year^{-1}$
t	=	time since land conversion, years
t_{lag}	=	time lag before ΔC becomes negative, years

Table A3–41 Soil Organic C for Forested and Agricultural Land in Eastern and Western Canada from the Canadian Soil Information System Database (0- to 30-cm soil depth)

Soil Texture	Soil Organic Carbon (Mg C/ha)		Difference (%)
	Forested Land[1]	Cropland[1]	
Eastern Canada			
Coarse	85 (26)	68 (42)	-20
Medium	99 (38)	77 (35)	-22
Fine	99 (58)	78 (36)	-21
Western Canada			
Coarse	73 (39)	74 (38)	0
Medium	66 (30)	73 (30)	4
Fine	74 (38)	77 (25)	1

Note:
1. Standard deviation in parentheses.

Figure A3–22 Century-simulated Soil Organic Carbon Following Conversion of Long-term Deciduous Forest to Cropland



For the example shown in Figure A3–22, 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 A3–19) 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 about 100 years after forest conversion; the ΔC_{Dmax} is therefore 1/0.927 times this value, or 22.1% of SOC under long-term forest. As the CanSIS soil database has more data on SOC for conditions under long term cropland than on SOC under long-term forest in areas where cropland exists, the maximal SOC losses were calculated relative to stabilized cropland SOC (i.e. loss = 0.221/(1−0.221) × SOC or loss = 0.284 × SOC under agriculture). Therefore, the final equation for estimating SOC loss for forest conversion to cropland in eastern Canada is:

Equation A3–66:

$$\Delta C(t) = 0.284 \times SOC_{agric} \times \left[1 - exp^{(-0.0262 \times t)}\right]$$

where:

ΔC(t)	=	change in SOC for the t^{th} year after conversion, Mg C/ha
SOC_{agric}	=	0- to 30-cm SOC from CanSIS for a cropland soil profile, Mg C/ha
-0.0262	=	rate constant for describing the decomposition /$year^{-1}$
t	=	time since conversion, years

Thus, the total amount of SOC lost from forest land converted to cropland is estimated using the following equation:

Equation A3–67:

$$\Delta C_{FLCL} = \sum_{1970-2012} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL})$$

where:

ΔC_{FLCL}	=	total SOC loss in 2012 from the conversion of forest land to cropland since 1970, Mg C/ha
t	=	time after the conversion, year
ALL SLC	=	all soil polygons that contain forest land converted to cropland
ΔC_t	=	change in SOC for the t^{th} year after conversion, Mg C/ha (See Equation A3–66)
$AREA_{FLCL}$	=	area of forest land converted to cropland annually since 1970, ha

Note that the SOC loss predicted by Equation A3–67 is in addition to C stock changes in tree biomass and woody DOM that existed in the forest at the time of forest conversion.

Based on the field observations, average N change in eastern Canada was -5.2%, representing 0.4 Mg N/ha (McConkey et al. 2007a). For those comparisons where both N and C losses were determined, the corresponding C loss was 19.9 Mg C/ha, and carbon loss was 50 times N loss. For simplicity, it was assumed that N loss was a constant 2% of C loss. Thus, N_2O emissions from forest land converted to cropland are estimated using the following equation:

Equation A3–68:

$$N_2O_{FLCL} = \sum_{1970\text{-}2012} \sum_{ALLSLC} \sum_{t} (\Delta C_t \times AREA_{FLCL}) \times 0.02 \times EF_{BASE} \times \frac{44}{28}$$

where:

N_2O_{FLCL}	=	emissions of N_2O subject to conversion of forest to cropland since 1970, kt
ALL SLC	=	all soil polygons that contain forest land conversion
ΔC_t	=	change in SOC for the t^{th} 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 A3.3.6)
44/28	=	coefficient converting N_2O-N to N_2O

Western Canada

Much of the current agricultural soil in western Canada was grassland prior to cultivation. Hence, forest conversion has been primarily of forest that adjoins grassland areas. There is also limited conversion of secondary forest that has grown on former grassland since the suppression of wildfires with agricultural development. Historically, forest conversion has been less important in western Canada than in eastern Canada, and fewer comparisons of SOC under forest and agriculture are available in the literature. Ellert and Bettany (1995) reported that there was no difference in SOC between native aspen forest and long term pasture that remained uncultivated since clearing for an Orthic Gray Luvisol near Star City, Saskatchewan.

The CanSIS data provide numerous comparisons of SOC under forest with that under cropland (Table A3–41). On average, these data indicate that there is no loss of SOC from forest conversion. This suggests that, in the long term, the balance between C input and SOC mineralization remains similar under agriculture to what it was under forest. It is important to recognize that the northern fringe of western Canadian agricultural areas, where most forest conversion is now occurring, is marginal for annual crops, and pasture and forage crops are the primary agricultural uses after clearing. In general, loss of C from forest to agriculture is least where agricultural land contains forages and pastures.

For western Canada, no loss of SOC over the long term was assumed from forest conversion to pasture and forage crops. Therefore, the C loss from land conversion in western Canada would be from losses of C in above- and below-ground tree biomass and coarse woody DOM that existed in the forest at the time of conversion. Similarly, average organic nitrogen change in western Canada for sites at least 50 years from breaking was +52% (McConkey et al. 2007a), reflecting substantial added N in agricultural systems compared with forests. However, recognizing the uncertainty about actual soil C–N dynamics upon conversion, forest land converted to cropland was assumed not to be a source of N_2O from the soil pool. N_2O emissions are reported wherever biomass burning occurs during conversion (see Section A3.4.2.1).

Data Sources

The approach used to estimate the area of forest land converted to cropland is described in Section A3.4.2.2. The annual forest conversion by reconciliation unit was disaggregated to SLC polygons on the basis of concurrent changes in the area of cropland within SLC polygons. Only polygons that showed an increase in cropland area for the appropriate time period were allocated to forest conversion, and the amount allocated was equivalent to that polygon's proportion of the total cropland increase within the reconciliation unit.

Uncertainty

The uncertainty of C change in each reporting zone was estimated differently for eastern and western Canada because of differences in C change estimation methods (McConkey et al. 2007b). For western Canada, an uncertainty of C change was estimated, although the mean value of SOC change factor was 0. The assumption was that the uncertainty of SOC change after forest land to cropland conversion in western Canada would follow a similar pattern as that for eastern Canada.

A3.4.4. Grassland

Land in the agricultural Grassland category is defined as "unimproved pasture" used for grazing domestic livestock, but only in geographical areas where grassland would not naturally grow into forest if abandoned: southern Saskatchewan and Alberta and a small area of southern British Columbia. These grasslands developed under millennia of grazing by large animals such as bison and periodic burning. Essentially, "agricultural Grassland" is 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 CH_4 and N_2O emissions from natural or prescribed fires on agricultural grassland in Canada, are presented in the following section.

A3.4.4.1. Grassland Remaining Grassland

The IPCC (2003) approach, which guided the development of the CO_2 estimate methodology, 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 A3–69:

$$SOC = SOC_{REF} \bullet F_{MG} \bullet F_I$$

where:

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 A3–70:

$$A_{2012} = GLGL_{1990} - \sum_{1990}^{2012} GLCL$$

where:

A_{2012}	=	the total area of grassland remaining grassland in 2012, 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 A3–71:

$$\Delta C_{GGMineral} = [(SOC_0 - SOC_{0\text{-}T}) \times A]/T$$

where:

$\Delta C_{GGMineral}$	=	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, yr (default 20 yr)

If no change in management practices or input occurs, the C stocks are assumed to be at equilibrium, and hence the change in C stocks is deemed zero.

There are a number of studies of the effects of grazing versus no grazing on SOC. Although the productivity of heavily grazed pasture is lower, which may lead to a decline in range conditions, this was not related to declines in SOC (Biondini and Manske 1996). The effect of grazing regime is complex, because of the effects of grazing on plant community and effects on C input to soil from both above- and below-ground plant growth (Schuman et al. 2002; Liebig et al. 2005). An additional influence of grazing regime is the increased return of C in fecal matter as stocking rate increases (Baron et al. 2002). Bruce et al. (1999) estimated that there was no opportunity to increase SOC from grazing management improvements on extensively managed rangeland in North America.

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 (IPCC 1997).

Equation A3–72:

$$EMISSION_{BURN} = \sum (AREA_i \times FUELLOAD_i \times C_{F,i} \times G_{EF}) / 1000$$

where:

$EMISSION_{BURN}$	=	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

Data sources for Grassland remaining Grassland are the same as A3.4.3.2 – Grassland converted to Cropland. 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).

A3.4.5. Wetlands

A3.4.5.1. Peatlands

Approximately 14 kha of peatlands are currently managed in Canada for the production of horticultural peat. The cumulative area of peatlands ever managed for this purpose amounts to 26 kha, the difference being peatlands that are no longer under production. The production consists of horticultural peat only; Canada does not produce peat for use as a fuel.

Virtually all peat extraction in Canada relies on the vacuum harvest technology. However, many abandoned peat extraction fields were once exploited with the cut-block method; this influences the post-abandonment dynamics of vegetation regrowth.

Owing to the extraction technology and desired properties of sphagnum peat, at the time of site selection, preference is given, among other factors, to open bog peatlands, which are classified as "other land" for the purpose of GHG reporting. On average, 5% of pre-conversion area meets the inventory definition of "forest land."

General Approach and Methods

Only CO_2 emissions from land converted to wetlands (peatlands) and peatlands remaining peatlands were estimated. The estimation included the following sources: vegetation clearing and subsequent decomposition, decay of soil organic matter on sites drained during the inventory year and from fields under production, peat stockpiles, abandoned peat fields, and restored peatlands. In any inventory year, emissions from land converted for peat extraction are expressed by Equation A3–73:

Equation A3–73:

$$CO_2 - C_{L\_Peat} = CO_2\text{-}C_{BIOMASS} + CO_2\text{-}C_{DOMresidual} + CO_2\text{-}C_{SOILSdrained} + CO_2\text{-}C_{SOILSextraction} + CO_2\text{-}C_{SOILS\ stockpiled}$$

where:

CO_2-C_{L_Peat}	=	total carbon emissions as CO_2 from land converted to wetlands (for peat extraction)
CO_2-$C_{BIOMASS}$	=	carbon emissions as CO_2 from the loss of carbon to forest products upon forest clearing
CO_2-$C_{DOM\ residual}$	=	carbon emissions as CO_2 from the decay of vegetation cleared no more than 20 years prior to the inventory year
CO_2-$C_{SOILS\ drained}$	=	carbon emissions as CO_2 from the oxidation of soil organic matter on peatland drained during the inventory year
CO_2-$C_{SOILS\ extraction}$	=	carbon emissions as CO_2 from the oxidation of soil organic matter on productive peatlands converted for no more than 20 years
CO_2-$C_{SOILS\ stockpiles}$	=	carbon emissions as CO_2 from the oxidation of stockpiled peat on productive peatlands converted for no more than 20 years

Preconversion biomass (or biomass cleared) is estimated at an average of 20 t C/ha and 2.8 t C.ha for forest land and other land, respectively. Upon clearing, all forest biomass carbon is transferred to forest products (estimated at 63% of biomass, which is considered emitted to the atmosphere as CO_2 in the year of harvest) or DOM; the latter begins to decay in the same year, following an exponential decay curve as expressed in Equation A3–74.

A3

Equation A3–74:

$$C_{DOM(t)} = C_{DOM(0)}\, e^{-kt}$$

where:

$C_{DOM(t)}$	=	amount of C in DOM for the t^{th} year after conversion, Mg C/ha
$C_{DOM(0)}$	=	initial amount of C in DOM from land conversion to peat extraction, Mg C/ha
k	=	rate constant for describing the decomposition, $year^{-1}$
t	=	time since land conversion, years

On wetlands remaining wetlands (peatlands), emissions are expressed as in Equation A3–75:

Equation A3–75:

$$CO_2 - C_{Peat} = CO_2\text{-}C_{DOMresidual} + CO_2\text{-}C_{SOILSextraction} + CO_2\text{-}C_{SOILSstockpile} + CO_2\text{-}C_{SOILSabandoned} + CO_2\text{-}C_{SOILSrestored}$$

where:

CO_2-C_{Peat}	=	total carbon emissions as CO_2 from wetlands remaining wetlands (peatlands)
CO_2-$C_{DOM\ residual}$	=	carbon emissions as CO_2 from the decay of biomass cleared more than 20 years ago
CO_2-$C_{SOILS\ extraction}$	=	carbon emissions as CO_2 from the oxidation of soil organic matter on peatlands converted for more than 20 years
CO_2-$C_{SOILS\ stockpiles}$	=	carbon emissions as CO_2 from the oxidation of stockpiled peat on peatlands converted for more than 20 years
CO_2-$C_{SOILS\ abandoned}$	=	carbon emissions/removals as CO_2 resulting from the net ecosystem production on abandoned peatlands
CO_2-$C_{SOILS\ restored}$	=	carbon emissions/removals as CO_2 resulting from the net ecosystem production on restored peatlands

Soil emissions from a productive peat field, "CO_2-$C_{SOILS\ extraction}$," are estimated with a single emission factor reflecting peat oxidation rates. Emissions from peat stockpiles are calculated as an exponential decay for half a year.

Abandoned peat fields remain a persistent source of atmospheric CO_2 (Waddington and McNeil 2002) until carbon uptake by regrowing vegetation exceeds soil and residual DOM decay. In the current model, the emission factor on abandoned fields is reduced by a fixed annual amount to reflect the effect of gradual vegetation establishment and the slow decrease of emissions over several decades.

Current restoration practices consist of blocking drainage ditches, sowing the field with fresh moss spores and spreading a layer of straw on abandoned peat fields (to prevent desiccation). In the initial years of restoration, straw decomposition may further increase CO_2 emissions until vegetation re-establishes. Net carbon sequestration on restored peat fields is assumed to occur after five years, and its rate is subsequently maintained constant.

It is assumed that the non-growing season is six months long. In that period, emissions represent 15% of the annual total ecosystem CO_2 respiration, and gross primary production is zero. Table A3–42 lists the main parameter values applied in estimate development.

Data Sources

Little information on the area of peat production in Canada is available. The Canadian Sphagnum Peat Moss Association confirmed that 14 kha were under production in 2004 (derived from Cleary 2003), having increased by approximately 76% since 1990; at that point in time, a total of 18 kha were either active or decommissioned.[18] Areas under production in the intervening years were estimated with simple linear regressions fitted to the general trends in total domestic peat production (NRCan 2008). The annual area drained for peat extraction was assumed to be equal to the difference in total production areas between successive years, minus abandoned and restored peatlands. With the vacuum harvest technology, the average lifetime of a productive peat field is approximately 35 years (Cleary 2003). By default, land converted for more than 20 years is reported in the category Wetlands remaining wetlands.

Uncertainties

Emission factors were derived from flux measurements made mostly over abandoned peatlands, which introduces significant uncertainty when applied to actively managed peatlands, and peat stockpiles. All measurements were conducted in eastern Canada, adding uncertainties to estimates in western Canada.

A3.4.5.2. Flooded Lands

General Approach and Methods

Following the *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003), emissions from land converted to wetlands (creation of flooded lands, namely reservoirs) are

18 Hood G, president Canadian Sphagnum Peat Association. 2006. Personal communication dated December 15, 2006, to Dominique Blain, Environment Canada.

Table A3–42 Parameters and Emission Factors for Estimating CO_2-C Emissions from Wetlands (Peatlands)

Emission Factor/Parameter	Unit	Value
Forest land biomass cleared	t C/ha	20
Other land biomass cleared	t C/ha	2.8
Exponential decay constant, DOM		0.05
Emission factor on newly drained fields	g CO_2-C/m^2 per year	350
Emission factor on productive fields	g CO_2-C/m^2 per year	1000
Exponential decay constant, stockpiles		0.05
Annual decreas in emission factor, abandoned fields		
Vacum-harvested	g CO_2-C/m^2 per year	15
Block-cut	g CO_2-C/m^2 per year	35
Emission factor, restored peatlands		
First year	g CO_2-C/m^2 per year	1800
> Five years	g CO_2-C/m^2 per year	-84

estimated for all known reservoirs flooded for 10 years or less. Only CO_2 emissions are reported. An IPCC Tier 2 method was used, whereby country-specific CO_2 emission factors were developed based on measurements, as described below. Details can be found in Blain et al. (2007). It is believed that the default approach, assuming that all biomass carbon would be emitted upon flooding, would overestimate immediate 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 carbon pools are estimated as in all forest conversion events since 1970, with the CBM-CFS3 (see Section A3.4.2.1). Note that emissions from forest clearing for infrastructure development are reported under the category Forest converted to settlements.

In the absence of such evidence, it was assumed that all vegetation was simply flooded, leading to the emission—as CO_2—of a fraction of the submerged carbon from the surface of the reservoir. The proportion of the area flooded that was previously forested was used to attribute these emissions to either the Forest land converted to wetlands category or the Other land converted to wetlands category.

Since 1993, measurements of CO_2 fluxes have been made above some 57 hydroelectric reservoirs in four different provinces: Quebec, Manitoba, British Columbia, and Newfoundland and Labrador (Duchemin 2006). In most studies, the reservoirs were located in watersheds little affected by human activities, with the notable exception of Manitoba. In almost all cases, only diffusive fluxes of CO_2, CH_4 or N_2O (in order of frequency) were measured. Studies on ebullition, degassing emissions and winter emissions are rare and insufficient to support the development of domestic emission factors. Measurements of diffusive fluxes above the surface of reservoirs were compiled for the entire country. Out of these measured reservoirs, a subset of 25 was selected to develop a national emission curve for the 50-year period following impoundment. These measurements were selected based on the availability of documentation on measurement procedures and measurement comparability. The emission curve was developed from 25 reservoirs and a total of 33 measurements (Figure A3–23). It is important to note that each of these measurements (data points in Figure A3–23) 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 A3–76:

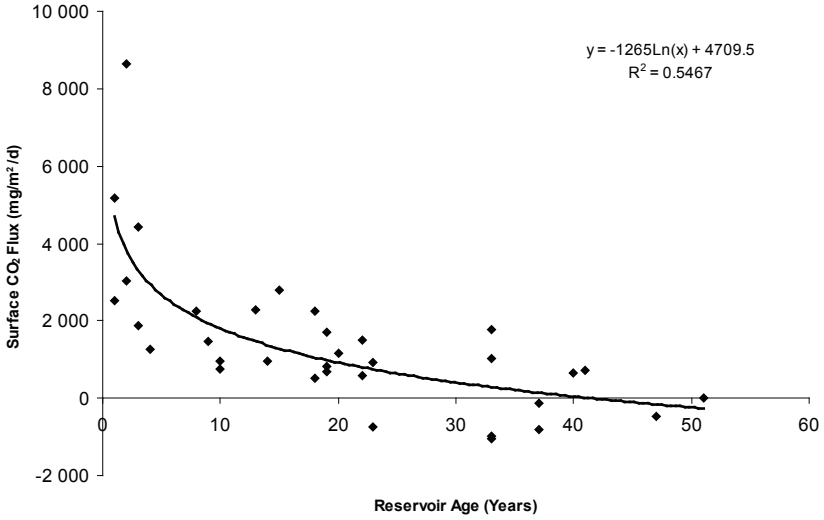
$$CO_{2\ rate\ L\_reservoir} = b_0 + b_1 \times In(t)$$

where:

$CO_{2\ rate\ L\_reservoir}$	=	rate of CO_2 emissions from land converted to wetlands (reservoirs), mg/m^2 per day
b_0, b_1	=	curve parameters, unitless
t	=	time since flooding, years

Total CO_2 emissions from the surface of reservoirs were estimated as the sum of all emissions from reservoirs flooded for 10 years or less:

Figure A3–23 Logarithmic Curve Fit for National Reservoir Emission Factors



Equation A3–77:

$$CO_{2\ L\_reservoirs} = \sum (CO_{2\ rate\ L\_reservoir} \times A_{reservoir} \times Days_{ice\ free} \times 10^{-8})$$

where:

$CO_{2\ L\_reservoirs}$	=	emissions from lands converted to flooded lands (reservoirs), Gg CO_2/year
$CO_{2\ rate\ L\_reservoir}$	=	rate of CO_2 emissions for each reservoir, mg/m^2 per day
$A_{reservoir}$	=	reservoir area, ha
$Days_{ice\ free}$	=	number of days without ice, days

$A_{reservoir}$ was used as the best available estimate of the area converted to managed wetlands (reservoirs), although in reality reservoirs may contain islands, i.e., emergent land areas. "Ice-free period" was defined as the average number of days between the observed freeze date and the breakup date of ice cover on a body of water (Magnuson et al. 2000). In the case of hydroelectric reservoirs, locations were mapped and estimates of the ice-free period were generated from the lakes–ice-free period isoline map of Canada (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.

Data Sources

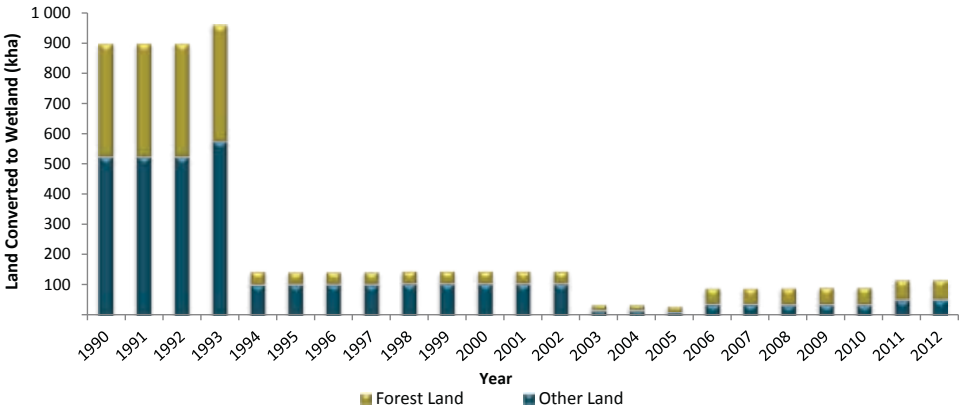
The three main data sources used to develop area estimates were 1) information on forest conversion due to reservoir impoundment in reporting zones 4 and 5 (see Section A3.4.2.2, Forest Conversion); 2) the Canadian Reservoir Database (Duchemin 2002); and 3) official industry numbers, derived from industry correspondence (Eichel 2006; Tremblay[19]).

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 but no changes occurred to the reservoir area.

As CO_2 emissions from the surface of reservoirs are reported only for the 10 years following impoundment, all flooding events since 1980 were used. The trend in area flooded is characterized by two distinct periods (Figure A3–24). The first, prior to 1994, was marked by large-scale flooding, which occurred in the early 1980s and still appeared under the Land converted to wetlands category in the 1990–1993 inventory years. After 10 years, these reservoirs were removed from the accounting, and there was a corresponding decrease in the area to a low in 1994. Four reservoirs (Toulnustouc, Peribonka, Eastmain-1 and Rupert Diversion) have been recently created; flooding for Toulnustouc and Eastmain-1 reservoirs was completed in 2005 and 2006, respectively. Accounting of reservoir emissions for Peribonka and the Rupert Diversion started in 2008 and 2011, respectively; the 2014 submission includes emissions from both the forest clearing and associated flooding for these four sites.

19 Tremblay A, Hydro-Québec. 2010. Personal communication dated 2010 Nov 19, 2010, to Dominique Blain, Environment Canada

Figure A3–24 Cumulative Areas in the Lands Converted to Wetlands (Flooded Lands) Category



It is important to note that fluctuations in the area of land converted to wetlands (reservoirs) reported in the CRF tables are not indicative of changes in current conversion rates, but reflect the difference between land areas recently (< 10 years ago) converted to reservoirs and older reservoirs (> 10 years), whose areas are thus transferred out of the accounting. The reporting system does not encompass all the reservoir areas in Canada, which are monitored separately in the Canadian Reservoir Database.

Uncertainty

A temporal curve better reflects the decreasing trends of emission rates after impoundment than a unique emission factor. Hence, the domestic approach is believed to reduce the uncertainty in estimation factors. However, there are still important remaining sources of uncertainty:

Seasonal variability. Some reservoirs display marked seasonal variability in CO_2 fluxes, which are not taken into account in estimate development. Anecdotal evidence suggests that algal bloom in the spring could be associated with this variability, especially in reservoirs subjected to anthropogenic nutrient inputs.

Reservoir area. There are variations in reservoir area due to water level fluctuations during the year.

Emission pathways. The omission of potentially important CO_2 emission pathways (e.g. degassing).

Planned Improvements

Planned improvements include developing improved estimates of the preconversion standing biomass, better understanding of conversion practices for both peat extraction and reservoir flooding, and integrating new emission measurements to the curve as they become available.

A3.4.6. Settlements

Emissions and removals in this category comprise urban tree growth (settlements remaining settlements) and emissions from land conversion to settlements. This submission reports emissions from the conversion of forest land to settlements and of tundra to settlements.

To estimate the very small sink from urban tree growth, a Tier 1 methodology was used. An average growth of 0.05 t biomass/ha per year every year over 1990–2012 was computed and applied to 1902 kha of non-built-up urban surface areas (Statistics Canada 1997).

Approaches, methods and data sources for estimating emissions from the conversion of forest land to settlements are covered in Section A3.4.2.2. This section describes estimate development for the conversion of non-forest land to settlements in the Canadian Arctic and sub-Arctic.

A3.4.6.1. General Approach and Methods

The Canadian northern regions (Arctic and sub-Arctic) cover nearly half of Canada's land mass and include five land categories (IPCC 2003), except Cropland. This assessment covered an area of about 359 million ha and included reporting zones 1, 2, 3 and 17, some small northern areas of reporting zones 4, 8 and 10, as well as reporting zones 13 and 18 north of 60°N latitude. The challenge was to capture land-use change and estimate associated emissions in this vast and remote landscape. An approach was developed specifically for this task and included the following components:

1. Map non-forest land-use change in Canada's Arctic/sub-Arctic prior to and including 1990 and between 1990 and 2000.

2. Estimate annual GHG emissions (above-ground biomass only) from non-forest land-use change in Canada's Arctic/sub-Arctic for the 1990–2000 period.

A comprehensive, wall-to-wall analysis over this area was clearly impractical, as this would require on the order of 100 Landsat satellite scenes for each date. Similarly, random sampling would likely not capture enough land-use change events to allow a reliable assessment. Instead, GIS data sets denoting the occurrence of cultural, mining and other human development were used to reduce and optimize the domain of investigation, by flagging areas with high probability of occurrence of land use change. These areas of concentrated land-use change potential were targeted for change detection analysis (change vector analysis – Johnson and Kasischke 1998) using 23 Worldwide Reference System Landsat frames from circa 1985, 1990 and 2000. The scenes cover more than 8.7 million ha, 56% of the potential land-use change area identified using the GIS data sets, or 70% of potential land-use change area if seismic survey lines are not included.[20] All 23 frames were located in the western Arctic and sub-Arctic regions.

The Land Use Change Mapping System for Canada's North (Butson and Fraser 2005), can be described as a hybrid change detection method based on two separate techniques: change vector analysis for identifying changed areas and constrained signature extension for labelling those changes (Olthof et al. 2005). A detailed description of how the Land Use Change Mapping System for Canada's North was used for the purpose of capturing non-forest land-use change in Canada's north is available in Fraser et al. (2005). The average rate of land-use change between 1985 and 2000 over the assessed area was 666 ha/year, and 60% of land-use change areas occurred in reporting zone 13. Lack of available imagery prevented the implementation of the system beyond 2000; therefore, the same annual rate of land-use change was applied for the years 2001–2012.

A series of above-ground biomass maps in 2000 were developed for the main land-use change areas, using relationships between above-ground biomass and remote sensing data constructed from and calibrated with ground measurements (Figure A3–25). These maps were used to determine CO_2 emissions from the clearing of above-ground biomass.

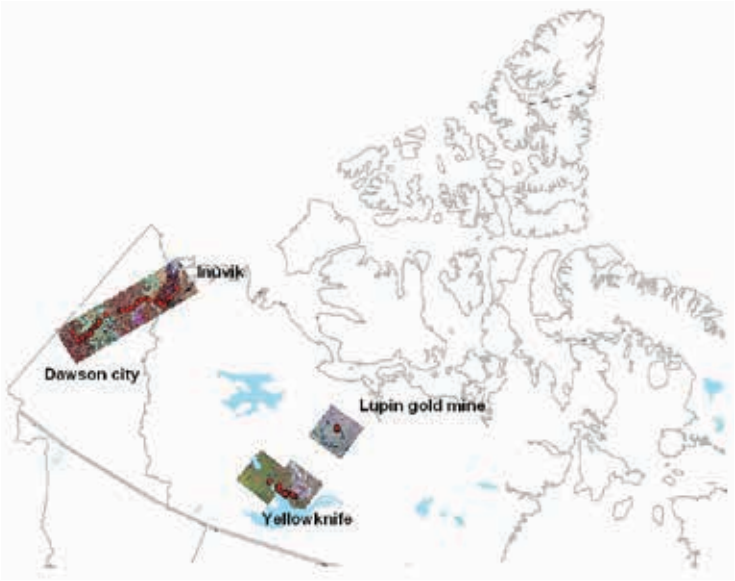
The dominant land cover types in the two study areas are rock, lichen, low to high shrub, grass and sparse woodland.

Multiple regressions were conducted between natural logarithm (ln) (above-ground biomass) and a combination of image signals for all vegetation covers combined (grass, shrub, sparse woodland). The best least square approximation had an $r^2 = 0.72–0.78$, dependent on approaches used, a relative mean square error of 75–80%, and a median value of the absolute percentage error of 33–53%. Biomass regressions were applied to the preconversion imagery for all land-use change areas to yield an estimate of the biomass cleared. All land-use change activities involved conversion of tundra vegetation to settlements, and all preconversion biomass carbon was deemed emitted upon clearing.

Since the 2007 submission, additional imagery was analyzed with the change detection method used for forest conversion area estimation. Reporting zone 4 and part of reporting zone 8 were fully mapped for both forest and non-forest conversion to settlements, adding 55 Mha to the area already mapped. The above-ground biomass of non-forest vegetation was derived from a

20 Recent, low-impact seismic lines have a narrow swath of approximately 2 m in width, as opposed to conventional ones, which were much larger (~8 m). Low-impact seismic lines were widely adopted over the past decade and considerably reduce the environmental impact of seismic exploration.

Figure A3–25 Study Areas for the Determination of Above-ground Biomass in Canada's Arctic and Sub-Arctic Region



literature search and estimated at 6 kt/ha (or 3 kt C/ha). For this region, there was an average rate of non-forest land-use change of 133 ha/year for the 1990–2006 period.

When only the above-ground biomass component is considered, land-use change activities for the non-forested regions of Canada's north released on average an estimated 153 kt CO_2 eq per year in the 1990–2012 period.

A3.4.6.2. Uncertainty

The uncertainty in land-use change area covered by the 23 Landsat scenes is estimated to be within 20% (Fraser et al. 2005). The biomass equations developed from field measurements in the Dawson City study area were validated on the other study areas of Yellowknife and the Lupin mine. The median values of the absolute percentage error in above-ground biomass estimation for both study areas are 33–53%.

A Monte Carlo simulation method was used to quantify the overall error in carbon emissions caused by uncertainties in land use change area and biomass estimation. At the 95% confidence level, the percentage error varies from 218% if there is only one land-use change site within a reporting zone to 15% if a reporting zone has 75 or more land-use change sites. The error in the total above-ground biomass carbon stock change estimate, if considered as one reporting area, is about 15%. A full discussion of uncertainty can be found in Chen et al. (2005, 2009).

A3.4.6.3. Planned Improvements

Planned improvements will include efforts to reduce uncertainty associated with the estimates of preconversion biomass in Canada's Arctic and sub-Arctic. Work will be undertaken to update the land-use change activity estimates for the post-2000 period. For estimates of removals related to urban trees, efforts are underway to improve and update the current estimates of urban area, tree stocks and management practices, which is intended to improve the current estimate approach and the data on which it is based.

A3.4.7. Estimation of Delayed CO_2 Emissions from Harvested Wood Products (HWPs)

There is broad scientific agreement on the inaccuracy introduced by the assumption that all carbon transferred out of managed forests from harvesting is immediately oxidized and released to the atmosphere. Instead, a large proportion of the carbon removed from forests is stored in wood products, and eventually released over the product lifetime and at the point of disposal.

In this submission, Canada has utilized the general framework of the production approach (IPCC 2006) to incorporate the long term storage of carbon in HWP from its domestic harvest. The approach tracks the fate of C in all woody biomass harvested domestically and taken off-site.

A country-specific model, the Carbon Budget Model Framework for Harvest Wood Products (CBM-FHWP) was developed to simulate and quantify the fate of carbon off-site from the point of harvest. Input to the model is the harvested biomass returned by the Carbon Budget Model of the Canadian Forest Sector, thus ensuring there are no gains or losses as C flows from forests to products. The on-site decay of harvest residues continues to be captured in C stock changes in the DOM pool of Forest Land. Unused fibre (e.g. carbon that is not converted into commodities) is collectively labelled "milling waste" and its C content is deemed immediately emitted to the atmosphere. The remaining fibre is either exported as roundwood or transformed into four types of commodities, which in turn can be exported or used domestically (Figure A3–26).

The model version used to produce the current estimates incorporates a domestic component and three main export destinations: the United States, Japan and all others. The FAO database of forestry trade flows was used to determine the proportion of Canadian roundwood and commodity production exported to the three main destinations. For example, in any given year 96% or more of industrial roundwood harvested in Canada remains in Canada for further transformation. Likewise, over the entire time series between 22% and 42% of sawnwood, 19% and 65% of wood-based panels and 0.1% and 13% of pulp and paper are used in the country.

Manufacturing efficiencies determine the proportion of industrial roundwood biomass converted into commodities—the unused fraction being milling waste. 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 U.S. and Japan separately; and jointly for all other export destinations. Default bark expansion factors and wood carbon content were used for all countries (Table A3–43). Default parameters were used to convert product volume to units of carbon for countries other than Canada and the U.S., and where country-specific parameters are not available for Canada or the U.S. (Table A3–44). Canada-specific wood density values were used for domestic roundwood, sawnwood, other industrial roundwood (OIR) and panels; and default values were used for domestic paper and market pulp (P & P). Country-specific values were used for all domestic quantities for the U.S. 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.

Figure A3–26 Schematic of Carbon Flows in Harvested Wood Products

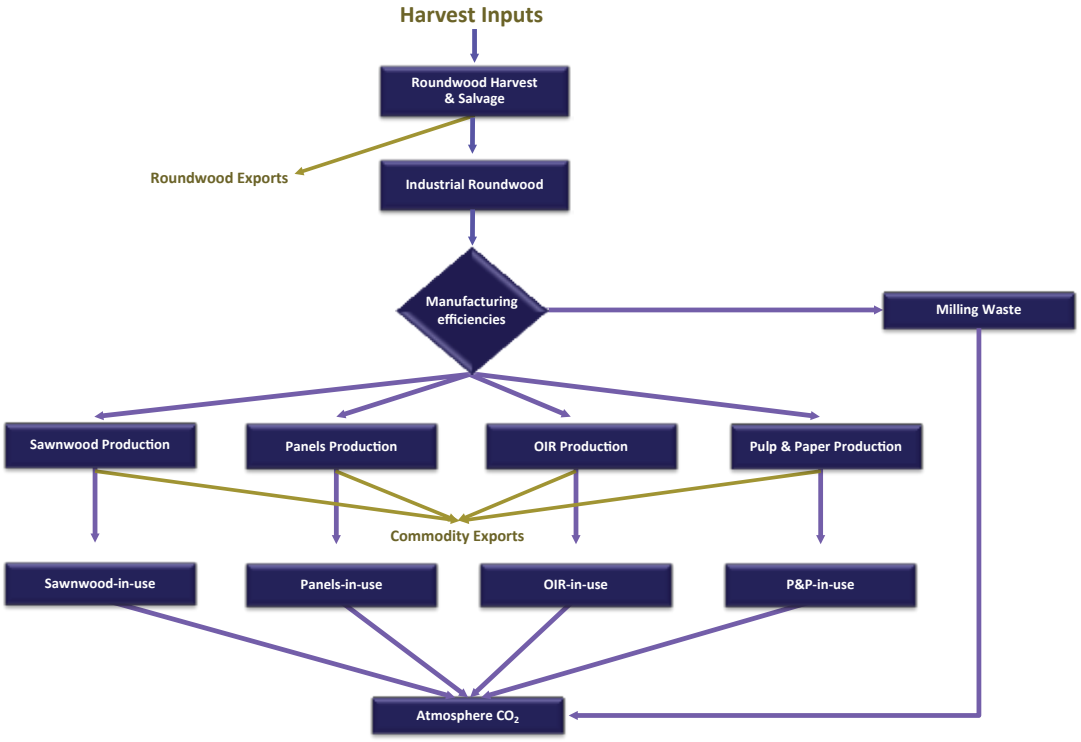


Table A3–43 Default Parameters Values Used in HWP Analysis

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[1]	0.5	IPCC 2006 (Vol. 4, Table 12.4)

1. Tonnes carbon per oven dry tonne of wood material

The model applies product in-use half-life parameters to four 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 CBM-FHWP (Table A3-45). The model only incorporates HWP harvested in 1990 and onward. Work is ongoing to develop other country specific half-lives, to incorporate the effects of wood and paper waste in solid waste disposal sites, to account for the use of wood fibre as bioenergy feedstock, and to expand the temporal coverage, currently limited by available FAO trade flow data and limited regionalized pre-1990 harvest and production data.

Table A3–44 Commodity wood density parameters values used in HWP analysis

Country/ Countries	Description	Units[1]	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	Environment Canada
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)

Note:
1. od tonne = oven dry tonne of wood material, ad tonne = air dry tonne of product

Table A3–45 Half-life parameters (years) of harvested wood products in-use

Country/ Countries	Description	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)

A3.5. Methodology for Waste

The Waste Sector consists of three sources of emissions: solid waste disposal on land (landfills), wastewater treatment, and waste incineration. This section of Annex 3 details the accounting methodologies that are used to describe the greenhouse gas (GHG) emission estimates for the following categories from the Waste Sector:

- CH_4 emissions from solid waste disposal on land;
- CH_4 and N_2O emissions from wastewater treatment; and
- CO_2, CH_4, and N_2O emissions from waste incineration.

A3.5.1. CH_4 Emissions from Solid Waste Disposal on Land

A3.5.1.1. Methodology

Emissions are estimated from two types of landfills in Canada:

- municipal solid waste (MSW) landfills; and
- wood waste landfills.

The Scholl Canyon model is used to estimate CH_4 generation from landfills using the following first-order decay equation (IPCC/OECD/IEA 1997):

Equation A3–78:

$$Q_{T,x} = kM_x L_0 e^{-k(T-x)}$$

where:

$Q_{T,x}$	=	the amount of CH_4 generated in the current year (T) by the waste Mx, kt CH_4/year
X	=	the year of waste input
M_x	=	the amount of waste disposed of in year x, Mt
k	=	CH_4 generation rate constant, yr^{-1}
L_0	=	CH_4 generation potential, kg CH_4/t waste

Equation A3–79:

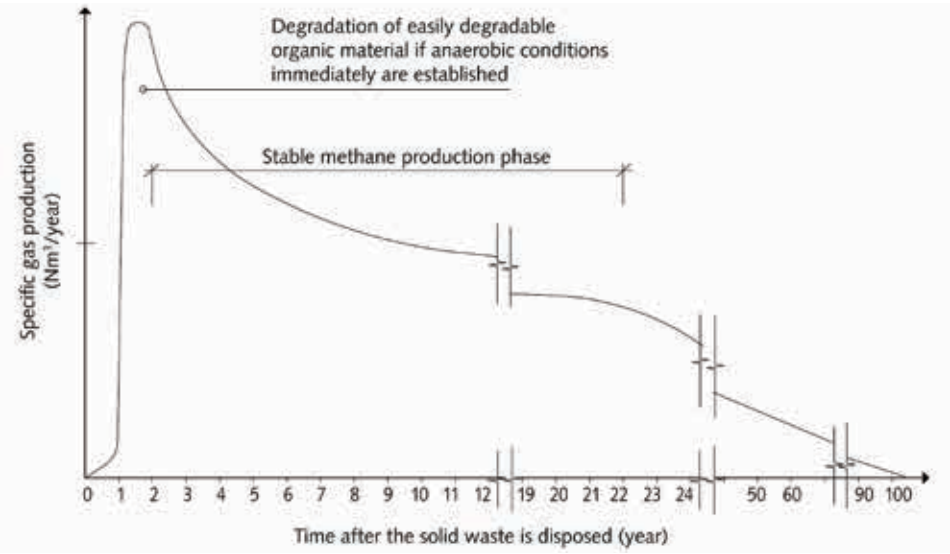
$$Q_T = \sum Q_{T,x}$$

where:

Q_T	=	The amount of CH_4 generated in the current year (T), kt CH_4/year

Figure A3–27 provides the typical landfill gas production rate variation over a time series after the waste has been deposited. The Canadian landfill emission estimation is based on the Scholl Canyon model and assumes that CH_4 production is highest in the early phase, followed by a slow steady decline in annual production rates. It also assumes that the initial lag time where anaerobic conditions are established is negligible, as shown in Figure A3–27.

Figure A3–27 Scholl Canyon Model Representation of Landfill Degradation



Note:
Figure is from Jensen and Pipatti (2003) and is shown as published without modification.

In order to estimate CH_4 emissions from landfills, information on several of the factors described above is needed. To calculate the net emissions for a specific year, from the sum of $Q_{T,X}$ for every portion of waste landfilled in past years, the captured gas quantities subtracted, and the CH_4 emitted from the incomplete combustion of the flared portion of captured gas is added to the result. A computerized model has been developed to estimate aggregate emissions on a regional basis in Canada.

Waste Disposed of Each Year (M_x)

MSW Landfills

For the purposes of the inventory, MSW includes residential; institutional, commercial and industrial (ICI); and construction and demolition (C&D) wastes. Two primary sources are used in obtaining landfill data for the GHG inventory. The amount of MSW landfilled in the years 1941 through 1990 was estimated by Levelton (1991). Starting from 1998 and biennially for subsequent years to 2010 inclusively, MSW disposal data were obtained from the *Waste Management Industry Survey*, which is conducted by Statistics Canada on a biennial basis (Statistics Canada, 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013a). MSW disposal values for the subsequent odd years (1999, 2001, 2003, 2005, 2007 and 2009) are obtained by taking an average of the adjacent even years. Disposal, with respect to the Statistics Canada data, refers to the combination of waste incinerated, exported and waste landfilled. Therefore, in order to obtain the amount of waste landfilled, incinerated waste and exported waste quantities are subtracted from the Statistics Canada disposal values for 1998 to 2012. The amount of waste exported is included in the waste disposal values for the Statistics Canada 2000 survey year and subsequent years.[21, 22] Waste disposal data compiled by Statistics Canada in the *Waste Management Industry Survey* are the most complete data available, as the coverage of respondents includes the collection and transportation of non-hazardous and hazardous waste disposal facilities, the operation of transfer stations and the treatment and disposal of waste deemed to be hazardous for activities undertaken by companies, local governments and other public waste management bodies. A methodology is used to account for those populations that do not meet the population threshold as detailed in the following extract from the survey text: "…a survey coverage population was developed using information provided by survey respondents as well as from other sources about the municipalities that were served by disposal and recycling facilities. Total populations were calculated for these municipalities using Statistics Canada data. The difference between the total population and the covered population was calculated. A provincial per capita disposal figure was applied to this undercovered population, and this total was added to the survey total to arrive at an adjusted disposal figure. The undercovered portion of the population is small and has been decreasing with each iteration of the survey."

Over the period 1991–1997, with the exception of Prince Edward Island, the Northwest Territories, Nunavut and Yukon, MSW landfill values were estimated by fitting a polynomial to the Levelton (1991) and Statistics Canada (2000, 2003, 2004) MSW landfill values. Data for 2011 and 2012 were trended from earlier waste quantity values. To estimate the coefficients in the polynomial, a multiple linear regression application (Microsoft Excel LINEST statistical tool for an array) is used. The choice of how many coefficients to use for the polynomial function depended on how well the data fit the lower order polynomials. Generally, the polynomial fit was improved with increasing number of coefficients. A polynomial of the order 13 is used in the inventory MSW estimates. This multiple linear regression method of estimation is consistent with the Intergovernmental Panel on Climate Change (IPCC) interpolation method (IPCC 2000). Table A3–46 shows the polynomial coefficients generated by the multiple linear regression method for each of the provinces.

The amounts of MSW landfilled for the years 1991–1997 are calculated according to the following equation:

Equation A3–80:

$$M_x = (C_{13} \times X^{13}) + (C_{12} \times X^{12}) + (C_{11} \times X^{11}) + (C_{10} \times X^{10}) + (C_9 \times X^9) + (C_8 \times X^8) + (C_7 \times X^7) + (C_6 \times X^6) + (C_5 \times X^5) + (C_4 \times X^4) + (C_3 \times X^3) + (C_2 \times X^2) + (C_1 \times X) + C$$

where:

M_X	=	MSW landfilled in year X, t
C_i	=	coefficient of the ith order (see Table A3–46)
x	=	year of interest

Statistics Canada MSW disposal data are unavailable for Prince Edward Island, the Northwest Territories, Nunavut and Yukon. Thus, MSW landfill values for this province and these territories for the period 1991–2012 are obtained by trending historical landfill data with the provincial populations for 1971–2012 (Statistics Canada 2006, 2013b). Three sources of landfill data are used to estimate the MSW landfill amounts for 1991–2012. The first set of data was provided by Levelton (1991) for 1971–1990. The second set of landfill data was provided by the Hazardous Waste Branch of Environment Canada for 1992 (Environment Canada 1996b). The third set of landfill data involves multiplying the 1992 percentage of waste landfilled for Prince Edward Island, the Northwest Territories, Nunavut and Yukon (Environment Canada 1996b) by the surplus of waste landfilled provided by Statistics Canada for 1998, 2000, 2002, 2004 and 2006 (Statistics

21 Marshall J. 2006. Personal communication (February 2006). Manager of the Waste Management Industry Survey: Business and Government Sectors, 2002 Report. Statistics Canada.

22 Marshall J. 2007. Personal communication (email dated February 21, 2006). Manager of the Waste Management Industry Survey: Business and Government Sectors, 2004 Report. Statistics Canada.

Table A3–46 Multiple Linear Regression Polynomial Coefficients Used in Estimating the Amount of MSW Landfilled for 1991–1997

	N.L.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
C	6.87E+09	8.60E+09	−1.87E+10	2.18E+11	−2.91E+10	−8.47E+09	3.96E+10	−4.35E+11	1.70E+12
C_1	−1.97E+06	−3.22E+06	4.22E+06	−4.70E+08	−2.37E+07	3.28E+06	6.20E+06	4.13E+08	−1.17E+09
C_2	3.14E+03	−1.02E+04	−7.88E+02	8.18E+05	2.49E+04	5.10E+03	−1.39E+04	−4.96E+04	2.53E+04
C_3	1.62E+00	2.65E+00	2.26E+00	−3.18E+02	1.50E+01	−5.77E−01	−1.75E+01	−3.04E+01	−1.65E+02
C_4	8.20E−06	−1.59E−03	1.30E−03	−2.15E−01	−5.96E−03	−1.51E−03	3.28E−03	−4.42E−03	8.23E−02
C_5	−9.81E−08	2.46E−06	−5.70E−07	4.76E−05	−1.68E−06	−2.78E−07	3.72E−06	2.21E−05	1.52E−06
C_6	−1.63E−10	8.20E−10	3.21E−10	4.16E−08	1.13E−09	1.51E−10	7.74E−10	−1.55E−08	3.39E−08
C_7	−8.88E−14	−2.11E−13	−2.43E−14	5.93E−12	−3.00E−14	2.72E−13	−4.58E−13	−1.02E−12	−5.11E−12
C_8	−6.34E−17	−1.50E−16	−1.09E−16	6.56E−15	−8.94E−16	−7.69E−17	8.21E−17	4.03E−15	−2.76E−15
C_9	5.40E−20	−2.03E−19	−2.03E−20	−5.89E−18	−2.33E−19	−5.56E−20	7.12E−20	−1.61E−18	−2.24E−19
C_{10}	−1.48E−24	3.34E−24	−1.30E−23	−1.91E−21	2.36E−22	1.74E−23	−1.54E−22	4.04E−22	3.44E−22
C_{11}	−6.62E−28	2.48E−26	9.41E−27	1.61E−25	1.08E−25	8.89E−27	6.66E−26	8.76E−26	−9.63E−25
C_{12}	3.03E−30	2.21E−29	2.63E−30	5.53E−28	−2.26E−29	−3.09E−30	−2.86E−29	−9.54E−29	3.59E−28
C_{13}	−1.32E−33	−7.77E−33	−3.92E−34	−1.00E−31	−1.03E−32	−6.66E−35	7.64E−33	1.57E−32	−6.11E−33

Notes:
Coefficients have been rounded and may not result in the correct totals for MSW landfilled.

Canada 2000, 2003, 2004, 2007a, 2008a). The surplus of waste landfilled for 1998, 2000, 2002, 2004 and 2006 is calculated by subtracting the sum of the provided provincial landfill values from the total Canadian landfill value.

The estimates of exported solid waste were developed from information solicited by Canada from the provincial environmental ministries and directly from the individual states in the United States where the waste was accepted for disposal (Environment Canada 2013a). It was found that the exporting provinces do not track the quantities of non-hazardous wastes leaving the province to the U.S. However, from information obtained from the U.S. CRS[23] Reports for Congress (CRS 1990, 1993, 1995–1998, 2000–2002, 2004 and 2007), the Michigan DEQ[24] Solid Waste Reports for 1996–2011 (Michigan 1996–2011) and from communications with state officials and with representatives of individual landfill facilities in pertinent waste receiving states—Michigan, Washington, New York, Ohio, Montana, Indiana, Pennsylvania and North Dakota—a more complete and accurate data set was compiled to replace the previous set that was based mostly on Ontario exports. A summary of the exported waste quantities is provided in Table A3–47.

Table A3–48 shows the amount of MSW landfilled for the period 1990–2012.

Wood Waste Landfills

The amount of wood waste landfilled in the years 1970 through 1992 is estimated at a national level based on the National Wood Residue Data Base (NRCan 1997). Data for the years 1998 and 2004 are provided in subsequent publications (NRCan 1999, 2005). A linear regression trend analysis is conducted to interpolate the amount of wood residue landfilled in the years

Table A3–47 Canadian Exports of Non-Hazardous Wastes

	Non-Hazardous Waste Exported to U.S. (t)			
Year	Ontario	Quebec	B.C.	Total
1989	100 000	7 000	20 283	127 283
1990	100 000	7 000	20 283	127 283
1991	100 000	7 000	20 283	127 283
1992	1 300 000	90 720	262 867	1 653 587
1993	1 300 000	90 720	262 867	1 653 587
1994	1 000 000	58 735	170 189	1 228 924
1995	1 049 007	26 750	77 511	1 153 268
1996	778 953	20 380	66 269	865 602
1997	770 829	17 195	55 027	843 051
1998	817 109	14 010	32 542	863 661
1999	782 286	73 826	35 235	891 347
2000	1 366 384	91 205	37 928	1 495 517
2001	1 792 287	9 718	46 318	1 848 323
2002	2 083 654	85 438	54 708	2 223 800
2003	2 937 902	85 354	71 487	3 094 742
2004	3 629 172	133 761	88 266	3 851 199
2005	3 728 170	136 236	96 656	3 961 062
2006	3 879 468	224 923	105 046	4 209 437
2007	3 988 280	667 026	118 168	4 773 475
2008	3 644 997	402 614	103 951	4 151 562
2009	3 127 662	389 620	115 428	3 632 711
2010	2 836 269	188 148	150 156	3 174 572
2011	2 199 851	88 153	227 554	2 515 558
2012	2 199 851	88 153	227 554	2 515 558

23 Congressional Research Service

24 Department of Environment Quality

Table A3–48 MSW Landfilled for 1990–2012[4]

Year	N.L.	P.E.I.	N.S.	N.B.	Que. 3	Ont.[3]	Man.	Sask.	Alta.	B.C.[3]	Yk.	N.W.T. & Nvt.	Canada
						tonnes							
1990[1]	366 004	51 293	493 010	462 391	3 699 833	5 957 104	696 174	638 942	1 577 585	1 760 621	16 608	34 493	15 754 058
1991	400 159	63 047	540 341	489 539	4 073 027	6 287 557	741 706	720 035	1 790 701	1 990 162	16 904	34 897	17 148 074
1992	402 670	74 800	533 426	488 826	4 152 266	6 390 940	755 034	729 362	1 837 539	2 012 191	17 200	35 300	17 429 552
1993	403 918	72 786	523 456	485 805	4 230 976	6 479 872	767 869	736 993	1 881 860	2 028 235	19 629	40 929	17 672 327
1994	403 775	74 911	510 179	480 262	4 309 123	6 552 824	780 167	742 752	1 923 350	2 037 746	20 505	42 899	17 878 493
1995	402 110	77 036	493 335	471 972	4 386 673	6 608 214	791 881	746 453	1 961 687	2 040 161	21 381	44 869	18 045 772
1996	398 783	79 161	472 655	460 706	4 463 598	6 644 405	802 966	747 906	1 996 538	2 034 895	22 257	46 839	18 170 708
1997	393 651	81 286	447 861	446 225	4 539 872	6 659 708	813 373	746 914	2 027 558	2 021 350	23 133	48 809	18 249 740
1998[2]	366 280	91 555	455 192	468 571	5 134 572	5 915 711	964 726	848 408	2 527 817	2 166 237	27 770	59 073	19 025 912
1999	382 549	86 211	402 202	441 815	5 299 103	6 919 164	939 619	835 177	2 638 911	2 229 875	26 149	55 625	20 256 397
2000[2]	398 818	80 866	349 827	415 058	5 411 108	7 294 405	914 511	821 946	2 750 004	2 287 008	24 528	52 176	20 800 255
2001	387 706	76 365	348 511	414 332	5 512 702	7 214 659	905 534	808 535	2 820 149	2 341 591	23 162	49 272	20 902 517
2002[2]	376 594	71 864	347 707	413 606	5 453 306	7 396 919	896 556	795 124	2 890 294	2 381 225	21 797	46 368	21 091 359
2003	388 321	75 268	355 501	427 890	5 754 175	6 610 800	912 337	795 029	2 983 803	2 404 564	22 830	48 564	20 779 081
2004[2]	400 048	78 672	362 721	442 173	6 006 198	5 987 923	928 117	794 933	3 077 311	2 427 985	23 862	50 761	20 580 704
2005	414 429	71 031	340 895	476 940	5 932 353	5 827 045	916 195	814 343	3 448 592	2 494 703	21 544	45 830	20 803 898
2006[2]	428 809	63 389	320 394	511 706	5 772 031	5 614 301	904 272	833 753	3 819 872	2 561 453	19 226	40 900	20 890 105
2007	404 493	59 462	315 235	495 584	5 240 331	5 456 751	924 857	868 348	3 983 715	2 496 045	18 035	38 366	20 301 221
2008[2]	380 176	55 535	313 570	479 461	5 414 619	5 749 868	945 441	902 943	4 147 558	2 458 063	16 844	35 832	20 899 911
2009	387 206	63 444	322 343	477 363	5 246 840	6 064 719	948 527	920 106	4 032 525	2 370 521	19 243	40 935	20 893 772
2010[2]	394 235	71 354	332 623	475 265	5 267 279	6 151 608	951 612	937 268	3 917 492	2 259 672	21 642	46 039	20 826 090
2011	401 265	63 821	341 461	473 167	5 186 745	6 584 327	954 698	954 431	3 802 459	2 105 943	19 358	41 179	20 928 853
2012	408 294	63 760	348 545	471 069	5 094 497	8 578 673	957 783	971 593	3 687 426	2 257 269	19 339	41 139	22 899 387

Notes:
1. 1990 data obtained from Levelton (1991).
2. 1998, 2000, 2002, 2004, 2006, 2008 and 2010 data obtained from Statistics Canada disposal data (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013a).
3. Exported MSW subtracted from the Statistics Canada disposal data (Environment Canada 2013a).
4. The data represented above were chosen from selected years. MSW landfill data from 1941 to 1990 (Levelton 1991) were used in the multiple linear regression method for estimation of MSW landfilled for 1991–1997.

1993–1997 and 1999–2003. An exponential growth function was used to extrapolate wood residue quantities landfilled for the years 2005–2012 so as to reflect the expected exponential reduction in landfilled quantities. These interpolation methods were selected because they are most suitable for the data distribution.

The breakdown in the amount of wood residue disposed of (defined as residue that is not further used in a product, used as a source of fuel, or converted into a chemical) for the solid wood operations and the pulp and paper industries is estimated based on information from a study of pulp and paper mill waste (MWA Consultants Paprican 1998). The proportion of wood waste disposal is estimated at 80% for solid wood operations and 20% for pulp and paper mills.

The breakdown of the portion of the wood residue directed to landfills from the solid wood and pulp and paper industry operations is estimated based on the National Wood Residue Data Base (NRCan 1997). The allocation of wood waste landfilled in private landfills is estimated at 15% for solid wood operations and 86% for pulp and paper mills. To avoid double counting, since emissions from public landfills are already accounted for in the emissions from MSW landfills, the ratio of wood waste landfilled in private versus public landfills, obtained from NRCan (1997), is used to isolate the quantity landfilled in dedicated private wood waste landfills. This portion is assumed to be also true for the years 1970–2012. Table A3–49 shows the amount of wood waste disposed of and landfilled for the period 1990–2012.

CH_4 Generation Rate Constant (k)

The CH_4 generation rate constant k represents the first-order rate at which CH_4 is generated after waste has been landfilled. The value of k is affected by four factors: moisture content, availability of nutrients, pH and temperature. In calculating provincial decay rates, however, the ambient temperature should not be considered, as the landfill temperature is independent of the ambient temperature at depths exceeding 2m. The moisture content should be the sole parameter considered (Maurice and Lagerkvist 2003; Thompson and Tanapat 2005).

Table A3–49 Wood Waste Generated and Landfilled in Canada for 1990–2012

Year	Wood Waste Disposed of (bone dry tonnes)		Wood Waste Landfilled (bone dry tonnes)		
	Pulp & Paper	Solid Wood Industry	Pulp & Paper	Solid Wood Industry	Total
1990	1 811 062	7 244 248	1 557 513	1 086 637	2 644 151
1991	1 811 062	7 244 248	1 557 513	1 086 637	2 644 151
1992	1 811 062	7 244 248	1 557 513	1 086 637	2 644 151
1993	1 537 557	6 150 226	1 322 299	922 534	2 244 833
1994	1 447 245	5 788 981	1 244 631	868 347	2 112 978
1995	1 356 934	5 427 736	1 166 963	814 160	1 981 124
1996	1 266 623	5 066 491	1 089 296	759 974	1 849 269
1997	1 176 311	4 705 246	1 011 628	705 787	1 717 415
1998	1 080 000	4 320 000	928 800	648 000	1 576 800
1999	995 689	3 982 755	856 292	597 413	1 453 706
2000	905 378	3 621 510	778 625	543 227	1 321 851
2001	815 066	3 260 265	700 957	489 040	1 189 997
2002	724 755	2 899 020	623 289	434 853	1 058 142
2003	634 444	2 537 775	545 622	380 666	926 288
2004	547 561	2 190 244	470 902	328 537	799 439
2005	536 030	2 144 120	460 986	321 618	782 604
2006	492 687	1 970 746	423 710	295 612	719 322
2007	452 848	1 811 392	389 449	271 709	661 158
2008	416 231	1 664 922	357 958	249 738	607 697
2009	382 574	1 530 297	329 014	229 544	558 558
2010	351 639	1 406 557	302 410	210 984	513 393
2011	323 206	1 292 822	277 957	193 923	471 880
2012	297 071	1 188 285	255 481	178 243	433 724

MSW Landfills

The k values used to estimate emissions from MSW landfills were obtained from a study conducted by Environment Canada's Greenhouse Gas Division that employed provincial precipitation data from 1941 to 2007 (Environment Canada 1941-2007). The provincial locations at which the average annual precipitations calculated were those indicated in the Levelton study where major landfills were located over the 1941 to 1990 period (Levelton 1991), with additional data for British Columbia from a study performed by Golder Associates Ltd. (2008). From these precipitation values, k values were determined using a relationship prepared by the Research Triangle Institute (RTI) for the U.S. Environmental Protection Agency (RTI 2004). RTI assigns default decay values of less than 0.02/year, 0.038/year and 0.057 /year to areas with an annual precipitation of less than 20 inch/year (< 500 mm), between 20 and 40 inch/year (500 to 1000 [average 750] mm) and greater than 40 inch/year (> 1000 mm), respectively. The plot of these decay values and precipitation data showed a linear relationship: k (yr^{-1}) = 7 x 10-5 x precipitation (mm)-0.0172. Using this relationship and Environment Canada's average provincial precipitation data for 1941–1975, 1976–1989 and 1990–2007, average provincial landfill decay rates were calculated (Environment Canada 1941-2007). The U.S. k values are related to precipitation, assuming that the moisture content of a landfill is a direct function of the annual precipitation. Based on both the U.S. k values and precipitation data and the average annual precipitation at Canadian landfills surveyed by Levelton (1991), k values were assigned to each of the provinces for the three respective time series: 1941–1975, 1976–1989 and 1990–2007. These three time intervals were selected to match those used to derive the provincial L_0 values in order to better represent the changing conditions over the 1941–2012 time series. It is assumed that the conditions for which the 1990–2007 k values were derived were also valid from 2008 to 2012.

Table A3–50 shows the mean annual precipitation and decay values assigned for each of the provincial landfill sites selected by Levelton (1991) and Golder Associates Ltd. (2008).

The k values used to estimate emissions from MSW landfills at a provincial level are derived from taking the average of k value estimates for each province for each of the three time series. These values are provided in Table A3–51.

Table A3–50 Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites

Region	Annual Precipitation (mm) from Environment Canada's Historical Climate Data			Rate constant k (yr-1)		
	1941–1975	1976–1989	1990–2007	1941–1975	1976–1989	1990–2007
British Columbia						
Campbell River	1 521.4	1 370.2	1 507.0	0.089	0.079	0.088
Chilliwack	1 674.4	1 736.9	1 678.0	0.100	0.104	0.100
Courtney	1 465.7	1 387.9	1 441.3	0.085	0.080	0.084
Kamloops	270.1	273.9	296.5	0.002	0.002	0.004
Matsqui	1 537.1	1 480.1	1 571.6	0.090	0.086	0.093
Port Alberni	1 954.2	1 870.8	2 050.1	0.120	0.114	0.126
Prince Rupert	2 636.2	3 082.7	2 538.7	0.167	0.199	0.161
Vancouver	1 846.0	1 599.8	1 564.5	0.112	0.095	0.092
Vernon	393.2	415.3	429.7	0.010	0.012	0.013
Victoria	864.6	978.6	1 197.7	0.043	0.051	0.067
Average	**1 416.3**	**1 419.6**	**1 427.5**	**0.082**	**0.082**	**0.083**
Alberta						
Calgary	429.9	406.8	426.5	0.013	0.011	0.013
Edmonton	451.9	480.2	446.8	0.014	0.016	0.014
Fort McMurray	441.1	445.8	417.9	0.014	0.014	0.012
Lethbridge	427.5	396.4	385.8	0.013	0.011	0.010
Medicine Hat	344.1	332.5	338.9	0.007	0.006	0.007
Red Deer	450.9	463.5	487.4	0.014	0.015	0.017
Average	**424.2**	**420.9**	**417.2**	**0.012**	**0.012**	**0.012**
Saskatchewan						
Moose Jaw	388.9	329.7	468.4	0.010	0.006	0.016
Prince Albert	333.2	425.9	458.7	0.006	0.013	0.015
Regina	390.2	359.9	404.2	0.010	0.008	0.011
Saskatoon	360.0	332.9	356.3	0.008	0.006	0.008
Swift Current	385.1	359.8	409.1	0.010	0.008	0.011
Yorkton	440.7	440.1	435.1	0.014	0.014	0.013
Average	**383.0**	**374.7**	**422.0**	**0.010**	**0.009**	**0.012**
Manitoba						
Brandon	464.8	434.7	480.8	0.015	0.013	0.016
Portage la Prairie	540.4	533.8	562.4	0.021	0.020	0.022
Thompson	566.8	517.5	500.7	0.022	0.019	0.018
Winnipeg	534.1	487.7	540.9	0.020	0.017	0.021
Average	**526.5**	**493.4**	**521.2**	**0.020**	**0.017**	**0.019**
Ontario						
Barrie	894.6	952.3	927.6	0.045	0.049	0.048
Belleville	868.3	898.7	920.6	0.044	0.046	0.047
Brantford	741.3	815.8	857.1	0.035	0.040	0.043
Brockville	961.2	977.2	1 013.0	0.050	0.051	0.054
Cornwall	934.7	969.0	1 044.9	0.048	0.051	0.056
Guelph	839.6	915.3	900.5	0.042	0.047	0.046
Hamilton	750.2	945.3	889.1	0.035	0.049	0.045
Kingston	810.3	975.2	964.2	0.040	0.051	0.050
Kitchener	885.9	985.5	844.0	0.045	0.052	0.042
London	921.5	997.8	993.3	0.047	0.053	0.052
North Bay	979.2	1 015.2	1 050.3	0.051	0.054	0.056
Oshawa	843.5	941.3	866.4	0.042	0.049	0.043
Ottawa-Hull	868.4	939.2	937.7	0.044	0.049	0.048
Peterborough	749.4	862.8	856.5	0.035	0.043	0.043
St. Catharines	806.7	860.2	866.5	0.039	0.043	0.043
Sarnia	752.4	842.6	972.8	0.035	0.042	0.051
Sudbury	760.6	907.7	911.6	0.036	0.046	0.047
Thunder Bay	734.8	696.1	578.4	0.034	0.032	0.023
Timmins	780.4	864.6	809.7	0.037	0.043	0.039
Toronto	794.4	843.2	808.1	0.038	0.042	0.039
Windsor	839.8	921.8	927.0	0.042	0.047	0.048
Average	**834.2**	**910.8**	**901.9**	**0.041**	**0.047**	**0.046**
Quebec						
Montréal	952.8	935.2	1 018.8	0.049	0.048	0.054
Québec	**1 137.9**	**1 174.9**	**1 148.6**	**0.062**	**0.065**	**0.063**
Rimouski	773.0	955.7	961.3	0.037	0.050	0.050
Saint-Étienne	1 021.0	994.2	981.4	0.054	0.052	0.051
Saint-Tite-des-Caps	1 009.7	1 102.4	1 178.3	0.053	0.060	0.065
Ste-Cécile	1 113.5	1 218.6	1 245.1	0.061	0.068	0.070
Ste-Sophie	1 047.3	1 031.2	1 063.4	0.056	0.055	0.057
Average	**1 007.9**	**1 058.9**	**1 085.3**	**0.053**	**0.057**	**0.059**
New Brunswick						
Bathurst	958.1	1 067.5	1 123.4	0.050	0.058	0.061
Campbellton	1 002.6	1 002.6	1 002.6	0.053	0.053	0.053
Edmundston	1 078.3	1 053.3	992.1	0.058	0.057	0.052
Fredericton	1 077.4	1 182.5	995.7	0.058	0.066	0.053
Moncton	1 159.4	1 116.7	1 172.1	0.064	0.061	0.065
Saint John	1 339.3	1 477.4	1 245.5	0.077	0.086	0.070
Average	**1 102.5**	**1 150.0**	**1 088.6**	**0.060**	**0.063**	**0.059**
Prince Edward Island						
Charlottetown	1 116.0	1 218.3	1 096.2	0.061	0.068	0.060
Summerside	987.6	1 052.7	1 149.1	0.052	0.056	0.063
Average	**1 051.8**	**1 135.5**	**1 122.6**	**0.056**	**0.062**	**0.061**

Table A3-50: Mean Annual Precipitation and MSW Landfill k Value Estimates for Provincial Landfill Sites (cont'd)

Region	Annual Precipitation (mm) from Environment Canada's Historical Climate Data			Rate constant k (yr-1)		
	1941–1975	1976–1989	1990–2007	1941–1975	1976–1989	1990–2007
Nova Scotia						
Dartmouth	1 492.8	1 449.5	1 349.6	0.087	0.084	0.077
Halifax	1 492.8	1 449.5	1 349.6	0.087	0.084	0.077
Lunenburg	1 456.2	1 475.2	1 559.5	0.085	0.086	0.092
New Glasgow	1 076.8	1 120.5	1 106.7	0.058	0.061	0.060
Sydney	1 359.1	1 514.9	1 413.0	0.078	0.089	0.082
Truro	1 087.7	1 226.1	1 110.8	0.059	0.069	0.061
Average	**1 327.6**	**1 372.6**	**1 314.9**	**0.076**	**0.079**	**0.075**
Newfoundland						
Carbonear	N/A	N/A	N/A	N/A	N/A	N/A
Corner Brook	1 127.1	1 255.9	1 196.1	0.062	0.071	0.067
St. John's	1 502.4	1 525.2	1 515.3	0.088	0.090	0.089
Average	**1 314.8**	**1 390.5**	**1 355.7**	**0.075**	**0.080**	**0.078**
Yukon						
Whitehorse	264.2	261.7	271.8	0.001	0.001	0.002
Average	**264.2**	**261.7**	**271.8**	**0.001**	**0.001**	**0.002**
Northwest Territories						
Yellowknife	261.2	273.0	287.0	0.001	0.002	0.003
Average	**261.2**	**273.0**	**287.0**	**0.001**	**0.002**	**0.003**
Nunavut						
Iqaluit	420.1	448.9	372.1	0.012	0.014	0.009
Average	**420.1**	**448.9**	**372.1**	**0.012**	**0.014**	**0.009**
Average (N.W.T. and Nvt.)	**340.6**	**360.9**	**329.5**	**0.007**	**0.008**	**0.006**

Note: N/A = not available.

Table A3–51 Provincial and Territorial MSW Landfill k (yr^{-1})Value Estimates

	Provinces and Territories											
Year	N.L.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	Yk.	N.W.T. & Nvt.
1941–1975	0.075	0.056	0.076	0.06	0.053	0.041	0.020	0.01	0.012	0.082	0.001	0.001
1976–1989	0.080	0.062	0.079	0.063	0.057	0.047	0.017	0.009	0.012	0.082	0.001	0.002
1990–2012	0.078	0.061	0.075	0.059	0.059	0.046	0.019	0.012	0.012	0.083	0.002	0.003

Wood Waste Landfills

Based upon the default value for estimating wood products industry landfill CH_4 emissions recommended by the National Council for Air and Stream Improvement Inc., a k value of 0.03/year was assumed to represent the CH_4 generation rate constant for all of the wood waste landfills in Canada (NCASI 2003).

CH_4 Generation Potential (L_0)

MSW Landfills

The CH_4 generation potential (L_0) represents the amount of CH_4 that could be theoretically produced per tonne of waste landfilled. The following equation, as presented in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, is used to calculate the CH_4 generation potential for MSW landfills (IPCC/OECD/IEA 1997):

Equation A3–81:

$$L_0 = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \times 1000 \frac{kgCH_4}{tCH_4}$$

where:

L_0	=	CH_4 generation potential, kg CH_4/t waste
MCF	=	CH_4 correction factor, fraction
DOC	=	degradable organic carbon, t C/t waste
DOC_F	=	fraction of DOC dissimilated
F	=	fraction of CH_4 in landfill gas
16/12	=	stoichiometric factor to convert CH_4 to carbon

The methane correction factor (MCF) accounts for the proportion of managed to unmanaged solid waste disposal sites. Unmanaged solid waste disposal sites produce less CH_4, since a larger fraction of waste decomposes aerobically in the top layers of the site. The IPCC default value for MCF for managed landfill sites is chosen to represent the MCF for MSW landfills, since it is

Table A3–52 Solid Waste Disposal Site CH_4 Correction Factors

Type of Site	MCF Default Values
Managed	1.0
Unmanaged: deep (≥ 5 m waste)	0.8
Unmanaged: shallow (< 5 m waste)	0.4
Default value: uncategorized solid waste disposal sites	0.6

assumed that all landfills covered by the data collected are engineered landfills. The IPCC default values for MCF are shown in Table A3–52 (IPCC/OECD/IEA 1997).

The IPCC default value for the fraction of CH_4 in landfill gas (F) ranges between 0.4 and 0.6. It can vary based on certain factors, including waste age and composition and potential air dilution effects that can lower the actual concentration of CH_4 in the landfill gas. The average value 0.5 is chosen for the fraction of CH_4 in landfill gas.

DOC_F represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal site. It accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. A value of 0.6 was selected from the IPCC DOC_F default range, for waste that includes lignin, of 0.5 to 0.6 (IPCC 2000). This value, taken from the upper end of this range, i.e., more easily degraded, best represents the Canadian situation where the majority of the wood wastes, that by definition have high lignin concentrations, from saw mills and pulp and paper industries, are disposed of in dedicated private landfills.

DOC represents the amount of organic carbon that is accessible to biochemical decomposition and is based on the composition of the waste. Waste composition percentages from across Canada are used to calculate the provincial DOC values according to the following equation (IPCC/OECD/IEA 1997):

Equation A3–82:

$$\%DOC(by\ net\ weight) = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D)$$

where:

A	=	% of MSW that is paper and textiles
B	=	% of MSW that is garden or park waste
C	=	% of MSW that is food waste
D	=	% of MSW that is wood or straw

The provincial and territorial DOCs were calculated from waste disposal composition values for three distinct time periods: 1941–1975, 1976–1989 and 1990–2006. Using waste composition data obtained from a Natural Resources Canada (NRCan) study, which were based on the 2002 data year (NRCan 2006), DOC values were derived and assumed to be constant over the period 1990 to 2012. The DOCs were developed from residential, ICI and C&D waste type compositions. Since the waste diversion programs were not significant prior to 1990, a second set of DOCs was developed to represent the waste composition at disposal from 1976 to 1989 by adding the NRCan landfill data to the 2004 Statistics Canada recycled waste composition data (Statistics Canada 2007a). A third set of DOCs was developed from a 1967 national study to cover the period from 1941 to 1975 (CRC Press 1973). Provincial and territorial DOCs and L_0s are summarized in Table A3–53.

From the NRCan (2006) document, the quantities for each standard category of waste from residential, ICI and C&D origins were added together to reflect the true composition at disposal at the MSW landfill sites. Therefore, by this methodology, the biodegradability of all three waste types is accounted for in the MSW waste composition. The NRCan report uses a consistent methodology to estimate the MSW waste composition at disposal for all provinces and territories.

Since significant results from waste diversion projects only began to be made manifest in the early 1990s in Canada, as supported by this document and expert opinion in the field, the "1990 to present" provincial/territorial DOCs given in Table A3–53 are used in the estimation of L0s and ultimately in the provincial/territorial specific methane emission generation for the period 1990–2012, inclusively.

For the period 1976–1989, DOC values were calculated based on the assumption that the waste composition at disposal could be represented by the generation waste composition for the year 2002. This was accomplished by summing the MSW (residential and ICI) waste quantities (NRCan 2006) at disposal for each waste category with the recycled quantities for the corresponding category for each province and territory. The latter data were obtained from Statistics Canada report *Waste Management Industry Survey: Business and Government Sectors 2004* (Statistics Canada 2007a). Where gaps were identified in the Statistics Canada report, due to confidentiality issues, regional factors (western, central and maritime provinces and northern territories) were used to populate the missing data.

The years 1941 to 1975 are covered by an L_0 developed by a third set of DOC values, based on national waste compositions provided in Table 1.1-9 of CRC Press (1973) The data from this table are derived from the article "World Survey Finds Less Organic Matter" (Anon. 1967a). Waste audit data for the time series 1976 to 1998 were obtained from Table 1: Waste Composition Data for Ontario, of the report *Residential Waste Composition Study*, Ontario Waste composition Study – Vol. 1 (Ontario Ministry of the Environment 1991). The waste audit studies were conducted in 1976, 1978 and 1980 and gave paper, wood, food wastes, textile and yard waste average percentages of 40%, 2.6%, 22%, 3.4% and 13%,

Table A3–53 Provincial and Territorial CH_4 Generation Potential (L_0) Values

Province/Territory	2002 Organic Waste Diversion[1] (%)	1941 to 1975		1976 to 1989		1990 to Present	
		DOC	L_0 (kg CH_4/t waste)	DOC	L_0 (kg CH_4/t waste)	DOC	L_0 (kg CH_4/t waste)
Newfoundland	N/A	0.30	121.01	0.18	71.60	0.18	71.50
Prince Edward Island	N/A	0.28	111.20	0.16	63.82	0.15	60.34
Nova Scotia	29.7	0.26	105.92	0.15	60.24	0.15	60.56
New Brunswick	19.8	0.24	97.53	0.16	63.23	0.15	59.98
Quebec	13.7	0.38	153.06	0.20	79.71	0.19	77.43
Ontario	16.4	0.37	147.61	0.20	79.19	0.20	78.34
Manitoba	4.9	0.34	137.60	0.19	74.28	0.18	73.41
Saskatchewan	4.3	0.37	149.93	0.21	82.63	0.21	82.33
Alberta	16.7	0.28	111.53	0.17	69.25	0.17	67.95
British Columbia	23.3	0.27	109.62	0.17	66.34	0.15	59.58
Territories (Yk., N.W.T. & Nvt.)	N/A	0.23	91.70	0.14	56.68	0.16	62.36

Notes:
Sources: Derived from data obtained from NRCan (2006), Statistics Canada (2007a) and CRC Press (1973).
1. Thompson et al. (2006).
N/A = Not available.

respectively. These are comparable to those from the 2002 generated estimates used for the 1976 to 1989 period. The 1967 article data (Anon. 1967a) gave paper and organic matter compositions of 70% and 10%, respectively. Therefore, 1975–1976 was judged to be an appropriate transition point to use to allow for a realistic change between the significantly different 1967 data set and the data derived from the 2002 waste composition without waste diversion employed to represent the waste composition for the late 1970s and 1980s. The breakdown of organic matter percentage (10%), obtained from Table 1.1-9:Summary of International Refuse Composition, into food and yard waste was based upon the waste composition (10.2% and 8.6%, respectively) given for Montréal, Quebec, from the same CRC Press (1973) text, Table 1.1-10:Composition of Household Garbage, where the data were obtained from a separate 1967 article (Anon. 1967b). The information on percentage of wood (2.4%) came from an article by the American Public Works Association (1964), and was presented in Table 1.1-2.8: Composition and Analysis of Average Municipal Refuse (CRC Press 1973).

A provincial profile was developed from the 1967 national average by pro-rating each of its DOC waste categories to match the same provincial profile as for the 1976 to 1989 period.

Wood Waste Landfills

Equation A3–81, as presented in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, is used to calculate the CH_4 generation potential for wood waste landfills (IPCC/OECD/IEA 1997). The IPCC default value for MCF for unmanaged deep landfill sites (0.8) is chosen to represent the MCF, as it best represents industry practices.

The value 0.5 is chosen for the fraction of CH_4 in landfill gas (F) from the IPCC default range of 0.4 to 0.6.

DOC_F represents the amount of organic carbon that is ultimately degraded and released from the solid waste disposal sites. It accounts for the fact that some of the organic carbon does not degrade or degrades very slowly. The *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) provides default values in the order of 0.5–0.6 for waste sites that include lignin. The lower end of this range, 0.5, is used in the calculation for the CH_4 generation potential to better represent the high lignin content in wood waste (IPCC/OECD/IEA 1997).

DOC represents the amount of organic carbon that is accessible to biochemical decomposition. Equation A3-5 is used to calculate the national wood waste DOC value, assuming a 100% wood composition (IPCC/OECD/IEA 1997).

Based on these considerations, an L_0 of 80 kg CH_4/t of wood waste is calculated from Equation A3–81.

Captured Landfill Gas

At many large MSW landfill facilities, landfill gas is captured to be flared or utilized, or both. Owing to the relatively high concentration of CH_4 in the landfill gas, the gas can be combusted for electricity or heat generation. To a lesser extent, in recent years, the captured gas is simply collected and vented. If not utilized, the captured landfill gas is flared. For the purposes of the inventory, captured gas includes only the gas that is flared or utilized. In order to calculate the net CH_4 emissions from landfills, the amount of captured CH_4 is subtracted from the CH_4 generated

as estimated by the Scholl Canyon model, and then this value is added to the portion of CH_4 emitted from the flaring operation. GHG emissions affiliated with the use of landfill gas for energy recovery are accounted for in the Energy Sector. The calculation of net CH_4 emissions is shown in the following equation:

Equation A3–83:

$$CH_{4(NET)} = CH_{4(generated)} - CH_{4(captured)} + CH_{4(emitted-F)}$$

where:

$CH_{4(NET)}$	=	net CH_4 emissions from MSW landfills, t
$CH_{4(generated)}$	=	CH_4 emissions generated from MSW landfills, t
$CH_{4(captured)}$	=	CH_4 emissions captured from MSW landfills, t
$CH_{4(emitted-F)}$	=	CH_4 emissions emitted from flaring of captured MSW landfill gas, t

A flaring emission control efficiency of 99.7% is used to determine the amount of CH_4 emitted. This value is obtained from Table 2.4-3 of Chapter 2.4 of EPA AP 42 (US EPA 1995). The amount of CH_4 emitted from flaring of landfill gas is calculated as follows:

Equation A3–84:

$$CH_{4(emitted-F)} = CH_{4(flared)} \times \left(1 - Eff_{(flare-control)}\right)$$

where:

$CH_{4(emitted-F)}$	=	CH_4 emissions emitted from flaring of MSW CH_4 gas, t/year
$CH_{4(flared)}$	=	CH_4 gas flared, t/year
$Eff_{(flare-control)}$	=	flare emission control efficiency, fraction

The quantities of CH_4 gas collected from 1983 to 1996 were obtained from ad hoc surveys conducted by Environment Canada[25] and for the years 1997–2003 were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 2003a). CH_4 gas capture data for 2005 were obtained through a study prepared for Environment Canada (Environment Canada 2007). CH_4 gas capture and utilization data for 2006 and 2007, 2008 and 2009, and 2010 and 2011 were obtained through survey studies conducted by the Greenhouse Gas Division of Environment Canada in 2008, 2010 and 2012, respectively (Environment Canada 2009, 2011, 2013b). Prior to the 2008 data collection survey, the landfill gas capture data were collected every odd year, and therefore, for the purposes of the national GHG inventory, the landfill gas capture data for the subsequent even years were averaged from the odd years starting from 1997. However, the subsequent biennial surveys collected data for two data years from the facilities; these data were first employed in the 2012 NIR submission estimates. In the absence of 2012 LFG collection data, it was assumed that they were identical to the 2011 data. Table A3–54 shows the amount of CH_4 captured and flared from 1990 to 2012.[26]

A3.5.1.2. Data Sources

Waste disposal data are collected from a Statistics Canada biennial waste survey (Statistics Canada 2000, 2003, 2004, 2007a, 2008a, 2010a, 2013a). The Statistics Canada data for 1998, 2000, 2002, 2004, 2006, 2008 and 2010 waste disposal are used in developing its MSW estimates for the national GHG inventory.

Landfill gas capture and flare data for 1997–2003 were collected directly from individual landfill operators biennially by Environment Canada's National Office of Pollution Prevention (Environment Canada 2003a). CH_4 gas capture data for 2005 were obtained through the study entitled "An Inventory of Landfill Gas Recovery and Utilization in Canada," prepared for Environment Canada (Environment Canada 2007). CH_4 gas capture data for 2006 and 2007, 2008 and 2009, and 2010 and 2011 were collected through the subsequent study conducted by the Greenhouse Gas Division (Environment Canada 2009, 2011, 2013b).

A3.5.2. CH_4 Emissions from Wastewater Treatment

A3.5.2.1. Methodology

Municipal Wastewater Treatment

The IPCC default method for calculating CH_4 emissions from domestic wastewater handling is not used, because the required data (i.e. volumes of wastewater treated) are not available. Instead, a method similar to the IPCC methodology, developed for Environment Canada (AECOM Canada 2011), is used to calculate an emission factor. A new maximum methane producing capacity (B_o) was derived. In past submissions, a methane emission factor developed by ORTECH (1994), 0.22 kg CH_4/kg five-day biological oxygen demand (BOD_5), was used. Following the 2009 centralized review, this value was questioned, because the default 2000 IPCC greenhouse gas emission factor (GHG EF) is given as 0.6 kg CH_4/kg BOD_5. Further to the expert review team (ERT) report, and having identified a problem with the derivation of the IPCC default B_o value, AECOM was commissioned to review the current data and confirm the emission factor (EF) to

25 Perkin. Personal communication (letter dated July 1998). National Office of Pollution Prevention, Environment Canada.

26 Where data were not made available from the landfill gas capture facilities, data from previous surveys were employed.

Table A3–54 Estimated MSW CH_4 Captured, Flared, and Emitted for 1990–2011

Year	CH_4 Generated (kt)	CH_4 Captured (kt)	CH_4 Flared (kt)	CH_4 Emitted from Flare (kt)	CH_4 Emitted (kt)
1990	902.51	192.66	23.61	0.07	709.92
1991	917.40	195.64	27.18	0.08	721.84
1992	932.45	204.78	35.29	0.11	727.77
1993	947.50	209.39	44.46	0.13	738.25
1994	962.44	223.36	56.73	0.17	739.25
1995	977.14	243.44	69.36	0.21	733.90
1996	991.46	264.55	78.67	0.24	727.14
1997	1 005.27	267.80	81.00	0.24	737.71
1998	1 019.87	271.82	90.80	0.27	748.33
1999	1 038.19	275.83	100.59	0.30	762.67
2000	1 057.53	294.29	117.90	0.35	763.60
2001	1 076.31	312.74	135.21	0.41	763.97
2002	1 094.69	312.56	137.06	0.41	782.54
2003	1 111.09	312.38	139.34	0.42	799.13
2004	1 125.95	312.95	146.92	0.44	813.44
2005	1 139.85	313.52	154.49	0.46	826.79
2006	1 152.26	304.70	130.80	0.39	847.95
2007	1 160.71	329.96	164.90	0.49	831.24
2008	1 170.43	347.87	162.55	0.49	823.05
2009	1 179.69	349.24	171.47	0.51	830.97
2010	1 188.47	421.51	217.44	0.65	767.61
2011	1 195.60	425.21	221.89	0.67	771.06
2012	1 207.72	425.21	221.89	0.67	783.18

be used. The B_o recommended by AECOM is 0.36 kg CH_4 per kg BOD_5. It was also recommended that the methane conversion factor (MCF) be changed from a percent of population served by anaerobic treatment to the product of a combined MCF (septic systems, facultative lagoons, anaerobic lagoons and direct discharge) and the provincial population served by these systems, i.e., not served by a centralized treatment system. An MCF of 0.3 was recommended, as it best reflected the reality of the distribution of the Canadian municipal wastewater treatment units for the best data available.

Therefore, an emission factor of 0.108 was derived from the product of a B_o of 0.36 kg CH_4 per kg BOD_5 and an MCF of 0.3. To provide the EF in units of kg CH_4/capita/yr., the following relation was used, given an organic loading rate of 0.050 kg BOD_5/person/day:

Equation A3–85:

$$EF_{CH_4}(kg\ CH_4\ /capita\ per\ year\ ) = (per\ capita\ BOD_5\ loading\ rate) \times (CH_4\ generation\ rate)$$
$$= \left(0.05 \frac{kgBOD_5}{capita \times day}\right) \times \left(365 \frac{days}{years}\right) \times \left(0.108 \frac{kgCH_4}{kgBOD_5}\right) = \left(1.971 \frac{kgCH_4}{capita \times year}\right)$$

The percentage of wastewater that is treated aerobically for each province is derived from the product of the percentage of rural population (AECOM Canada 2011) and the population of the province or territory. It is assumed that anaerobic primary and secondary wastewater treatment, septic tanks and out-falls where the effluent is discharged without treatment, where CH_4 emissions are not captured, are present in rural areas. Canadian urban municipalities can be assumed to be serviced by aerobic treatment systems and/or anaerobic systems that have full capture of the biogases where they are utilized or flared with near complete combustion. Using the Statistics Canada definition of an urban area[27] and the 2006 census data, which give the provincial populations, the percentage of rural population is obtained.

Emissions are calculated by multiplying the emission factor by the population of the respective province (Statistics Canada 2006, 2013b) and the fraction of wastewater that is anaerobically treated.

27 Statistics Canada definition of urban area: "An urban area has a minimum population concentration of 1000 persons and a population density of at least 400 persons per square kilometre, based on the current census population count. All territory outside urban areas is classified as rural. Taken together, urban and rural areas cover all of Canada."

Equation A3–86:

$$CH_{4(x)} = EF_{CH_4} \times P_x \times FRAC_{AN(x)}$$

where:

$CH_{4(x)}$	=	CH_4 emissions from wastewater treatment for province x, t/year
EF_{CH4}	=	CH_4 emission factor for wastewater treatment, t/capita per year
P_x	=	population of province x
$FRAC_{AN(x)}$	=	fraction of wastewater treated anaerobically for province x

Table A3–55 shows the percentage of wastewater treated anaerobically, including untreated wastewater for 1990–2012. The remaining percentage of wastewater is treated aerobically (primary and secondary wastewater treatment).

Industrial Wastewater Treatment – CH_4 & N_2O

Data were collected through in-house surveys of industrial facilities either known or likely to be employing anaerobic units to treat their effluent on-site. The information gained allowed for the estimation of CH_4 emissions for each site. Methodologies for the estimation of N_2O emissions from industrial wastewater treatment are not provided in either the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) or the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), and, therefore, this category was not estimated. N_2O emissions from this source are not expected to be significant, in view of the relatively few units in operation, and given that that wastewater from pulp and paper and the effluent from potato processing (the two larger industries involved) do not contain large quantities of nitrogenous matter.

Emissions from industrial wastewater handling at a plant-site level are typically difficult to quantify, due to confidentiality issues and the variety of biological treatment units available that focus on biodegradable organics or nitrogen removal, or that can serve both functions.

Based on the responses to inquiries submitted to industrial associations and provincial ministries of the environment for the first survey in 2006, which indicated that anaerobic industrial wastewater units were relatively few in Canada, it was decided to implement a Tier 3 approach to collect information from the individual facilities directly. To use the default data and methodology—without knowledge regarding those industry sectors using anaerobic treatment, the existence of biogas recovery systems,

Table A3–55 Percentage of Wastewater Treated Anaerobically by Province for the 1990–2012 Time Series

	Fraction of Wastewater Treated Anaerobically (%)												
Year	NL	PE	NS	NB	QC	ON	MB	SK	AB	BC	NU	NT	YT
1990	92	56	76	40	43	9	30	44	18	23	100	97	57
1991	92	56	76	40	43	9	30	44	18	23	100	97	57
1992	92	56	76	40	43	9	30	44	18	23	100	97	57
1993	92	56	76	40	43	9	30	44	18	23	100	97	57
1994	92	56	76	40	43	9	30	44	18	23	100	97	57
1995	92	56	76	40	43	9	30	44	18	23	100	97	57
1996	92	56	76	40	43	9	30	44	18	23	100	97	57
1997	92	56	76	40	41	9	30	44	18	23	100	97	57
1998	92	56	76	40	37	9	30	44	18	23	100	97	57
1999	92	56	76	40	32	9	30	44	18	23	100	97	57
2000	92	56	76	40	27	9	30	44	18	23	100	97	57
2001	92	56	76	40	25	9	30	44	18	23	100	97	57
2002	92	56	76	40	25	9	30	44	18	23	100	97	57
2003	92	56	76	40	25	9	30	44	18	23	100	97	57
2004	92	56	76	40	25	9	30	44	18	23	100	97	57
2005	92	56	76	40	25	9	30	44	18	23	100	97	57
2006	92	56	76	40	25	9	30	44	18	23	100	97	57
2007	92	56	76	40	25	9	30	44	18	23	100	97	57
2008	92	56	76	40	25	9	30	44	18	23	100	97	57
2009	92	56	76	40	25	9	30	44	18	23	100	97	57
2010	92	56	76	40	25	9	30	44	18	23	100	97	57
2011	92	56	76	40	25	9	30	44	18	23	100	97	57
2012	92	56	76	40	25	9	30	44	18	23	100	97	57

Source: 1996–2006 data obtained from AECOM (2011). Subsequent and prior years were assumed constant.

and the quantities actually recovered, would invite an unacceptable overestimation of methane emissions.

As recommended by the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), the Decision Tree for CH_4 Emissions from Industrial Wastewater Handling was followed as a framework for the Tier 3 approach. Using the information gathered for previous National Inventory Reports (NIRs), detailed in Annex 3.5 of Canada's original 2010 submission, for industries with large volumes of wastewater produced, industry sectors were prioritized for the plant-specific data to be collected through surveys in order of importance: pulp and paper, chemicals and chemical products, food, beverages, petroleum and coal products, rubber products, plastic products, and total textiles.

The following industrial sectors were ruled out based on confirmations from industry representatives that anaerobic treatment was not taking place at facilities in their sectors: chemicals and chemical products,[28] beverages,[29] petroleum and coal products,[30] rubber products,[31] plastic products,[32],[33] and total textiles.[34] Requests were submitted to the Canadian Chemical Producers' Association (CCPA), Canadian Soft Drink Association (CSDA), Canadian Association of Petroleum Producers (CAPP) and Rubber Association of Canada (RAC) in 2006 to obtain a confirmation for recent years, and of those members who replied, none confirmed the use of an anaerobic system. Nineteen facilities were identified to have anaerobic systems: two in the pulp and paper sector, fifteen in the food industry and two in the beverage industry. Lecture notes from a seminar in 2004 show the existence of 13 sites (Crolla et al. 2004), so it may be assumed that the coverage for this sector is complete. Of all the subject industry sectors, the two pulp and paper facilities treat by far the largest portion of process water.

From Internet searches and direct communications with the facilities, we identified only two pulp and paper facilities in Canada using anaerobic treatment. This was confirmed by the industry sector association, i.e., the Forest Products Association of Canada (FPAC).[35] These facilities directly provided the methane production in volumetric units. These quantities were converted to mass units using the density of methane at 25°C and 1 atm. Fugitive losses from the digesters and the piping system were estimated to be 0.5%, which was an average of the 0.6% for losses in pipelines and leakage at the end user for processing, transmission and distribution of natural gas, and 0.4% for leakage from residential and commercial sectors as given in the IPCC Reference Manual, Table 1.6, page 1.29 (IPCC/OECD/IEA 1997). However, a representative from the engineering design firm for one of the systems confirmed that there should not be any leaks, because the system was under negative pressure and oxygen sensors were provided in the system to alert the operators of a breach. Therefore, these emissions should be non-existent if the other facility used a similar system. Methane emissions from the inefficiencies of the flare and utilization devices were also accounted for. These methane destruction efficiencies were 0.995 for an enclosed flare and 0.98 for a boiler (Climate Action Reserve 2009). Therefore, the total emissions were the sum of the piping losses and the quantities of methane circumventing combustion in the flare and boiler.

Similarly, the emissions for the food industry were calculated. However, where no production data were made available (i.e. from a cheese manufacturer, potato processor and candy bar manufacturer), design parameters (process wastewater volumes, chemical oxygen demand [COD]) were used from the engineering firm that supplied the units to these facilities in conjunction with the default IPCC EF (IPCC/OECD/IEA 1997), to generate gas quantities. As it is known that the gas is collected, it was assumed that the losses, i.e., emissions, would consist of piping losses and utilization by a boiler.

Table A3–56 shows the industry sectors included within the Environment Canada surveys (Environment Canada 1986, 1991, 1996a) and the corresponding IPCC default COD values that are chosen to represent the industry sectors (IPCC 2000).

A3.5.2.2. Data Sources

Volumes of biogas collected, the fraction of CH_4 in the biogas, and information on the combustion of the collected biogas (utilization and/or flaring) were provided directly from the industrial facility. Where the information was not available, design specifications obtained from the engineering firms that designed the specific systems or that were made available from the facility

28 CCPA. Personal communication (email dated December 4, 2006). Bruce Caswell, Canadian Chemical Producers' Association, to Paula Critchley, Waste Sector, Greenhouse Gas Division.

29 CSDA. Personal communication (telephone conversation dated December 2006). Canadian Soft Drink Association and Paula Critchley, Waste Sector, Greenhouse Gas Division.

30 CAPP. Personal communication (email dated October 24, 2006). Sonia Simard, Canadian Association of Petroleum Producers, to Paula Critchley, Waste Sector, Greenhouse Gas Division

31 RAC. Personal communication (telephone conversation dated December 2006). Rubber Assocation of Canada and Paula Critchley, Waste Sector, Greenhouse Gas Division.

32 CPIA. Personal communication (email dated December 4, 2006). Ray Kelsey, Canadian Plastics Industry Association, to Paula Critchley, Waste Sector, Greenhouse Gas Division.

33 CPIA. Personal communication (email dated October 6, 2010). Fred Edgecombe, Canadian Plastics Industry Association, to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division.

34 Lincoln Fabrics. Personal communication (email dated October 4, 2010). Steve Thistle, Plant Manager of Lincoln Fabrics Ltd., to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division.

35 FPAC. Personal communication (email dated October 4, 2010). Roger Cook, Forest Products Association of Canada, to Shanta Chakrovortty, Waste Sector, Greenhouse Gas Division

Table A3–56 COD Values Used in CH_4 Emission Estimates per Industry Type

Industry Group	IPCC Industry Type	IPCC Degradable Organic Component—COD (g/L)
Food	Vegetables, Fruits & Juices	5
Beverages	Soft Drinks	2
Rubber Products	Organic Chemicals	3
Plastic Products	Plastics and Resins	3.7
Primary Textiles & Textile Products	Textiles (Natural)	0.9
Wood Products	N/A	N/A
Paper & Allied Products	Pulp & Paper (Combined)	9
Primary Metals	N/A	N/A
Fabricated Metals	N/A	N/A
Transportation Equipment	N/A	N/A
Non-Metallic Mineral Products	N/A	N/A
Petroleum & Coal Products	Petroleum Refineries	1
Chemicals & Chemical Products	Organic Chemicals	3

Notes:
Sources: IPCC (2000), except for Industry Group, which is from Environment Canada (1986, 1991, 1996a).

were used to derive the emissions, which would be conservative estimations.

A3.5.3. N_2O Emissions from Wastewater Treatment

A3.5.3.1. Methodology

The N_2O emissions from municipal wastewater treatment facilities are calculated using the IPCC default method (IPCC/OECD/IEA 1997). This method estimates emissions based on the amount of nitrogen in sewage and the assumption that 0.01 kg N_2O-N/kg sewage nitrogen will be generated.

To estimate the amount of nitrogen in sewage, it is assumed that protein is 16% nitrogen (IPCC/OECD/IEA 1997). The Canadian protein consumption is obtained from the annual food statistics publication (Statistics Canada 2007b, 2008b, 2010b), as shown in Table A3–57. The protein consumption data also account for retail, household, cooking and plate losses. Data are provided for the years 1991, 1996 and 2001–2009. Protein consumption data for missing years are estimated by applying a multiple linear regression application to the Statistics Canada data. In the absence of protein consumption data for 2010, 2011 and 2012, a growth function was used to extrapolate protein consumption.

Protein consumption, (accounting for food wastage at the retail, household cooking and plate level) is employed in this case rather than protein availability because it provides a more realistic and accurate estimate of the N_2O emissions. In a 2011 ERT review of the 2011 submission from Canada, the emissions from this category were adjusted in the belief that the use of protein consumption data resulted in an underestimation of the N_2O emissions. The following is an extract from the annual report review (ARR) dated April 26, 2012:

Table A3–57 Canadian Protein Consumption

Year	Protein Consumption (g/capita per day)
1990	65.26
1991[a]	66.19
1992	66.55
1993	67.20
1994	67.86
1995	68.52
1996[a]	68.59
1997	69.87
1998	70.56
1999	71.25
2000	71.95
2001[a]	72.97
2002	72.79
2003[a]	71.76
2004[a]	72.18
2005[b]	71.12
2006[b]	71.03
2007[b]	71.79
2008[b]	70.25
2009[b]	69.85
2010[b]	69.77
2011[b]	69.43
2012[b]	69.09

Sources :
a. Statistics Canada (2008b), Food Statistics, Catalogue No. 21-020-X: the data have been adjusted for retail, household cooking and plate loss.

b. Statistics Canada (2010b), Food Statistics, Catalogue No. 21-020-X: the data have been adjusted for retail, household cooking and plate loss.

"The rationale for adjustment

132. Canada uses correction factors from the United States in the estimation of emissions from human sewage to account for food wastage. Neither the Revised 1996 IPCC Guidelines nor the IPCC good practice guidance considers the concept of loss factors, nor does either guideline provide any guidance on making these corrections. In the 2006 IPCC Guidelines (used by the United States) the methodology takes losses into account but simultaneously includes non-consumed protein added to wastewater and industrial and commercial co-discharged protein into the sewerage system. Accounting for the losses (for which there is no methodology in the Revised 1996 IPCC Guidelines) without taking into account the emissions from non consumed protein (for which there is also not a methodology in the Revised 1996 IPCC Guidelines) can lead to an underestimation of emissions.

The recommendation to the Party

133. If country-specific loss factors are not available and the Party is not able to provide evidence that the methodology used does not underestimate emissions, the ERT FCCC/ARR/2011/CAN34 recommends that Canada use the uncorrected values for protein consumption as reported by the Party to FAO in its reporting of N_2O emissions from human sewage, in order to ensure that emissions are not underestimated."

As a consequence of this decision, the 2011 resubmission and the subsequent 2012 submission used protein availability. Following the adjustment by the UNFCCC ERT, Canada commissioned a study conducted by AECOM (2012) to review the ERT's justification for the adjustment, as well as the data and the methodologies utilized to derive the Canadian protein consumption data. The report concluded the following:

"1. Canada is compliant with the requirements of the Revised 1996 IPCC Guidelines and IPCC Good Practice Guidance.

2. 1996 IPCC Guidelines estimates N_2O emissions from "human sewage" based on "annual per capita protein intake". The use of annual per capita protein available for consumption results in an overestimate of emissions.

3. Canada adjusts the protein available using USDA[36] Food Loss statistics to obtain an estimate of the protein consumed. FAO datasets provide annual per capita protein available for consumption; use of this data overestimates annual per capita protein consumption.

   Consumer and retail level losses should be considered when developing protein consumption estimates; particularly in developed countries, such as Canada, where most of the loss occurs at the retail and consumer levels. In developing countries, 40% of the losses occur post-harvest and processing. Therefore, FAO[37] data does not adequately account for major losses in developed countries.

   Canada does not have country specific information required to estimate these food losses, and therefore uses USDA ERS[38] loss estimates.

   Although Canada and U.S. have demonstrably different food consumption patterns, the categories of food consumed are almost identical and food processing and food intake style are comparable for a given food. Therefore, the U.S. food loss estimates, which are available by food item, are applicable to Canadian food consumption estimates.

4. The approach used in the 2011 Canadian National Inventory Submission should not be compared to that used by the U.S., without taking into account the differences in the methodologies used. The U.S. follows the IPCC 2006 Guidelines, which applies factors to account for non-consumed nitrogen and industrial/commercial inputs of nitrogen. Although it may appear that the use of these factors provides a more conservative estimate of N_2O emissions from wastewater, it must be recognized that the emission factor used in the IPCC 2006 Guidelines is half that of the Revised IPCC 1996 Guidelines (IPCC/OECD/IEA,1997). The net result is that the U.S. reports lower N_2O emissions per capita than Canada.

5. The IPCC 2006 Guidelines default FNON-CON[39] value of 1.4 is not appropriate for Canada. The IPCC 2006 Guidelines suggest the use of a default value for FNON-CON of 1.4 for developed countries using FWDs[40]. Fewer than 10% and 50% of households in Canada and the U.S., respectively, use FWD units. Food waste in Canada is typically managed through the solid waste management or on-site composting streams. Therefore, if Canada was to adopt the IPCC 2006 Guidelines, it would not be appropriate to use the FNON-CON value of 1.4.

6. Per capita nitrogen loading rates based on individual sewage contributions to the sewer system reflect the nitrogen loading basis of the Revised 1996 IPCC Guidelines. A typical wastewater industry value for nitrogen produced by an individual when FWD units are not used is 13 g N/capita/day. As discussed in Section 7.1, Canadian nitrogen loading based on 2009 per capita protein consumption and protein available data is 11.2 g N/capita/day and 16.5 g N/capita/day, respectively. The former value is a more accurate estimate of the nitrogen produced by an individual at the household and is aligned with the Revised IPCC 1996 Guidelines intent to account for proteins from human sewage, and not include industrial and non-consumed proteins.

7. The use of the Revised IPCC 1996 Guidelines with available protein data provides a higher per capita N_2O-N generation estimate than the use of IPCC 2006 Guidelines with all combinations of available and consumed protein and FNON-CON default values.

36 United States Department of Agriculture

37 Food and Agriculture Organization of the United Nations

38 Economic Research Service of the United States Department of Agriculture

39 Fraction of non-consumed protein

40 Food waste disposal

> The Revised IPCC 1996 Methodology is based on consumed protein; using available Canadian consumed protein data, N_2O generation of 0.1118 g N_2O-N/capita/day is calculated. However, the ERT argues that Canada should use available protein in this calculation, which would result in an N_2O generation of 0.1644 g N_2O-N/capita/day. This value does not appear to be reasonable when compared to equivalent calculations using the IPCC 2006 Guidelines. Using all combinations of available or consumed protein and FNON-CON values of 1.1 or 1.4, the Canadian per-capita N_2O-N emissions calculated by the IPCC 2006 approach are lower than that calculated using the Revised IPCC 1996 approach with available protein data. Therefore, there appears to be little justification that Canada should use the ultra-conservative approach recommended by the ERT."

Therefore, Canada has reinstated the use of protein consumption, which accounts for losses at the retail, cooking, household and plate level.

The N_2O emission factor is calculated as follows:

Equation A3–87:

$$EF_{N_2O} = PC \times EF_{N_2O-N} \times FRAC_{NPR} \times \frac{44}{28}$$

where:

EF_{N2O}	=	emission factor: kg N_2O/capita per year
PC	=	annual per capita protein consumption, kg/capita per year (Statistics Canada 2007b, 2008b, 2010b)
EF_{N2O-N}	=	emission factor: default 0.01 (0.002–0.12) kg N_2O-N/kg sewage nitrogen produced
$FRAC_{NPR}$	=	fraction of nitrogen in protein: default = 0.16 kg N/kg protein
44/28	=	stoichiometric factor to convert nitrogen to N_2O

Emissions are calculated by multiplying the emission factor by the population of the respective provinces (Statistics Canada 2006, 2013b):

Equation A3–88:

$$N_2O_s = EF_{N_2O} \times NR_{PEOPLE}$$

where:

N_2O_s	=	N_2O emissions from human sewage, kg N_2O/year
EF_{N2O}	=	emission factor: kg N_2O/capita per year (Equation A3–87).
NR_{PEOPLE}	=	number of people in country

A3.5.3.2. Data Sources

The Canadian protein consumption data are obtained from the annual food statistics publication (Statistics Canada 2008b, 2010b).

The provincial populations are obtained from Statistics Canada (Statistics Canada 2006, 2013b).

A3.5.4. CH_4 and N_2O Emissions from Municipal Wastewater and Industrial Sludge Handling

Methane emissions from these two sources are assumed as not occurring. The sludge from municipal wastewater treatment is typically either placed in landfills or applied to soils, and therefore they are accounted for within the emissions from MSW landfills, or, when land-applied, the application is on the surface, meaning that the degradation is aerobic with no significant CH_4 emissions.

Methodologies for the estimation of N_2O emissions from industrial sludge treatment are not provided in either the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997) or the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) and, therefore, this category was not estimated.

A3.5.5. CO_2 Emissions from Waste Incineration

A3.5.5.1. Methodology

Municipal Solid Waste Incineration

The IPCC decision tree in Figure 5.5 of IPCC (2000) for CO_2 emissions from waste incineration defines good practice in adapting the methods in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997). Country-specific carbon contents are not available; thus, Box 2 of the decision tree in Figure 5.5 (IPCC 2000) is the chosen methodology for calculation of CO_2 emissions.

The following steps detail the methodology for the estimation of CO_2 emissions from waste incineration:

Calculating the Amount of Waste Incinerated: The amount of waste incinerated each year is based on two primary sources. The amount of MSW incinerated in the year 1992 was estimated based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The amount of MSW incinerated for the years 1999, 2000 and 2001 was estimated based on the study "Municipal Solid Waste Incineration in Canada: An Update on Operations 1999–2001, performed by

A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b). A polynomial curve-fitting equation is employed to estimate the amount of MSW incinerated over the period 1991–1998 based on the values provided by A.J. Chandler & Associates Ltd. and Environment Canada. To estimate the coefficients in the polynomial, a multiple linear regression application (Microsoft Excel LINEST statistical tool for an array) is used. A polynomial of the order 13 provides the best fit. This multiple linear regression method of estimation is consistent with the IPCC interpolation method (IPCC 2000). To estimate the amount of MSW incinerated for 2002–2012, a trend extrapolation was performed with the A.J. Chandler & Associates Ltd. and Environment Canada MSW incineration values for all relevant provinces except Quebec and Ontario, for which only the former MSW incineration values were used. In the province of Ontario, one of the incineration plants closed at the end of 2001. Therefore, the amount of waste incinerated in Ontario for the period 2002–2012 is estimated by trending the A.J. Chandler & Associates Ltd. incineration values for 1999–2001 with population (Statistics Canada 2006, 2013b), assuming that the Ontario incineration plant was closed for this period.

MSW incineration estimates for the period 1990–2011 are shown in Table A3–58.

Developing Emission Factors: Provincial CO_2 emission factors are developed based on a study performed by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The CO_2 emission factors are founded on the assumption that carbon contained in waste undergoes complete oxidation to CO_2.

The provincial breakdown in the type of waste incinerated for 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The quantity of waste incinerated was divided into three categories: paper, plastics and organics. Table A3–59 summarizes these waste quantities.

Consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/OECD/IEA 1997), only CO_2 emissions resulting from the incineration of carbon in waste of fossil origin (e.g. plastics, certain textiles, rubber, liquid solvents and waste oil) are included in emission estimates (IPCC 2000). Therefore, it is necessary to estimate the fossil origin portion of the waste in order to develop an emission factor that excludes emissions due to the incineration of biomass. The breakdown in organic composition is estimated by averaging waste composition data from three published documents (Environment Canada 1994a, 1995a, 1995b). Table A3–60 shows the averaged breakdown in organic composition as well as the moisture and carbon content employed to develop the MSW incineration emission estimates.

Table A3–58 Estimated MSW Incinerated by Province for 1990–2012

Year	MSW Incinerated (t)					
	N.L.	P.E.I.	N.S.	Que.	Ont.	B.C.
1990	0	32 000	76 500	619 522	258 700	239 752
1991	0	32 000	53 458	564 219	266 361	252 214
1992	35 500	29 800	56 700	541 100	277 000	257 500
1993	0	32 000	57 953	530 107	255 272	262 964
1994	0	32 000	57 564	508 308	251 779	265 179
1995	0	32 000	55 924	483 314	249 873	265 668
1996	0	32 000	53 421	455 098	249 719	264 723
1997	0	32 000	50 443	423 631	251 484	262 637
1998	0	32 000	47 385	388 882	255 337	259 705
1999	0	32 212	45 000	298 904	258 429	254 800
2000	0	33 000	42 000	303 887	270 811	256 400
2001	0	32 224	42 000	303 910	281 671	246 700
2002	0	32 662	41 487	307 715	165 060	251 949
2003	0	32 824	39 079	310 700	178 747	251 718
2004	0	33 036	37 246	314 041	192 169	251 406
2005	0	33 214	38 641	317 108	204 647	251 009
2006	0	33 125	38 711	320 440	216 690	250 581
2007	0	33 058	41 433	324 499	225 977	250 111
2008	0	33 547	40 661	329 085	236 694	249 554
2009	0	34 083	38 395	334 552	247 106	248 970
2010	0	34 912	34 623	340 281	259 538	248 443
2011	0	36 018	32 292	345 502	271 165	248 126
2012	0	36 546	31 716	350 598	284 598	247 705

Note: Ontario incineration plant closed as of 2001 year-end.

Table A3–59 Quantities of Waste Incinerated in 1992

	Waste Quantities Incinerated in 1992											
Waste Types	N.L.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	N.W.T. & Nvt.	Yk.
Paper	13 600	10 100	19 940	n.I.	171 610	96 200	n.I.	n.I.	n.I.	92 170	n.I.	n.I.
Plastic	2 650	2 800	5 250	n.I.	42 490	23 200	n.I.	n.I.	n.I.	23 700	n.I.	n.I.
Organics	9 820	9 670	17 710	n.I.	190 480	102 000	n.I.	n.I.	n.I.	65 580	n.I.	n.I.

Source: Environment Canada (1996b), tables 2.3-2.26.
Note: n.I. means that no incineration occurs in that province.

Table A3–60 Estimated MSW Organic Composition and Moisture and Carbon Content

Component	Composition of Total Organics (%)	Moisture Content (%)	Carbon Content (%)
Yard/Garden Waste	41	60.0	47.8
Food Waste	31	70.0	48.0
Wood Waste	16	20.0	49.5
Textiles	10	10.0	55.0
Rubber	2	2.0	69.7
Total Organics	100	50.5	49.3

Sources:
Tchobanoglous et al. (1993), pages 70, 80.
Carbon constants for Textiles and Yard Waste from Peavy et al. (1985).

The amount of fossil fuel-based carbon available in the waste incinerated is determined using typical percent weight carbon content values. Carbon and moisture content values were provided by Tchobanoglous et al. (1993) and Peavy et al. (1985). The carbon content for plastic is 80%, an average of the 75–85% range provided by the Good Practice Guidance (IPCC 2000), based upon a recommendation from a 2011 ERT centralized review. The amount of carbon per tonne of waste is estimated by subtracting the moisture content from the mass of fossil origin waste and multiplying by the carbon content value of the waste type. The fossil origin portion of the organic waste is determined by multiplying the organic waste by the percent fossil origin composition as follows:

Equation A3–89:

$$Waste\ Type_{Fossil-Origin} = M_{Total} \times \left(1 - \%\ Organic_{Comp}\right)$$

where:

$WasteType_{Fossil\text{-}Origin}$	=	amount of fossil fuel–based waste incinerated, t
M_{Total}	=	amount of waste incinerated, t (1992 data provided by Environment Canada [1996b])
$\%Organic_{Comp}$	=	% organic composition per waste type (Environment Canada 1994a, 1995a, 1995b)

The amount of fossil fuel-based carbon is converted to tonnes of CO_2 per tonne of waste by multiplying by the ratio of the molecular mass of CO_2 to that of carbon. The derivation of the CO_2 emission factor is shown in the following equations:

Equation A3–90:

$$C_{Avail(y)} = \left(Waste\ Type\ _{Fossil-Origin}\right) \times (1 - \%\ Moisture) \times \%\ C_{Waste\ Type}$$

where:

$C_{Avail(y)}$	=	available carbon per waste type for province y, t
$WasteType_{Fossil\text{-}Origin}$	=	amount of fossil fuel-based waste incinerated, t (1992 data provided by Environment Canada [1996b])
% Moisture	=	% moisture content per waste type (Tchobanoglous et al. 1993)
$\%\ C_{WasteType}$	=	% carbon content per waste type (dry basis) (Tchobanoglous et al. 1993)

Equation A3–91:

$$EF_{CO_2-1992_{(y)}} = \left(\frac{\sum C_{Avail(y)}}{M_{Inc(y)}}\right) \times \frac{44}{12}$$

where:

$EF_{CO2-1992(y)}$	=	1992 CO_2 emission factor for incineration for province y, t CO_2/t waste incinerated
$C_{Avail(y)}$	=	available carbon per waste type for province y, t (See Equation A3–90)
$M_{Inc\ (y)}$	=	total mass waste incinerated in 1992 for province y, t
44/12	=	stoichimetric factor to convert carbon to CO_2

Calculating CO_2 Emissions: Emissions were calculated on a provincial level by multiplying the amount of waste incinerated by the appropriate emission factors.

Equation A3–92:

$$CO_{2(x)} = EF_{CO_2-1992} \times \left(M_{Inc(x)/province}\right)$$

where:

$CO_{2(x)}$	=	CO_2 emissions from waste incineration in year x, t/province per year
$EF_{CO2-1992}$	=	1992 provincial CO_2 emission factor for incineration, t CO_2/t incinerated
$M_{Inc(x)/province}$	=	mass waste incinerated per province in year x, t/year

Hazardous Waste Incineration

CO_2 emissions were estimated from activity data provided directly by facilities engaged in hazardous waste incineration in Canada through successive surveys conducted in 2006, 2008 and 2010 (Environment Canada 2010). The waste quantities and emissions are presented at a national level in Table A3–61.

These amounts incinerated include contaminated substrates such as soils, wood, metal and other material, and therefore are conservative. The hazardous waste quantities also include inorganic wastes such as aqueous solutions containing heavy metals, or that have relatively low fossil carbon origin wastes such as water-based urethanes, as opposed to solvent-based urethane wastes.

The good practice guidance IPCC defaults were used for the CO_2 estimation: carbon content (50%), and fossil carbon as % of total carbon (90%). In the absence of IPCC default values for N_2O and CH_4 emission factors, EFs were derived from one hazardous waste incineration facility that had provided total emissions based on direct measurements of N_2O and CH_4 emissions for the year 2007. The site burned 177 tons of hazardous waste (HW) and emitted 0.03 tons CH_4 and 0.56 tons N_2O in 2007. The emission factors were then calculated as 0.0001695 t CH_4/t HW and 0.003164 t N_2O/t HW.

A3.5.5.2. Data Sources

The amount of MSW incinerated in the year 1992 was estimated by the Hazardous Waste Branch of Environment Canada (Environment Canada 1996b). The amount of MSW incinerated for the years 1999, 2000, and 2001 was estimated by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

The amount of fossil fuel-based carbon available in the waste incinerated is determined using typical percent weight carbon constants. Carbon constants and moisture contents were provided by Tchobanoglous et al. (1993) and Peavy et al. (1985).

Hazardous incineration activity data were obtained directly from facilities. Surveys were conducted by Environment Canada in 2006, 2008 and 2010 (Environment Canada 2010) and 2012 (Environment Canada 2013c).

Table A3–61 Activity Data and Emissions from Hazardous Waste Incineration for 1990–2012

Year	Quantitiy of Hazardous Waste Incinerated	Estimated GHG Emissions		
	tonnes	kt CO_2	kt N_2O	kt CH_4
1990	100 762	166.3	0.319	0.017
1991	109 111	180.0	0.345	0.018
1992	117 879	194.5	0.373	0.020
1993	125 109	206.4	0.396	0.021
1994	142 050	234.4	0.449	0.024
1995	164 727	271.8	0.521	0.028
1996	146 125	241.1	0.462	0.025
1997	132 348	218.4	0.419	0.022
1998	155 511	256.6	0.492	0.026
1999	140 820	232.4	0.446	0.024
2000	168 379	277.8	0.533	0.029
2001	179 525	296.2	0.568	0.030
2002	184 845	305.0	0.585	0.031
2003	144 036	237.7	0.456	0.024
2004	161 891	267.1	0.512	0.027
2005	157 788	260.4	0.499	0.027
2006	147 775	243.8	0.468	0.025
2007	134 878	222.5	0.427	0.023
2008	154 573	255.0	0.489	0.026
2009	140 995	232.6	0.446	0.024
2010	138 031	227.8	0.437	0.023
2011	130 503	215.3	0.413	0.022
2012[a]	130 503	215.3	0.413	0.022

A3.5.6. N_2O Emissions from Waste Incineration

A3.5.6.1. Methodology

Municipal Solid Waste Incineration

Emissions of N_2O from MSW incineration are estimated using the assumption that the IPCC five-stoker facility factors are most representative. The average N_2O emission factor over the range given as IPCC default values for MSW five-stoker facilities is 0.148 kg/t waste incinerated (IPCC/OECD/IEA 1997). To estimate emissions, the calculated factor is multiplied by the amount of waste incinerated by each province. The national emission values are then determined as the summation of these emissions for all provinces.

Equation A3–93:

$$N_2O_{MSW} = M_{MSW} \times EF_{N_2O-MSW}$$

where:

N_2O_{MSW}	=	N_2O emissions from municipal solid waste incineration, t/year
M_{MSW}	=	mass of municipal solid waste incinerated, t/year
$EF_{N2O-MSW}$	=	MSW N_2O emission factor (0.148 kg N_2O/t MSW incinerated / 1000 kg/t)

Sewage Sludge Incineration

Emissions of N_2O from sewage sludge incineration are estimated using the IPCC default emission factor for fluidized beds, 0.8 kg/t of dried sewage sludge incinerated (IPCC 2000). To estimate emissions, the calculated factor is multiplied by the amount of waste incinerated by each province. The national emission values are then determined as the summation of these emissions for all provinces.

Equation A3–94:

$$N_2O_{ss} = M_{ss} \times EF_{N_2O-SS}$$

where:

N_2O_{SS}	=	N_2O emissions from sewage sludge incineration, t/year
M_{SS}	=	mass of dried sewage sludge incinerated, t/year
EF_{N2O-SS}	=	sewage sludge N_2O emission factor (0.8 kg N_2O/t dried sludge incinerated / 1000 kg/t)

Hazardous Waste Incineration

Refer to Section A3.5.5.1.

A3.5.6.2. Data Sources

Data sources for MSW incineration are described in Section A3.5.5.2.

Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994. Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

Hazardous incineration activity data were obtained directly from facilities. Surveys were conducted by Environment Canada in 2006, 2008 and 2010 (Environment Canada 2010) and 2012 (Environment Canada 2013c).

A3.5.7. CH_4 Emissions from Waste Incineration

A3.5.7.1. Methodology

MSW Incineration

CH_4 emissions from the incineration of MSW are assumed to be negligible, as supported by the findings of a recent study commissioned by Environment Canada (CRA 2011). However, waste incineration of the biosolids resulting from municipal wastewater treatment does produce CH_4 emissions. The IPCC does not provide a methodology for CH_4 emissions from waste incineration, but recommends that national experts use existing published methods (IPCC 2000).

Emissions of CH_4 are estimated based on emission factors obtained from the U.S. Environmental Protection Agency (US EPA 1995). The emission factors are 1.6 t/kt of total dried solids for fluidized bed sewage incinerators and 3.2 t/kt of dried solids for multiple hearth incinerators, both equipped with venturi scrubbers. It is assumed that all incinerators are of the fluidized bed type.

CH_4 emissions from sewage sludge incineration are dependent on the amount of dried solids incinerated. To calculate the CH_4 emissions, the amount of dried solids incinerated is multiplied by an appropriate emission factor. Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994 (Environment Canada

1994b). Data for the years 1993–1996 were acquired through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b). To estimate the amount of sewage sludge incinerated in the years 2002–2012, a linear regression analysis was completed using the A.J. Chandler & Associates Ltd. and Compass Environmental Inc. MSW incineration values.

In view of the relatively small number of facilities that incinerate sewage sludge in Canada, we believe that all relevant facilities were contacted, and we expect that the activity data collected from all three sources of information are complete. As such, our approach in estimating the amount of sewage sludge incinerated over the time series years is consistent.

Sewage sludge incineration estimates for the period 1990–2012 are shown in Table A3–62.

CH_4 emissions are calculated as follows:

Equation A3–95:

$$CH_{4(s)} = S_{Inc} \times EF_{CH_4-FB}$$

where:

$CH_{4(s)}$	=	CH_4 emissions from waste incineration, t/year
S_{Inc}	=	sewage sludge incinerated, dry t/year
EF_{CH4-FB}	=	CH_4 emission factor for fluidized bed incinerators: 1.6 t CH_4/kt sewage sludge incinerated / 1000 kg/t

Hazardous Waste Incineration

Refer to Section A3.5.5.1.

A3.5.7.2. Data Sources

Estimates of the amount of dried solids in the sewage sludge incinerated in the years 1990–1992 are based on a study completed in 1994. Data for the years 1993–1996 were acquired

Table A3–62 Estimated Sewage Sludge Incinerated for 1990–2012

	Sewage Sludge Incinerated (t, dry basis)				
Year	Que.	Ont.	Sask.	Alta.	National Total
1990	49 200	222 795	1 840	0	273 835
1991	59 400	222 795	1 840	0	284 035
1992	79 800	222 795	1 840	0	304 435
1993	64 833	129 125	71	0	194 029
1994	100 181	93 072	59	0	193 311
1995	101 356	113 985	152	0	215 493
1996	93 276	112 697	70	0	206 043
1997	15 424	0	0	4 885	20 310
1998	18 341	0	0	4 951	23 292
1999	22 032	0	0	0	22 032
2000	24 651	0	0	0	24 651
2001	27 960	0	0	0	27 960
2002	31 096	0	0	0	31 096
2003	34 234	0	0	0	34 234
2004	37 373	0	0	0	37 373
2005	40 511	0	0	0	40 511
2006	43 649	0	0	0	43 649
2007	46 787	0	0	0	46 787
2008	49 925	0	0	0	49 925
2009	53 064	0	0	0	53 064
2010	56 202	0	0	0	56 202
2011	59 340	0	0	0	59 340
2012	62 478	0	0	0	62 478

Note:
A large step change is observed in the quantities of sewage sludge incinerated in Ontario for the period 1996–1997. This is as a result of two pilot projects that were approved in the mid-1990s for the non-incineration waste disposal of sewage sludge. The first project involved the spreading of treated sewage sludge on farmers' fields outside of Toronto, and the second project involved the transportation of sewage sludge to be spread on mine tailings. Both projects proved to have difficulties, owing to odour problems and the large quantities of waste that were to be spread on farmers' fields. From 1996 to 2000, Toronto sludge was stored during periods when excess quantities of waste were unable to be applied on land. In 2001, a new contract commenced that involved the spread of biosolids on Ontario farmers' fields, with excess biosolids being shipped to U.S. landfill sites.

through telephone surveys of facilities that incinerate sewage sludge (Environment Canada 1997). Data for the years 1997 and 1998 are based on a study prepared by Compass Environmental Inc. for Environment Canada (Environment Canada 1999). Activity data for the years 1999, 2000 and 2001 are taken from a study prepared by A.J. Chandler & Associates Ltd. for Environment Canada (Environment Canada 2003b).

Hazardous incineration activity data were obtained directly from facilities. Surveys were conducted by Environment Canada in 2006, 2008 and 2010 (Environment Canada 2010) and 2012 (Environment Canada 2013c).

Annex 4

Comparison of Sectoral and Reference Approaches

This annex covers the energy and the CO_2 emission results from the reference approach (RA), a comparison of the results from the RA with those estimated by the sectoral approach (SA), and a summary of the national energy balance, which is the main energy data source for both the RA and the SA.

A4.1. Comparison of Reference Approach with Sectoral Approach

Results from the RA were compared with the SA as a check of energy consumed and CO_2 emissions from the combustion of fossil fuels. The check was performed for all years from 1990 to 2012 and is an integral part of reporting to the United Nations Framework Convention on Climate Change (UNFCCC).

Direct comparison of energy results in the RA and SA show significant discrepancies, given that the SA total does not include some of the non-energy use of fossil fuels and feedstocks. Comparison of the RA and SA shows a 4.1–6.6% variation in energy. This is corrected by excluding the non-combustion energy of certain feedstocks and fossil fuels to ensure that the RA and the SA are comparing similar sources. When the RA energy amounts include adjustments for non-energy use of feedstocks and fossil fuels, the difference between the SA and adjusted RA varies from

Table A4–1 Comparison of Adjusted Reference Approach and Sectoral Approach for Canada (1990–2000)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Overall Energy Comparison											
Reference Approach (PJ)	6,887	6,558	6,761	6,811	7,055	7,237	7,393	7,619	7,745	7,960	8,320
Sectoral Approach (PJ)	6,387	6,231	6,470	6,481	6,707	6,863	7,079	7,235	7,325	7,611	7,955
Percentage Difference without Adjustment (%)	6.4	5.7	5.1	5.5	5.6	5.9	6.5	6.4	6.6	5.9	5.2
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	6,297	6,091	6,298	6,306	6,538	6,692	6,898	7,012	7,130	7,392	7,743
Percentage Difference with Adjustment - 100% x (RA-SA)/SA	4.23	1.06	0.57	0.63	0.69	0.95	-1.12	-0.36	0.34	-0.62	0.05
Adjusted Non-Energy Fossil Fuels and Feedstocks											
Non-Energy Use of Gaseous Fuels (PJ)	159	181	177	201	208	210	273	282	276	273	234
Non-Energy Use of Liquid Fuels (PJ)	63	73	70	81	89	92	113	119	111	116	119
Non-Energy Use of Solid Fuels (PJ)	9	8	8	9	9	10	11	11	11	10	12
Overall Emission Comparison											
Overall - Reference Approach (Gg CO_2)	422,638	403,223	413,845	413,502	427,481	438,601	443,419	458,582	469,252	480,567	508,396
Overall - Sectoral Approach (Gg CO_2)	413,899	404,055	417,808	414,994	427,627	438,531	451,393	464,271	471,495	487,687	509,934
Overall - Percentage Difference (%)	2.11	-0.21	-0.95	-0.36	-0.03	0.02	-1.77	-1.23	-0.48	-1.46	-0.30
Liquid Fuels											
Reference Approach (Gg CO_2)	193,638	197,332	203,313	203,727	204,742	215,029	220,601	220,192	224,475	224,834	224,636
Sectoral Approach (Gg CO_2)	189,388	191,219	195,942	197,693	203,651	210,707	215,009	217,169	219,632	222,712	221,963
Percentage Difference (%)	2.24	3.20	3.76	3.05	0.54	2.05	2.60	1.39	2.20	0.95	1.20
Solid Fuels											
Reference Approach (Gg CO_2)	83,695	87,689	89,721	82,842	86,720	89,640	90,776	97,019	103,459	103,657	113,549
Sectoral Approach (Gg CO_2)	85,870	89,073	91,576	83,940	88,287	89,698	91,603	98,566	104,206	104,359	113,360
Percentage Difference (%)	-2.53	-1.55	-2.03	-1.31	-1.77	-0.06	-0.90	-1.57	-0.72	-0.67	0.17
Gaseous Fuels											
Reference Approach (Gg CO_2)	131,990	122,128	130,394	133,156	137,098	144,953	147,614	146,394	144,978	156,510	170,127
Sectoral Approach (Gg CO_2)	128,650	128,238	136,752	139,663	143,047	150,859	155,853	154,858	152,066	165,950	176,696
Percentage Difference (%)	2.60	-4.76	-4.65	-4.66	-4.16	-3.91	-5.29	-5.47	-4.66	-5.69	-3.72

Table A4-1 Comparison of Adjusted Reference Approach and Sectoral Approach for Canada (2001–2012)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Overall Energy Comparison												
Reference Approach (PJ)	8,099	8,245	8,792	8,558	8,423	8,290	8,704	8,485	8,059	8,376	8,467	8,458
Sectoral Approach (PJ)	7,854	7,964	8,191	8,132	8,055	7,942	8,328	8,123	7,771	7,943	8,083	7,985
Percentage Difference without Adjustment (%)	5.3	5.0	5.8	5.9	5.4	4.1	5.6	6.2	5.2	6.0	6.0	5.3
Reference Approach with Non-Energy Use of Fossil Fuels and Feedstock Adjustment (PJ)	7,635	7,769	8,062	7,852	7,855	7,553	8,108	7,978	7,558	7,704	7,704	7,751
Percentage Difference with Adjustement - 100% x (RA-SA)/SA	-2.28	-0.95	2.12	-0.62	-0.69	-1.16	-0.83	-0.39	-1.61	0.42	-0.10	0.34
Adjusted Non-Energy Fossil Fuels and Feedstocks												
Non-Energy Use of Gaseous Fuels (PJ)	268	201	219	240	201	211	194	166	176	161	192	187
Non-Energy Use of Liquid Fuels (PJ)	150	150	203	224	177	182	206	192	207	213	202	262
Non-Energy Use of Solid Fuels (PJ)	10	10	10	18	49	51	49	40	34	30	4	1
Overall Emission Comparison												
Overall - Reference Approach (Gg CO_2)	494,721	503,125	537,560	517,352	514,415	503,259	530,156	513,308	483,163	496,834	494,478	489,261
Overall - Sectoral Approach (Gg CO_2)	504,789	508,392	523,353	519,944	514,322	505,668	529,857	513,417	486,244	495,556	497,751	489,587
Overall - Percentage Difference (%)	-1.99	-1.04	2.71	-0.50	0.02	-0.48	0.06	-0.02	-0.63	0.26	-0.66	-0.07
Liquid Fuels												
Reference Approach (Gg CO_2)	258,749	250,674	245,937	239,964	248,558	241,263	234,905	240,769	236,015	235,850	236,015	235,850
Sectoral Approach (Gg CO_2)	236,950	245,290	241,184	237,789	245,198	236,028	231,506	235,135	233,676	230,340	233,676	230,340
Percentage Difference (%)	9.20	2.19	1.97	0.91	1.37	2.22	1.47	2.40	1.00	2.39	1.00	2.39
Solid Fuels												
Reference Approach (Gg CO_2)	109,880	108,759	106,978	99,273	100,952	99,425	105,949	96,714	80,761	82,982	75,750	68,186
Sectoral Approach (Gg CO_2)	111,752	109,327	108,369	101,036	102,277	98,626	103,579	97,791	82,087	83,121	74,055	68,155
Percentage Difference (%)	-1.67	-0.52	-1.28	-1.75	-1.30	0.81	2.29	-1.10	-1.61	-0.17	2.29	0.04
Gaseous Fuels												
Reference Approach (Gg CO_2)	159,770	169,358	171,470	167,007	167,238	163,558	175,221	174,901	167,168	172,745	182,369	184,881
Sectoral Approach (Gg CO_2)	170,089	176,732	177,671	173,220	170,574	168,941	180,653	179,169	172,323	176,962	189,675	190,747
Percentage Difference (%)	-6.07	-4.17	-3.49	-3.59	-1.96	-3.19	-3.01	-2.38	-2.99	-2.38	-3.85	-3.08

-4.2 to -2.3%. 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, because Common Reporting Format (CRF) software supplied by the UNFCCC correctly removes non-energy-associated and feedstock-associated emissions, and allocates them to industrial processes. Comparison of the RA and SA emission estimates, as seen in Table A4–1 shows an overall -1.8 to 2.7% variation.

A4.2. Reference-approach Methodology

The RA follows the Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guideline's designated method with the use of country-specific energy conversion factors (in higher heating value [HHV]/gross calorific value [GCV]) and emission factors. In Canada, as in the United States, HHV is used to record the energy content of fuels. Fuel quantities from the most recent *Report on Energy Supply–Demand in Canada* (RESD; Statistics Canada catalogue no. 57-003) are entered in their physical units, with the exception of international bunkers. A discussion of the data for international bunkers is presented in the following sections: Chapter 3.4.1, International Bunker Fuels; A2.4.2.3, Civil Aviation; and A2.4.2.4, Navigation. For primary fuels (crude oil, coal and natural gas), the stock change data have been adjusted to account for inter-product transfers, stock variation and other adjustments, and are then transformed to other fuels to determine the apparent consumption values. The stock change data for secondary fuels take into consideration imports, exports, international bunkers, stock variations, non-energy use and other adjustments.

Once the apparent consumption is determined, country-specific energy conversion factors and carbon emission factors are used to calculate the carbon content and emissions. These factors are taken from the following sources: Statistics Canada's annual *Report on Energy Supply–Demand in Canada* (RESD, catalogue no. 57-003); *Canada's Greenhouse Gas Emissions: Estimates for 1990* (Jaques 1992); the *1998 Fossil Fuel and Derivative Factors* (McCann

2000); and Measurement Canada, an Industry Canada agency. For the majority of fossil fuels, the applied emission factors and oxidation factors are from McCann (2000), Jaques (1992) and from IPCC/OECD/IEA (1997).

Table A4–2 presents the applied emission factor, energy conversion factor and oxidation value in the RA. Energy conversion factors are taken directly from the RESD, with the exception of crude oil, natural gas, petroleum coke and still gas, where weighted factors have been developed to account for the quantity and variation of energy content at the point of consumption such as commercial usage or self-generated usage. For example, for provinces with natural gas production, there are two emission factors for natural gas: marketable natural gas, which is sold to

Table A4–2 Reference Approach Energy Conversion and Emission Factors for Canada

Fuel Types			Energy Conversion Factor, GCV			Carbon Emission Factor – 2012 Value (t C/TJ GCV)	Reference	Oxidation Factors (IPCC Default)	Comments
			2012 Value	Unit	Reference				
Liquid	**Primary Fuels**	Crude Oil	39.13	TJ/ML	See Comments	19.26	Refer to Comments	0.99	Weighted energy conversion and emission factor are based on country-specific data.
		Orimulsion	NA	–	–	NA	–	0.99	
		Natural Gas Liquids	IE	–	–	IE	–	–	1) Ethane from natural gas liquids reported in Gaseous fuel category. 2) Depending on source, butane and propane have been allocated to the Gaseous and Liquid Fossil fuel category.
	Secondary Fuels	Bitumen	44.46	TJ/ML	4	21.11	3	0.99	Use of asphalt.
		Butane	28.44	TJ/GL	4	16.67	2	0.995	Refinery sourced butane
		Gas/ Diesel Oil	38.3	TJ/ML	4	18.86	2	0.99	Use of diesel fuel oil.
		Gasoline	35	TJ/ML	4	17.84	2	0.99	
		Jet Kerosene	37.4	TJ/ML	4	18.67	2	0.99	Use of aviation turbo fuel.
		Other Kerosene	37.68	TJ/ML	4	18.53	2	0.99	
		LPG	25.31	TJ/GL	4	16.35	2	0.99	Propane and butane from refineries are allocated to the Liquid Fossil fuel category.
		Lubricants	39.16	TJ/ML	4	19.66	3	0.99	
		Naphtha	35.17	TJ/ML	4	19.33	3	0.99	
		Other Oil	38.8	TJ/ML	4	19.15	2	0.99	Use of light fuel oil.
		Petroleum Coke – Refinery and Upgrader	44.11	TJ/ML	4	22.81	4	0.99	Reallocated to the Liquid Fossil fuel category for 2013 submission. Country-specific weighted emission factors based on available emission factors for refining and upgrading (of oil sands to synthetic crude oil).
		Propane	25.31	TJ/GL	4	16.35	2	0.995	Refinery sourced propane.
		Refinery Feedstocks	35.17	TJ/ML	4	19.33	3	0.99	Use of petrochemical feedstock in industrial processes
		Residual Fuel Oil	42.5	TJ/ML	4	20.07	2	0.99	Use of heavy fuel oil.
		Shale Oil	NA	–	–	NA	–	–	
		Still Gas – Refinery and Upgrader Fuel Gas	39.42	TJ/ML	4	12.81	4	0.99	Country-specific weighted emission factor based on factors from refinery and from upgrading (of crude from oil sands to synthetic crude oil) activities.

Table A4-2 Reference Approach Energy Conversion and Emission Factors for Canada (cont'd)

Fuel Types			Energy Conversion Factor, GCV			Carbon Emission Factor – 2012 Value (t C/TJ GCV)	Reference	Oxidation Factors (IPCC Default)	Comments
			2012 Value	Unit	Reference				
	Other Liquid Fuels	Aviation Gasoline	33.52	TJ/ML	4	19.25	3	0.99	
		Other Product Feedstocks	39.82	TJ/ML	4	19.84	3	0.99	
Solid	Primary Fuels	Anthracite	27.7	TJ/kt	4	23.50	3	0.99	
		Other Bituminous Coal	26.9	TJ/kt	4	22.20	5	0.99	Use of Canadian bituminous coal
		Sub-bituminous Coal	19.15	TJ/kt	4	24.84	5	0.99	
		Lignite	15	TJ/kt	4	26.36	5	0.99	
		Oil Shale	NA	–	–	NA	–	–	
		Peat	NA	–	–	NA	–	–	
	Secondary Fuels	Coke	28.83	TJ/kt	4	23.69	2	0.99	Previously reported as Coking Coal.
		BKB & Patent Fuel	NA	–	–	NA	–	–	
		Coke Oven Gas	19.14	TJ/GL	4	12.52	2	–	Previously reported in Gaseous fuel category.
	Other Solid Fuels	Foreign Bituminous Coal	29.82	TJ/kt	4	23.43	5	0.99	
Gaseous	Primary Fuels	Natural Gas	38.46	TJ/GL	4	13.84	2	0.995	Country-specific weighted emission factor based on proportion of marketable and non-marketable natural gas.
	Other Gaseous Fuels	Ethane	17.22	TJ/GL	4	15.46	2	0.995	Total available ethane is consumed as a feedstock in industrial processes.
		Propane	25.31	TJ/GL	4	16.35	2	0.995	NGL sourced propane.
		Butane	28.44	TJ/GL	4	16.67	2	0.995	NGL sourced butane
Biomass		Solid Biomass	18	TJ/kt	4	28.41	3	0.99	1) Consists of industrial and residential biomass consumption. 2) Assumed 99% oxidation.
		Liquid Biomass	16.18	TJ/kt	4	18.80	3	0.955	1) Consists of spent pulping liquor, ethanol and biodiesel. 2) Weighted oxidation factor.
		Gas Biomass	39.82	TJ/Gl	1	14.97	1	0.99	1) Consists of methane from landfill gas. 2) Assumed a 99% oxidation factor.

References: : (1) IPCC/OECD/IEA (1997); (2) McCann (2000); (3) Jaques (1992); (4) Statistics Canada, #57-003 (2012 data); (5) Radovan R, Hassani N. et al. (2012).
NA = Not applicable; BKB = Charcoal briquettes; NGL = natural gas liquids; LPG = liquified petroleum gas; IE = included elsewhere.

consumers, and non-marketable natural gas, which is consumed directly by the producers of natural gas.

To adjust the RA for comparison with the SA, non-energy use of fossil fuels and feedstocks and the corresponding carbon dioxide emitted must be calculated using the storage and emission factors for industrial processes presented in Annex 8 of the NIR.

A4.3. National Energy Balance

Statistics Canada provides Environment Canada with a large portion of the underlying activity data to estimate GHG emissions for the Energy Sector and the Industrial Processes Sector. Statistics Canada's Manufacturing and Energy Division (MED) is responsible for the collection, compilation and dissemination of the energy balance in the RESD. The objective of MED is to ensure that the information as collected under the authority of the *Statistics Act* and used in the development of the energy balance meets the

following quality criteria: completeness, consistency, coherency and accuracy. The quality management system for the energy balance also includes an internal and external review process. MED's quality assurance framework and methodological reports are documented and made available through Statistics Canada's Integrated Meta Database.

The energy balance is an accounting of all available energy forms in Canada from import and export activities through production and domestic consumption (refer to Figure A4–1 for a sample of an energy flow diagram). Energy and fossil fuel data are collected by various methods, such as a mix of annual or monthly surveys and some censuses from industry, federal agencies (such as the National Energy Board [NEB], the Energy Resources Conservation Board [ERCB] and the Alberta Utilities Commissions [AUC]), provincial energy departments, and from the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC). Refer to Figure A4–2 for a sample of the energy and fossil fuel data input to MED and what information is provided by each of the data sources or respondents. Oil and gas information as provided by the ERCB is highly accurate, since it is tied to oil and gas exploitation permits and to federal and provincial royalty schemes.

There are also other internal data quality checks of the information collected through provincial energy departments and from various supply, disposition and consumption surveys. For example, the quantity of crude oil shipped as reported by the producer is verified against report receipts from pipeline companies, and the information as reported by pipelines is verified against refinery receipts. MED also applies both a top-down approach through the supply and disposition surveys and a bottom-up approach through the *Industrial Consumption of Energy survey* to verify the quality of the data for manufacturing industries, including the petroleum refining industry. In addition, technical information on energy characteristics is collected to verify reported fuels in physical and energy units.

The energy balance consists of information on crude oil, natural gas, coal, refined petroleum product (RPPs), electricity, steam, non-energy use of fossil fuels, feedstock and other secondary energy forms for all Canadian industrial sectors and other energy use, such as the transportation, residential and commercial sectors.

Both the I*ndustrial Consumption of Energy survey* product and the energy balance are used by various federal departments for energy efficiency programs, policy development, reporting to the International Energy Agency, energy and emission forecasting, and reporting to the UNFCCC. As such, MED has established partnerships with various federal government departments, provincial energy ministries, industrial associations and centres of excellence to assist with their quality assurance process.

For example, a "work-in-progress" review has been established with Environment Canada and Natural Resources Canada (NRCan) to review the industrial consumption of energy estimates and the

Figure A4–1 Sample of an Energy Balance Flow Diagram for Canada (RESD)

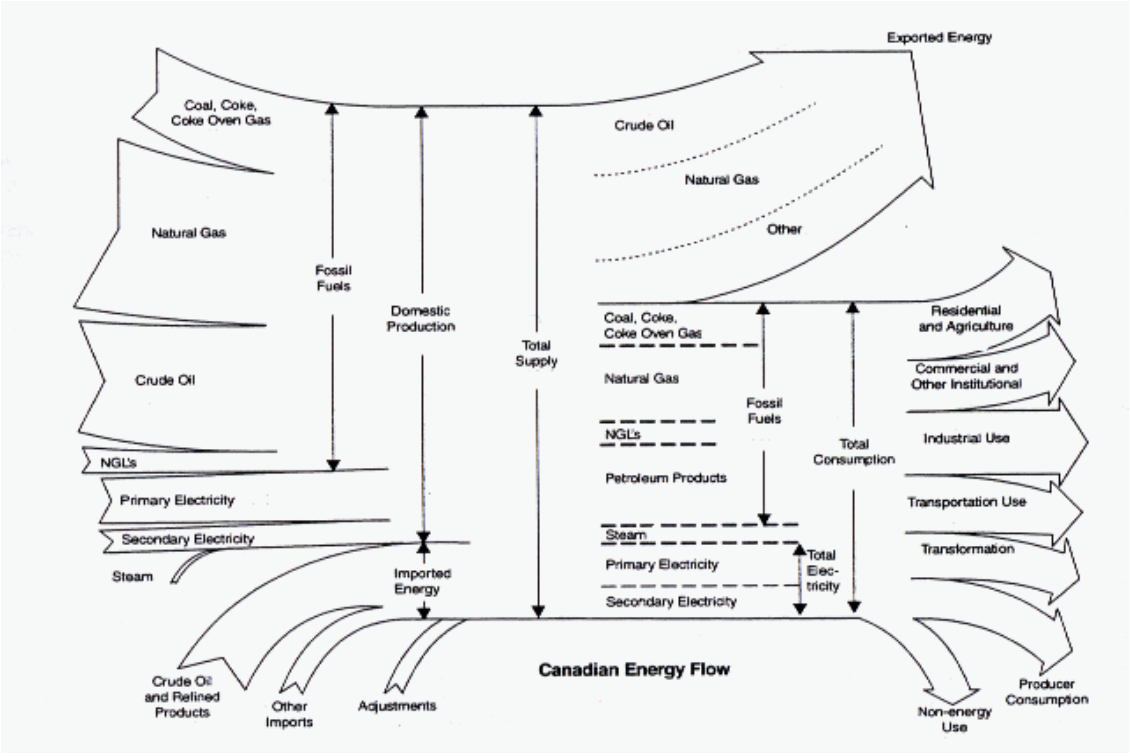
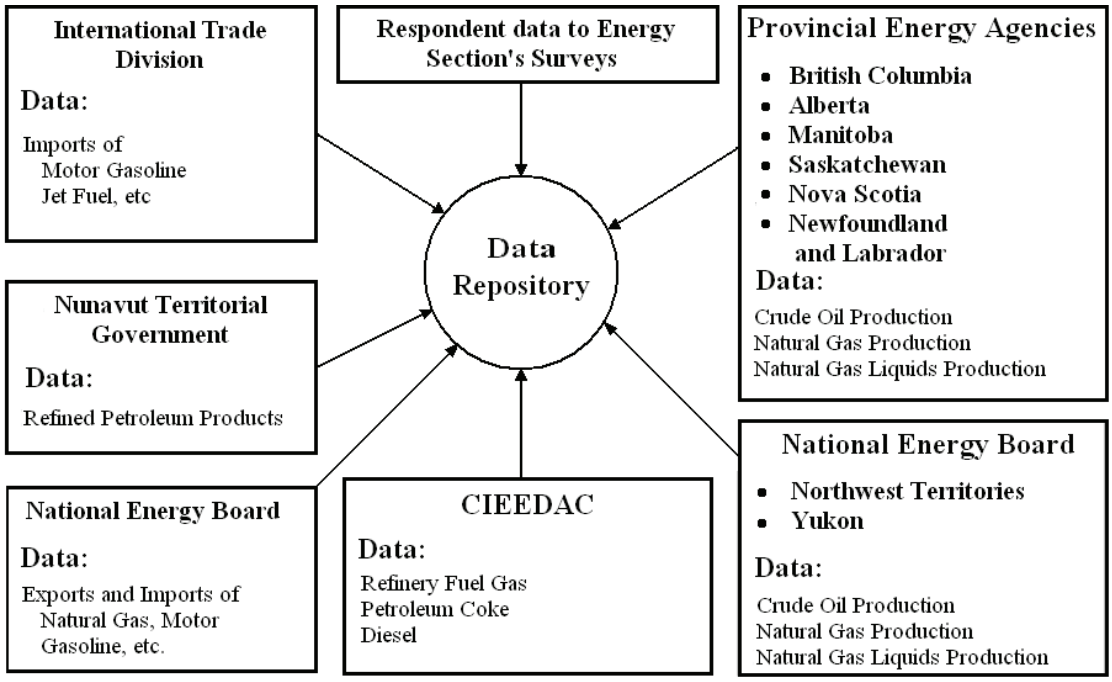


Figure A4–2 Fossil Fuel and Energy Data Input



energy balance prior to their official release. Canadian industrial members also participate in the review of industrial data through the Canadian Industrial Program for Energy Conservation group. The Canadian Industrial Energy End-Use Data and Analysis Centre also participates in the review of refinery data and the industrial energy statistics.

Owing to the complexity of energy data, a working group on energy statistics was established to provide advice, direction and recommendations. The working group consists of members from Statistics Canada, Environment Canada, Industry Canada, Transport Canada, Foreign Affairs Canada and Natural Resources Canada. Its mandate is to identify and address issues related to the collection of a comprehensive set of energy data for various sectors of the economy and to improve existing energy statistics.

Annex 5

Assessment of Completeness

Although this inventory report serves as a comprehensive assessment of anthropogenic greenhouse gas (GHG) emissions and removals in Canada, some categories have not been included or have been included with other categories for reasons explained in the Common Reporting Format (CRF) tables and in this annex.

A5.1. Energy

Overall, the Energy Sector of the national inventory provides a full estimate of all significant sources.

A5.2. Industrial Processes

Overall, the Industrial Processes Sector of the national inventory provides a comprehensive estimate of all significant sources. Discussed in the following subsections are sources that are not currently estimated or for which estimates are included in other sources. For the sources that are not estimated their magnitudes are assumed to be small and not affecting the overall completeness of the GHG inventory.

A5.2.1. Mineral Products

Carbon dioxide (CO_2) emissions from asphalt roofing and road paving with asphalt are not estimated. There is currently no country-specific information on this. However, based on Chapter 5, Volume 3 of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines (IPCC 2006), CO_2 emissions from this category are thought to be negligible.

The CO_2 emissions resulting from the use of limestone, dolomite, and soda ash are reported under the source categories of 2.A.3 Limestone and Dolomite Use, and 2.A.4 Soda Ash Production and Use. The use of soda ash in glass manufacturing is included in 2.A.4. Other uses of these minerals, not identified in 2.A.3 and 2.A.4, are not estimated and are considered to be minor based on Chapter 2, Volume 3 of the 2006 IPCC Guidelines (IPCC 2006).

Soda ash was produced in Canada until 2001. The Solvay process in which soda ash was produced results in some CO_2 emissions. However, as CO_2 is also a necessary component in the process reactions, it is most commonly recovered for reuse. Hence, the quantity of recovered CO_2 is estimated in the inventory for the years 1990–2001, but the net amount of non recovered (i.e. emitted) CO_2 coming from soda ash production is not estimated and is considered to be minimal.

A5.2.2. Chemical Production

Nitrous oxide (N_2O) emissions associated with the production of chemicals other than nitric acid, adipic acid and ethylene are reported as "Not Estimated" ("NE"). According to a recent study (Cheminfo Services 2010), production of chemicals, such as ammonia and methanol, is not a large source of N_2O emissions (i.e. not more than 10 kt CO_2 eq/year).

Process-related CO_2 emissions from adipic acid production are not inventoried (i.e. not estimated) and are considered negligible in comparison with the amount of CO_2 emitted from fuel combustion.[1]

A5.2.3. Metal Production

Process methane (CH_4) emissions associated with the production of metals are currently reported as "Included Elsewhere" ("IE") in the case of Iron Production, and "NE" for the rest of the Metal Production subsector. The CH_4 emissions resulting from coal coke used as a reductant for iron and steel production (2.C.1) are accounted for in the Energy Sector. The CH_4 emissions from coke production under 2.C.1 have changed notation in this NIR from "NE" to "IE," indicating its inclusion in the Energy Sector.

A5.2.4. Production and Consumption of Halocarbons and SF6

The pre-1995 consumption levels (and emissions) of hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) in Canada have been assumed to be negligible; therefore, these emissions are "NE" ("Not Estimated"). The ban on the production and use of chlorofluorocarbons (CFCs) came into effect in 1996 as a result of the implementation of the Montreal Protocol. This resulted in the adoption of PFCs and HFCs as alternatives to CFCs from 1995 onwards. The data on PFCs used in aerosols are currently unavailable; as a result, the associated emissions are not inventoried (i.e. reported as "NE"). There are also some PFCs emitted from the electronic industry, and these emissions are reported under 2.F.9 Other (Contained and Emissive Emissions from Electronic Industries).

1 Lauridsen S. 2005. Personal communication (email dated November 3, 2005). Invista Canada. Lauridsen S. 2005. Personal communication (email dated November 3, 2005). Invista Canada.

HFC emissions from electronic industries are reported under the category 2.F.5 Solvents, not 2.F.9 Other (Contained and Emissive Emissions from Electronic Industries), in the CRF reporter, since it is not possible for this submission to separate HFC consumption as solvent in electronic industries from other types of solvent use; hence the "IE" notation in category 2.F.9. HFC emissions coming from electrical equipment are reported as "Not Occurring" ("NO") because there is no known use of HFCs for electrical insulation and arc quenching in equipment used in the electricity industry.

According to the electricity industry, carbon tetrafluoride (CF_4) has been used in some outdoor electrical equipment. Specifically, it is found in gas mixtures with sulphur hexafluoride (SF_6), since SF_6 alone cannot function properly as an insulating gas in low temperatures. There are ongoing discussions with the industry, so that CF_4 use and emission data can be collected and reported by Environment Canada in future inventories.

Potential emissions of SF_6, which should be derived from the information on imports and exports of SF_6 (in bulk and in product), are reported as "NE" since there is currently no comprehensive information on SF_6 imports/exports. Based on information provided by major SF_6 gas distributors, there is no bulk SF_6 exported from Canada. The electricity industry has also indicated that destruction or recycling of SF_6 found in electrical equipment is done in the United States. The notation for SF_6 emissions in category 2.F.9 ("Other") is changed from "NO" to "NE" as per the Expert Review Team's (ERT's) recommendation. The subject (residual) emission source of SF_6 will need further examination to assess its potential level.

A5.2.5. Other and Undifferentiated Production

CO_2 emissions from the non-energy use of hydrocarbons are estimated using two types of emission factors. The first type was developed by simply converting the national carbon contents for non-energy fuel types to GHG emission factors, while the second type was derived based on both national carbon contents and IPCC default fractions of carbon stored. The IPCC default fractions of carbon stored take into account the release of carbon from the use or destruction of the manufactured products over a short term only. CO_2 emissions from the combustion of waste fuels (made from non-energy use of hydrocarbons) need to be researched further. This, to understand to what extent the IPCC default fraction of carbon stored represents the release of carbon from use or destruction of the product in the short term (versus the long term).

A5.3. Solvent and Other Product Use

In this sector, only N_2O emissions associated with the use of anaesthetics and propellants are estimated. CO_2 emissions from use of solvents in dry cleaning, printing, metal degreasing, and a variety of industrial applications as well as household use are reported as "IE"—in category 2.G Other and Undifferentiated Production, which considers CO_2 emissions from use of refinery output products (solvents). According to a recent study (Cheminfo Services 2010), there has been no N_2O used in fire extinguishers because the decomposition of N_2O provides a source of oxygen for flammable materials that would sustain, not suppress, any fire. As such, N_2O from fire extinguishers (category 3.D.2 in the CRF) is reported as "NO."

A5.4. Agriculture

Overall, the Agriculture Sector of the national inventory provides a complete estimate of the significant sources. The following list includes sources that are not currently estimated. These are considered to be minor sources.

A5.4.1. Enteric Fermentation and Manure Management

Some minor animal categories, such as ranched deer, wild boar, elk and ducks, have not yet been included. Complete IPCC default emission factors and parameters are unavailable for these categories, and they have relatively low populations. Mules, asses and camels are reported as not occurring because Statistics Canada does not compile populations of these animals due to their low occurrence, and as such no national population estimates are available. At this time, information on animal waste manure systems using anaerobic lagoons, and daily spread, by livestock category, is not available. These manure management systems are considered minor by Canadian experts when compared with liquid/slurry and solid and dry lot storage. There are plans to collect information on animal waste management systems—including distributions for anaerobic lagoons, daily spread and dry lot—as well as plans to report emissions from these sources in the mid-to-long term.

A5.4.2. Prescribed Burning of Savanna

Prescribed Burning of Savanna is not a relevant reporting category for Canada.

A5.4.3. Rice Production

CH_4 emissions from rice production are not currently inventoried, as rice production is not occurring in Canada.

A5.5. Land Use, Land-use Change and Forestry

The Land Use, Land use Change and Forestry (LULUCF) Sector is generally complete in terms of carbon pools and geographic coverage. Uncertainty ranges are provided for estimates in the Forest Land and Cropland categories, and for the area of forest conversion to other land and Land Converted to Forest Land categories. They are under preparation for all other land categories.

A5.5.1. Forest Land

Forest land estimates are provided for both forest land remaining forest land and land converted to forest land. These estimates include carbon stock changes and emissions from all pools (biomass, dead organic matter and soil) in managed forests resulting from growth and mortality, fire and insect disturbances, and management activities. Emissions of CO_2, CH_4, carbon monoxide (CO) and N_2O are estimated. Emissions of NO_x are not estimated. CO emissions occur during biomass burning only; they are reported as CO_2 emissions in the CRF Biomass Burning tables. Carbon stock changes and emissions reported from forest soils are assumed to include both mineral and organic soils, as specific data on organic soils are not readily available.

A5.5.2. Cropland

Estimates of cropland remaining cropland include soil and partial biomass estimates. Estimates for mineral soils capture the major land management changes (crop mixture, tillage practices and summerfallow). Other practices, such as irrigation, manure application and fertilization, which are also known to have some positive impacts on soil organic carbon (SOC), are not represented. The current estimate in the land converted to cropland category includes CO_2 emissions from all pools and N_2O emissions due to forest and grassland conversion to cropland. Non-CO_2 emissions (CH_4, CO, N_2O) from biomass burning during land conversion are also reported; NO_x estimates have not been estimated. GHG emissions and removals from the conversion of wetlands and settlements to cropland have not been estimated as default IPCC methodologies, and values are not provided.

A5.5.3. Grassland

Canada has made progress on collecting data on prescribed burning and wildfires from grassland remaining grassland by expert consultations, and reported emissions of CH_4 and N_2O in this submission. According to the land category definitions, the conversion of forest land to grassland cannot occur. Cropland conversion to grassland is not occurring. Emissions from the conversion of wetlands to grassland have not been estimated as default IPCC methodologies, and values are not provided.

A5.5.4. Wetlands

GHG emissions in land converted to flooded land, land converted to (managed) peatland, and (managed) wetlands remaining wetlands have been prepared but cannot be reported separately in the CRF tables. CO_2 estimates were developed in all categories; non-CO_2 (CH_4, CO and N_2O) estimates associated with biomass burning are reported in forest land converted to flooded land. Emissions of NO_x have not been estimated. Cropland and grassland converted to wetlands were not estimated as default IPCC methodologies, and values are not provided; however, emissions from land converted to flooded land would include those arising from the flooding of un-managed wetlands and grassland (tundra), which are reported in the category "Other Land converted to Wetlands."

A5.5.5. Settlements

The current estimates in the land converted to settlements category include forest loss to settlements and the conversion of tundra (unmanaged grasslands) to settlements in the Canadian north. Non-CO_2 emissions (CH_4, CO and N_2O) are reported only when biomass burning has occurred in the course of conversion activities. Emissions of NO_x have not been estimated. Emissions and removals from the conversion of cropland, agricultural grassland, wetlands and other land to settlements have not been estimated as default IPCC methodologies, and values are not provided. CO_2 estimates in settlements remaining settlements include only net carbon sequestration in the above ground biomass of urban trees.

A5.6. Waste

This category is for the most part complete, with the exception of the following.

A5.6.1. Unmanaged Solid Waste Disposal

For the purpose of complying with the completeness principle, emissions from unmanaged landfills are denoted as "IE." The disposal data related to unmanaged landfills are already included in the managed landfill data. The separation of the waste quantities placed in unmanaged landfills from those placed in managed landfills would have caused the uncertainty of estimates from the solid waste landfills to increase based on Environment Canada's assessment. The provincial waste quantities disposed of, from which the landfilled waste quantities are derived, are provided by

Statistics Canada (Statistics Canada 2000, 2003, 2004, 2007, 2008, 2010, 2013). The methodology employed in this survey accommodates inclusion of the population that may not have access to formal disposal facilities, i.e., unmanaged landfills.

A5.6.2. Domestic and Commercial Wastewater

The notation for CH_4 emissions from sludge of commercial and domestic wastewater has changed from "NE" to "NO" in this report as per the ERT's recommendation. Considering the description provided in Chapter 8, the CH_4 generated from the source is assumed to be completely destroyed, either in its utilization for energy or through flaring.

The notation for N_2O emissions from the wastewater "subsector is "NE" ("Not Estimated"), to be consistent with the domestic and commercial wastewater without the human sewage–sludge subcategory. No methodology is provided for the estimation of N_2O emissions from domestic and commercial wastewater without human sewage in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) or the IPCC Good Practice Guidance (IPCC 2000) documents. CH_4 emissions from the Municipal and Commercial Wastewater Sludge subcategory are reported as "NO," because sludge is either landfilled or applied to land to degrade aerobically.

A5.6.3. Industrial Wastewater

The notation "NE" is used for N_2O emissions from industrial wastewater, as this information is not readily available from facilities, and no methodology to estimate these emissions is provided in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) or the IPCC Good Practice Guidance (IPCC 2000). The notation for CH_4 emissions from sludge of industrial wastewater has changed from "NE" to "NO" in this report as per the ERT's recommendation. Considering the description provided in Chapter 8, the CH_4 generated from the source is assumed to be completely destroyed, either in utilization for energy or through flaring.

Also, in regards to other sludge that is not processed at the site: the majority of pulp and paper sludges are disposed of in landfills, and food processing sludges are either landfilled or applied to land to degrade aerobically. The landfilled sludge CH_4 emissions are dealt with in the Solid Waste Disposal on Land subsector. N_2O emissions from industrial wastewater sludge treatment are noted as "NE," since this information is not readily available from facilities and no methodology is provided in the Revised 1996 IPCC Guidelines (IPCC/OECD/IEA 1997) or the IPCC Good Practice Guidance (IPCC 2000) to estimate these emissions.

A5.6.4. MSW Waste Incineration

CH_4 emissions from municipal solid waste (MSW) incineration are considered to be negligible and have not been estimated. This assumption is supported by a recent report (CRA 2011). Approximately less than 5% of all MSW is incinerated in Canada. Therefore, CH_4 emissions from this source are not expected to contribute significantly to the national inventory and are reported as "NE."

Annex 6

Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) procedures are an integral part of the inventory development and submission processes. These procedures ensure that Canada is able to meet the United Nations Framework Convention on Climate Change (UNFCCC) requirements of transparency, consistency, comparability, completeness and accuracy. The Government of Canada is committed to continuously improving data and methods to ensure that a credible and defensible inventory is developed, and that Canada meets its international reporting obligations.

A6.1. Overview of Canada's Quality Management System

The development of Canada's greenhouse gas (GHG) inventory is based on a continuous process of methodological improvements, data collection, refinement and review. Ensuring the inventory is of high quality is a top priority, and QA/QC procedures take place at all stages of the inventory development cycle (which is described in detail in Chapter 1).

In order to ensure that an inventory of high quality is produced every year, a quality management system has been developed and implemented for the annual compilation and publication of the national GHG inventory. The system includes a QA/QC plan; processes for creation, documentation and archiving of information; a standardized process for implementing methodological change; the identification of key roles and responsibilities; and activities for verification and continuous improvement.

A6.2. Canada's Quality Control / Quality Assurance Plan

Canada has developed a QA/QC plan that uses an integrated approach to managing the inventory quality and works towards achieving continuously improved emission and removal estimates. It is designed so that QA/QC and verification procedures are implemented throughout the entire inventory development process, from initial data collection through development of emission and removal estimates to publication of the National Inventory Report (NIR) in English and French.

The plan, originally developed in 2006, incorporates a system of continuous improvement that includes, but is not limited to, procedures to capture lessons learned as part of the inventory cycle; the use of QA/QC, feedback from the Expert Review Team (ERT) review reports, and other tools as a means to identify and prioritize improvements; and processes to ensure that improvements identified are incorporated into the operating procedures.

Documentation of QA/QC procedures is at the core of the system. Standard checklists are used for the consistent, systematic documentation of all QA/QC activities in the annual inventory preparation and submission. QC checks are completed during each stage of the annual inventory preparation and archived along with other procedural and methodological documentation, by inventory category and by submission year. The plan requires the coordination of QA/QC activities, with outside agencies and organizations providing activity data and/or developing greenhouse gas (GHG) emission and removal estimates for Environment Canada.

A6.3. Quality Control Procedures

QC procedures are routine technical checks to measure and control the quality of the inventory; ensure data consistency, integrity, correctness and completeness; and identify and address errors and omissions. The QC procedures used during the inventory development cycle cover a wide range of inventory processes, from data acquisition and handling to application of approved procedures and methods to calculation of estimates and documentation.

A6.3.1. Tier 1 QC

A series of systematic Tier 1 QC checks are performed annually on at least the key categories and across sectors by inventory experts in the inventory agency. Tier 1 QC follows the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), including (but not limited to)

- preventing easily avoidable data errors (e.g. during data flow, use of appropriate units and basic calculations);
- consistency checks among data used in multiple sectors;
- basic trend analysis and comparison with previous estimates;
- checks for transcription errors in data input, and that parameter and emission units are correct and appropriate conversion factors are used;

- proper documentation of assumptions, expert credentials, and selection criteria for emission factors, parameters and methodologies; and
- completeness checks.

Category-specific QC procedures complement general inventory QC procedures, and are directed at specific types of data used. These procedures require knowledge of the specific category, including the methodology, the types of data available and the parameters associated with emissions or removals. It is good practice that inventory agencies applying higher-tier methods in compiling national inventories use category-specific QC procedures, which may include the following:

Emissions data QC:

- Assessments of the reasonableness of Intergovernmental Panel on Climate Change (IPCC) default emission factors, country-specific emission factors and direct emissions measurements
- Review of the background data used to develop emission factors
- Investigations towards using higher-tier (country-, region- or plant-specific) emission factors

Activity data QC:

- Reasonableness and quality assessments on data provided from outside sources, including documentation of QA/QC activities of the agencies responsible for data collection and compilation

To facilitate these checks, QC checklists have been developed to standardize and document QC procedures that are performed. The QC checklists include a record of any corrective action taken and refer to supporting documentation. Minor updates to the QC checklist were made in 2010.

Cross-cutting QC checks are conducted on the final NIR documents (English and French) prior to submission. Quality checks are also performed on the data entered into the Common Reporting Format (CRF) Reporter by the CRF coordinators, in addition to the review of the tables by the sector experts, for the entire time series of CRF tables prior to submission.

External partners are relied upon to provide activity data and/or develop GHG estimates (e.g. Statistics Canada, LULUCF partners, industry). In cases where these data are relied upon, inventory experts perform additional QC procedures on the data in addition to QC procedures already implemented by the external agencies. As well, inventory experts must assess and document the QA/QC procedures in their respective data collection systems to determine whether they meet the minimum requirements of the QA/QC plan.

A6.3.2. Tier 2 QC

A Tier 2 QC assessment is an opportunity to review and investigate improvements of a specific category or categories. There is a need for a comprehensive assessment to ensure that the category will remain current and relevant for a number of years beyond the year of analysis. The investigation is broad and uses a variety of approaches, including

- making assessments of continued applicability of methods, emission factors (EFs), activity data, uncertainty, etc.;
- understanding the flow of information, secondary data and data inputs, and being able to trace inputs to their root sources;
- cleaning and updating documentation (not covered by Tier 1 checks); and
- laying the foundation for future activities, including making and prioritizing recommendations for improvement and making preparations for subsequent QA.

Documentation of the Tier 2 QC checks may be done through a standard checklist or with an in-depth study to complete a comprehensive assessment.

A6.4. Quality Assurance Procedures

As per the IPCC *Good Practice Guidance*, QA activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process, and is performed following the implementation of QC procedures. QA helps to ensure that the inventory represents the best possible estimates of emissions and removals given the current state of scientific knowledge and data availability, and it supports the effectiveness of the QC program. As with QC, QA is undertaken every year on components of the inventory. Selected underlying data and methods are independently assessed each year by various groups and individual experts in industry, provincial governments, academia and other federal government departments. QA is undertaken for the assessment of the activity data, methodology and emission factor utilized for developing estimates, and is preferably carried out prior to making a decision on implementing a methodological change.

A6.4.1. Planning and Prioritization of Improvements

Priorities for inventory improvements are guided by analysis of key categories (level and trend), uncertainty surrounding existing emission and removal estimates, recommendations received from previous international reviews of Canada's inventory, and outcomes of QA procedures.

To facilitate continuous improvements to the inventory, the Prioritization and Planning Committee (P&PC) has been established

to prioritize and plan short- and long-term activities. The P&PC comprises inventory team managers and, in accordance with the QA/QC Plan, performs the following activities:

- Evaluates proposed activities, and prioritizes and recommends allocation of resources based on the prioritization of proposed activities
- Identifies and advises on resource constraints
- Assesses issues identified during the QA/QC process and the results of annual lessons-learned reviews, and recommends corrective actions
- Identifies involvement with committees assessing national data, to allow for a coordinated effort of these activities
- Approves/prioritizes methodological changes based on their justification as provided by section chiefs; in particular, the P&PC makes recommendations with respect to implementation and QA/QC requirements
- Discusses approaches and assigns tasks related to cross-cutting issues, such as risk management, uncertainty analysis and key category assessment
- Implements QA/QC initiatives, such as new requirements (domestic and international), and changes to procedures and schedules
- Determines timing and scope of QA activities, and prioritizes them
- Advises the Director on priorities and planning with respect to improving the quality of the national inventory

In addition, all proposed methodological changes are presented to the P&PC by inventory experts, and must be approved/prioritized by the P&PC prior to implementing. This standardized process for adopting a methodological change has been developed to formalize the prioritizing and documenting of methodological changes, in order to

- ensure that methodological changes are thoroughly considered for soundness, are applied consistently across sectors, are in compliance with IPCC guidelines, and are consistent with other priorities identified by the P&PC;
- provide easy reference for comparisons in methods between inventory years, in order to track the evolution of methodological changes over time and provide a clearinghouse for all methodological changes through a single body (P&PC); and
- allow for a coordinated approach when a change may impact another sector.

A6.5. Verification

Verification is the use of third-party information to confirm the veracity of the inventory. Verification activities include comparisons with emission or removal estimates prepared by other bodies, and comparisons with estimates derived from fully independent assessments.

For example, where appropriate facility-level GHG data exist from Canada's facility-level Greenhouse Gas Emissions Reporting Program, analysis is undertaken to perform bottom-up versus top-down comparisons.

A6.6. Annual Inventory Review

Since 2003, Canada's national GHG inventory has been reviewed annually by independent ERTs following the *UNFCCC Review Guidelines for Annual Inventories for Annex I Parties*. The review process plays a key role in ensuring that inventory quality is improved over time, and that Parties comply with agreed-upon reporting requirements. The completeness, accuracy, transparency, comparability and consistency of inventory estimates can also be attributed to the well-established review process. The inventory has been subjected to both centralized and in-country reviews.

Annex 7

Uncertainty

A7.1. Introduction

All Annex I parties are required to report estimated uncertainties associated with both annual estimates of emissions and with 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 2000). Canada performed its first uncertainty assessment of its 1990 estimates in 1994 (McCann 1994). In 2003–2004, Canada carried out a comprehensive Monte Carlo analysis (Approach 2) to provide an assessment of the uncertainty associated with the methodology used to estimate emissions from the 2001 GHG inventory (the latest inventory estimates available at the time of the study); the results of this assessment were discussed in several subsequent submissions (Environment Canada 2009). Since 2004, many methodological changes, refinements and updates, including updates to uncertainty parameters themselves, have been made; uncertainty estimates have also been developed for Agricultural methane estimates and the Land Use, Land-use Change and Forestry (LULUCF) Sector (see Chapters 6 and 7). The overall results of the previous assessment are no longer applicable to the inventory as a whole.

In this submission, Canada used the error propagation method (Approach 1), as outlined in Chapter 6 of the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) to assess the uncertainty in emission estimates for 2012. Uncertainty estimates were combined by completing Table A7–1 at the source category level. Uncertainty estimates for each source/sink category were either retained from the previous studies; improved upon on the basis of these studies; or derived independently as in the Agriculture (methane), Energy (some fuel combustion categories and fugitive emissions), Industrial Processes and LULUCF Sectors.

A7.2. Uncertainty Assessment on 2012 Greenhouse Gas Emissions and Removals

Separate analyses were conducted for the inventory as a whole with and without LULUCF. The 2012 national emission estimate (not including the LULUCF Sector) of 699 Mt CO_2 eq lies within an uncertainty range of 669 Mt CO_2 eq to 728 Mt CO_2 eq (±4%) (Table A7–1). These results are consistent with those published in previous NIR submissions that ranged from 3% to +6%. The Energy Sector had the lowest uncertainty, at ±3%, while the Agriculture Sector had the highest uncertainty, at ±41%. The Industrial Processes Sector, the Solvent and Other Product Use Sector, and the Waste Sector had uncertainties of ±8.0, ±19 and ±34%, respectively. The emission source categories that made the largest contributions to uncertainty at the national level when LULUCF is not included were:

i. Agriculture – Indirect Agricultural Soils, N_2O;
ii. Energy – Fuel Combustion – Public Electricity and Heat Combustion, CO_2;
iii. Energy – Fuel Combustion – Other (off-road) Transportation, N_2O;
iv. Waste – Solid Waste Disposal on Land, CH_4; and
v. Energy – Fuel Combustion – Manufacturing Industries and Construction, CO_2.

The national emission estimate including LULUCF emissions and removals of 739 Mt CO_2 eq lies within an uncertainty range of 694 Mt CO_2 eq to 784 Mt CO_2 eq (±6%)

(Table A7–2). Typically, uncertainty is high for LULUCF estimates due to the fact that emissions are primarily driven by highly variable natural disturbance factors. The top five contributors influencing the national uncertainty when LULUCF is included were:

vi. Agriculture – Indirect Agricultural Soils, N_2O;
vii. Energy – Fuel Combustion – Public Electricity and Heat Combustion, CO_2;
viii. Energy – Fuel Combustion – Other (off-road) Transportation, N_2O;
ix. Waste – Solid Waste Disposal on Land, CH_4; and
x. Energy – Fuel Combustion – Manufacturing Industries and Construction, CO_2.

The calculation of trend uncertainty was only performed without the LULUCF Sector. Given the high interannual variability in the LULUCF estimates, and the fact that it is primarily driven by natural factors such as wildfires in managed forests, this sector was not considered in the trend analysis of uncertainties in anthropogenic GHG emissions and removals. The trend uncertainty,

excluding LULUCF, was found to be 1.1%. Therefore, the total increase in emissions since 1990 of 108 Mt CO_2 eq (+18.2%) falls within an uncertainty range of a minimum of +101 Mt CO_2 eq to a maximum of +114 Mt CO_2 eq (+17.1% to +19.3%).

Although a full uncertainty assessment is presented, it should be noted that, in accordance with information provided in previous submissions, Canada recognizes the limitations of the current methodology. Uncertainty values for the emission estimates from the previous Monte Carlo analyses were used in this error propagation model. In many instances the parameters did not conform to the assumption of non-correlated, normally distributed parameters and therefore required simplification for the purposes of this analysis. The full impact of these simplifications, i.e., whether leading to an underestimation or overestimation of uncertainty, was not evaluated as part of this submission. However, the assumptions are expected to be reviewed and/or updated in future submissions in conjunction with Canada's quality assurance / quality control (QA/QC) program. Individual sectors have focused on more detailed uncertainty analyses within their respective areas of expertise. For further details on uncertainty related to specific sectors see the uncertainty sections throughout Chapters 3–8.

A7.3. 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. In addition, many sectors have plans to improve the uncertainty estimates within their respective areas of expertise.

Canada notes that the expert reviews of previous submissions have identified several priority areas for improvement, such as performing uncertainty analyses on a regular basis, developing in-house capacity to perform uncertainty analyses and make full use of the results, and performing Tier 2 key category analysis. All these steps will help to further integrate QA/QC, key category analysis and uncertainty analysis in order to prioritize improvements. Canada's longer-term vision with respect to performing uncertainty assessments is consistent with these expert recommendations.

A7

Table A7–1 Uncertainty Assessment Level and Trend without LULUCF

	IPCC Source Category	Gas	Base Year Emissions	2012 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2012 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		**590,908**	**698,626**	**0.79**	**4.2**	**4.2**	**4.2**	*Assumption: Emission factors are fully correlated between years*	*Assumption: Activity data is fully correlated between years*	**1.1**
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CO_2	93 043	87 566	0.54	1.1	11	0.02	0.40	0.02	0.00
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CH_4	37	134	0.87	35	35	0.00	0.01	0.00	0.00
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	N_2O	532	554	0.54	48	48	0.00	0.01	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	CO_2	16 708	16 751	1.1	11	11	0.00	0.05	0.01	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	CH_4	6	5	0.65	52	52	0.00	0.00	0.00	0.00
1.A.1.b	Fuel Combustion - Petroleum Refining	N_2O	49	37	0.59	52	52	0.00	0.00	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO_2	32 263	44 490	0.92	10	10	0.00	0.11	0.01	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 561	1 898	1	42	42	0.00	0.00	0.00	0.00
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	N_2O	250	306	0.89	80	80	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CO_2	63 604	84 463	4.5	7.8	8	0.01	0.12	0.07	0.00

Table A7-1 Uncertainty Assessment Level and Trend without LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2012 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2012 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		**590,908**	**698,626**	**0.79**	**4.2**	**4.2**	**4.2**	*Assumption: Emission factors are fully correlated between years*	*Assumption: Activity data is fully correlated between years*	**1.1**
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CH_4	53	69	4.2	14	14	0.00	0.00	0.00	0.00
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	N_2O	619	885	4.1	19	19	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion - Civil Aviation	CO_2	7 047	5 988	-	-	0.6	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion - Civil Aviation	CH_4	10	7	-	-	59	0.00	0.00	0.00	0.00
1.A.3.a	Fuel Combustion - Civil Aviation	N_2O	70	56	-	-	540	0.00	0.02	0.00	0.00
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CO_2	93 212	129 444	-	-	0.5	0.00	0.02	0.00	0.00
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CH_4	304	209	-	-	72	0.00	0.02	0.00	0.00
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	N_2O	3 195	2 808	-	-	29	0.00	0.05	0.00	0.00
1.A.3.c	Fuel Combustion - Railways	CO_2	6 159	6 721	-	-	1.7	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion - Railways	CH_4	7	8	-	-	65	0.00	0.00	0.00	0.00
1.A.3.c	Fuel Combustion - Railways	N_2O	790	878	-	-	270	0.00	0.03	0.00	0.00
1.A.3.d	Fuel Combustion - Navigation	CO_2	4 693	5 436	-	-	2.9	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion - Navigation	CH_4	7	9	-	-	180	0.00	0.00	0.00	0.00
1.A.3.d	Fuel Combustion - Navigation	N_2O	339	305	-	-	280	0.00	0.05	0.00	0.00
1.A.3.e	Fuel Combustion - Other Transportation (Off-road)	CO_2	21 758	33 884	-	-	1	0.00	0.01	0.00	0.00
1.A.3.e	Fuel Combustion - Other Transportation (Off-road)	CH_4	204	227	-	-	120	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion - Other Transportation (Off-road)	N_2O	1 871	3 512	-	-	270	0.02	0.60	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	CO_2	6 652	5 534	0.99	3	3.1	0.00	0.01	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	CH_4	141	117	1	40	40	0.00	0.00	0.00	0.00
1.A.3.e	Fuel Combustion - Pipeline Transport	N_2O	57	47	0.97	87	87	0.00	0.00	0.00	0.00
1.A.4	Fuel Combustion - Other Sectors	CO_2	68 760	69 310	3.4	2.6	3.8	0.00	0.05	0.07	0.00
1.A.4	Fuel Combustion - Other Sectors	CH_4	2 118	2 200	5.7	12	12	0.00	0.01	0.00	0.00
1.A.4	Fuel Combustion - Other Sectors	N_2O	702	793	4.7	13	13	0.00	0.00	0.00	0.00
1.B.1.a	Fugitive Sources - Coal Mining	CH_4	2 199	1 006	-	-	57	0.00	0.15	0.00	0.00
1.B.2. (a+b)	Fugitive Sources - Oil & Gas	CO_2	117	288	-	-	15	0.00	0.00	0.00	0.00
1.B.2. (a+b)	Fugitive Sources - Oil & Gas	CH_4	15 454	25 523	-	-	11	0.00	0.13	0.00	0.00
1.B.2. (a+b)	Fugitive Sources - Oil & Gas	N_2O	31	31	-	-	49	0.00	0.00	0.00	0.00
1.B.2.c	Fugitive Sources - Venting	CO_2	6 992	10 061	-	-	22	0.00	0.07	0.00	0.00
1.B.2.c	Fugitive Sources - Flaring	CO_2	4 352	4 664	-	-	16	0.00	0.01	0.00	0.00
1.B.2.c	Fugitive Sources - Venting & Flaring	CH_4	13 219	19 526	-	-	18	0.00	0.12	0.00	0.00
1.B.2.c	Fugitive Sources - Venting & Flaring	N_2O	0.4	9	-	-	49	0.00	0.00	0.00	0.00
2.A.1	Industrial Processes - Cement Production	CO_2	5 436	6 287	-	-	14	0.00	0.00	0.00	0.00
2.A.2	Industrial Processes - Lime Production	CO_2	1 759	1 440	-	-	8.2	0.00	0.01	0.00	0.00

Table A7-1 Uncertainty Assessment Level and Trend without LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2012 Year Emissions	Activity Data Uncertainty[1]	Emission Factor Uncertainty[1]	Combined Uncertainty	Combined uncertainty as % of 2012 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		**590,908**	**698,626**	**0.79**	**4.2**	**4.2**	**4.2**	*Assumption: Emission factors are fully correlated between years*	*Assumption: Activity data is fully correlated between years*	**1.1**
2.A.3	Industrial Processes - Limestone and Dolomite Use	CO_2	805	427	-	-	21	0.00	0.02	0.00	0.00
2.A.4	Industrial Processes - Soda Ash Production and Use	CO_2	246	107	-	-	10	0.00	0.00	0.00	0.00
2.A.7.2	Industrial Processes - Magnesite Use	CO_2	147	91	-	-	8.1	0.00	0.00	0.00	0.00
2.B.1	Industrial Processes - Ammonia Production	CO_2	4 510	5 772	-	-	4	0.00	0.00	0.00	0.00
2.B.2	Industrial Processes - Nitric Acid Production	N_2O	1 012	1 146	-	-	10	0.00	0.00	0.00	0.00
2.B.3	Industrial Processes - Adipic Acid Production	N_2O	10 718	0	-	-	0	0.00	0.00	0.00	0.00
	Industrial Processes - Petrochemical Production	CH_4	99	56	-	-	19	0.00	0.00	0.00	0.00
	Industrial Processes - Petrochemical Production	N_2O	8	8	-	-	10	0.00	0.00	0.00	0.00
2.C.1	Industrial Processes - Iron and Steel Production	CO_2	10 193	9 844	-	-	5.4	0.00	0.02	0.00	0.00
2.C.3	Industrial Processes - Aluminium Production	CO_2	2 715	4 707	-	-	7.1	0.00	0.02	0.00	0.00
2.C.3	Industrial Processes - Aluminium Production	PFCs	6 539	1 519	-	-	9.1	0.00	0.10	0.00	0.00
2.C.4.1	Industrial Processes - Aluminium Production	SF_6	59	5	-	-	3.3	0.00	0.00	0.00	0.00
2.C.4.2	Industrial Processes - Magnesium Production	SF_6	2 870	-	-	-	5.7	0.00	0.03	0.00	0.00
2.C.5	Industrial Processes - Magnesium Casting	SF_6	236	257	-	-	4	0.00	0.00	0.00	0.00
2.E	Industrial Processes - Production of Halocarbons	HFCs	767	-	-	-	36	0.00	0.05	0.00	0.00
2.E	Industrial Processes - Production of Halocarbons	PFCs	-	-	-	-	23	0.00	0.00	0.00	0.00
2.E	Industrial Processes - Production of SF_6	SF_6	-	-	-	-	32	0.00	0.00	0.00	0.00
2.F	Industrial Processes - Consumption of Halocarbons	HFCs	-	7 783	-	-	36	0.00	0.47	0.00	0.00
2.F	Industrial Processes - Consumption of Halocarbons	PFCs	-	32	-	-	23	0.00	0.00	0.00	0.00
2.F.7	Industrial Processes - Consumption of SF_6 for Semi-Conductor	SF_6	212	185	-	-	30	0.00	0.00	0.00	0.00
2.F.8	Industrial Processes - Consumption of SF_6 for Electrical Equipment	SF_6	15	1	-	-	45	0.00	0.00	0.00	0.00
2.G	Industrial Processes - Other (Undifferentiated Processes)	CO_2	7 360	16 790	-	-	20	0.00	0.27	0.00	0.00
3.D	Solvent and Other Product Use	N_2O	179	310	-	-	19	0.00	0.00	0.00	0.00
4.A	Agriculture - Enteric Fermentation	CH_4	16 111	17 568	1.4	21	21	0.00	0.05	0.00	0.00
4.A	Agriculture - Manure Management	CH_4	2 563	2 758	1.5	32	32	0.00	0.01	0.00	0.00
4.A	Agriculture - Manure Management	N_2O	3 159	3 640	24	96	99	0.00	0.02	0.00	0.00
4.D.1	Agriculture - Direct Agricultural Soils	N_2O	16 091	19 866	12	31	33	0.01	0.04	0.02	0.00
4.D.3	Agriculture - Indirect Agricultural Soils	N_2O	8 704	11 662	16	180	180	0.09	0.42	0.04	0.00
4.F	Field Burning of Agricultural Residues	CH_4	148	25	50	40	64	0.00	0.01	0.01	0.00

Table A7-1 Uncertainty Assessment Level and Trend without LULUCF (cont'd)

	IPCC Source Category	Gas	Base Year Emissions	2012 Year Emissions	Activity Data Uncertainty1	Emission Factor Uncertainty1	Combined Uncertainty	Combined uncertainty as % of 2012 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		**590,908**	**698,626**	**0.79**	**4.2**	**4.2**	**4.2**	*Assumption: Emission factors are fully correlated between years*	*Assumption: Activity data is fully correlated between years*	**1.1**
4.F	Field Burning of Agricultural Residues	N_2O	57	10	50	48	69	0.00	0.00	0.00	0.00
6.A	Waste - Solid Waste Disposal on Land	CH_4	17 437	18 899	-	-	37	0.01	0.11	0.00	0.00
6.B	Waste - Wastewater Handling	CH_4	316	317	-	-	43	0.00	0.00	0.00	0.00
6.B	Waste - Wastewater Handling	N_2O	514	683	-	-	63	0.00	0.01	0.00	0.00
6.C	Waste - Waste Incineration	CO_2	507	482	-	-	35	0.00	0.01	0.00	0.00
6.C	Waste - Waste Incineration	CH_4	10	3	-	-	60	0.00	0.00	0.00	0.00
6.C	Waste - Waste Incineration	N_2O	223	187	-	-	85	0.00	0.01	0.00	0.00

1. 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, Industrial Processes, Solvent, and Waste Sectors – the reader is referred to uncertainty sections in respective NIR chapters.

Table A7–2 Uncertainty Assessment with LULUCF

	IPCC Source Category	Gas	2012 Year Emissions	Combined Uncertainty
			kt CO_2 eq	%
	TOTALS		**739 487**	**6.14**
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CO_2	87 566	11
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	CH_4	134	35
1.A.1.a	Fuel Combustion - Public Electricity and Heat Production	N_2O	554	48
1.A.1.b	Fuel Combustion - Petroleum Refining	CO_2	16 751	11
1.A.1.b	Fuel Combustion - Petroleum Refining	CH_4	5	52
1.A.1.b	Fuel Combustion - Petroleum Refining	N_2O	37	52
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CO_2	44 490	10
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	CH_4	1 898	42
1.A.1.c	Fuel Combustion - Manufacture of Solid Fuels and Other Energy Industries	N_2O	306	80
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CO_2	84 463	8
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	CH_4	69	14
1.A.2	Fuel Combustion - Manufacturing Industries and Construction	N_2O	885	19
1.A.3.a	Fuel Combustion - Civil Aviation	CO_2	5 988	0.6
1.A.3.a	Fuel Combustion - Civil Aviation	CH_4	7	59
1.A.3.a	Fuel Combustion - Civil Aviation	N_2O	56	540
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CO_2	129 444	0.5
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	CH_4	209	72
1.A.3.b	Fuel Combustion - Road Transportation (Gas, Diesel, Natural Gas, Propane)	N_2O	2 808	29
1.A.3.c	Fuel Combustion - Railways	CO_2	6 721	1.7
1.A.3.c	Fuel Combustion - Railways	CH_4	8	65
1.A.3.c	Fuel Combustion - Railways	N_2O	878	270
1.A.3.d	Fuel Combustion - Navigation	CO_2	5 436	2.9
1.A.3.d	Fuel Combustion - Navigation	CH_4	9	180
1.A.3.d	Fuel Combustion - Navigation	N_2O	305	280
1.A.3.e	Fuel Combustion - Other Transportation (Off-road)	CO_2	33 884	1
1.A.3.e	Fuel Combustion - Other Transportation (Off-road)	CH_4	227	120
1.A.3.e	Fuel Combustion - Other Transportation (Off-road)	N_2O	3 512	270
1.A.3.e	Fuel Combustion - Pipeline Transport	CO_2	5 534	3.1
1.A.3.e	Fuel Combustion - Pipeline Transport	CH_4	117	40
1.A.3.e	Fuel Combustion - Pipeline Transport	N_2O	47	87
1.A.4	Fuel Combustion - Other Sectors	CO_2	69 310	3.8
1.A.4	Fuel Combustion - Other Sectors	CH_4	2 200	12
1.A.4	Fuel Combustion - Other Sectors	N_2O	793	13
1.B.1.a	Fugitive Sources - Coal Mining	CH_4	1 006	57
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	CO_2	288	15
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	CH_4	25 523	11

Table A7-2 Uncertainty Assessment with LULUCF (cont'd)

	IPCC Source Category	Gas	2012 Year Emissions	Combined Uncertainty
			kt CO_2 eq	%
	TOTALS		**739 487**	**6.14**
1.B.2.(a+b)	Fugitive Sources - Oil & Gas	N_2O	31	49
1.B.2.c	Fugitive Sources - Venting	CO_2	10 061	22
1.B.2.c	Fugitive Sources - Flaring	CO_2	4 664	16
1.B.2.c	Fugitive Sources - Venting & Flaring	CH_4	19 526	18
1.B.2.c	Fugitive Sources - Venting & Flaring	N_2O	9	49
2.A.1	Industrial Processes - Cement Production	CO_2	6 287	14
2.A.2	Industrial Processes - Lime Production	CO_2	1 440	8.2
2.A.3	Industrial Processes - Limestone and Dolomite Use	CO_2	427	21
2.A.4	Industrial Processes - Soda Ash Production and Use	CO_2	107	10
2.A.7.2	Industrial Processes - Magnesite Use	CO_2	91	8.1
2.B.1	Industrial Processes - Ammonia Production	CO_2	5 772	4
2.B.2	Industrial Processes - Nitric Acid Production	N_2O	1 146	10
2.B.3	Industrial Processes - Adipic Acid Production	N_2O	0	0
	Industrial Processes - Petrochemical Production	CH_4	56	19
	Industrial Processes - Petrochemical Production	N_2O	8	10
2.C.1	Industrial Processes - Iron and Steel Production	CO_2	9 844	5.4
2.C.3	Industrial Processes - Aluminium Production	CO_2	4 707	7.1
2.C.3	Industrial Processes - Aluminium Production	PFCs	1 519	9.1
2.C.4.1	Industrial Processes - Aluminium Production	SF_6	5	3.3
2.C.4.2	Industrial Processes - Magnesium Production	SF_6	-	5.7
2.C.5	Industrial Processes - Magnesium Casting	SF_6	257	4
2.E	Industrial Processes - Production of Halocarbons	HFCs	-	36
2.E	Industrial Processes - Production of Halocarbons	PFCs	-	23
2.E	Industrial Processes - Production of SF_6	SF_6	-	32
2.F	Industrial Processes - Consumption of Halocarbons	HFCs	7 783	36
2.F	Industrial Processes - Consumption of Halocarbons	PFCs	32	23
2.F.7	Industrial Processes - Consumption of SF_6 for Semi-Conductor	SF_6	185	30
2.F.8	Industrial Processes - Consumption of SF_6 for Electrical Equipment	SF_6	1	45
2.G	Industrial Processes - Other (Undifferentiated Processes)	CO_2	16 790	20
3.D	Solvent and Other Product Use	N_2O	310	19
4.A	Agriculture - Enteric Fermentation	CH_4	17 568	21
4.A	Agriculture - Manure Management	CH_4	2 758	32
4.A	Agriculture - Manure Management	N_2O	3 640	99
4.D.1	Agriculture - Direct Agricultural Soils	N_2O	19 866	33
4.D.3	Agriculture - Indirect Agricultural Soils	N_2O	11 662	180
4.F	Field Burning of Agricultural Residues	CH_4	25	64
4.F	Field Burning of Agricultural Residues	N_2O	10	69
5.A.1	Forest Land Remaining Forest Land	CO_2	18 102	190
5.A.1	Forest Land Remaining Forest Land	CH_4	9 036	38
5.A.1	Forest Land Remaining Forest Land	N_2O	5 611	45
5.A.2	Land Converted to Forest Land	CO_2	-652	-10
5.B	Cropland	CO_2	-12 327	24
5.B	Cropland	N_2O	1	50
5.D	Wetlands	CO_2	1 308	-
5.E	Settlements	CO_2	-16	-
	Conversion of Forest Land	CO_2	18 047	11
	Conversion of Forest Land	CH_4	227	29
	Conversion of Forest Land	N_2O	145	19
5.C	Grasslands	CH_4	997	64
5.C	Grasslands	N_2O	381	69
6.A	Waste - Solid Waste Disposal on Land	CH_4	18 899	37
6.B	Waste - Wastewater Handling	CH_4	317	43
6.B	Waste - Wastewater Handling	N_2O	683	63
6.C	Waste - Waste Incineration	CO_2	482	35
6.C	Waste - Waste Incineration	CH_4	3	60
6.C	Waste - Waste Incineration	N_2O	187	85

Annex 8

Emission Factors

This annex summarizes the development and selection of emission factors for use in estimating greenhouse gas emissions. Additional details on sector-specific methodologies for the use of these factors are presented in Annex 2 and Annex 3.

A8.1. Fuel Combustion

A8.1.1. Natural Gas and Natural Gas Liquids

A8.1.1.1. CO_2

CO_2 emission factors for fossil fuel combustion are dependent primarily on fuel properties such as carbon content, density and heating value and, to a lesser extent, on the combustion technology.

For natural gas, there are two major qualities of fuel combusted in Canada: marketable fuel (processed for commercial sale) and non-marketable fuel (unprocessed, for internal use). 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 A8–1) have been developed based on data from chemical analysis of representative natural gas samples (McCann 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC/OECD/IEA1997). Both imported and domestic natural gas were included, where applicable, in the mix of gas samples used for chemical analysis. Non marketable natural gas emission factors are higher than those of marketable fuels as a result of their raw nature; in addition to methane, non-marketable natural gas may include ethane, propane and butane in the fuel mix.

CO_2 emission factors (Table A8–3) for natural gas liquids (NGL) such as ethane, propane and butane were developed based on chemical analysis data for marketable fuels (McCann 2000) and an assumed fuel combustion efficiency of 99.5% (IPCC/OECD/IEA 1997). These emission factors are lower than those developed on the assumption of pure fuels (Jaques 1992) owing to the presence of impurities in the fuels.

A8.1.1.2. CH4

Emissions of CH_4 from fuel combustion are technology-dependent. Sectoral emission factors (Table A8–2and Table A8–3) have been developed based on technologies typically used in Canada. The factors were developed based on a broad review of emission factors for combustion technologies (SGA Energy 2000). The emission factor for producer consumption of natural gas was developed based on a technology split for the upstream oil and gas industry (CAPP 1999) and technology-specific emission factors from the U.S. EPA report AP 42 (U.S. EPA 1996a).

A8.1.1.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors (Table A8–2 and Table A8–3) have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

A8.1.2. Refined Petroleum Products

A8.1.2.1. CO_2

CO_2 emission factors for fossil fuel combustion are dependent primarily on fuel properties and, to a lesser extent, on the combustion technology.

Table A8–1 CO_2 Emission Factors for Natural Gas

Province	Emission Factor[3] (g/m^3)	
	Marketable[1]	Non-marketable[2]
Newfoundland and Labrador	1 891	2 482
Nova Scotia	1 891	2 482
New Brunswick	1 891	NO
Quebec	1 878	NO
Ontario	1 879	NO
Manitoba	1 877	NO
Saskatchewan	1 820	2 429
Alberta	1 918	2 380
British Columbia	1 916	2 151
Yukon	1 891	2 389
Northwest Territories	2 454	2 454

Notes:

NO = Not occurring

1. The term "marketable" applies to fuel consumed by the Electric Utilities, Manufacturing
2. Industries, Residential/Commercial and Transport subsectors.
3. The term "non-marketable" applies to raw gas consumption, mainly by natural gas producers
4. Adapted from McCann (2000)

Table A8–2 CH_4 and N_2O Emission Factors for Natural Gas

Source	Emission Factor (g/m^3)[1]	
	CH_4	N_2O
Electric Utilities	0.490	0.049
Industrial	0.037	0.033
Producer Consumption (Non-marketable)	6.4[2]	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:
1. SGA Energy (2000)
2. Adapted from U.S. EPA (1996b) and CAPP (1999)

Table A8–3 Emission Factors for Natural Gas Liquids

Source	Emission Factor (g/L)		
	CO_2	CH_4	N_2O
Propane			
Residential	1 507[1]	0.027[2]	0.108[2]
All Other Uses	1 507[1]	0.024[2]	0.108[2]
Ethane	976[1]	0.024[2]	0.108[2]
Butane	1 730[1]	0.024[2]	0.108[2]

Notes:
1. Adapted from McCann (2000)
2. SGA Energy (2000)

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Emission factors have been developed for each major class of refined petroleum products (RPP) based on their heating value, carbon content and destiny (McCann 2000) with an assumed fuel combustion efficiency of 99% (IPCC/OECD/IEA 1997), to ensure consistency with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*.

The composition of petroleum coke is process-specific. Factors have been developed for both refinery (catalytic cracker) derived cokes and coke used in upgrading facilities. These factors (Table A8–5) have been developed based on data provided by industry to the Canadian Industrial Energy End-Use Data Analysis Centre (CIEEDAC) in their *Review of Energy Consumption* reports on the refining and upgrading industry (CIEEDAC 2003, 2010). The bulk of the coke consumed by refineries is catalytic cracker-derived, and the emission factor is an average of petroleum coke and catalytic cracker coke emission factors.

Emission factors for still gas (Table A8–5) from refining operations and upgrading facilities were also developed based on data provided by industry and reported by CIEEDAC (2003, 2010).

Emission factors for refinery liquified petroleum gases (LPGs) were adapted from propane and butane emission factors (McCann 2000) based on the propane/butane fuel mix outlined in the *Report on Energy Supply–Demand in Canada* (RESD) (Statistics Canada 2013).

A8.1.2.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors have been developed (Table A8–4) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

The emission factor for petroleum coke was assumed to be the same for both catalytic cracker-derived cokes and coke used in upgrading facilities. An emission factor for still gas is not available, according to the 2000 SGA Energy study.

The emission factor for refinery LPGs was adapted from propane and butane emission factors (SGA Energy 2000).

A8.1.2.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for RPPs, with the exception of petroleum coke, have been developed (Table A8–4) based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

Emission factors for petroleum coke (Table A8–6) were based on 2006 IPCC default emission factors and were calculated on an annual basis using energy conversion factors provided by Statistics Canada (2008).

The emission factor for refinery LPGs was adapted from propane and butane emission factors (SGA Energy 2000).

A8.1.3. Coal and Coal Products

A8.1.3.1. CO_2

CO_2 emission factors for coal combustion are dependent primarily on the properties of the fuel and, to a lesser extent, on the combustion technology. Coal emission factors (Table A8–7) have been developed for each province based on the rank of the coal and the region of supply. Emission factors have been developed based on data from chemical analysis of coal samples for electric utilities, which account for the vast majority of coal consumption, and a fuel combustion efficiency of 99.0% (Jaques 1992). The emission factors were revised for the current submission using data from a multi-year project carried out in collaboration between Environment Canada and the Geological Survey of Canada.

Table A8–4 Emission Factors for Refined Petroleum Products

Source	Emission Factor (g/L)		
	CO_2	CH_4	N_2O
Light Fuel Oil			
Electric Utilities	2 725[1]	0.18[2]	0.031[2]
Industrial	2 725[1]	0.006[2]	0.031[2]
Producer Consumption	2 643[1]	0.006[2]	0.031[2]
Residential	2 725[1]	0.026[2]	0.006[2]
Forestry, Construction, Public Administration and Commercial/Institutional	2 725[1]	0.026[2]	0.031[2]
Heavy Fuel Oil			
Electric Utilities	3 124[1]	0.034[2]	0.064[2]
Industrial	3 124[1]	0.12[2]	0.064[2]
Producer Consumption	3 158[1]	0.12[2]	0.064[2]
Residential, Forestry, Construction, Public Administration and Commercial/Institutional	3 124[1]	0.057[2]	0.064[2]
Kerosene			
Electric Utilities	2 534[1,3]	0.006[2]	0.031[2]
Industrial	2 534[1,3]	0.006[2]	0.031[2]
Producer Consumption	2 534[1,3]	0.006[2]	0.031[2]
Residential	2 534[1,3]	0.026[2]	0.006[2]
Forestry, Construction, Public Administration and Commercial/Institutional	2 534[1,3]	0.026[2]	0.031[2]
Diesel - Refineries and Others	2 663[1]	0.133[2]	0.4[2]
Diesel - Upgraders[4]	2 663	0.15	1.1
Petroleum Coke	(see Table A8-5)	0.12[2]	(see Table A8-5)
Still Gas	(see Table A8-5)	N/A	0.00002[2]
Refinery LPGs[5]	(see Table A8-5)	0.024	0.108
Motor Gasoline	2 289[1]	N/A	0.02[6]

Notes:
1. Adapted from McCann (2000)
2. SGA Energy (2000)
3. Assumed McCann (2000) aviation turbo-fuel emission factor
4. Assumed Off-road Diesel emission factors (see Table A8-11) since fuel is consumed in oil sands mining trucks.
5. Adapted from propane and butane emission factors
6. Adapted from IPCC/OECD/IEA (1997)

N/A = Not available

Table A8–5 CO_2 Emission Factors for Petroleum Coke, Still Gas and Refinery LPGs

	Emission Factor									
	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011 - 2012
Petroleum Coke	g/L									
Upgrading Facilities[1]	3 556	3 551	3 481	3 494	3 494	3 494	3 494	3 494	3 494	3 494
Refineries & Others[2]	3 766	3 787	3 711	3 814	3 817	3 820	3 817	3 816	3 826	3 814
Still Gas	g/m^3									
Upgrading Facilities[1]	2 310	2 090	2 120	2 140	2 140	2 140	2 140	2 140	2 140	2 140
Refineries & Others[2]	1 678	1 748	1 683	1 719	1 753	1 760	1 705	1 723	1 700	1 600
Refinery LPGs[3]	g/L									
All Stationary	1 581	1 597	1 586	1 585	1 591	1 604	1 615	1 613	1 613	1 613

Notes:
1. Adapted from CIEEDAC (2003)
2. Adapted from CIEEDAC (2010)
3. Adapted from propane and butane emission factors

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Table A8–6 N_2O Emission Factors for Petroleum Coke

	Emission Factor											
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001–2012
Petroleum Coke	g/m³											
Upgrading Facilities[1,2]	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 & Others[1,2]	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:
1. Adapted from IPCC (2006)
2. Energy content from Statistics Canada Cat. No. 57-003 (2013)

Table A8–7 CO_2 Emission Factors for Coal

Province	Coal Type	Source	Emission Factor (kg CO_2/tonne)[1,2,3]			
			Mean	Uncertainty (95% Confidence Interval)		Moisture (wt %)
				Low	High	
Newfoundland & Labrador, P.E.I., Quebec, Nova Scotia (prior to 2000)	Canadian Bituminous (Eastern)	Nova Scotia	2 321	-33%	22%	3.2
Newfoundland & Labrador, P.E.I., Quebec, Nova Scotia (2000 onward)	Canadian Bituminous (Western)	Alberta	2,190	-26%	26%	7.7
New Brunswick	Canadian Bituminous (Eastern)	New Brunswick	2 310	-12%	12%	3.2
Atlantic[4]	Foreign Bituminous	Non-U.S.	2 545	-7%	7%	8.3
Ontario	Canadian Bituminous (Western)	Alberta	2 190	-23%	21%	7.6
Ontario, Quebec	Foreign Bituminous	U.S. (Pennsylvania)	2 600	-7%	7%	N/A
Ontario, Manitoba	Foreign Sub-bituminous	U.S. (Wyoming)	1 726	-7%	7%	N/A
Saskatchewan	Lignite	Saskatchewan	1 450	-13%	13%	36
Alberta, Saskatchewan, B.C.	Canadian Sub-bituminous (Western)	Alberta	1 745	-20%	16%	19
Alberta, Saskatchewan, B.C.	Canadian Bituminous (Western)	Alberta	2 190	-26%	26%	7.7
All Provinces & Territories	Anthracite	--	2 387	N/A	N/A	N/A

Notes:
1. Factors presented on a "wet basis." Moisture content shown is that for the "weighted average" emission factor.
2. Radovan et al. (2012)
3. 95% confidence intervals, which were determined through statistical analysis of Canadian coal data
4. Atlantic refers to the Maritime provinces and Newfoundland & Labrador

N/A = not available

Factors presented in Table A8–7 were developed based on the statistical analysis of over 3000 analytical samples for a variety of coal types and producing/consuming regions. The analysis and uncertainty calculations were conducted using the @Risk software package. The coal emission factors are presented with uncertainty estimates, because the supply and quality of coal can vary over time. The average coal carbon and moisture content for each coal type was used to develop CO_2 emission factors. Factors for coal imported from the United States are from Annex 2 of the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008 (U.S. EPA 2010).

Coke and coke oven gas emission factors are presented in Table A8–8. The coke emission factor was developed based on industry data (Jaques 1992). It is representative of coke use in the cement, non-ferrous metal and other manufacturing industries. The coke oven gas emission-factor value is from McCann (2000) and represents use in the iron and steel industry.

A8.1.3.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Emission factors for sectors (Table A8–9 have been developed based on technologies typically used in Canada. The factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

A8.1.3.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Emission factors for sectors (Table A8–9 have been developed based on technologies typically used in Canada. The emission factors were developed from an analysis of combustion technologies and a review of their emission factors (SGA Energy 2000).

A8.1.4. Other Fuels

A8.1.4.1. CO_2

Alternative fuels such as tires, refuse, and waste oil and solvents are used 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 A8–10.

A8.1.4.2. CH_4

CH_4 emission factors for alternative fuels were adapted from the 1996 IPCC guidelines (IPCC/OECD/IEA 1997).

A8.1.4.3. N_2O

N_2O emission factors for alternative fuels were adapted from the 1996 IPCC guidelines (IPCC/OECD/IEA 1997).

A8.1.5. Mobile Combustion

A8.1.5.1. CO_2

CO_2 emission factors for mobile combustion are dependent on fuel properties and are generally the same as those used for stationary combustion fuels.

A8.1.5.2. CH_4

Emissions of CH_4 from fuel combustion are technology-dependent. Mode-specific CH_4 emission factors have been developed based on technologies typically used in Canada, and are summarized in Table A8–11. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies (SGA Energy 2000). 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).

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 A8–11 displays a national overall average implied emission factor, for conciseness (refer to Section A2.4.2.3 for more information on AGEM).

Table A8–8 CO_2 Emission Factors for Coal Products

Coal Product - Fuel Type	Emission Factor
Coke Oven Gas[1]	687 g/m^3
Coke[2]	2 479 g/kg

Notes:
1. McCann (2000)
2. Adapted from Jaques (1992)

Table A8–9 CH_4 and N_2O Emission Factors for Coals [1]

Source	Emission Factor	
	CH_4	N_2O
	g/kg	
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/m^3	
Coke Oven Gas	0.04	0.04

Note:
1. SGA Energy (2000)

Table A8–10 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 - 2012
Cement Industry Waste Fuel	CO_2[1]	78.8	77.6	78.6	80.6	82.6	81.5	81.2	83.8	87.7	86.3	79.2	80.1
	CH_4[2]	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[2]	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:
1. Adapted from WBSCD (2005)
2. Adapted from IPCC/OECD/IEA (1997)

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Table A8–11 Emission Factors for Energy Mobile Combustion Sources

	Emission Factor (g/L fuel)		
Mode†	**CO_2**	**CH_4**	**N_2O**
Road Transport			
Gasoline Vehicles			
Light-duty Gasoline Vehicles (LDGVs)			
Tier 2	2 289[1]	0.14[2]	0.022[3]
Tier 1	2 289[1]	0.23[4]	0.47[4]
Tier 0	2 289[1]	0.32[5]	0.66[6]
Oxidation Catalyst	2 289[1]	0.52[7]	0.20[5]
Non-catalytic Controlled	2 289[1]	0.46[7]	0.028[5]
Light-duty Gasoline Trucks (LDGTs)			
Tier 2	2 289[1]	0.14[2]	0.022[3]
Tier 1	2 289[1]	0.24[4]	0.58[4]
Tier 0	2 289[1]	0.21[7]	0.66[6]
Oxidation Catalyst	2 289[1]	0.43[7]	0.20[5]
Non-catalytic Controlled	2 289[1]	0.56[5]	0.028[5]
Heavy-duty Gasoline Vehicles (HDGVs)			
Three-way Catalyst	2 289[1]	0.068[7]	0.20[7]
Non-catalytic Controlled	2 289[1]	0.29[5]	0.047[5]
Uncontrolled	2 289[1]	0.49[5]	0.084[5]
Motorcycles			
Non-catalytic Controlled	2 289[1]	0.77[2]	0.041[2]
Uncontrolled	2 289[1]	2.3[5]	0.048[5]
Diesel Vehicles			
Light-duty Diesel Vehicles (LDDVs)			
Advanced Control*	2 663[1]	0.051[5]	0.22[5]
Moderate Control	2 663[1]	0.068[5]	0.21[5]
Uncontrolled	2 663[1]	0.10[5]	0.16[5]
Light-duty Diesel Trucks (LDDTs)			
Advanced Control*	2 663[1]	0.068[5]	0.22[5]
Moderate Control	2 663[1]	0.068[5]	0.21[5]
Uncontrolled	2 663[1]	0.085[5]	0.16[5]
Heavy-duty Diesel Vehicles (HDDVs)			
Advanced Control	2 663[1]	0.11[8]	0.151[8]
Moderate Control	2 663[1]	0.14[5]	0.082[5]
Uncontrolled	2 663[1]	0.15[5]	0.075[5]
Natural Gas Vehicles	1.89[1]	9E-03[5]	6E-05[5]
Propane Vehicles	1 507[1]	0.64[5]	0.028[5]
Off-road			
Off-road Gasoline	2 289[1]	2.7[5]	0.050[5]
Off-road Diesel	2 663[1]	0.15[5]	1.1[5]
Railways			
Diesel Train	2 663[1]	0.15[5]	1.1[5]
Marine			
Gasoline Boats	2 289[1]	1.3[5]	0.066[5]
Diesel Ships	2 663[1]	0.15[5]	1.1[5]
Light Fuel Oil Ships	2 725[1]	0.26[5]	0.073[5]
Heavy Fuel Oil Ships	3 124[1]	0.28[5]	0.079[5]
Aviation			
Aviation Gasoline	2 342[9]	2.2[9]	0.23[9]
Aviation Turbo Fuel	2 534[1]	0.029[10]	0.071[11]
Renewable Fuels			
Ethanol	1 494[12]	**	**
Biodiesel	2 449[12,13]	***	***

Notes:
† In the context of Transportation Modes, Tiers 0–2 refer to increasingly stringent U.S. EPA emission standards, enabled through advancements in emission control technologies. It should not be confused with IPCC GHG estimation methodologies. EPA Tiers apply to on-road vehicles under the following model year breakdown, with some overlap due to technology penetration (refer to Figure A2-2 of Annex 2 for more details): Tier 0: 1980-1995; Tier 1: 1994-2003; Tier 2: 2004-2012.

1. Adapted from McCann (2000)
2. Adapted from Environment Canada ERMD Report 04-44 (2006)
3. Adapted from Environment Canada ERMD Report 04-44 (2006) and Graham et al. (2009)
4. Adapted from Environment Canada ERMS Report 07-14A (2009)
5. SGA Energy (2000)
6. Adapted from Barton & Simpson (1994)
7. ICF Consulting (2004)
8. Graham et al. (2008)
9. Jaques (1992)
10. National overall average emission factor based on 2006 IPCC Guidelines (IPCC 2006). Refer to Section A2.4.2.3 of Annex 2 for further information
11. IPCC (2006)
12. Refer to Section 3.4.2.3 and 3.4.2.4 of Chapter 3 for further information.
13. BioMer (2005)

* Advanced control diesel emission factors are used for Tier 2 diesel vehicle populations.
** Gasoline CH_4 and N_2O emission factors (by mode and technology) are used for ethanol.
*** Diesel CH_4 and N_2O emission factors (by mode and technology) are used for biodiesel.

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A8.1.5.3. N_2O

Emissions of N_2O from fuel combustion are technology-dependent. Mode-specific N_2O emission factors have been developed based on technologies typically used in Canada. The factors were initially adopted from a review of available knowledge and an analysis of combustion technologies (SGA Energy 2000). Similar to the CH_4 emission factors of Section A8.1.5.2, 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).

A8.2. Industrial Processes

A8.2.1. Mineral Products

To estimate emissions from the production and use of mineral products, emission factors are listed in Table A8–12.

A8.2.2. Chemical Industry

Table A8–13, Table A8–14 and Table A8–15 are the emission factors used for categories included under the Chemical Industry, as well as the sources from which these factors were obtained.

A8.2.3. Metal Production

The emission factors for metallurgical coke use are year-specific, and they are obtained from Cheminfo Services (2010). The range of the metallurgical coke emission factors and other parameters used for estimating emissions from iron and steel production are found in Table A8–16.

Tier 1-type emission factors for the category of Aluminium Production and the sources from which these emission factors were obtained are shown in Table A8–17. The parameter values of other tier types, which were also used in the estimation of emissions from aluminium production, are found in Section 4.17.2 of Chapter 4.

8.2.4. Consumption of Halocarbons

The use of halocarbons in various applications, such as air conditioning (AC), refrigeration, aerosols, foam blowing, solvents, fire extinguishing and semiconductor manufacturing (for PFCs only), can result in hydrofluorocarbon/perfluorocarbon (HFC/PFC) emissions.

As mentioned in Chapter 4 of this report, detailed 1995 HFC activity data were not available. Therefore, a modified Tier 1, instead of Tier 2, methodology was used to estimate 1995 HFC emissions for the following use types: aerosols, foam blowing, AC original equipment manufacturing (OEM), AC servicing, refrigeration and total flooding systems. Shown in Table A8–18 are the emission factors used in the modified Tier 1 estimation method and the assumptions made to derive and to use these factors.

A8.2.5. Other and Undifferentiated Production

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 A8–20 shows the emission factors used to develop CO_2 emission estimates for non-energy applications of natural gas liquids and non-energy petroleum products, respectively. The emission factors for NEU petroleum coke are found in Table A8–5. The 2011 emission-factor value for Upgrading Facilities in Table A8–5 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 A8–7.

A8.3. Solvent and Other Product Use

N_2O emissions can result from the use of N_2O as an anaesthetic and propellant. The development of the emission factors shown in Table A8–21 is described in the Solvent and Other Product Use chapter of the Inventory Report (Chapter 5).

A8.4. Agriculture

The sources of agricultural GHGs are enteric fermentation, manure management, field burning of crop residues and agricultural soils. Methodologies for generating country-specific CH_4 emission factors for enteric fermentation (cattle only) and manure management emission estimates are detailed in Section A3.3. Other emission factors and related information are provided below, in Table A8–22 to Table A8–25.

Table A8–12 Carbon Dioxide (CO_2) Emission Factors for Mineral Products

Category	Mineral Product	Emission Factor (g CO_2/kg of mineral product)
Cement Production	Clinker	507.1[1]
Lime Production	High-Calcium Lime	751[2]
	Dolomitic lime	889[2]
Limestone and Dolomite Use	Limestone	418[3]
	Dolomite	468[3]
Soda Ash Use	Soda Ash	415[3]
Magnesite Use	Magnesite	506[3]

Notes:
1. IPCC/OECD/IEA (1997)
2. Developed based on information provided by Kenefick (2008). Personal communication (email to Amy Shen, Greenhouse Gas Division, dated October 7, 2008). Canadian Lime Institute (CLI)
3. AMEC (2006)

Table A8–13 Emission Factors for Ammonia Production

		Fuel Factor m^3natural gas/tonne of NH_3	Emission Factor CO_2/ m^3 of natural gas
Ammonia Production	Feedstock use of natural gas to manufacture ammonia	Facility-specific fuel factors are used and these are confidential. See Annex 3.2 for details	Marketable natural gas emission factors found on Table A8–1 are used

Table A8–14 N_2O Emission Factors for Nitric Acid and Adipic Acid Production

Category	Process Description	N_2O Emission Factor (kg/t)
Nitric Acid Production	Dual-pressure plants with extended absorption "Type 1"	9.4[1]
	Dual-pressure plants with extended absorption "Type 2"	12[1]
	High-pressure plants with non-selective catalytic reduction	0.66[1]
	High-pressure plants with selective catalytic reduction	8.5[2]
Adipic Acid Production	Oxidation reaction of cyclohexanone and cyclohexanol mixture without N_2O abatement	0.3[2]

Notes:
1. Collis G. 1992. Personal communication (letter from Collis G to Art Jaques, Greenhouse Gas Division, dated March 23, 1992). Canadian Fertilizer Institute
2. IPCC (2000)

Table A8–15 Emission Factors for Petrochemical Products

Petrochemical Product	Emission Factor	Type
Silicon Carbide	11.6 kg CH_4 / t (tonne) product	IPCC default[1]
Calcium Carbide	4.8 kg CH_4 / t product	Derived from IPCC data[2]
Carbon Black	1.29 kg CH_4 / t product	Sector-wide weighted average[3]
Ethylene	0.013 kg CH_4 / t product	Sector-wide weighted average[3]
	0.0055 kg N_2O / t product	Sector-wide weighted average[3]
Ethylene Dichloride	0.4 kg CH_4 / t product	IPCC default[1]
Styrene	4 kg CH_4 / t product	IPCC default[1]
Methanol	0.031 kg CH_4 / t product	Sector-wide weighted average[3]

Notes:
1. Default value from IPCC (2006)
2. Derived from IPCC (2006) data. See section 4.10.2 for details
3. Cheminfo Services (2010)

Table A8–16 CO_2 Emission Factors for Iron and Steel Industry

Parameter	Emission Factor	Unit
Iron ore reduction with coke	3.2–3.3[1]	t CO_2/t (tonne) coke used
Electrode consumption in electric arc furnaces	4.53[2]	kg CO_2/ t steel
Electrode consumption in basic oxide furnaces	0.23[2]	kg CO_2/ t steel

Notes:
1. Year-specific emission factors provided in Cheminfo Services (2010)
2. Provided by the Canadian Steel Producers Association. Chan K. 2009. Personal communication (email from Chan K to Maryse Pagé, Greenhouse Gas Division, dated July 21, 2009). Canadian Steel Producers Association.

Table A8–17 Tier 1 Emission Factors for Aluminium Production

Cell Technology Type	Emission Factor[1] (kg /t product)		
	CO_2	Carbon Tetrafluoride (CF_4)	Carbon Hexafluoride (C_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

Notes:
1. IAI (2006)

Table A8–18 Emission Factors for Consumption of HFCs in 1995

Application	Emission Factor (kg loss/ g consumed)	Assumptions
Aerosols	0.8	For aerosol products, the IPCC (2000) suggests a default emission factor of 50% of the initial charge per year. It was assumed that 1994 production was 50% of that of 1995, meaning that emissions from 1994 production that occurred in 1995 would be equivalent.
Foams	1	For foam blowing, it was assumed that all HFCs used for foam blowing in 1995 were for the open cell type. According to the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*,[1] emissions equal 100% of the quantity sold for blowing open cell.
AC OEM	0.04	For AC OEM, a typical range of 2–5% loss rate is noted in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*.[1] Therefore, a loss rate of 4% was assumed here.
AC Service	1	For AC Service, it was assumed that most service HFCs were used to replace operating losses. In other words, it was assumed that service HFCs replace an identical amount of HFCs that was previously vented. Hence, the loss rate was 100%.
Refrigeration	0.1	As shown in Equation 4-18 of Chapter 4, the emission factor for refrigeration is (0.17/1.17), which equals roughly 0.1.
Total Flooding Systems	0.35	For total flooding systems, the default loss rate, as shown in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*,[1] is 35%.

Notes:
1. IPCC/OECD/IEA (1997)

A8.5. Biomass Combustion

A8.5.1. CO_2

Emissions of CO_2 from the combustion of biomass (whether for energy use, from prescribed burning or from wildfires) are not included in National Inventory totals. These emissions are estimated and recorded as a loss of biomass stock in the Land Use, Land-use Change and Forestry (LULUCF) Sector.

The emissions related to energy use are reported as memo items in the common reporting format (CRF) tables as required by the United Nations Framework Convention on Climate Change (UNFCCC). Emission factors for residential combustion (Table A8–26) are technology-dependent.

Table A8–19 Emission Rates for Consumption of HFCs and PFCs [1]

Application	HFC Emission Rate (%)	PFC Emissions Rate (%)
Assembly		
Residential Refrigeration Equipment	2% (of charge)	3.5% (of charge) [2]
Commercial Refrigeration Equipment	3.5% (of charge) [2]	
Stationary AC Equipment	3.5% (of charge) [2]	3.5% (of charge) [2]
Mobile AC Equipment	4.5% (of charge) [3]	4.5% (of charge) [3]
Operation		
Residential Refrigeration Equipment	1% (of stock in existing systems)	17% (of stock in existing systems)
Commercial Refrigeration Equipment	17% (of stock in existing systems)	
Stationary AC Equipment	17% (of stock in existing systems)	17% (of stock in existing systems)
Mobile AC Equipment	15% (of stock in existing systems) [4]	30% (of stock in existing systems)
Other Applications		
Foam Blowing - open cell	100% (of use)	100% (of use)
Foam Blowing - closed cell	10% of charge released during manufacturing and 4.5% of the original quantity charge released per year over the product's lifetime	10% of charge released during manufacturing and 4.5% of the original quantity charge released per year over the product's lifetime
Fire Extinguishing – portable	60% (of HFC use in new systems)	NA
Fire Extinguishing – total flooding systems	35% (of HFC use in new systems)	NA
Aerosol Products	50% (of use) in the first year and the other 50% (of use) in the second year	NA
Solvents	50% (of use) in the first year and the other 50% (of use) in the second year	50% (of use) in the first year and the other 50% (of use) in the second year
Other Products – contained	NA	1% of the quantity sold is emitted during manufacturing and 2% of stock is emitted per year during the product's lifetime
Other Products – emissive	NA	50% (of use) in the first year and the other 50% (of use) in the second year

Notes:
1. IPCC/OECD/IEA (1997)
2. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* provide two ranges for values: 2–3% and 4–5%. The mid-point of the two ranges was used.
3. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* provide a range of 4–5% as values. The average value was used.
4. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* provide a range of 10–20% as values. The average value was used.

NA = Not applicable

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The CO_2 emission factor (Table A8–26) for industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (one million British thermal units; U.S. EPA 2003). The U.S. EPA data were converted to kg/tonne at 50% moisture content (m.c.) using a higher heating value (HHV) of 10.47 MJ/kg at 50% m.c., which was developed from an internal review of available moisture content and heating value data. The emission factor for spent pulping liquor is calculated from data collected by the National Council for Air and Stream Improvement (NCASI), based on carbon content assuming a 1% correction for unoxidized carbon (NCASI 2010). The NCASI emission factors were reported in units of kg/GJ HHV, which was converted to kg/tonne at 50% m.c. based on the same HHV vs. moisture content relationship used to convert wood waste.

CO_2 emissions occur during forest wildfires and from controlled burning during forest conversion activities. The carbon emitted as CO_2 (CO_2-C) during forest fires is considered in the forest carbon balance, whereas the CO_2-C emitted during controlled burns is reported under the new land-use categories. There is no unique CO_2 emission factor applicable to all fires, as the proportion of CO_2-C emitted for each pool can be specific to the pool, the type of forest and disturbance, and the ecological zone (see Section A3.4.2).

A8.5.2. CH_4

Emissions of CH_4 from residential combustion of firewood are technology-dependent. The emission factors are taken or adapted from the U.S. EPA AP 42 Supplement B (U.S. EPA 1996b).

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. The emission factor (Table A8–26) for CH_4 from industrial wood waste has been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA 2003) and converted to kg/tonne at 50% m.c. as discussed in Section A8.5.1 above.

Table A8–20 CO_2 Emission Factors for Non-energy Use of Natural Gas Liquids and Petroleum Products

Product	Fraction of Carbon Stored in Product	CO_2 Emission Factor (g CO_2/L)
Natural Gas Liquids		
Propane	0.8[1]	303[2]
Butane	0.8[1]	349[2]
Ethane	0.8[1]	197[2]
Petroleum Products		
Petrochemical Feedstocks[3]	0.8[1]	500[7]
Naphthas[4]	0.75[1]	625[7]
Lubricating Oils and Greases[5]	0.5[1]	1 410[7]
Petroleum Used for Other Products[6]	0.5[1]	1 450[7]

Notes:
1. IPCC/OECD/IEA (1997)
2. McCann (2000)
3. Carbon factor for Petrochemical Feedstocks is 680 g of carbon per litre (C/L) (Jaques 1992)
4. Carbon factor for Napthas is 680 g C/L (Jaques 1992)
5. Carbon factor for Lubricating Oils and Greases is 770 g C/L (Jaques 1992)
6. Carbon factor for Petroleum Used in Other Products is 790 g C/L (Jaques 1992)
7. The resulting CO_2 emission factor is calculated by multiplying the carbon factor for each product by the molecular weight ratio between CO_2 and Carbon (44/12) and by (1-fraction of carbon stored in product).

Table A8–21 Emission Factors for Solvent and Other Product Use

Product	Application	N_2O Emission Rate (%)
N_2O Use	Anaesthetic Usage	100
	Propellant Usage	100

Source: IPCC (2006)

Table A8–22 Methane Emission Factors for Enteric Fermentation for Non-cattle Animals

Non-cattle Animal Category	Enteric Fermentation Emission Factor[1] (kg CH_4/head per year)
Pigs	
Boars	1.5
Sows	1.5
Pigs < 20 kg	1.5
Pigs 20–60 kg	1.5
Pigs > 60 kg	1.5
Other Livestock	
Sheep	8
Lambs	8
Goats	5
Horses	18
Buffalo	55
Poultry	
Chickens	N/A
Hens	N/A
Turkeys	N/A

Notes:
1. IPCC Tier 1 default emission factors (IPCC/OECD/IEA 1997)
N/A = Not available

The emission factor for CH_4 from spent pulping liquor is adapted from the IPCC (2006). It is converted from the units reported in the IPCC (kg/TJ lower heating value [LHV]) to kg/tonne at 50% m.c. based on the assumption that the LHV is 20% lower than the HHV along with the same HHV vs. moisture content relationship discussed in Section A8.5.1.

Emission factors from landfill gas (Table A8–27) are adapted from the IPCC (2006).

Table A8–23 Maximum Methane-Producing Potential (B_0) by animal category[1]

Animal Category	Maximum CH_4 Producing Potential (B_0) (m^3/kg VS)[4]
Dairy Cattle[2]	0.24
Non-dairy Cattle[3]	0.19
Sheep	0.19
Goats	0.18
Horses	0.30
Swines	0.48
Hens	0.39
Broilers	0.36
Turkeys	0.36

Notes:
1. Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9
2. Dairy cattle include dairy cows and dairy heifers.
3. The non-dairy cattle value is also used for buffalo.
4. VS = volatile solids

Table A8–24 Methane Conversion Factors (MCFs) by Animal Category and Manure Management System[1]

Animal Categories	Liquid Systems (MCF_L)	Solid Storage and Dry-lot (MCF_{SSD})	Pasture, Range and Pad-dock (MCF_{PRP})	Other Systems (MCF_O)
Dairy Cattle	0.2	0.02	0.01	0.01
Non-dairy Cattle[2]	0.2	0.02	0.01	0.01
Swine	0.2	0.02	NA	0.01
Poultry	0.2	0.015	0.015	NA
Horses	NA	0.01	0.01	NA
Goats	NA	0.01	0.01	NA
Sheep	NA	0.01	0.01	NA
Lambs	NA	0.01	0.01	NA

Notes:
1. Data source: IPCC (2006), Volume 4: Agriculture, Forestry and Other Land Uses, Tables 10A-5 to 10A-9 (cool climate, average annual temperature 12°C)
2. Non-dairy cattle values are also used for buffalo.
3. NA = Not applicable

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Table A8–25 Emission Factors (EFs) for Manure Nitrogen (N) Lost as N_2O-N by Animal Category and Animal Waste Management Systems (IPCC/OECD/IEA 1997))

	Liquid Systems (EF_L)	Solid Storage and Drylot (EF_{SSD})	Pasture, Range and Paddock (EF_{PRP})	Other Systems (EF_O)
Non-dairy Cattle	0.001	0.02	0.02	0.005
Dairy Cattle	0.001	0.02	0.02	0.005
Poultry	0.001	0.02	0.02	0.005
Sheep and Lambs	0.001	0.02	0.01[1]	0.005
Swine	0.001	0.02	0.02	0.005
Goats	0.001	0.02	0.01[1]	0.005
Horses	0.001	0.02	0.01[1]	0.005
Buffalo	0.001	0.02	0.02	0.005

Notes:
1. Source: IPCC (2006), Volume 4, Agriculture, Forestry and Other Land Uses, Table 11.1

Emissions of carbon as CH_4 (CH_4-C) from wildfires and controlled burning are always equal to 1/90th of CO_2-C emissions.

A8.5.3. N_2O

Emissions of N_2O from residential combustion of firewood are technology-dependent. The emission factors (Table A8–26) were

chosen based on a review of emission factors for combustion technologies and an analysis of combustion technologies typically used in Canada (Jacques 1992).

Emissions from industrial combustion of biomass are dependent primarily on the characteristics of the fuel being combusted. Emission factors (Table A8–26) for industrial wood waste have been developed from facility source sampling data collected by the U.S. EPA in units of lb/MMBTU (U.S. EPA 2003) and converted to kg/tonne at 50% m.c. as discussed in Section A8.5.2 above. The emission factor for CH_4 from spent pulping liquor is adapted from the IPCC (2006). It is converted from the units reported in the IPCC (kg/TJ LHV) to kg/tonne at 50% m.c. based on the assumption that the LHV is 20% lower than the HHV along with the same HHV vs. moisture content relationship discussed in A8.5.1.

Emission factors for landfill gas (Table A8–27) are 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 A3.4.2).

A8.6. Waste

A8.6.1. Municipal Wastewater Handling – Wastewater

A8.6.1.1. CH_4

Emissions from municipal wastewater handling are dependent upon the organic loading of the effluent stream, population and the type of wastewater treatment provided. The emission factor in this case is the product of the methane correction factor (MCF), which is an estimate of the fraction of biological oxygen demand (BOD) that will ultimately degrade anaerobically (MCF) and the maximum methane producing capacity (B_0), which is expressed in terms of kg CH_4/kg BOD removed. From a recent study by AECOM Canada (2010), commissioned by Environment Canada, it is recommended that the following country-specific values be used: an MCF of 0.3, which is a blended category that represents the Canadian proportion of septic tanks, anaerobic lagoons and untreated effluents as well as the degree of degradation of the organics expected of the treatment or discharge and a B_0 of 0.36 kg CH_4/kg BOD_5. Therefore, the emission factor is 0.108 kg CH_4/kg BOD_5.

The IPCC default emission factor of 0.6 kg CH_4/kg BOD was not used, as the AECOM study confirmed that its derivation from the 0.25 kg CH_4/kg COD was erroneous, where COD is the chemical oxygen demand.

Table A8–26 Emission Factors for Biomass

Source [1]	Description	Emission Factor (g/kg fuel)		
		CO_2	CH_4	N_2O
Wood Fuel / Wood Waste	Industrial Combustion	840[4]	0.09[4]	0.06[4]
Forest Wildfires	Open Combustion	NA	NA[2]	NA[3]
Controlled Burning	Open Combustion	NA	NA[2]	NA[3]
Spent Pulping Liquor	Industrial Combustion	891[5]	0.02[6]	0.02[6]
Stoves and Fireplaces	Residential Combustion			
Conventional Stoves		1 696[7]	15[7]	0.16[9]
Conventional Fireplaces and Inserts		1 696[7]	15[7]	0.16[9]
Stoves/Fireplaces with Advanced Technology or Catalytic Control		1 696[7]	6.9[8]	0.16[9]
Other Wood-burning Equipment		1 696[7]	15[7]	0.16[9]

Notes:
1. 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.
2. Emission ratio for CH_4 is 1/90th CO_2. See Section A3.4 in Annex 3.
3. Emission ratio for N_2O is 0.017% CO_2. See Section A3.4 in Annex 3.
4. Adapted from U.S. EPA (2003)
5. Adapted from NCASI (2010)
6. Adapted from IPCC (2006)
7. U.S. EPA (1996b)
8. Adapted from U.S. EPA (1996b). Average of the Non-Catalyst Stove and Catalyst Stove Emission factors
9. Jacques (1992)

NA = not applicable

A8.6.2. Municipal Wastewater Handling – Human Sewage

A8.6.2.1. N_2O

N_2O emissions from human sewage are a function of protein consumption per capita, population and the nitrogen content in protein. The emission factor used is the IPCC default value of 0.01 kg N_2O-N/kg sewage-N (IPCC/OECD/IEA 1997).

A8.6.3. Waste Incineration

A8.6.3.1. CH_4 from Sewage Sludge Incinerators

CH_4 emissions from sewage sludge incinerators are estimated from an emission factor of 1.6 kg CH_4/tonne of dry sludge, which is obtained from the U.S. EPA (1995).

A8.6.3.2. N_2O from MSW Incinerators

The emission estimates from municipal solid waste (MSW) incineration are calculated from an average IPCC default emission factor for MSW five-stoker facilities of 0.148 kg N_2O/tonne of waste (IPCC/OECD/IEA 1997). For wastewater sludge incineration, the emission factor is taken from the IPCC Good Practice Guidance and has the value of 0.8 kg N_2O/tonne of dry sludge.

A8.6.3.3. CH_4 from Hazardous Waste Incinerators

In the absence of an IPCC default value, the emission factor used for the estimation of CH_4 from hazardous waste incinerators is based on country-specific measured emissions from data obtained from a facility in Canada that responded to a biennial survey conducted by Environment Canada on waste incineration (Environment Canada 2010). Based on the CH_4 emitted and the hazardous waste quantities incinerated in 2009, an emission factor of 1.695 x 10^{-4} kt CH_4/kt of hazardous waste was estimated.

A8.6.3.4. N_2O from Hazardous Waste Incinerators

In the absence of an IPCC default value, similarly to the description in Section A8.6.3.3 regarding the calculation of CH_4 from this source, the N_2O emission factor is based on the set of data from the same facility (Environment Canada 2010). Based on the N_2O emitted and the hazardous waste quantities incinerated in 2009, an emission factor of 3.164x 10^{-4} kt CH_4/kt of hazardous waste was estimated.

A8.6.3.5. CO_2 from Hazardous Waste Incinerators

For the estimation of the emission factor for CO_2 emissions from hazardous waste incineration, the IPCC default values (IPCC 2000) are used for the carbon content of 50% and percent fossil carbon content over total carbon of 90% for hazardous waste. The emission factor is then 1.65 kt CO_2/kt hazardous waste.

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Table A8–27 Emission Factors for Landfill Gas Combustion

Source	Description	Emission Factor (kg /t)		
		CO_2	CH_4	N_2O
Landfill Gas	Industrial Combustion	2 752	0.05	0.005

Source: Adapted from IPCC (2006), Volume 2, Energy, Table 2.2

Annex 9

Rounding Protocol

A rounding protocol has been developed for the emission and removal estimates in order to reflect their uncertainty levels. The accuracy of a value is reflected by presenting the emission and removal estimates rounded to an appropriate number of significant figures based on the uncertainty of the category in question. The number of significant figures to which each source and sink category has been rounded, using the rounding rules provided in this protocol, can be found in Table A9–1.

A large number of the uncertainty ranges that are used for the various categories were developed using Monte Carlo analysis, as performed by ICF Consulting (ICF Consulting 2004, 2005), using the 2001 inventory estimates submitted in the NIR 2003. Default uncertainty values published by the IPCC (IPCC/OECD/IEA 1997; IPCC 2001) and those resulting from expert elicitation were also utilized for some ranges. Since 2004-05, many methodological changes , refinements and updates, including updates to the uncertinty paramenter themselves, have been made. The uncertainty ranges have been calculated around the mean values established by these analyses.

For a more complete description of the analysis of uncertainty in Canada's emission estimates, please refer to Annex 7, which includes tables of current uncertainty values. Recent updates to uncertainty estimates are provided in the respective sectoral chapters.

The following uncertainty values have been used to establish the number of significant figures to which the estimates have been rounded:

- uncertainty greater than 50%: one significant figure;
- uncertainty between 10% and 50%: two significant figures: and
- uncertainty equal to or less than 10%: three significant figures.

All calculations, including the summing of emission totals, were made using unrounded data. The rounding protocol was applied only after the calculations had been completed. The reader should also note that formatting in Annex 11 and Annex 12 limits the maximum number of decimal places and, therefore, even though a zero entry is recorded, some emissions may exist in that category (zero emissions are identified with a dash "-"). Because of these procedures, individual values in the emission tables may not add up to the subtotals and/or overall totals.

Table A9–1 Number of Significant Figures Applied to GHG Summary Tables

GHG Source/Sink Categories		Number of Significant Figures						
		CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	TOTAL
TOTAL		**3**	**2**	**2**	**2**	**2**	**2**	**3**
ENERGY		**3**	**2**	**1**				**3**
a.	Stationary Combustion Sources	3	1	1				3
	Electricity and Heat Generation	3	2	1				3
	Fossil Fuel Industries	3	1	1				2
	Petroleum Refining and Upgrading	3	2	2				3
	Fossil Fuel Production	2	2	3				2
	Mining & Oil and Gas Extraction	3	2	1				3
	Manufacturing Industries	3	1	1				3
	Iron and Steel	3	1	1				3
	Non-ferrous Metals	3	1	1				3
	Chemical	3	2	1				3
	Pulp and Paper	3	1	1				3
	Cement	3	2	1				3
	Other Manufacturing	3	2	1				3
	Construction	3	2	1				3
	Commercial & Institutional	3	2	1				3
	Residential	3	1	1				3
	Agriculture & Forestry	3	2	2				3
b.	Transportation	3	1	1				3
	Domestic Aviation	3	1	1				2
	Road Transportation	3	1	2				3
	Light-duty Gasoline Vehicles	3	2	2				3
	Light-duty Gasoline Trucks	3	2	2				3
	Heavy-duty Gasoline Vehicles	3	2	2				3
	Motorcycles	3	2	2				3
	Light-duty Diesel Vehicles	3	1	1				3
	Light-duty Diesel Trucks	3	1	1				3
	Heavy-duty Diesel Vehicles	3	1	1				3
	Propane & Natural Gas Vehicles	3	1	1				2
	Railways	3	1	1				2
	Domestic Marine	3	1	1				2
	Others	3	1	1				2
	Off-road Gasoline	3	1	1				2
	Off-road Diesel	3	1	1				2
	Pipelines	3	2	1				3
c.	Fugitive Sources	2	2	1				2
	Coal Mining		1					1
	Oil and Natural Gas	2	2	1				2
	Oil	2	2	1				2
	Natural Gas	2	2					2
	Venting	2	2					2
	Flaring	2	2	1				2
INDUSTRIAL PROCESSES		**3**	**2**	**3**	**2**	**2**	**2**	**3**
a.	Mineral Production	2						2
	Cement Production	2						2
	Lime Production	3						3
	Mineral Product Use	2						2
b.	Chemical Industry	3	2	2				3
	Ammonia Production	3						3
	Nitric Acid Production			2				2
	Adipic Acid Production			2				2
	Petrochemical Production		2	2				2
c.	Metal Production	3				3	3	3
	Iron and Steel Production	3						3
	Aluminium Production	3				3	3	3
	SF_6 Used in Magnesium Smelters and Casters						3	3
d.	Consumption of Halocarbons and SF_6				2	2	2	2
e.	Other & Undifferentiated Production	2						2
SOLVENT AND OTHER PRODUCT USE				**2**				**2**
AGRICULTURE			**2**	**1**				**2**
a.	Enteric Fermentation		2					2
b.	Manure Management		2	3				2
c.	Agricultural Soils			2				2
	Direct Sources			2				2
	Pasture, Range, and Paddock Manure			2				2
	Indirect Sources			1				1
d.	Field Burning of Agricultural Residues		1	1				1
WASTE		**2**	**2**	**1**				**2**
a.	Solid Waste Disposal on Land		2					2
b.	Wastewater Handling		2	1				2
c.	Waste Incineration	2	1	1				2
LAND USE, LAND-USE CHANGE AND FORESTRY		**1**	**1**	**1**				**1**
a.	Forest Land	1	1	1				1
b.	Cropland	2	1	1				2
c.	Grassland		1	1				1
d.	Wetlands	1						1
e.	Settlements	1	1	1				1

Annex 10

Ozone and Aerosol Precursors

The 2012 national summary table for carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur oxides (SOx) is included in this annex (Table A10–1). Emissions of these gases are reported[1] to the United Nations Economic Commission for the Environment (UNECE) under the Convention on Long-range Transboundary Air Pollution (CLRTAP). As recommended by the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (FCCC/SBSTA/2006/9 – UNFCCC 2006), Annex I Parties should provide information on indirect greenhouse gases (GHGs) such as CO, NO_x, NMVOC and 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 the terrestrial radiation absorption, as in the case of SO_x. These gases can impact the climate by acting as short-lived GHGs, alter atmospheric lifetimes of other GHGs and form GHGs, as in the case of CO reacting with a hydroxyl radical to form CO_2 in the atmosphere. These emissions are produced by a number of sources, such as fossil fuel combustion in the energy and transportation sectors, industrial production and biomass combustion.

National emission summaries for key air pollutants, along with historical national emission trends, are also available on Environment Canada's website.[2]

1 Data and subsequent updates reported to the UNECE are available online at www.ceip.at.

2 Canada's 2012 Air Pollutant Emission Summaries and Historical Emissions Trends can be found at http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=F98AFAE7-1.

Table A10–1 Carbon Monoxide, Nitrogen Oxides, Non-methane Volatile Organic Compounds and Sulphur Oxides 2012 Emissions Summary for Canada

NFR Sectors Reported to CLRTAP[1]		CO	NO_x	NMVOC	SO_x
		kt			
1 A 1 a	Public Electricity and Heat Production	32.29	165.77	1.16	275.77
1 A 1 b	Petroleum Refining	0.00	0.00	0.01	0.00
1 A 1 c	Manufacture of Solid Fuels and Other Energy Industries	409.45	422.65	45.58	236.92
1 A 2 a	Stationary Combustion in Manufacturing Industries and Construction: Iron and steel	2.35	7.85	0.05	10.09
1 A 2 b	Stationary Combustion in Manufacturing Industries and Construction: Non-ferrous metals	12.49	0.78	0.05	1.70
1 A 2 c	Stationary Combustion in Manufacturing Industries and Construction: Chemicals	0.95	5.43	0.25	5.13
1 A 2 d	Stationary Combustion in Manufacturing Industries and Construction: Pulp, Paper and Print	338.28	24.61	26.54	21.54
1 A 2 e	Stationary Combustion in Manufacturing Industries and Construction: Food processing, beverages and tobacco	0.23	0.75	0.01	0.54
1 A 2 f i	Stationary Combustion in Manufacturing Industries and Construction: Other	61.82	47.43	3.21	42.04
1 A 2 f ii	Mobile Combustion in Manufacturing Industries and Construction	0.00	0.02	0.00	0.00
1 A 3 a ii (i)	Civil Aviation (Domestic, LTO)	28.86	9.31	7.78	0.99
1 A 3 a i (i)	International Aviation (LTO)	IE	IE	IE	IE
1 A 3 b i	Road Transport: Passenger Cars	1 598.66	63.56	76.72	0.69
1 A 3 b ii	Road Transport: Light-duty Vehicles	1 484.11	81.13	74.66	0.80
1 A 3 b iii	Road Transport: Heavy-duty Vehicles	95.39	162.42	12.93	0.74
1 A 3 b iv	Road Transport: Mopeds & Motorcycles	21.37	1.17	2.92	0.00
1 A 3 b v	Road Transport: Gasoline Evaporation	NA	NA	IE	NA
1 A 3 b vi	Road Transport: Automobile Tire and Brake Wear	NA	NA	NA	NA
1 A 3 b vii	Road Transport: Automobile Road Abrasion	NA	NA	NA	NA
1 A 3 c	Railways	16.16	92.08	2.72	0.47
1 A 3 d i (ii)	International Inland Waterways	IE	IE	IE	IE
1 A 3 d ii	National Navigation (Shipping)	10.61	126.77	4.19	88.08
1 A 3 e	Pipeline Compressors	IE	IE	IE	IE
1 A 4 a i	Commercial / Institutional: Stationary	1.05	3.14	0.23	0.83
1 A 4 a ii	Commercial / Institutional: Mobile	IE	IE	IE	IE
1 A 4 b i	Residential: Stationary Plants	0.00	0.00	0.00	0.00
1 A 4 b ii	Residential: Household and Gardening (mobile)	IE	IE	IE	IE
1 A 4 c i	Agriculture/Forestry/Fishing: Stationary	IE	IE	IE	IE
1 A 4 c ii	Agriculture/Forestry/Fishing: Off-road Vehicles and Other Machinery	2 727.99	385.58	253.37	0.36
1A 4 c iii	Agriculture/Forestry/Fishing: National Fishing	IE	IE	IE	IE
1 A 5 a	Other, Stationary (including Military)	IE	IE	IE	IE
1 A 5 b	Other, Mobile (including Military, Land-based and Recreational Boats)	IE	IE	IE	IE
1 B 1 a	Fugitive Emission from Solid Fuels: Coal Mining and Handling	0.09	0.35	0.13	0.04
1 B 1 b	Fugitive Emission from Solid Fuels: Solid Fuel Transformation	0.89	1.36	6.61	10.97
1 B 1 c	Other Fugitive Emission from Solid Fuels	1.06	0.93	5.52	0.36
1 B 2 a i	Exploration, Production, Transport	NA	NA	0.03	0.00
1 B 2 a iv	Refining / Storage	0.00	0.00	29.80	0.00
1 B 2 a v	Distribution of Oil Products	NA	NA	53.68	0.00
1 B 2 b	Natural Gas	3.16	3.85	515.66	12.95
1 B 2 c	Venting and Flaring	29.37	28.78	2.95	69.32
1 B 3	Other Fugitive Emissions from Geothermal Energy Production, Peat and Other Energy Extraction Not Included in 1 B 2	IE	IE	0.10	IE
2 A 1	Cement Production	12.10	26.98	0.32	17.48
2 A 2	Lime Production	1.94	2.94	0.02	1.03
2 A 3	Limestone and Dolomite Use	NA	NA	NA	NA
2 A 4	Soda ash Production and Use	NA	NA	NA	NA
2 A 5	Asphalt Roofing	0.00	NA	0.00	NA
2 A 6	Road Paving with Asphalt	3.71	1.09	0.64	0.51
2 A 7 a	Quarrying and Mining of Minerals Other Than Coal	0.69	1.16	0.12	0.18
2 A 7 b	Construction and Demolition	0.30	1.67	0.02	6.91
2 A 7 c	Storage, Handling and Transport of Mineral Products	NA	NA	NA	NA
2 A 7 d	Other Mineral Products	0.64	0.24	0.17	0.89
2 B 1	Ammonia Production	2.62	6.79	0.39	1.66
2 B 2	Nitric Acid Production	NA	IE	NA	NA
2 B 3	Adipic Acid Production	IE	NE	NA	NA
2 B 4	Carbide Production	IE	NE	NA	NA
2 B 5 a	Other Chemical Industry	8.68	10.67	5.70	7.98
2 B 5 b	Storage, Handling and Transport of Chemical Products	IE	IE	IE	IE
2 C 1	Iron and Steel Production	0.00	0.00	0.00	0.00
2 C 2	Ferroalloys Production	48.81	0.14	0.39	0.05

Notes:
1. Nomenclature for Reporting (NFR) sectors reported to the Convention on Long-range Transboundary Air Pollution (CLRTAP).
2. Includes NH_3 from Enteric Fermentation and emissions from Cultivation of Rice.
3. Includes PM sources.
4. Excludes waste incineration for energy (this is included in 1 A 1) and in industry (if used as fuel).
5. Includes accidental fires.
6. "National Total" refers to the territory declared upon ratification of the relevant CLRTAP Protocol.

NA = Not applicable; NE = Not estimated; NO = Not occurring; IE = Included elsewhere; LTO = Landing and takeoff; POPs = Persistent organic pollutants.

Table A10-1 Carbon Monoxide, Nitrogen Oxides, Non-methane Volatile Organic Compounds and Sulphur Oxides 2012 Emissions Summary for Canada (cont'd)

NFR Sectors Reported to CLRTAP[1]		CO	NO_x	NMVOC	SO_x
		kt			
2 C 3	Aluminium Production	0.00	0.00	0.00	0.00
2 C 5 a	Copper Production	0.00	0.00	0.00	0.00
2 C 5 b	Lead Production	0.00	0.00	0.00	0.00
2 C 5 c	Nickel Production	0.00	0.00	0.00	0.00
2 C 5 d	Zinc Production	IE	IE	IE	IE
2 C 5 e	Other Metal Production	408.70	5.94	2.60	424.88
2 C 5 f	Storage, Handling and Transport of Metal Products	IE	IE	IE	IE
2 D 1	Pulp and Paper	27.77	12.54	14.28	6.34
2 D 2	Food and Drink	NA	NA	8.06	NA
2 D 3	Wood Processing	19.33	3.37	35.80	0.19
2 E	Production of POPs	0.00	0.00	0.00	0.00
2 F	Consumption of POPs and Heavy Metals (e.g. electricial and scientific equipment)	NA	NA	NA	NA
2 G	Other Production, Consumption, Storage, Transportation or Handling of Bulk Products	780.14	75.73	202.21	31.36
3 A 1	Decorative Coating Application	NA	0.00	IE	NA
3 A 2	Industrial Coating Application	NA	0.00	IE	NA
3 A 3	Other Coating Application	NA	NA	93.31	NA
3 B 1	Degreasing	NA	NA	229.88	NA
3 B 2	Dry Cleaning	NA	NA	0.28	NA
3 C	Chemical Products	0.00	0.00	1.42	0.00
3 D 1	Printing	NA	NA	27.79	NA
3 D 2	Domestic Solvent Use Including Fungicides	NA	NA	IE	NA
3 D 3	Other Product Use	0.00	0.00	0.00	0.00
4 B 1 a	Cattle Dairy	NA	0.00	39.83	NA
4 B 1 b	Cattle Non-Dairy	NA	0.00	206.35	NA
4 B 2	Buffalo	NA	NE	NE	NA
4 B 3	Sheep	NA	0.00	1.29	NA
4 B 4	Goats	NA	0.00	IE	NA
4 B 6	Horses	NA	0.00	1.86	NA
4 B 7	Mules and Asses	NA	NE	NE	NA
4 B 8	Swine	NA	0.00	2.36	NA
4 B 9 a	Laying Hens	NA	0.00	0.06	NA
4 B 9 b	Broilers	NA	0.00	0.14	NA
4 B 9 c	Turkeys	NA	0.00	0.02	NA
4 B 9 d	Other Poultry	NA	0.00	0.00	NA
4 B 13	Other	NA	0.00	0.00	NA
4 D 1 a	Synthetic N-fertilizers[2]	NA	0.00	0.00	NA
4 D 2 a	Farm-level Agricultural Operations Including Storage, Handling and Transport of Agricultural Products	NA	NA	NA	NA
4 D 2 b	Off-farm Storage, Handling and Transport of Bulk Agricultural Products	0.12	0.24	2.26	0.12
4 D 2 c	N-excretion on Pasture Range and Paddock Unspecified	NA	0.00	NA	NA
4 F	Field Burning of Agricultural Wastes	NE	NE	NE	NE
4 G	Agriculture Other[3]	IE	IE	IE	IE
6 A	Solid Waste Disposal on Land	2.23	0.69	8.89	0.06
6 B	Waste-water Handling	NA	NA	IE	NA
6 C a	Clinical Waste Incineration[4]	IE	IE	IE	IE
6 C b	Industrial Waste Incineration[4]	1.90	0.66	0.65	0.49
6 C c	Municipal Waste Incineration[4]	13.82	3.28	4.89	2.44
6 C d	Cremation	0.00	0.00	0.00	0.00
6 C e	Small-scale Waste Burning	0.00	0.00	0.00	0.00
6 D	Other Waste[5]	0.65	0.50	0.16	0.06
7 A	Other (included in National Total for Entire Territory)	3.95	0.17	2.61	0.00
National Total for Entire Territory[6]		8 214.72	1 789.49	2 021.65	1 282.97

Notes:
1. Nomenclature for Reporting (NFR) sectors reported to the Convention on Long-range Transboundary Air Pollution (CLRTAP).
2. Includes NH_3 from Enteric Fermentation and emissions from Cultivation of Rice.
3. Includes PM sources.
4. Excludes waste incineration for energy (this is included in 1 A 1) and in industry (if used as fuel).
5. Includes accidental fires.
6. "National Total" refers to the territory declared upon ratification of the relevant CLRTAP Protocol.

NA = Not applicable; NE = Not estimated; NO = Not occurring; IE = Included elsewhere; LTO = Landing and takeoff; POPs = Persistent organic pollutants.

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