SPECIFIED GAS EMITTERS REGULATION

TECHNICAL GUIDANCE FOR THE QUANTIFICATION OF SPECIFIED GAS EMISSIONS FROM LANDFILLS

NOVEMBER 2008

Version 1.2

Alberta

ALBERTANS & CLIMATE CHANGE

Disclaimer:

The information provided in this document is intended as guidance only and is subject to revisions as learnings and new information comes forward as part of a commitment to continuous improvement. This document is not a substitute for the law. Please consult the *Specified Gas Emitters Regulation* and the legislation for all purposes of interpreting and applying the law. In the event that there is a difference between this document and the *Specified Gas Emitters Regulation* or legislation, the *Specified Gas Emitters Regulation* or the legislation prevail.

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Abbreviation	Description
AENV	Alberta Environment
BEI	Baseline Emissions Intensity
CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
EC	Environment Canada
GHG	Greenhouse Gas
GJ	Gigajoule
GWP	Global Warming Potential
h	Hour
IP	Industrial Process Emissions
kg	Kilogram
kJ	Kilojoule
kt	Kilotonne
LFG	Landfill Gas
LFGWG	Landfill Gas Working Group
LHV	Lower Heating Value
MWh	Megawatt-hour
MSW	Municipal Solid Waste
N_2O	Nitrous Oxide
N/A	Not Applicable
P	Production
SGER	Specified Gas Emitters Regulation
t	tonne

Abbreviations Specific to the Guidance Document

Abbreviation	Description	Unit
k	Methane Generation Rate	[1/a]
M_x	Amount of Waste Disposed in year x	[t]
L_o	Methane Generation Potential	[t CH4/t waste]
C	Current Year	[a]
x	Year of Waste Input	[a]
PCPN	Annual Precipitation at the nearest Weather Station	[mm/a]
AL	Amount of Additional Liquids into the Landfill Cell	[mm/a]
MCF	Methane Correction Factor	[-]
DOC	Fraction of Degradable Organic Carbon	[-] wet weight
DOC_F	Fraction of DOC dissimilated	[-]
$M_{res. MSW}$	Tonnage of residential MSW	[t/a]
M_{ICI}	Tonnage of ICI	[t/a]
$M_{Fract.}$	Fraction of Waste Stream	[t/a]
$M_{C\&D}$	Tonnage of Construction and Demolition Waste	[t/a]
$M_{Non-MSW}$	Tonnage of Non-MSW	[t/a]
M_{Waste}	Tonnage of Total Waste Stream	[t/a]
CH_4 g	Methane generated	[t CH_4/time]
CH_4 g,x	Methane generated in current year T, by the waste mass M_x	[t CH_4/a]
CO_2 g	Carbon Dioxide generated	[t CO_2/time]
δ_{CO2}	Density of Carbon Dioxide	[t CO_2/m^3]
δ_{CH4}	Density of Methane	[t CH_4/m^3]
CH_4 r,c	Methane collected	[t CH_4/time]
CO_2 r,c	Carbon Dioxide collected	[t CO_2/time]
F_{CO2}	Fraction of Carbon Dioxide in LFG	[-];[Vol.-%]
F_{CH4}	Fraction of Methane in LFG	[-], [Vol.-%]
Q_{LFG}	Flow of LFG measured at the Outlet of the LFG Collection System	[m^3 LFG/time]
LFG_{CE}	LFG Collection Efficiency	[%]
CH_4 r,s	Methane stored	[t CH_4/time]
CO_2 r,s	Carbon Dioxide stored	[t CO_2/time]
GFP	Gas-filled Porosity	[Vol.-%]
Vol_{LF}	Volume of Landfill	[m^3]
ΔCH_4 r,s	Change in Methane stored	[t CH_4/time]
ΔCO_2 r,s	Change in Carbon Dioxide stored	[t CO_2/time]
CH_4 e,w	Methane emitted by the waste, which is not collected or stored	[t CH_4/time]
CO_2 e,w	Carbon Dioxide emitted by the waste, which is not collected or stored	[t CO_2/time]
CH_4 e,w,ss	Methane emitted by the waste into the base liner, which is not collected or stored	[t CH_4/time]

CO_2 e,w,ss	Carbon Dioxide emitted by the waste into the base liner, which is not collected or stored	[t CO_2/time]
CH_4 r,o	Methane oxidized	[t CH_4/time]
f_{ox}	Methane Oxidation Factor	[%]
CH_4 e,w,s	Methane emitted by the waste into the capping system, which is not collected or stored	[t CH_4/time]
CO_2 e,w,s	Carbon Dioxide emitted by the waste into the capping system, which is not collected or stored	[t CO_2/time]
CO_2 e,o	Carbon Dioxide generated during Methane Oxidation	[t CO_2/time]
CH_4 e,s	Methane emitted over the Landfill Surface	[t CH_4/time]
CO_2 e,s	Carbon Dioxide emitted over the Landfill Surface	[t CO_2/time]
CH_4 e,ss	Methane emitted over the Landfill Sub Surface	[t CH_4/time]
CO_2 e,ss	Carbon Dioxide emitted over the Landfill Sub Surface	[t CO_2/time]
CH_4 e,c	Methane emitted after LFG Control System	[t CH_4/time]
DE_{CH4}	Methane Destruction Efficiency of Combustion Device	[%]
CO_2e,c	Carbon Dioxide emitted after the LFG Control System	[t CO_2/a]
CO_2e,conv	Carbon Dioxide Generated through Conversion from Methane	[t CO_2/a]
CH_4 e,t	Methane emitted from On-Site Transportation	[t CH_4/time]
CO_2 e,t	Carbon Dioxide emitted from On-Site Transportation	[t CO_2/time]
N_2O e,t	Nitrous Oxides emitted from On-Site Transportation	[t N_2O /time]
$EF_{CH4Fueltype}$	Methane Emission Factor based on Type of Fuel	[gCH_4/l]
$EF_{CO2Fueltype}$	Carbon Dioxide Emission Factor based on Type of Fuel	[gCO_2/l]
$EF_{N2OFueltype}$	Nitrous Oxides Emission Factor based on Type of Fuel	[gN_2O /l]
Q_{Fuel}	Quantity of Fuel Used	[l/a]
N_2Oe,s	Nitrous Oxide emitted over the Landfill Surface	[tN_2O/time]
$EF_{N2O\text{-}Soli}$	Nitrous Oxides Emission Factor based on Soil Cover Material	[gN_2O/m^2a]
A	Landfill Area with Final Cover	[m_2]
GHG e	Greenhouse Gas Emissions from Landfills	[t CO_2e/time]
GWP_{CH4}	Global Warming Potential of Methane = 21	[t CO_2e]
GWP_{CO2}	Global Warming Potential of Carbon Dioxide = 1	[t CO_2e]
GWP_{N2O}	Global Warming Potential of Nitrous Oxides = 310	[t CO_2e]

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1 Alberta's Climate Change Legislation

In 2002, the Government of Alberta released an action plan for climate change: *"Albertans & Climate Change: Taking Action"* which establishes a framework to reduce greenhouse gas emissions. The plan focused on improving energy efficiency, enhancing technology to control industrial emissions, seeking out renewable energy sources and better emissions management.

Since 2004 Alberta has required facilities that emit more than 100,000 tonnes of carbon dioxide equivalent (CO_2e) ,including carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, to submit annual reports on their greenhouse gas (GHG) emissions.

The Specified Gas Emitters Regulation (SGER) (http://environment.alberta.ca/3.html), which became effective July 1, 2007, is a strategic regulation that confirms Alberta's intent to set greenhouse gas intensity limits for large emitters of greenhouse gases in Alberta. The Regulation is an important step in delivering on the current Alberta climate change action plan. The Regulation applies to all facilities in Alberta that emitted equal to or greater than 100,000 tonnes of greenhouse gas emissions in carbon dioxide equivalent (CO2e) units in 2003 or in any year since. This includes waste management facilities such as landfills, composting facilities, biogas plants, incinerators and waste-to-energy facilities. Facilities subject to this regulation will be required to reduce emission intensity by 12%.

A report published by Environment Canada (EC) in 2005 stated that the net greenhouse gas (GHG) emissions from landfills in the year 2002 accounted for 3 percent of the national GHG emissions or 22 Mt of CO_2e (Environment Canada, 2005). The Alberta Government recently announced a long term waste strategy: 'Too Good to Waste'. The new strategy is a road map for waste reduction and management in the province. It identifies the opportunities, outcomes and strategies to help Alberta move forward with innovative waste management programs. Alberta's goal is to decrease the amount of material sent to landfills from 986 to 500 kg/capita/yr by the year 2010. Almost 40% of municipal solid waste that goes to landfills is organic matter which contributes to methane production.

2 Technical Guidance Document For Landfill Specified Gas Emission Quantification

Alberta is the only province in Canada that regulates landfills based on the quantity of GHG emitted. Ontario and Quebec have regulations that require landfill gas (LFG) collection for larger landfills based on the size of the facility. The Alberta Landfill Gas Working Group (LFGWG) was established in May 2007 to develop a guidance document to assist landfills in Alberta to quantify LFG emissions by way of modelling, and fulfill the requirements of both the Specified Gas Reporting Regulation and Specified Gas Emitters Regulation under the *Climate Change and Emissions Management Act*. Another key objective of the guidance document was to standardize modeling parameters while taking into account site specific conditions for the province of Alberta. This landfill specified gas emission quantification guidance document will be recognized by AENV as the standardized method for landfill specified gas quantification until such time when standardized field quantification methods are approved in the future.

2.1 Landfill Gas Composition

Landfill gas in steady methanogenic phase is comprised of 50-60% methane (CH_4) and 40–50% carbon dioxide (CO_2) (v/v). There are also trace amounts of other gases such as non methane organic compounds (NMOC), nitrous oxides (N_2O), and oxygen (O_2) contributing less than 1%. Landfill gas is generated from the decomposition of waste and is emitted through the surface of the landfill or subsurface through the liner in facilities where there is no LFG collection in place. It is known that factors such as waste composition, moisture content, pH, temperature, depth of landfill, particle size and waste density influences the quantity and rate of LFG generation.

Methane and CO_2 are the main specified gases that concern landfills. It is important to note that other sources of specified gases exist at a landfill, such as emissions from equipment (tractors, compactors etc), N_2O from cover soils, and emissions from LFG combustion (flares, turbines etc.) once a LFG collection and control system is implemented.

2.2 Application to open or closed Landfills

The Specified Gas Emitters Regulation applies to all landfills that emit over the established CO_2e threshold limit regardless of which stage of operation that landfill is at. This technical guidance document for Alberta landfill specified gas emission quantification can be used for active and closed landfills or landfill cells.

2.3 Total Direct Emissions (TDE)

Total Direct Emissions (TDE) from a landfill is used to determine whether a landfill has exceeded the 100,000 tonnes of CO_2e threshold per year as specified in the Specified Gas Reporting Regulation. This is referred to as the 'Threshold Calculation'. All sources of biogenic and non-biogenic CH_4, CO_2, and N_2O emitted from a landfill are included in the calculation of TDE. Furthermore, landfills that are not subject to the regulation can voluntarily report TDE under the Specified Gas Reporting program. Landfills that do not meet the threshold limit can participate in reducing GHG emissions by creating emission offsets. Figure 1 shows the trend of TDE from a landfill. More specific information on what parameters are contributing to TDE from landfills is provided in sections III and IV of this guidance document.

2.4 Total Annual Emissions (TAE)

Landfills that have reported a TDE of over 100,000 tCO_2e in 2003 or any year since, are required to reduce emission according to the SGER. Emission reductions are applied differently to established versus new facilities. This is explained in more detail in the "Technical Guidance Document for Baseline Emissions Intensity Applications" published by AENV. A 12% reduction will be applied to the landfill's baseline emission intensity (BEI, see section IIh) for landfills established prior to the year 2000. Emission intensity reductions for new facilities will be phased over a 6 year period starting at the 4th year of operation. It is unlikely that any landfill in Alberta defined in the SGER as a 'new facility' will have a TDE of over 100,000 tonnes of CO_2e. Thus, the majority of landfills will that have TDE over the threshold will be in the 'established' facilities category. More specific information on what parameters are contributing to TDE from landfills is provided in sections III and IV of this guidance document.

The Total Annual Emission (TAE) is used to calculate baseline emission intensity and does not include biogenic CO_2. Landfills are not required to reduce CO_2 emissions produced from the anaerobic degradation of wastes. Figure 1 shows the trend of TAE from a landfill.

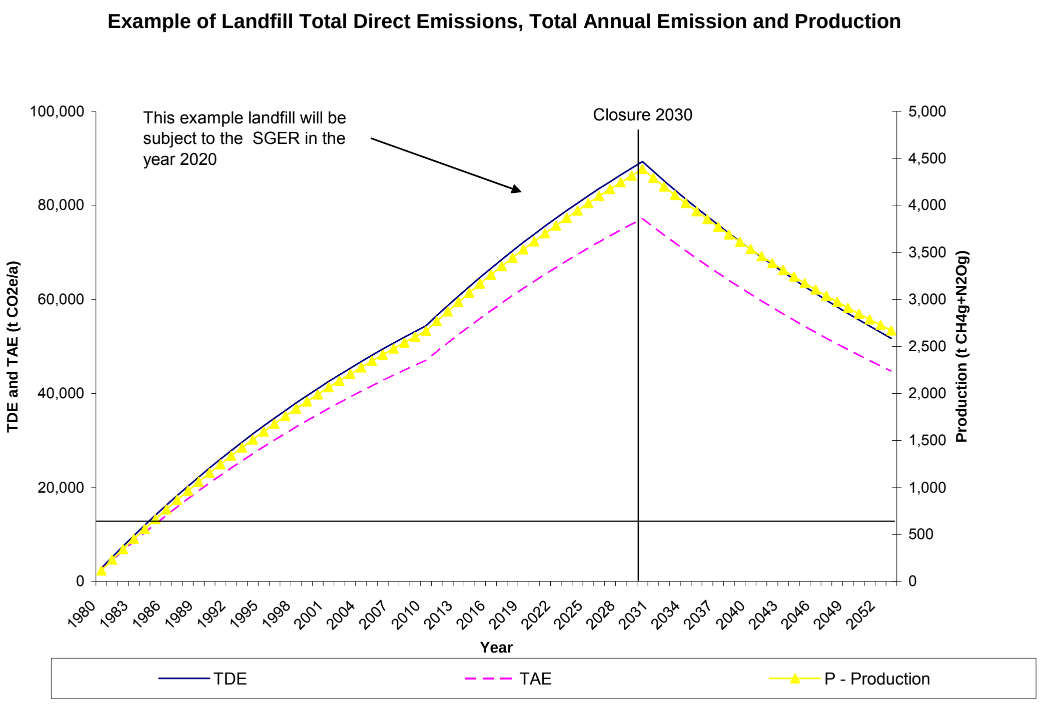

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Figure 1: Example of TDE, TAE and Production (P) from a landfill without LFG collection which started operation in 1980 accepting 75,000 t/a of MSW and closed in 2030.

2.5 Source Categories

Landfills that need to apply for baseline emission intensity should complete the baseline emission intensity application form, available at http://environment.alberta.ca/1167.html. Section B of the application form requires that landfills disaggregate and report emissions of CO_2, CH_4, N_2O according to source categories. The source categories are defined in Table 2 of the "Technical Guidance Document for Baseline Emissions Intensity Applications" published by AENV. Table 1 summarizes the specified gases and the source categories for threshold and baseline calculations for landfills.

NOTE: At the time of publication of this document, the baseline emission intensity application form does not have a category for biogenic CO_2 from anaerobic decomposition of wastes. Therefore, these emissions should be entered in Section 7 until the application form is otherwise updated.

Carbon dioxide emissions from flaring of landfill gas must be reported in the 'CO_2 Emissions from the Combustion of Biomass' source category, as landfill gas is considered a biomass material. It must be included in the determination of the emissions threshold (TDE) but not included in the calculation of the TAE for the facility. The CH_4 and N_2O emissions from flaring of landfill gas must be included in the 'Waste and Wastewater' source category, included in the emissions threshold calculation and the TAE for the landfill. Furthermore, surface emissions of N_2O must be reported under 'Other Fugitive' emissions category.

		Calculation of Threshold			Calculation of Baseline Emission Intensity		
		Specified Gases that must be included for calculation of Total Direct Emissions (TDE)			Specified Gases that must be included for calculation of Total Annual Emissions (TAE)		
Source Catergory	Specified Gas	CO2	CH4	N20	CO2	CH4	N20
Stationary Fuel Combustion		NA	Utilization	NA	NA	Utilization	NA
Industrial Process	CO2, N2O,CH4	NA	NA	NA	NA	NA	NA
Venting	All*	NA	NA	NA	NA	NA	NA
Flaring	CO2, N2O,CH4	NA	NA	NA	NA	NA	NA
Other Fugitive	CO2, N2O,CH4	NA	NA	Emissions from landfill cover soil	NA	NA	Emissions from landfill cover soil
Vented Raw Gas	CO2	NA	NA	NA	NA	NA	NA
Waste and Wastewater	CO2, N2O,CH4	Waste decomposition*	Waste decomposition, Flaring	NA	NA	Waste decomposition, Flaring	NA
On-site Transportation	CO2, N2O,CH4	On-Site Transportation	On-Site Transportation	On-Site Transportation	On-Site Transportation	On-Site Transportation	On-Site Transportation
CO2 emissions from the Combustion of Biomass	CO2	Flaring, Utilization (Conversion of CH4 to CO2)	NA	NA	NA	NA	NA

Red is biogenic CO2

NA : Not applicable to landfill activity as of status of protocol

* Biogenic CO_2 from waste decomposition should not be entered under the waste and wastewater source category in the baseline emission intensity application form and should be entered in Section F.

Table 1: Summary of Specified Gases and Source Category for Landfills

2.6 Landfill Production

Landfills do not exist for the purpose of producing end products. However, as the regulation stipulates that all facilities must determine baseline emission intensity for reduction target purposes, production and a unit of production is defined for landfills.

Production for landfills is the sum of CH_4 and N_2O generated from a landfill. These values for methane are obtained by modelling using the Scholl Canyon Model. Currently there is insufficient information on N_2O generation in landfills available so that this value can be assumed <u>zero</u> until such information will be available. The unit of production is expressed in tonnes. Figure 1 shows the trend of landfill production over a 50 year period.

LFG production is believed to be directly related to the amount of waste deposited into the landfill. There are various first order decay models that predict the amount of LFG generated by each tonne of waste buried. These models were developed mostly for landfills accepting municipal solid waste (MSW). However, total waste in place is not the only factor that influences methane generation rates. A landfill's methane generation rate is dependant on a number of factors, including size and depth of the landfill, the age of the landfill, waste composition, operations, and regional climatic factors. Furthermore, LFG continues to be produced even when the landfill is closed and does not accept waste for disposal. The correlation of waste in place to methane generation is low, thus this is not a valid factor to be considered as landfill production.

The only true product from a landfill is landfill gas and leachate. Landfill gas is regularly produced as a consequence of depositing waste into the landfill. This option was chosen to be the most suitable production for landfills. Since CO_2 generated from the degradation of wastes is considered biogenic and not regulated, landfill production was chosen to be 'total CH_4 and N_2O generated'.

2.7 Emissions Intensity for Landfills (EI)

"Emission intensity" (EI) is defined as the quantity of specified gases released by a facility per unit of production from that facility. Figure 2 shows an example of the trend of EI for a landfill over a fifty year period.

Thus, emission intensity for a landfill is calculated as follows:

$$EI = \frac{TAE}{P} \qquad \frac{[tCO_2e]}{[t]} \qquad (1)$$

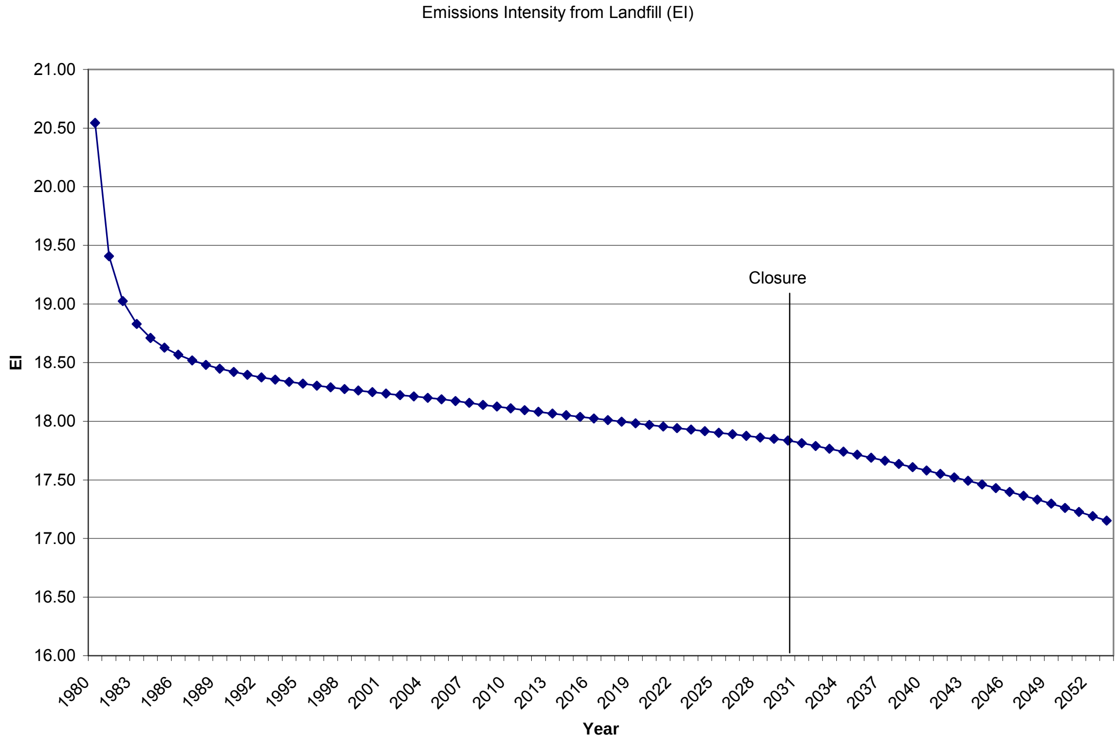


Figure 2: Example of Emission Intensity for a Landfill without LFG collection system that started Operations in 1980 and closed in 2030.

2.8 Baseline Emissions Intensity (BEI) Application for Landfills

The landfill baseline emissions intensity (BEI) is calculated by averaging the EI of the three baseline years. These years will be 2003, 2004, 2005 unless otherwise specified.

$$BEI = \frac{EI_1 + EI_2 + EI_3}{3} \quad (2)$$

with:

BEI	Baseline Emissions Intensity	
$EI_{1,2,3}$	Emission Intensity during the 1^{st}, 2^{nd} and 3^{rd} baseline year	[t CO_2e/t]

The SGER requires the person responsible for a facility that is subject to the Regulation to establish baseline emission intensity. AENV has published a "Technical Guidance Document for Baseline Emissions Intensity Applications".

Landfills should follow the requirements to establish BEI as prescribed in Part 4 of the SGER and submit the baseline emission intensity application form to AENV accordingly.

2.9 Net Emissions Intensity (NEI)

The Net Emission Intensity (NEI) for the landfill cannot be greater than 88% of the BEI. A landfill must calculate the EI for the compliance year and determine the required emissions offsets, fund credits or performance credits that needs to be applied to meet the target 12% intensity target reduction.

Landfills can reduce the EI through improvements to their operations such as organics diversion, implementation of LFG collection systems, or enhanced methane oxidation biofiltration. If intensity reduction target is still not met through improvements to landfills operations, landfills can:

a) Pay $15/tonne of CO_2e into the Climate Change and Emission Management fund
b) Purchase Alberta –based emission offsets generated by projects not subject to the regulations
c) Purchase emissions performance credits from another Alberta facility.

2.10 Landfill Emission Offsets and Credits

Alberta's regulatory system for managing Greenhouse Gases enables a compliance-based carbon market to develop in this province by:

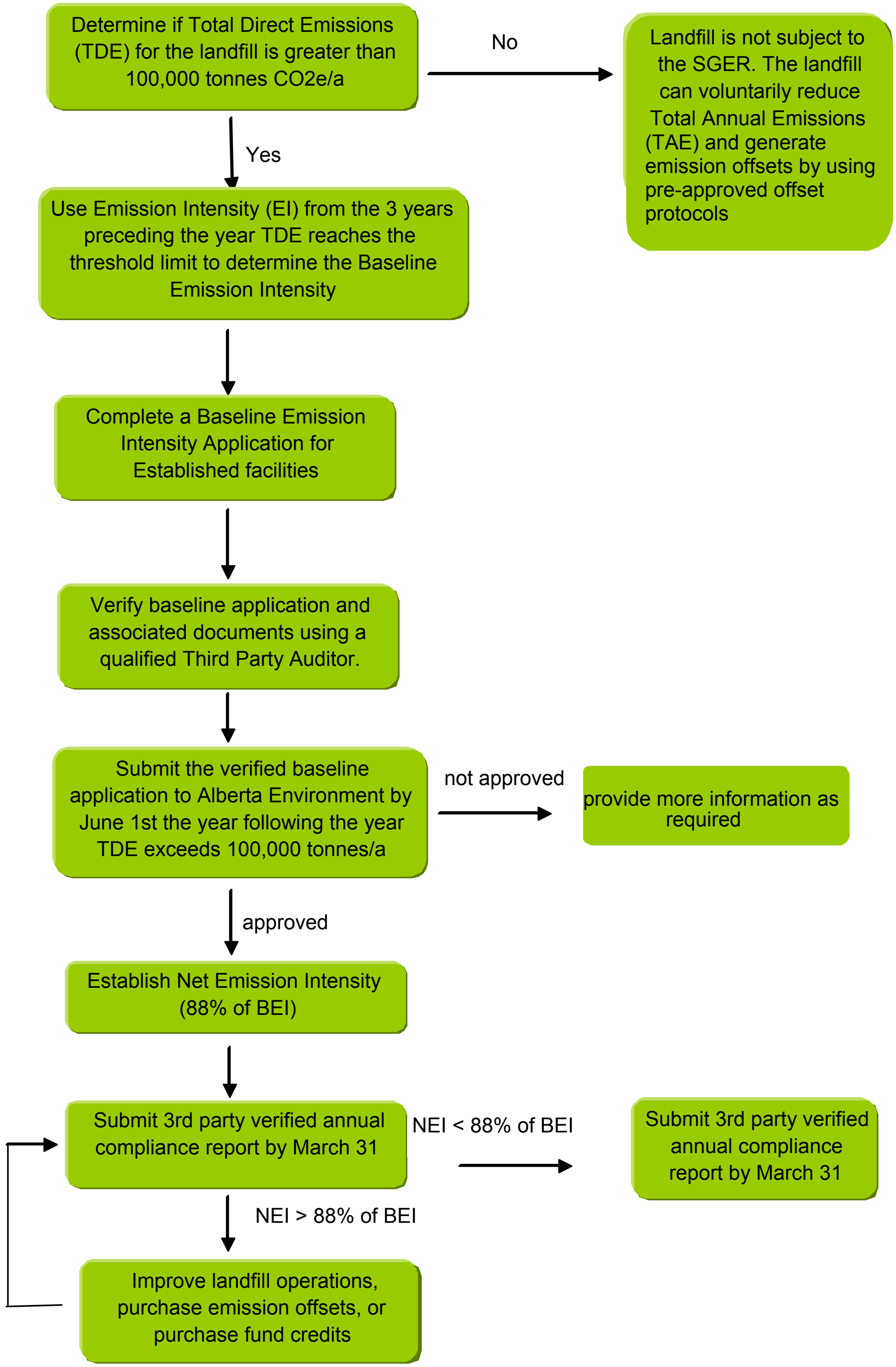
- Establishing market demand through regulated emission reduction targets for large emitters; and
- Enabling market supply through allowing emission offsets as a compliance option for regulated emitters.

Regulated firms can buy verified emission reductions and/or removals of greenhouse gases (i.e. offsets) from voluntary actions arising from unregulated activities (i.e. offset projects) in Alberta.
The ability to sell offsets provides an incentive for Albertans, from all sectors of the economy, to be innovative and invest in activities that will reduce greenhouse gas emissions beyond regulated activities.

The terms "emissions offsets" and "emissions credits" are defined in the Specified Gas Emitters Regulation. Landfills subject to the regulation that are able to reduce TAE greater than the 12% target will generate emission credits. Landfills that are not subject to the regulation and voluntarily reduce TAE will generate offsets. Emissions offsets or credits can be sold in the offset market or banked for later use.

The Alberta government has published a series of Guidance Documents to provide market participants more certainty about where investments can be made in the Alberta Offset Market. This Project Guidance Document is one of a series of guidance documents prepared for the Regulatory Framework. These guidance documents can be found at: http://www.environment.alberta.ca/3.html.

3 Regulation of Landfill Gas Emissions Summary



4 Principles of the LFG Quantification Guidance

In the following the principles and methodologies for calculating the Total Direct Emission (TDE) and Total Annual Emissions (TAE) from landfills in Alberta are presented. With the help of the TAE the respective Emissions Intensity (EI) and Baseline Emissions Intensity (BEI) can be calculated.

4.1 Description of Total Direct Emissions from Landfills

In the Specified Gas Emitters Regulation the TDE from landfills in Alberta are defined as the release of CH_4, CO_2 (biogenic and non-biogenic), and N_2O from all sources actually located on a landfill in a year, expressed in [t CO_2e/a]. TDE is used for threshold calculations, so the outcome confirms a landfill being subject to the Regulation or not.

The TDE from Alberta landfills can be calculated using the following formula:

$$TDE = (CH_4 e,s + CH_4 e,ss + CH_4 e,c + CH_4 e,t) * GWP_{CH_4}$$
$$+ (CO_2 e,s + CO_2 e,ss + CO_2 e,c + CO_2 e,t) * GWP_{CO_2} + (N_2Oe,t + N_2Oe,s) * GWP_{N_2O} \quad (3)$$

with

CH_4 e,s	Methane emitted over the Landfill Surface	[t CH_4/a]
CH_4 e,ss	Methane emitted over the Landfill Sub Surface	[t CH_4/a]
CH_4 e,c	Methane emitted after LFG Control System	[t CH_4/a]
CH_4 e,t	Methane emitted from On-Site Transportation	[t CH_4/a]
GWP_{CH4}	Global Warming Potential of Methane = 21	[t CO_2e]
CO_2 e,s	Carbon Dioxide emitted over the Landfill Surface	[t CO_2/a]
CO_2 e,ss	Carbon Dioxide emitted over the Landfill Sub Surface	[t CO_2/a]
CO_2 e,c	Carbon Dioxide emitted after LFG Control System	[t CO_2/a]
CO_2 e,t	Carbon Dioxide emitted from On-Site Transportation	[t CO_2/a]
GWP_{CO2}	Global Warming Potential of Carbon Dioxide = 1	[t CO_2/a]
N_2O e,t	Nitrous Oxide emitted from On-Site Transportation	[t N_2O/a]
N_2O e,s	Nitrous Oxide emitted from Landfill Surface	[t N_2O/a]
GWP_{N2O}	Global Warming Potential of Nitrous Oxide = 310	[t CO_2e]

The sources of N_2O emissions at landfill sites are believed to be landfill soils, on-site transportation activities, flaring/utilization activities, and some quantities in the generated LFG. However, since there is insufficient information on the generation rates of N_2O in LFG and during flaring and utilization processes at landfill sites at this time, these emission paths are set to <u>zero</u> and will be neglected until such information becomes available.

An overview on the single emission pathways for the specified gases methane, carbon dioxide, and nitrous oxide from a landfill for the TDE calculation is given in Figure 3.

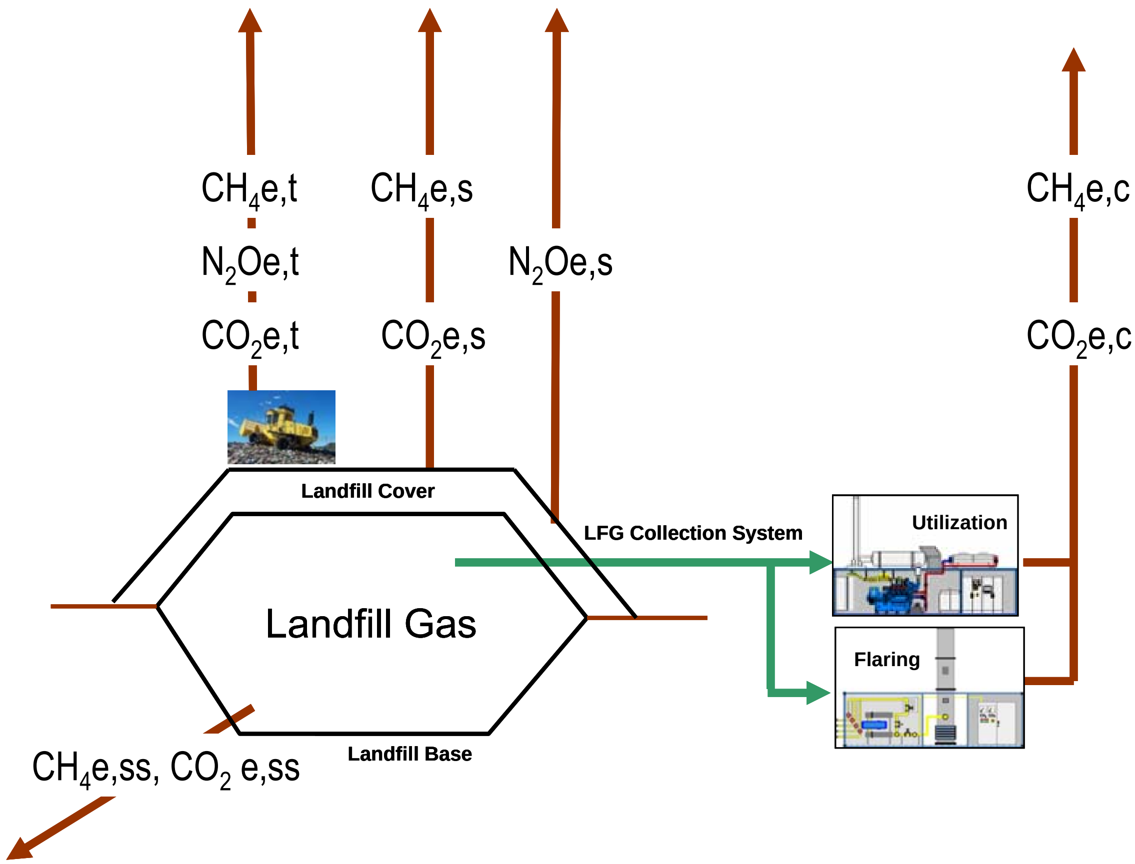


Figure 3: Schematic Overview of Total Direct Emissions Pathways from Landfills

4.2 Description of Total Annual Emissions and Emissions Intensity from Landfills

In the Specified Gas Emitters Regulation the Total Annual Emissions (TAE) from landfills in Alberta are defined as the total emissions of CH_4, N_2O, and non-biogenic CO_2 in a year, expressed in [t CO_2e/a]. TAE is used for baseline emission intensity calculations.

The TAE from Alberta landfills can be calculated with the following formula:

$$TAE = (CH_4 e,s + CH_4 e,ss + CH_4 e,c + CH_4 e,t) * GWP_{CH_4} + (CO_2 e,t) * GWP_{CO_2} + (N_2Oe,t + N_2Oe,s) * GWP_{N_2O} \quad (4)$$

with

CH_4 e,s	Methane emitted over the Landfill Surface	[t CH_4/a]
CH_4 e,ss	Methane emitted over the Landfill Sub Surface	[t CH_4/a]
CH_4 e,c	Methane emitted after LFG Control System	[t CH_4/a]
CH_4 e,t	Methane emitted from On-Site Transportation	[t CH_4/a]
GWP_{CH4}	Global Warming Potential of Methane = 21	[t CO_2e]
CO_2 e,t	Carbon Dioxide emitted from On-Site Transportation	[t CO_2/a]
GWP_{CO2}	Global Warming Potential of Carbon Dioxide = 1	[t CO_2e]
N_2O e,t	Nitrous Oxide emitted from On-Site Transportation	[t N_2O/a]
N_2O e,s	Nitrous Oxide emitted from Landfill Surface	[t N_2O/a]
GWP_{N2O}	Global Warming Potential of Nitrous Oxide = 310	[t CO_2e]

The Emissions Intensity (EI) is defined as the total emissions of CH_4 and N_2O and non biogenic CO_2 in a year expressed in [t CO_2e/a] divided by the total CH_4 +N_2O produced in that year expressed in [t /a]. The Baseline Emissions Intensity (BEI) for landfills is calculated based on the average EI's of the three years preceding the compliance year. However, since there is insufficient information on the generation rates of N_2O in the LFG, this emission path is set to zero and will be neglected until such information becomes available.

An overview on the single emission pathways for the specified gases methane, carbon dioxide, and nitrous oxides from a landfill for the TAE calculation is given in Figure 4.

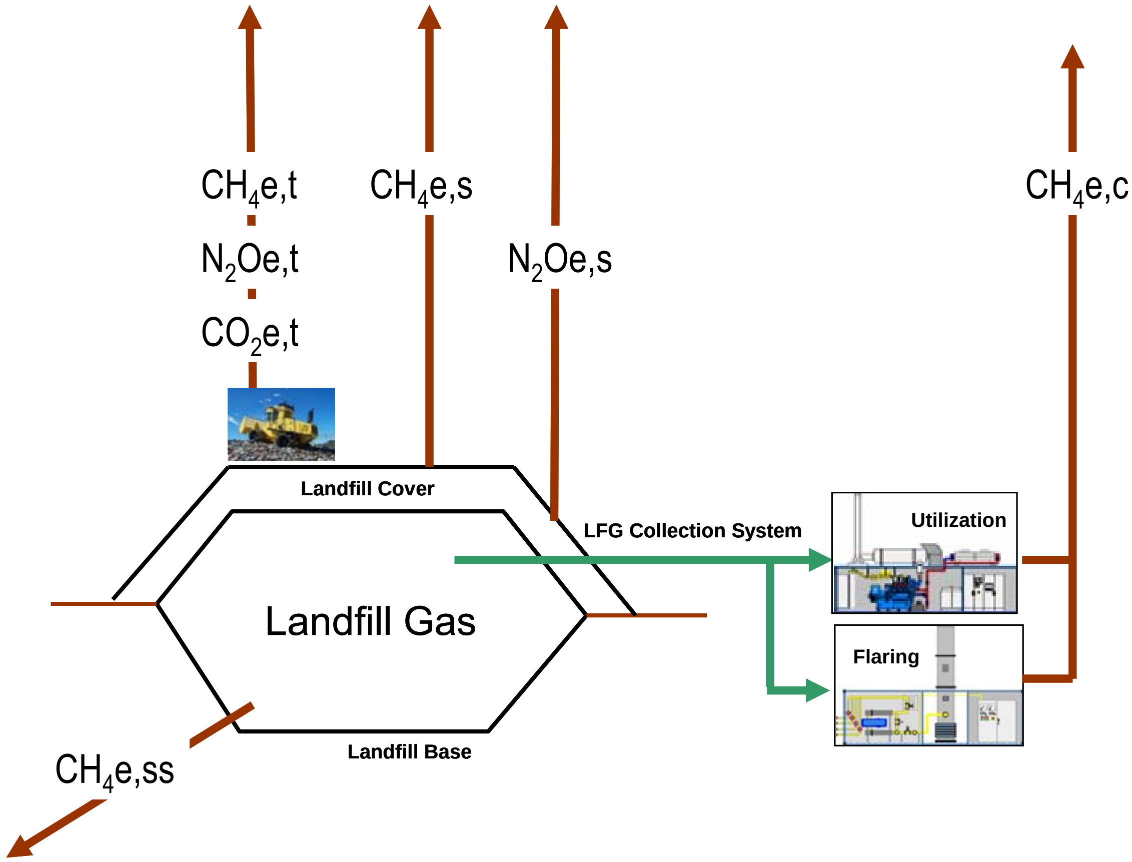


Figure 4: Schematic Overview of Total Annual Emissions Pathways from Landfills

4.3 Methodologies for Determination of Total Direct and Annual Emissions and Emission Intensity from Landfills

In order to estimate the Total Direct Emissions (TDE), the Total Annual Emissions (TAE) and the Emission Intensity (EI) from landfills the LFGWG distinguished between different landfill operational modes. These are

- Landfills without an active LFG collection system.
- Landfills with an active LFG collection system, and
- Landfills with a partial active LFG collection system.

One of the major differences in the methodologies to calculate TDE, TAE, and EI from Alberta landfills is the starting point of calculation. While landfills with an active LFG collection system in place are more likely to have real available data on their LFG generation, composition, and collection efficiency, landfills with no such data will have to model their LFG generation in an initial step. A step-by-step presentation of the methodology to determine the TDE, TAE, and EI from a landfill without an active LFG collection system is presented in Table 2.

Step	TDE, TAE and EI	Abbreviation	Calculation
1	"Methane Generated"	CH_4 g	
2	"Carbon Dioxide Generated"	CO_2 g	
3	"Change in Methane Stored"	ΔCH_4 r,s	
4	"Change in Carbon Dioxide Stored"	ΔCO_2 r,s	
5	"Methane Emitted from Waste"	CH_4 e,w	CH_4e,w=CH_4g-ΔCH_4 r,s
6	"Carbon Dioxide Emitted from Waste"	CO_2 e,w	CO_2e,w=CO_2g-ΔCO_2r,s
7	"Methane Emitted from Waste into the Base Liner"	CH_4 e,w,ss	
8	"Carbon Dioxide Emitted from Waste into the Base Liner"	CO_2 e,w,ss	
9	"Methane Emitted from Waste over the Surface"	CH_4 e,w,s	CH_4e,w,s=CH_4e,w-CH_4e,w,ss
10	"Carbon Dioxide Emitted from Waste over the Surface"	CO_2 e,w,s	CO_2e,w,s=CO_2e,w-CO_2e,w,ss
11	"Methane Oxidized"	CH_4 r,o	
12	"Carbon Dioxide generated during Methane Oxidation"	CO_2 e,o	
13	"Methane Emitted over the Landfill Surface"	CH_4 e,s	CH_4e,s=CH_4e,w,s-CH_4 r,o
14	"Carbon Dioxide Emitted over the Landfill Surface"	CO_2 e,s	CO_2e,s=CO_2e,w,s+CO_2e,o
15	"Carbon Dioxide Emitted from On Site Transportation"	CO_2 e,t	
16	"Nitrous Oxides Emitted from On Site Transportation"	CH_4 e,t	
17	"Methane Emitted from On Site Transportation"	N_2O e,t	
18	"Nitrous Oxides Emitted from Landfill Surface"	N_2O e,s	
19	"Total Direct Emission"	TDE	TDE=(CH_4e,w,ss+CH_4e,s+CH_4e,t)*(GWP_{CH4})+(CO_2e,w,ss+CO_2e,s+CO_2e,t)*(GWP_{CO2})+ (N_2Oe,t+N_2Oe,s)*(GWP_{N20})
20	"Total Annual Emission"	TAE	TDE=(CH_4e,w,ss+CH_4e,s+CH_4e,t)*(GWP_{CH4})+(CO_2e,t)*(GWP_{CO2})+ (N_2Oe,t+N_2Oe,s)*(GWP_{N20})
21	"Production"	P	P=CH_4 g
22	"Emission Intensity"	EI	EI = TAE/P

Table 2: Methodology to determine TDE, TAE and EI from Landfills without active LFG Collection

More detailed information on how to derive the single parameters is provided in Chapter IV of this report. A spreadsheet has been created and is attached to this guidance, which will support the calculation of TDE, TAE, and EI from landfills without an active LFG collection system.

In Table 3 the methodology is provided to determine the TDE, TAE, and EI from landfills with an active LFG collection system.

Step	TDE, TAE and EI	Abbreviation	Calculation
1	"Methane Collected"	CH_4 r,c	
2	"Carbon Dioxide Collected"	CO_2 r,c	
3	"Methane Emitted from Waste"	CH_4 e,w	CH_4e,w=(CH_4r,c/LFG_{CE})-CH_4r,c
4	"Carbon Dioxide Emitted from Waste"	CO_2 e,w	CO_2e,w=(CO_2r,c/LFG_{CE})-CO_2r,c
5	"Methane Emitted from Waste into the Base Liner"	CH_4 e,w,ss	
6	"Carbon Dioxide Emitted from Waste into the Base Liner"	CO_2 e,w,ss	
7	"Methane Emitted from Waste over the Surface"	CH_4 e,w,s	CH_4e,w,s=CH_4e,w-CH_4e,w,ss
8	"Carbon Dioxide Emitted from Waste over the Surface"	CO_2 e,w,s	CO_2e,w,s=CO_2e,w-CO_2e,w,ss
9	"Methane Oxidized"	CH_4 r,o	
10	"Carbon Dioxide generated during Methane Oxidation"	CO_2 e,o	
11	"Methane Emitted over the Landfill Surface"	CH_4 e,s	CH_4e,s=CH_4e,w,s-CH_4 r,o
12	"Carbon Dioxide Emitted over the Landfill Surface"	CO_2 e,s	CO_2e,s=CO_2e,w,s+CO_2e,o
13	"Methane emitted after LFG Control System"	CH_4 e,c	CH_4e,c=(1-DE_{CH4})*CH_4r,c
14	"Carbon Dioxide emitted after LFG Control System"	CO_2 e,c	CO_2e,c=CO_2r,c+CO_2e,conv
15	"Carbon Dioxide Emitted from On Site Transportation"	CO_2 e,t	
16	"Nitrous Oxides Emitted from On Site Transportation"	N_2O e,t	
17	"Methane Emitted from On Site Transportation"	CH_4 e,t	
18	"Nitrous Oxides Emitted from Landfill Surface"	N_2O e,s	
19	"Total Direct Emission"	TDE	TDE=(CH_4e,w,ss+CH_4e,s+CH_4e,c+CH_4e,t)*(GWP_{CH4})+(CO_2e,w,ss+CO_2e,s+CO_2e,c+CO_2e,t)*(GWP_{CO2})+ (N_2Oe,t+N_2Oe,s)*(GWP_{N20})
20	"Total Annual Emission"	TAE	TDE=(CH_4e,w,ss+CH_4e,s+CH_4e,c+CH_4e,t)*(GWP_{CH4})+(CO_2e,t)*(GWP_{CO2})+ (N_2Oe,t+N_2Oe,s)*(GWP_{N20})
21	"Production"	P	P=CH_4 r,c+CH_4 e,w
22	"Emission Intensity"	EI	EI = TAE/P

Table 3: Methodology to determine TDE, TAE, and EI from Landfills with active LFG Collection

More detailed information on how to derive the single parameters is given in Chapter IV of this guidance. A spreadsheet has been created and is attached to this guidance, which will support the calculations of TDE, TAE, and EI from landfills with an active LFG collection system.

In Table 4 the methodology is provided to determine the TDE, TAE, and EI from landfills with a partial active LFG collection system. Please note that the single calculating steps are divided into four parts:

Part A: Landfill part with LFG collection system
Part B: Landfill part without LFG collection system
Part C: Other emissions from landfill
Part D: Complete emissions from landfill

Also note that CH_4g and CO_2g represent the gas generated in the part of the landfill without a LFG collection system. In most cases this will be calculated by estimating the total gas generation for the entire landfill and subtracting the collected volumes.

Step	TDE, TAE and EI	Abbreviation	Calculation
A	***Landfill Part with LFG Collection System***		
A.1	"Methane Collected"	CH_4 r,c	
A.2	"Carbon Dioxide Collected"	CO_2 r,c	
A.3	"Methane Emitted from Waste"	CH_4 e,w	CH_4e,w=(CH_4r,c/LFG_{CE})-CH_4r,c
A.4	"Carbon Dioxide Emitted from Waste"	CO_2 e,w	CO_2e,w=(CO_2r,c/LFG_{CE})-CO_2r,c
A.5	"Methane Emitted from Waste into the Base Liner"	CH_4 e,w,ss	
A.6	"Carbon Dioxide Emitted from Waste into the Base Liner"	CO_2 e,w,ss	
A.7	"Methane Emitted from Waste over the Surface"	CH_4 e,w,s	CH_4e,w,s=CH_4e,w-CH_4e,w,ss
A.8	"Carbon Dioxide Emitted from Waste over the Surface"	CO_2 e,w,s	CO_2e,w,s=CO_2e,w-CO_2e,w,ss
A.9	"Methane Oxidized"	CH_4 r,o	
A.10	"Carbon Dioxide generated during Methane Oxidation"	CO_2 e,o	
A.11	"Methane Emitted over the Landfill Surface"	CH_4 e,s	CH_4e,s=CH_4e,w,s-CH_4 r,o
A.12	"Carbon Dioxide Emitted over the Landfill Surface"	CO_2 e,s	CO_2e,s=CO_2e,w,s+CO_2e,o
A.13	"Methane emitted after LFG Control System"	CH_4 e,c	CH_4e,c=(1-DE_{CH4})*CH_4r,c
A.14	"Carbon Dioxide emitted after LFG Control System"	CO_2 e,c	CO_2e,c=CO_2r,c+CO_2e,conv
B	***Landfill Part without LFG Collection System***		
B.1	"Methane Generated"	CH_4 g	
B.2	"Carbon Dioxide Generated"	CO_2 g	
B.3	"Change in Methane Stored"	ΔCH_4 r,s	
B.4	"Change in Carbon Dioxide Stored"	ΔCO_2 r,s	
B.5	"Methane Emitted from Waste"	CH_4 e,w	CH_4e,w=CH_4g-ΔCH_4 r,s
B.6	"Carbon Dioxide Emitted from Waste"	CO_2 e,w	CO_2e,w=CO_2g-ΔCO_2r,s
B.7	"Methane Emitted from Waste into the Base Liner"	CH_4 e,w,ss	
B.8	"Carbon Dioxide Emitted from Waste into the Base Liner"	CO_2 e,w,ss	
B.9	"Methane Emitted from Waste over the Surface"	CH_4 e,w,s	CH_4e,w,s=CH_4e,w-CH_4e,w,ss
B.10	"Carbon Dioxide Emitted from Waste over the Surface"	CO_2 e,w,s	CO_2e,w,s=CO_2e,w-CO_2e,w,ss
B.11	"Methane Oxidized"	CH_4 r,o	
B.12	"Carbon Dioxide generated during Methane Oxidation"	CO_2 e,o	
B.13	"Methane Emitted over the Landfill Surface"	CH_4 e,s	CH_4e,s=CH_4e,w,s-CH_4 r,o
B.14	"Carbon Dioxide Emitted over the Landfill Surface"	CO_2 e,s	CO_2e,s=CO_2e,w,s+CO_2e,o
C	***Other Emissions from Landfill***		
C.1	"Carbon Dioxide Emitted from On Site Transportation"	CO_2 e,t	
C.2	"Nitrous Oxides Emitted from On Site Transportation"	CH_4 e,t	
C.3	"Methane Emitted from On Site Transportation"	N_2O e,t	
C.4	"Nitrous Oxides Emitted from Landfill Surface"	N_2O e,s	
D	***Complete Emissions from Landfill***		
D.1	"Total Direct Emission"	TDE	TDE=(ΣCH_4e,w,ss+ΣCH_4e,s+CH_4e,c+CH_4e,t)*(GWP_{CH4})+(ΣCO_2e,w,ss+ΣCO_2e,s+CO_2e,c+CO_2e,t)*(GWP_{CO2})+ (N_2Oe,t+N_2Oe,s)*(GWP_{N20})
D.2	"Total Annual Emission"	TAE	TAE=(ΣCH_4e,w,ss+ΣCH_4e,s+CH_4e,c+CH_4e,t)*(GWP_{CH4})+(CO_2e,t)*(GWP_{CO2})+ (N_2Oe,t+N_2Oe,s)*(GWP_{N20})
D.3	"Production"	P	P=CH_4 r,c+CH_4 g+CH_4 e,w (Part A only)
D.4	"Emission Intensity"	EI	EI = TAE/P

Table 4: Methodology to determine TDE from Landfills with a partial LFG Collection

More detailed information on how to derive the single parameters is provided in Chapter V of this guidance. A spreadsheet has been created and is attached to this guidance document, which will help support the calculation of TDE, TAE, and EI from landfills with a partial LFG collection system.

5 Development of Default Parameters

In the following chapter the main parameters for the methodologies provided in Chapter III are described in more detail.

It should be noted that the default values which are presented are strictly for landfills where site specific data is not available. Alberta Environment recognizes the significance of site specific values that take into account individual aspects of landfills and LFG management. Site specific values will be accepted over default values providing the values are scientifically defensible.

Emission calculations are conducted on a yearly basis. All parameters should be adjusted to the annual cycle. That will be necessary e.g. during equipment maintenance or experienced down time.

The single parameters will be ordered by the specified gas emitted. These are methane, carbon dioxide and nitrous oxides.

5.1 Methane

5.1.1 Methane Generated CH_4g

The factor methane generated is defined in this guidance as the potential methane generation by a waste mass in a landfill. A variety of LFG prediction models are in existence and are applied and compared worldwide (e.g. Thompson et al., 2006, ADEME, 2003, IPCC, 1996, Scharff and Jacobs, 2006; Spokas et al., 2006). In general they can be distinguished between mass balance models and first-order decay models (FOD). According to the latest IPCC Guidelines for National Greenhouse Inventory (IPCC, 2006) all countries should be able to implement a FOD method.

For Canada a recent review of four LFG generation models by Thompson et al. (2006) came to the conclusion that the Scholl-Canyon Model is the model of choice for the Canadian context as it follows the basic IPCC principles and assumes that methane production occurs immediately after waste placement. The Scholl-Canyon Model is therefore recommended by Environment Canada in their recent National Inventory Report of Greenhouse Gas Emissions (Environment Canada, 2007).

The model, in the context of this guidance, is only proposed for those landfills or landfill parts with no LFG collection, when no other data is available from actual field tests or experience from LFG collection on the landfill.

The principle formula for the Scholl Canyon Model is (Environment Canada, 2007):

$$CH_4g, x = k * M_x * L_o * e^{-k(C-x)} \qquad (5)$$

with

CH_4 g,x	Methane generated in current year C, by the waste mass M_x	[t CH_4/a]
k	Methane Generation Rate	[1/a]
M_x	Amount of Waste Disposed in year x	[t]
L_o	Methane Generation Potential	[t CH_4/t waste]
C	Current Year	[a]
x	Year of Waste Input	[a]

The methane generated in any year is the sum of methane generation of all historical and current disposed waste masses during the respective year.

$$CH_4g = \sum CH_4g, x \qquad [t\ CH_4/a] \qquad (6)$$

Critical input parameter for the Scholl-Canyon Model is the waste tonnage M_x, the methane generation rate k and the methane generation potential L_o.

In the following, the chosen methodologies and procedures for generating site specific k and L_o values are presented.

The choice of the methane generation rate k is the most critical at this time in terms of methodology. The k rate is influenced by a variety of factors namely moisture content, nutrient availability, pH, and temperature. The LFGWG revised several methodologies and ideas but decided to streamline efforts for k generation with Environment Canada only to pursue research activities in that area in the future. Recommendations to Environment Canada through Thompson et al. (2006) were based on a critical review of data from Levelton (1991) and the USEPA plus current research findings eliminating the need for reviewing temperature as one input in the generation of k values.

Based on these suggestions the following equation defines k as a function of local precipitation regime:

$$k = 0.00003 * PCPN + 0.01 \qquad [1/a] \qquad (7)$$

with:

PCPN	Annual Precipitation at the nearest Weather Station	[mm/a]

In order to provide an initial overview the LFGWG generated k values for several weather station in Alberta with consistent data. The data is presented in Table 5.

Location	Weather Station	Meet WMO Standard	Climate ID	Mean Annual Precipitation - Canadian Climate Normals 1971-2000	k-Value
		*		[mm/a]	[1/a]
Athabasca	Athabasca 2		3060321	503.7	0.025
Banff	Banff		3050520	472.3	0.024
Brooks	Brooks North		3030862	354.2	0.021
Calgary	Elbow View	*	303A0Q6	445.5	0.023
Calgary	Int'l Airport	*	3031093	412.6	0.022
Camrose	Camrose	*	3011240	477.7	0.024
Cold Lake	Cold Lake A	*	3081680	426.6	0.023
Drumheller	Drumheller Andrew		3022136	367.6	0.021
Edmonton	Edmonton Namao A		3012210	466.3	0.024
Edmonton	City Centre	*	3012208	476.9	0.024
Edmonton	Int'l Airport	*	3012205	482.7	0.024
Edmonton	Edmonton Stony Plain	*	301222F	536.0	0.026
Edmonton	Edmonton Woodbend	*	3012230	531.0	0.026
Edson	Edson A		3062244	567.8	0.027
Fort McMurray	Fort McMurray A	*	3062693	455.5	0.024
Grande Prairie	Grande Prairie A	*	3072920	446.6	0.023
High River	High River	*	3033240	517.5	0.026
Jasper	Jasper Gate	*	3063523	620.2	0.029
Lacombe	Lacombe CDA		3023720	438.0	0.023
Lethbridge	Lethbridge CDA		3033890	365.0	0.021
Lethbridge	Lethbridge A	*	3033880	386.3	0.022
Lloydminster	Lloydminster A		3013961	408.1	0.022
Medicine Hat	Medicine Hat A	*	3034480	333.8	0.020
Peace River	Peace River A	*	3075040	387.6	0.022
Red Deer	Red Deer	*	3025441	487.2	0.025
Red Deer	Red Deer A	*	3025480	482.7	0.024
Vegreville	Vegreville CDA		3016761	402.8	0.022
White Court	White Court A		3067372	577.7	0.027
Average				426.4	0.023

Table 5: Generation of k-values for Alberta Weather Stations

In cases of landfill operations where additional liquids are introduced into the landfill as e.g. at a bioreactor landfill, the amount of additional liquids should be converted and added to the amount of precipitation at the site. For these cases the formula for k would be:

$$k = 0.00003 * (PCPN + AL) + 0.01 \quad [1/a] \quad (8)$$

with:

AL Amount of Additional Liquid into the Landfill Cell [mm/a]

The methane generation potential represents the amount of methane that can be potentially produced per tonne of waste (Environment Canada, 2007). According to the IPCC methodology L_o (IPCC, 1996/2006) is calculated by:

$$L_o = MCF * DOC * DOC_F * F_{CH_4} * \left(\frac{16}{12}\right) \qquad [\text{t } CH_4/\text{t waste}] \qquad (9)$$

With:

L_o	Methane Generation Potential	[t CH_4/t waste]
MCF	Methane Correction Factor	[-]
DOC	Degradable Organic Carbon	[-] by wet weight
DOC_F	Fraction of DOC dissimilated	[-]
L_o	Methane Generation Potential	[t CH_4/t waste]
F_{CH4}	Fraction of Methane in LFG	[-];[Vol.-%]
16/12	Stoichiometric Factor to convert Methane to Carbon	[-]

Table 6 provides an overview on default values for MCF, DOCF and F.

Factor	Remark	Default Value
MCF	Landfill - anaerobic[1]	1
	Managed - semi-aerobic[2]	0.5
	Unmanaged[3]: deep ≥ 5.0 m waste and/or high water table	0.8
	Unmanaged[4]: deep < 5.0 m waste	0.4
	Uncategorized solid waste disposal site[5]	0.6
DOC_F	Excluding Lignin	0.77
	Including Lignin	0.5
F	Typical Range	0.4-0.6
	Average	0.5

1- Anaerobic managed solid waste disposal sites: These must have controlled placement of waste (i.e. waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: (i) cover material, (ii) mechanical compacting, (iii) levelling of the waste

2- Semi-aerobic managed solid waste disposal sites: These must have controlled placement of waste and will include all of the following structures for introducing air to waste layer: (i) permeable cover material, (ii) leachate drainage system, (iii) regulating pondage; and (iv) gas ventilation system.

3- Unmanaged solid waste disposal sites - deep and/or high water table: All SWDS not meeting the criteria of managed SWDS and which have depths of greater or equal to 5 metres and/or high water table at near ground level. Latter situation corresponds to filling inland water, such as pond, river or wetland, by waste.

4- Unmanaged shallow solid waste disposal sites: All SWDS not meeting the criteria of managed SWDS and which have depths of less then 5 metres.

5- Uncategorized solid waste disposal sites: Only if countries cannot categorize their SWDS into the above four categories of mnaged, unmanaged SWDS, the MCF for this category can be used.

Table 6: Default Values for MCF, DOCF and F (Environment Canada, 2007; Thompson et al., 2006, IPCC, 2006)

The DOC is derived from the following equation (Environment Canada, 2007):

$$DOC = (0.4 * A) + (0.17 * B) + (0.15 * C) + (0.3 * D) \quad [-] \text{ by wet weight} \quad (10)$$

With:

A	Fraction of Waste that is Paper and Textiles	[-]
B	Fraction of Waste that is Garden or Park Waste	[-]
C	Fraction of Waste that is Food Waste	[-]
D	Fraction of Waste that is Wood or Straw	[-]

If detailed information on the landfill waste stream is not available Environment Canada has generated and updated provincial L_o values for the residential/ICI fraction of MSW waste stream in Alberta for certain time periods (Environment Canada, 2008). These values for Alberta are presented in Table 7.

Province/Territory	1941 to 1975		1976 to 1989		1990 to Present	
	DOC	Lo	DOC	Lo	DOC	Lo
		(kg CH4/t waste)		(kg CH4/t waste)		(kg CH4/t waste)
Alberta	0.39	157.63	0.26	104.46	0.18	71.87

Table 7: Proposed provincial Lo default values of MSW (residential and ICI) waste stream by Environment Canada (Environment Canada, 2008)

It should be noted that these are default values based on findings from an NRCan report (2006). A clear understanding of which waste streams are accepted at each individual landfill is essential. Individual Lo for these waste streams should be calculated using the methodology provided (Formula 9 and 10, Table 6).

It should be noted that the determination of average L_o can potentially conducted two ways.

a. Consideration of a certain fraction of the waste stream (e.g. residential MSW and ICI)
b. Consideration of the total waste stream.

In both cases the choice of L_o should be adjusted to the considered waste stream. As an example that would include for point a:

$$L_o = \left(L_{o_{res.MSW}} * \left(\frac{M_{res.MSW}}{M_{Fract.}} \right) \right) + \left(L_{o_{ICI}} * \left(\frac{M_{ICI}}{M_{Fract.}} \right) \right) \quad [t\ CH_4/t_{Bio}] \quad (11)$$

With:

$M_{Fract.}$	Fraction of MSW in this case residential and ICI Waste Stream	[t/a]
	$M_{Fract.} = M_{res.MSW} + M_{ICI}$	(12)

$M_{res.\,MSW}$	Tonnage of residential MSW	[t/a]
M_{ICI}	Tonnage of ICI	[t/a]

Or for point b:

$$L_o = \left(L_{o_{res.MSW}} * \left(\frac{M_{res.MSW}}{M_{Waste}} \right) \right) + \left(L_{o_{ICI}} * \left(\frac{M_{ICI}}{M_{Waste}} \right) \right) + \left(L_{C\&D} * \left(\frac{M_{C\&D}}{M_{Waste}} \right) \right) + \left(L_{o_{NonWaste}} * \left(\frac{M_{NonWaste}}{M_{Waste}} \right) \right) \quad [t\ CH_4/t] \quad (13)$$

With:

M_{Waste}	Tonnage of Total Waste Stream	[t/a]
	$M_{Waste}=M_{res.MSW}+M_{ICI}+M_{C\&D}+M_{NonMSW}$	(14)
$M_{C\&D}$	Tonnage of Construction and Demolition Waste	[t/a]
$M_{NonWaste}$	Tonnage of Non-MSW	[t/a]

5.1.2 Methane Collected CH_4r,c

The factor methane collected is defined as the amount of methane in LFG collected through the implementation of an active LFG collection system.

With the implementation of such a system the collected methane can be calculated as shown below.

$$CH_4r,c = Q_{LFG} * F_{CH_4} * \delta_{CH_4} \quad [t\ CH_4/a] \quad (15)$$

With:

Q_{LFG}	Flow of LFG measured at the Outlet of the LFG Collection System	[m^3 LFG/a]
F_{CH4}	Fraction of Methane in LFG at the Outlet	[-];[Vol.-%]
δ_{CH4}	Density of Methane (at 1.013 bar and 15°C)	[t CH_4/m^3]

5.1.3 LFG Collection Efficiency LFG_{CE}

The LFG_{CE} is defined as the amount of LFG collected in an active LFG collection system as compared to the amount generated in the landfill.

The LFG collection efficiency depends on the type of cover system applied to the landfill and the form of landfill gas collection system itself, in general distinguished between active and passive LFG collection systems and landfills for perimeter LFG control or complete LFG collection for air emission control.

For determining default values for LFG collection efficiency two studies were used to come up with default values for this guidance. These are the French Environmental Agency (ADEME) study for landfill gas regulation in France and a study conducted by SCS Engineers in the US, which both were based on a series of case studies in the relevant geographic zone. The individual generated values show no major differences and are summarized in Table 8. Landfills with implemented LFG mitigation control system have to be evaluated on a site specific basis as the primary goal is the reduction of the environmental footprint of the landfill site and not primarily energy recovery.

Type of Cover System	LFG Collection Efficiency		Developed Area
	Range	Default	
	[%]	[%]	[m²]
Operating Cell		35.0	A
Temporary Covered Cell	65 to 68	66.5	B
Final Clay Covered Cell	85 to 92	88.5	C
Composite Liner System	90 to 97	93.5	D
LFG Mitigation Control System	Site Specific	Site Specific	E

Table 8: Default Values for LFG Collection Efficiencies (ADEME, 2003; SCS Engineers, 2007)

For the case of various cover systems applied to different landfill areas an average LFG_{CE} can be calculated by:

$$LFG_{CE_{Average}} = \frac{[(35\% * A) + (66.5\% * B) + (88.5\% * C) + (93.5\% * D)]}{(A + B + C + D)} \qquad (16)$$

5.1.4 Methane Stored CH_4r,s

The factor methane stored is defined as the maximum temporary amount of methane which can be stored in a landfill without an active LFG collection system.

The amount of methane stored in landfills is the most neglected factor in most methane balances from landfills (Spokas et al., 2006). Storage is very hard to monitor as it is so much dependent on various landfill site related factors, such as waste composition, ambient climate, settlement, biodegradation, leachate volume and flow and waste compaction.

In order to simplify and streamline existing knowledge it is suggested to set CH_4 r,s equal zero for landfills with an active LFG collection system implemented at the landfill site. For landfills without an active LFG collection system implemented the average value of the gas-filled porosity (GFP) of 0.2 (20%) should be applied. This value was found as a default value in the extensive study in France where storage and change in storage were monitored for three landfills (Spokas et al., 2006).

$$CH_4 r,s = GFP * F_{CH_4} * Vol_{LF} * \delta_{CH_4} \quad \text{[t CH4/a]} \quad (17)$$

With

GFP	Gas Filled Porosity	[%]
F_{CH4}	Fraction of Methane in LFG	[-];[Vol.-%]
Vol_{LF}	Volume of Landfill	[m^3]
δ_{CH4}	Density of Methane (at 1.013 bar and 15°C)	[t CH_4/m^3]

To factor in the changes in CH_4 r,s over time the difference in pore space being available for methane storage has to be determined. The factor "Change in Methane stored" Δ CH_4r,s can be calculated as:

$$\Delta CH_4 r,s_C = CH_4 r,s_C - CH_4 r,s_{C-1} \quad \text{[t } CH_4\text{/a]} \quad (18)$$

With

CH_4r,s_C	Methane Stored in Current Year	[t CH_4/a]
CH_4r,s_{C-1}	Methane Stored in Year preceding the Current Year	[t CH_4/a]

5.1.5 Methane Emitted by the Waste $CH_4e,w,$

Methane emitted by the waste is defined as the amount of methane which is generated but not collected or stored in the landfill. It can be distinguished into CH_4 e,w,s , which is the methane portion emitting via the waste surface into the landfill cover system and CH_4 e,w,ss , which is the amount of methane emitting via the subsurface into the landfill base liner system.

The Alberta Standards for Landfills require all landfills to have a sub-surface landfill gas monitoring program. Throughout the active life and post-closure care period of the landfill, sub-surface landfill gas shall not exceed prescribed landfill gas explosive limits. If at any time subsurface landfill gas is detected above the limits the contingency plan shall be implemented.

Methane migration through the subsurface can be controlled by a variety of engineered liner systems, such as geomembrane, clay and GCL liners. The rate of flow is controlled by the slowest diffusion rate of the engineered liners (Spokas et al., 2006). In addition, LFG concentrations are regularly controlled in the landfill perimeter through subsurface gas probes. For this guidance CH_4e,w,ss is set to equal zero, if no signs of subsurface LFG migration is monitored. It is critical to monitor subsurface LFG migration as it represents a safety hazard for landfills. Once no signs of subsurface migration are found, for the purpose of this guidance CH_4e,w is equal CH_4e,w,s. Once subsurface LFG migration is detected prompt action should be followed to remediate the landfill site.

5.1.6 Methane Oxidized CH_4r,o and Methane Oxidation Rates f_{ox}

CH_4r,o is defined as the amount of methane removed by methane oxidizing processes during the passage of LFG through the landfill cover system. Methane oxidation is a biological process occurring in landfill cover systems converting methane into carbon dioxide, water and biomass.

The LFGWG has reviewed relevant research and development work in the field of optimizing methane oxidation performance on landfills all over the world, realizing that strong efforts and progress has been made in that area. Studies have shown methane oxidation rates up to 100% (IPCC, 2006). In most of these cases and experiments long term, full facility studies are scarce. Well managed and aerated material can certainly improve oxidation performance, but the spatial extent of measurements should be wide enough (IPCC, 2006).

The methane oxidation removal can be expressed by:

$$CH_4 r,o = f_{OX} * CH_4 e,w,s \qquad [\text{t } CH_4/\text{a}] \qquad (19)$$

With

f_{ox} Methane Oxidation Factor [%]

Default values for methane oxidation rates are provided in Table 9. These values were taken from the 2006 IPCC Guidelines for National Inventory (IPCC, 2006).

Type of Site	Methane Oxidation Rates	Developed Area
	f_{ox}	
	[%]	[m2]
Managed[1], unmanaged and uncategorized landfill	0	A
Managed covered with CH_4 oxidizing material[2]	10	B

[1] Managed but not covered with aerated material

[2] Examples: soil / compost

Table 9: Default Values for Methane Oxidation Rates

For the case of site types existing at different landfill areas an average methane oxidation rate can be calculated by:

$$f_{OX,avergae} = \frac{[(0\% * A) + (10\% * B)]}{(A + B)} \tag{20}$$

Recent studies in Europe (e.g. Börjesson et al, 2007; Scharff, 2007) have shown the relevance of methane oxidation performance at fully closed, capped landfills sites. A potential for methane mitigation through oxidation was given between 5 and 20% of total landfill emission over the complete lifespan of a landfill, obviously resulting in higher methane oxidation performance during landfill closure and post-closure period.

The use of an oxidation value higher than 10% in the context of this guidance should be clearly documented, referenced and supported by data relevant to the geographical context (IPCC, 2006).

5.1.7 Methane Destruction Efficiency DE_{CH4}

The methane destruction efficiency DE_{CH4} is defined as the amount of methane destroyed through flares, engines or turbines. Most LFG control devices come with destruction efficiencies from e.g. vendor/manufacturers. The following default values are taken from the USEPA (1998) for non –halogenated species. They are distinguished between boiler/steam and gas turbines, flares and IC engines.

For landfills who are actively and passively venting their LFG into the atmosphere the destruction efficiency should be set to zero.

Type of LFG Control Device	Methane Destruction Efficiency	Methane Destruction Efficiency
	Range	Average
	[%]	[%]
Boiler/Steam Turbines	67-99+	99.8
Gas Turbine	97-99+	98.2
Flares	38-99+	99.7
IC Engines	25-99+	86.1* (98+)
Passive Venting		0

* A recent review of literature and experiences from members of the LFGWG have shown average destruction efficiencies for IC Engines of 98+ %

Table 10: Default Values for Methane Destruction Efficiency (USEPA, 1998)

5.1.8 Methane Emitted during On-Site Transportation CH_4e,t

Transportation activities on the landfill will cause methane emissions from fuel combustion. For this guidance only emissions from on-site transportation activities on the landfill that are there as part of the normal operations, or that are integral to the production process should be accounted for. These are emissions from the use of loaders and compactors on-site placing, moving, or compacting the waste in the landfill. Emissions from cell construction and installation of LFG collection systems or any kind of landfill infrastructure are excluded as well as emissions from collection trucks or private traffic as they are not directly related.

Methane emissions from fuel combustion are technology dependent (Environment Canada, 2007). A methodology developed by Environment Canada was followed and applied for this guidance. This methodology is based upon the physical quantity of fuel combusted. During the combustion of carbon-based fuels a small portion of the fuel remains un-oxidized as methane (Environment Canada, 2007).
Methane emitted during on-site transportation CH_4e,t can be calculated as.

$$CH_4e,t = EF_{CH4\,Fueltype} * Q_{Fuel} * 10^{-6} \quad [\text{t } CH_4/\text{a}] \qquad (21)$$

with

$EF_{CH4Fueltype}$	Methane Emission Factor based on Type of Fuel	[gCH_4/l]
Q_{Fuel}	Quantity of Fuel Used	[l/a]

Methane emission factors were developed by Environment Canada based on fuel type and technologies. If site specific data is not available these emissions factors should be used as default values. The specific data and information on the respective emission factors can be found in Appendix A.

It should also be mentioned that the calculation of CH_4e,t can also be done on an individual equipment basis, which the sum of individual CH_4e,t being the total value of methane emitted during on-site transportation. This type of calculation might be necessary due to the use of different kind of equipment on site.

5.2 Carbon Dioxide

5.2.1 Carbon Dioxide Generated CO_2g

The amount of carbon dioxide generated from waste decomposition processes can be derived from the Scholl-Canyon Model, which is presented in Chapter V a.

The model, in the context of this guidance, is only proposed for those landfills or landfill parts with no LFG collection, when no other data is available from actual field tests or experience from LFG collection/testing on the landfill.

The amount of carbon dioxide generated CO_2g can be calculated as follows:

$$CO_2g = \frac{CH_4g}{\delta_{CH_4}} * \left(\frac{CO_2}{CH_4}\right) * \delta_{CO_2}$$ [t CO_2/a] (22)

with

CO_2 g	Carbon Dioxide generated	[t CO_2/a]
CH_4 g	Methane generated	[t CH_4/a]
δ_{CH4}	Density of Methane (at 1.013 bar and 15°C)	[t CH_4/m^3]
CO_2/CH_4	Volume ratio CO_2 to CH_4 in fraction of LFG	[-]
δ_{CO2}	Density of Carbon Dioxide (at 1.013 bar and 15°C)	[t CO_2/m^3]

5.2.2 Carbon Dioxide Collected CO_2r,c

The factor carbon dioxide collected is defined as the amount of carbon dioxide in LFG collected through the implementation of an active LFG collection system.

With the implementation of such a system the collected methane can be calculated as shown below.

$$CO_2r,c = Q_{LFG} * F_{CO_2} * \delta_{CO_2}$$ [t CO_2/a] (23)

With:

Q_{LFG}	Flow of LFG measured at the Outlet of the LFG Collection System	[m^3 LFG/a]
F_{CO2}	Fraction of Carbon Dioxide in LFG	[-];[Vol.-%]
δ_{CO2}	Density of Carbon Dioxide (at 1.013 bar and 15°C)	[t CO_2/m^3]

5.2.3 Carbon Dioxide Stored CO_2r,s

The factor carbon dioxide stored is defined as the maximum temporary amount of carbon dioxide which can be stored in a landfill without an active LFG collection system.

In order to simplify and streamline existing knowledge it is suggested to set CO_2r,s equal zero for landfills with an active LFG collection system implemented at the landfill site. For landfills without an active LFG collection system implemented the average value of the gas-filled porosity (GFP) of 0.2 (20%) should be applied. This value was found as a default value in the extensive study in France where storage and change in storage were monitored for three landfills (Spokas et al., 2006).

$$CO_2r,s = GFP * F_{CO_2} * Vol_{LF} * \delta_{CO_2}$$ [t CO_2/a] (24)

with

GFP	Gas Filled Porosity	[Vol.-%]
F_{CO2}	Fraction of Carbon Dioxide in LFG at the Outlet	[-];[Vol.-%]
Vol_{LF}	Volume of Landfill	[m^3]
δ_{CO2}	Density of Carbon Dioxide (at 1.013 bar and 15°C)	[t CO_2/m^3]

To factor in the changes in CO_2 r,s over time the difference in pore space being available for carbon storage has to be determined. The factor "Change in Carbon Dioxide stored" Δ CO_2r,s can be calculated as:

$$\Delta CO_2 r, s_C = CO_2 r, s_C - CO_2 r, s_{C-1} \quad \text{[t } CO_2\text{/a]} \qquad (25)$$

With

CO_2r,s_C	Methane Stored in Current Year	[t CO_2/a]
CO_2r,s_{C-1}	Methane Stored in Year preceding the Current Year	[t CO_2/a]

5.2.4 Carbon Dioxide Emitted by the Waste CO_2e,w

Carbon dioxide emitted by the waste is defined as the amount of carbon dioxide which is generated but not collected or stored in the landfill. It can be distinguished into CO_2e,w,s , which is the carbon dioxide portion emitting via the waste surface into the landfill cover system and CO_2e,w,ss , which is the amount of carbon dioxide emitting via the subsurface into the landfill base liner system.

The Alberta Standards for Landfills require all landfills to have a sub-surface landfill gas monitoring program. Throughout the active life and post-closure care period of the landfill, sub-surface landfill gas shall not exceed prescribed landfill gas explosive limits. If at any time subsurface landfill gas is detected above the limits the contingency plan shall be implemented.

The rate of flow is controlled by the slowest diffusion rate of the engineered liners (Spokas et al., 2006). In addition, LFG concentrations are regularly controlled in the landfill perimeter through subsurface gas probes. For this guidance CO_2e,w,ss is set to equal zero, if no signs of subsurface LFG migration is monitored. It is critical to monitor subsurface LFG migration as it represents a safety hazard for landfills. Once no signs of subsurface migration are found, for the purpose of this guidance CO_2e,w is equal CO_2e,w,s. Once subsurface LFG migration is detected prompt action should be followed to remediate the landfill site.

5.2.5 Carbon Dioxide generated during Methane Oxidation CO_2e,o

During methane oxidation processes in the cover layer carbon dioxide is produced. Hoeks (1972) states that per unit of volume of oxidized methane the carbon dioxide production ranged between 0.2 and 1.0 volume units. In experiments this was further specified to the range between 0.7 and 1.0. Nikiema et al. (2005) confirmed that range with higher factors for inorganic substrate then organic (compost). For the purpose of that guidance we assume that this ratio is a default 0.85.

The amount of carbon dioxide generated during methane oxidation can then be calculated by

$$CO_2e,o = 0.85 * 2.74271 * CH_4r,o \quad [\text{t } CO_2/\text{a}] \quad (26)$$

With

0.85	Fraction of methane converted to carbon dioxide (Range 0.7-1.0)	[-]
2.74271	Conversion factor assuming 1mol CH_4 converted to 1 mol CO_2	[-]
CH_4r,o	Methane oxidized	[t CH_4/a]

5.2.6 Carbon Dioxide Emitted after LFG Control System CO_2e,c

The amount of carbon dioxide emitted after the LFG control system represents the sum of the carbon dioxide generated from waste composition which is collected and the amount of carbon dioxide which is generated from methane converted during passage of the LFG control system. CO_2e,c can be calculated as.

$$CO_2e,c = CO_2r,c + CO_2e,conv \quad [\text{t } CO_2/\text{a}] \quad (27)$$

With

CO_2r,c	Carbon Dioxide Collected	[t CO_2/a]
CO_2e,conv	Carbon Dioxide Generated through Conversion from Methane	[t CO_2/a]

The amount of carbon dioxide generated through conversion from methane can be calculated using the amount of methane collected, the LFG destruction efficiency of the LFG control system (Table 7), and the assumption that at complete conversion 1 mol of methane is converted to 1 mol of carbon dioxide.

$$CO_2e,conv = CH_4r,c * DE_{CH_4} * 2.74271 \quad [\text{t } CO_2/\text{a}] \quad (28)$$

With

CH_4r,c	Methane Collected	[t CH_4/a]
DE_{CH4}	Methane Destruction Efficiency	[%]
2.74271	Conversion factor assuming 1mol CH_4 converted to 1 mol CO_2	[-]

5.2.7 Carbon Dioxide Emitted from On-Site Transportation CO_2e,t

Transportation activities on the landfill will cause carbon dioxide emissions from fuel combustion. For this guidance only emissions from on-site transportation activities on the landfill that are there as part of the normal operations, or that are integral to the production process should be accounted for. These are emissions from the use of loaders and compactors on-site placing, moving, or compacting the waste in the landfill. Emissions from cell construction and installation of LFG collection systems or any kind of landfill infrastructure are excluded as well as emissions from collection trucks or private traffic as they are not directly related.

Carbon dioxides emissions from fuel combustion are dependent on fuel properties (Environment Canada, 2007). A methodology developed by Environment Canada was followed and applied for this guidance. This methodology is based upon the physical quantity of fuel combusted. Carbon dioxide emissions from fuel combustion activities depend upon the amount of fuel consumed, the carbon content of the fuel, and the fraction of the fuel oxidized (Jaques,1992).

Carbon dioxide emitted during on-site transportation can be calculated as.

$$CO_2e,t = EF_{CO2\,Fueltype} * Q_{Fuel} * 10^{-6} \qquad [t\ CO_2/a] \qquad (29)$$

with

$EF_{CO2Fueltype}$	Carbon Dioxide Emission Factor based on Type of Fuel	$[gCO_2/l]$
Q_{Fuel}	Quantity of Fuel Used	[l/a]

Carbon dioxide emission factors were developed by Environment Canada based on fuel type and technologies. If site specific data is not available at the landfill site these should be used as default values. The specific data and information on the respective emission factors can be found in Appendix A.

It should also be mentioned that the calculation of CO_2e,t can also be done on an individual equipment basis, which the sum of individual CO_2e,t being the total value of carbon dioxide emitted during on-site transportation. This type of calculation might be necessary due to the use of different kind of equipment on site.

5.3 Nitrous Oxides

5.3.1 Nitrous Oxides Emitted from On-Site Transportation N_2Oe,t

Transportation activities on the landfill will cause nitrous oxides emissions from fuel combustion. For this guidance only emissions from on-site transportation activities on the landfill that are there as part of the normal operations, or that are integral to the production process should be accounted for. These are emissions from the use of loaders and compactors on-site placing, moving, or compacting the waste in the landfill. Emissions from cell construction and installation of LFG collection systems or any kind of landfill infrastructure are excluded as well as emissions from collection trucks or private traffic as they are not directly related.

Nitrous oxides emissions from fuel combustion are technology dependent (Environment Canada, 2007). A methodology developed by Environment Canada was followed and applied for this guidance. This methodology is based upon the physical quantity of fuel combusted. During combustion some of the nitrogen in the fuel and air is converted to N_2O. The production of N_2O is dependent upon the combustion temperature and the control technology employed.

Nitrous oxides emitted during on-site transportation can be calculated as.

$$N_2Oe,t = EF_{N20\,Fueltype} * Q_{Fuel} * 10^{-6} \qquad [t\ N_2O/a] \qquad (30)$$

with

$EF_{N2OFueltype}$	Nitrous Oxides Emission Factor based on Type of Fuel	[gN_2O/l]
Q_{Fuel}	Quantity of Fuel Used	[l/a]

Nitrous oxides emission factors were developed by Environment Canada based on fuel type and technologies. If site specific data is not available at the landfill site these should be used as default values. The specific data and information on the respective emission factors can be found in Appendix A.

It should also be mentioned that the calculation of N_2Oe,t can also be done on an individual equipment basis, with the sum of individual N_2Oe,t being the total value of nitrous oxides emitted during on-site transportation. This type of calculation might be necessary due to the use of different kind of equipment on site.

5.3.2 Nitrous Oxides Emitted from Landfill Surface N_2Oe,s

The production of nitrous oxides in soils can occur during the microbiological processes of denitrification and nitrification. Soil moisture and composition will influence the production of nitrous oxides during these processes (Mandernack et al., 2000). Another source of nitrous oxides in a landfill environment can be nitrification processes by methanotrophic bacteria.

The amount of nitrous oxides emitted from a landfill environment as.

$$N_2Oe,s = EF_{N_2O-Soil} * A * 10^{-6} \qquad [t\ N_2O/a] \qquad (31)$$

with

$EF_{N2O-Soil}$	Nitrous Oxides Emission Factor based on Soil Cover	[gN_2O/m^2a]

	Material	
A	Landfill Area with Final Cover	[m2]

For the purpose of this guidance only the area of a landfill is considered on which a final cover is applied.

The emission of nitrous oxides from soils represents a complex process. A very limited amount of site specific emission factors from covered landfills are reported in the literature (e.g. Mandernack et al., 2000; Borjesson and Svensson, 1997;Rinne et al., 2005; and McBain et al., 2005). Data from these investigations show that nitrous oxides emissions from landfill exceed emissions measured from natural soils. Only McBain et al. (2005) found no differences in emission values from a landfill and natural soil environment. In general more field work is needed to arrive at more specific conclusions for N_2O emissions from landfill cover soil. A default value based on work conducted by Bowden et al. (1990) for grasslands (0.079 g N_2O/m^2*a) should be used if no other values are available.

6 Example Calculations

In the following the example calculations for the in Chapter III and IV described methodologies and parameters are presented. The example calculations for TDE and TAE/EI determination in the spreadsheet are presented for landfills with and without LFG collection system. The yellow patterned cells are user input data. No example calculation for landfills with partial LFG collection systems are shown as they represent a mixture of the ones shown.

Landfill without LFG Collection System - Determination of TDE/TAE and EI

Year: 2008

Step	Description	Substeps	Value	Unit
1	Determine " LFG Generated" CH4 g + CO g			
	a	CH_4 g	944	[t CH_4/a]
	b	CO_2 g	2,595	[t CO_2/a]
2	Determine "Change in LFG Stored": ΔCH_4 r,s + ΔCO_2 r,s			
	a	Determine "Change in Methane Stored" ΔCH_4r,s	2	[t CH_4/a]
	b	Determine "Change in Carbon Dioxide Stored" ΔCO_2r,s	6	[t CO_2/a]
3	Determine "LFG Emitted from the Waste, which is not collected or stored": CH_4 e,w + CO_2 e,w			
	a	CH_4 e,w = CH_4 g - ΔCH_4 r,s	942	[t CH_4/a]
	b	CO_2 e,w = CO_2 g - ΔCO_2 r,s	2,589	[t CO_2/a]
4	Determine "LFG Emitted from the Waste into the Base Liner": CH_4 e,ss + CO_2 e,ss			
	a	Determine "Methane Emitted from the Waste into the Base Liner": CH_4 e,w,ss	0	[t CH_4/a]
	b	Determine "Carbon Dioxide Emitted from the Waste into the Base Liner": CO_2 e,w,ss	0	[t CO_2/a]
	c	CH_4 e,ss = CH_4 e,w,ss	0	[t CH_4/a]
	d	CO_2 e,ss = CO_2 e,w,ss	0	[t CO_2/a]
5	Determine "LFG Emitted over the Landfill Surface": CH_4 e,s + CO_2 e,s			
	a	Determine "Methane Oxidized": CH_4 r,o		
	b	Determine "Methane Emitted from the Waste into the Capping System": CH_4 e,w,s	942	[t CH_4/a]
	c	Determine "Methane Oxidation Factor": f ox	10%	[%]
	d	CH_4 r,o = f ox * CH_4 e,w,s	94	[t CH_4/a]
	e	CO_2 e,o = 0.85*2.74271*CH_4 r,o	220	[t CO_2/a]
	f	CH_4 e,s = CH_4 e,w,s - CH_4 r,o	848	[t CH_4/a]
	g	CO_2 e,s = CO_2 e,w+CO_2 e,o	2,809	[t CO_2/a]
6	Determine "SG Emitted from On Site Transportation": CO_2 e,t + CH_4 e,t + N_20 e,t			
	a	Determine "Carbon Dioxide Emitted from On Site Transporation": CO_2 e,t	328	[t CO_2/a]
	b	Determine "Methane Emitted from On Site Transporation": CH_4 e,t	0.02	[t CH_4/a]
	c	Determine "Nitrous Oxide Emitted from On Site Transporation": N_2O e,t	0.13	[t N_2O/a]
7	Determine "Nitrous Oxides Emitted from Landfill Surface": N_20 e,s			
	a	Determine "Nitrous Oxide Emitted from Landfill Surface": N_2O e,s	0.00	[t N_2O/a]
8	Determine "Total Direct Emissions from Landfill": TDE			
	a	"Methane Emitted from the Landfill": CH_4 e	848	[t CH_4/a]
	b	"Carbon Dioxide Emitted from the Landfill": CO_2 e	3,137	[t CO_2/a]
	c	"Nitrous Oxides Emitted from the Landfill": N_20 e	0.13	[t N_2O/a]
	f	TDE = (CH_4e *$GWP_{CH4)}$+(CO_2e*$GWP_{CO2)}$+(N_2Oe*GWP_{N2O})	20,981	[t $CO_{2equiv.}$/a]
9	Determine "Total Annual Emissions from Landfill": TAE			
	a	"Methane Emitted from the Landfill": CH_4 e	848	[t CH_4/a]
	b	"Carbon Dioxide Emitted from the Landfill": CO_2 e	328	[t CO_2/a]
	c	"Nitrous Oxides Emitted from the Landfill": N_20 e	0.13	[t N_2O/a]
	f	TAE = (CH_4e *$GWP_{CH4)}$+(CO_2e*$GWP_{CO2)}$+(N_2Oe*GWP_{N2O})	18,173	[t $CO_{2equiv.}$/a]
10	Determine "Production from Landfill" Total: P			
		"Production from the Landfill": P	944	[t CH_4/a]
11	Determine "Emissions Intensity from Landfill" Total: EI			
		"Emissions Intensity from Landfill" Total: EI	19.25	[t $CO_{2equiv.}$/t CH_4]

Table 11: Spreadsheet Example of TDE, TAE, and EI Calculation for Landfills with no LFG Collection System

Landfill with LFG Collection System - Determination of TDE, TAE, and EI

Year:

Step		Description / Substeps	Value	Unit
1		Determine "LFG Collected" CH_4 r,c + CO_2 r,c		
	a	Determine "LFG Flow from LFG Collection System": Q_{LFG}	9,000,000	[m^3/a]
	b	Determine "Fraction of Methane in LFG": F_{CH4}	50%	[Vol.-%]
	c	Determine "Density of Methane": δ_{CH4}	0.00068	[t/m^3]
	d	Determine "Fraction of Carbon Dioxide in LFG": F_{CO2}	50%	[Vol.-%]
	e	Determine "Density of Carbon Dioxide": δ_{CO2}	0.00187	[t/m^3]
	f	CH_4 r,c = Q_{LFG} * F * δ_{CH4}	3,060	[t CH_4/a]
	g	CO_2 r,c = Q_{LFG} * F * δ_{CO2}	8,415	[t CO_2/a]
2		Determine "LFG Emitted from the Waste, which is not collected or stored": CH_4 e,w + CO_2 e,w		
	a	Determine "Landfill Gas Collection Efficiency": LFG_{CE}	88.5%	[%]
	b	CH_4 e,w = (CH_4 r,c/LFG_{CE})-CH_4r,c	398	[t CH_4/a]
	c	CO_2 e,w = (CO_2 r,c/LFG_{CE})-CO_2r,c	1,093	[t CO_2/a]
3		Determine "LFG Emitted from the Waste into the Base Liner": CH_4 e,ss +_ CO_2 e,ss		
	a	Determine "Methane Emitted from the Waste into the Base Liner": CH_4 e,w,ss	0	[t CH_4/a]
	b	Determine "Carbon Dioxide Emitted from the Waste into the Base Liner": CO_2 e,w,ss	0	[t CO_2/a]
	c	CH_4 e,ss = CH_4 e,w,ss	0	[t CH_4/a]
	d	CO_2 e,ss = CO_2 e,w,ss	0	[t CO_2/a]
4		Determine "LFG Emitted over the Landfill Surface": CH_4 e,s + CO_2 e,s		
	a	Determine "Methane Oxidized": CH_4 r,o and CO_2 e,s		
	b	Determine "Methane Emitted from the Waste into the Capping System": CH_4 e,w,s	398	[t CH_4/a]
	c	Determine "Methane Oxidation Factor": f ox	10%	[%]
	d	CH_4 r,o = f ox * CH_4 e,w,s	40	[t CH_4/a]
	e	CO_2 e,o = 0.85*2.74271*CH_4 r,o	93	[t CO_2/a]
	f	CH_4 e,s = CH_4 e,w,s - CH_4 r,o	358	[t CH_4/a]
	g	CO_2 e,s = CO_2 e,w+CO_2 e,o	1,186	[t CO_2/a]
5		Determine "LFG Emitted after LFG Control System": CH_4 e,c + CO_2 e,c		
	a	"Methane Collected": CH_4 r,c	3,060	[t CH_4/a]
	b	Determine "Methane Destruction Efficiency" DE_{CH4}	98.0%	[%]
	c	CO_2 e,conv = CH_4 r,c *DE_{CH4}*2.74271	8,225	[t CO_2/a]
	d	CH_4 e,c = (1-$DE_{CH4)}$)*CH_4 r,c	61	[t CH_4/a]
	e	CO_2 e,c = CO_2 r,c + CO_2 e, conv	16,640	[t CO_2/a]
6		Determine "SG Emitted from On Site Transportation": CO_2 e,t + CH_4 e,t + N_20 e,t		
	a	Determine "Carbon Dioxide Emitted from On Site Transporation": CO_2 e,t	683	[t CO_2/a]
	b	Determine "Methane Emitted from On Site Transporation": CH_4 e,t	0.02	[t CH_4/a]
	c	Determine "Nitrous Oxide Emitted from On Site Transporation": N_2O e,t	0.06	[t N_2O/a]
7		Determine "Nitrous Oxides Emitted from Landfill Surface": N_20 e,s		
	a	Determine "Nitrous Oxide Emitted from Landfill Surface": N_2O e,s	0.04	[t N_2O/a]
8		Determine "Total Direct Emissions from Landfill": TDE		
	a	"Methane Emitted from the Landfill": CH_4 e	419	[t CH_4/a]
	b	"Carbon Dioxide Emitted from the Landfill": CO_2 e	18,509	[t CO_2/a]
	c	"Nitrous Oxides Emitted from the Landfill": N_20 e	0.10	[t N_2O/a]
	f	TDE = (CH_4e *$GWP_{CH4)}$+(CO_2e*$GWP_{CO2)}$+(N_2Oe*GWP_{N2O})	27,341	[t $CO_{2equiv.}$/a]
9		Determine "Total Annual Emissions from Landfill": TAE		
	a	"Methane Emitted from the Landfill": CH_4 e	419	[t CH_4/a]
	b	"Carbon Dioxide Emitted from the Landfill": CO_2 e	683	[t CO_2/a]
	c	"Nitrous Oxides Emitted from the Landfill": N_20 e	0.10	[t N_2O/a]
	f	TAE = (CH_4e *$GWP_{CH4)}$+(CO_2e*$GWP_{CO2)}$+(N_2Oe*GWP_{N2O})	9,515	[t $CO_{2equiv.}$/a]
10		Determine "Production from Landfill" Total: P		
		"Production from the Landfill": P	3,458	[t CH_4/a]
11		Determine "Emissions Intensity from Landfill" Total: EI		
		"Emissions Intensity from Landfill" Total: EI	2.75	[t $CO_{2equiv.}$/t CH_4]

Table 12: Spreadsheet Example of TDE, TAE, and EI Calculation for Landfills with LFG Collection System

7 Glossary of Terms in the Landfill Context

Baseline emissions intensity (BEI) means the total emissions of CH_4 and N_2O from surface and flaring emissions , and non biogenic CO_2 (on site transportation emissions) in a year expressed in [t CO_2e/a] divided by the total CH_4 +N_2O produced in that year expressed in [t /a]. BEI for landfills is calculated based on the average of the three years preceding the compliance year.

Direct emissions means the release of specified gases (CH_4, CO_2 and N_2O from flaring, non biogenic CO_2) from all sources actually located at a landfill, expressed in [t CO_2e/a].

Emissions intensity means the sum of tonnes of CH_4 and N_2O, non-biogenic CO_2 emitted (total annual emissions) expressed in [t CO_2e/a] per tonne of CH_4 + N_2O generated (production) in [t/a].

Facility means any plant, structure or thing where an activity listed in section 2 of the Schedule of Activities to the Environmental Protection and Enhancement Act occurs, and a site or one or more contiguous or adjacent sites that are operated and function in an integrated fashion where an activity listed in any of sections 3 to 11 of the Schedule of Activities to the Environmental Protection and Enhancement Act occurs, including all the buildings, equipment, structures, machinery and vehicles that are an integral part of the activity (source: Specified Gas Emitters Regulation).

Net emissions intensity (NEI) means the total emissions of CH_4 and N_2O from surface and flaring emissions and non-biogenic CO_2 in a year minus offsets, fund credits, or performance credits expressed in [t CO_2e/a], per tonne of CH_4 + N_2O produced in [t /a].

On-site transportation emissions means direct emissions resulting from fuel combustion in machinery used for the on-site transportation of products and material integral to the production process (source: Specified Gas Reporting Standard – March 2007).

Production for landfills means quantity of CH4 and N2O that is generated by a landfill per year.

Total annual emissions (TAE) means the total emissions of CH_4 and N_2O, and non-biogenic CO_2 in a year, expressed in [t CO_2e/a]. TAE is used for baseline calculations.

Total direct emissions (TDE) means the release of CH_4, CO_2 (biogenic and non-biogenic) and N_2O from all sources actually located at a landfill in a year, expressed in [t CO_2e/a]. TDE is used for threshold calculations.

Unit of production for landfill means tonnes of CH_4 and N_2O generated.

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Appendix A: Emission Factors for Energy Mobile Combustion Sources (based on Environment Canada, 2007)

Mode			Emission Factors		
			CO_2	CH_4	N_2O
			g/l fuel	g/l fuel	g/l fuel
Road Transport	Gasoline Vehicles	Light Duty	2360	0.34	0.27
	Gasoline Vehicles	Heavy- Duty	2360	0.28	0.11
	Diesel Vehicles	Light Duty	2730	0.07	0.20
	Diesel Vehicles	Heavy Duty	2730	0.14	0.08
	Natural Gas Vehicles		1.89	0.009	0.00006
	Propane Vehicles		1510	0.64	0.03
Off-Road	Off-Road Gasoline		2360	2.70	0.05
	Off-Road Diesel		2730	0.15	1.10
Renewable Fuels	Ethanol		1490		

Table 13: Emission Factors for Energy Mobile Combustion Sources (based on Environment Canada, 2007)