QUANTIFICATION PROTOCOL FOR LANDFILL GAS CAPTURE AND COMBUSTION:

ABRIDGED

Submitted to:

Alberta Environment

and

Alberta Agriculture, Food and Rural Development

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Disclaimer

The following document presents an abridged version of the Landfill Gas Capture and Combustion protocol prepared for Alberta Environment and Alberta Agriculture, Food and Rural Development which has completed an initial round of technical review. This document has been prepared as a means of supporting a broader stakeholder consultation process. As such, this document should not be used as a quantification protocol.

The full-length protocol is largely based on the *Draft Quantification Protocol for Landfill Gas Capture and Combustion* dated April 11, 2006. This document was prepared by Enviro-Access Inc. for submission to Environment Canada.

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1.0 Project and Methodology Scope and Description

This quantification protocol is applicable to the quantification of direct and indirect reductions in greenhouse gas (GHG) emissions resulting from the collection and use of landfill gas (LFG) under controlled conditions. LFG is passively emitted from landfills during the anaerobic decomposition of the organic components within the landfill. As the carbon dioxide component of the LFG is biogenic, this protocol is focused on the methane component. Landfill gas collection reduces the quantity of methane emissions from the landfill. The destruction of the methane component of the landfill gas results in emissions of biogenic carbon dioxide thus achieving a reduction of emissions in anthropogenic GHGs. In addition, the generation of heat, power and electricity will offset other sources which can include the combustion of fossil fuels.

The use of LFG under controlled conditions may include:

- Combustion for the generation of heat and/or power;
- Combustion for the generation of electricity;
- Destruction during controlled flaring; and/or
- Pipeline distribution to an end-user for combustion purposes.

Combustion of the LFG may occur on- or off-site, and must be occur under controlled conditions. **FIGURE 1.1** offers a project element life cycle chart for a typical project.

This protocol serves as a generic 'recipe' for project proponents to follow in order to meet the measurement, monitoring and GHG quantification requirements for reductions due to LFG capture and usage under controlled conditions.

The baseline condition for projects applying this protocol is defined as the volume of methane captured that would otherwise have been released to the atmosphere, less the volume of methane that would have been captured under any other existing regulations. The baseline condition is thus dependent on the volume of LFG captured and combusted, and not on the size, waste composition, operational method or other characteristics of the project landfill. This allows the protocol to be applied across a variety of landfills with an equivalent result. The baseline scenario for conversion from an open flare to controlled combustion is considered to be the same as the baseline scenario for conversion from no flare to controlled combustion. The baseline is thus project-specific. **FIGURE 1.2** offers an element life cycle chart for a typical baseline configuration.

The approach to quantifying the baseline will be calculation based as there are suitable data available for the applicable baseline condition that can provide reasonable certainty. The baseline scenario for this protocol is dynamic as the volume of methane would be expected to change materially relative to the age of the landfill, and the baseline condition may vary from project to project.

FIGURE 1.1: Project Element Life Cycle Chart

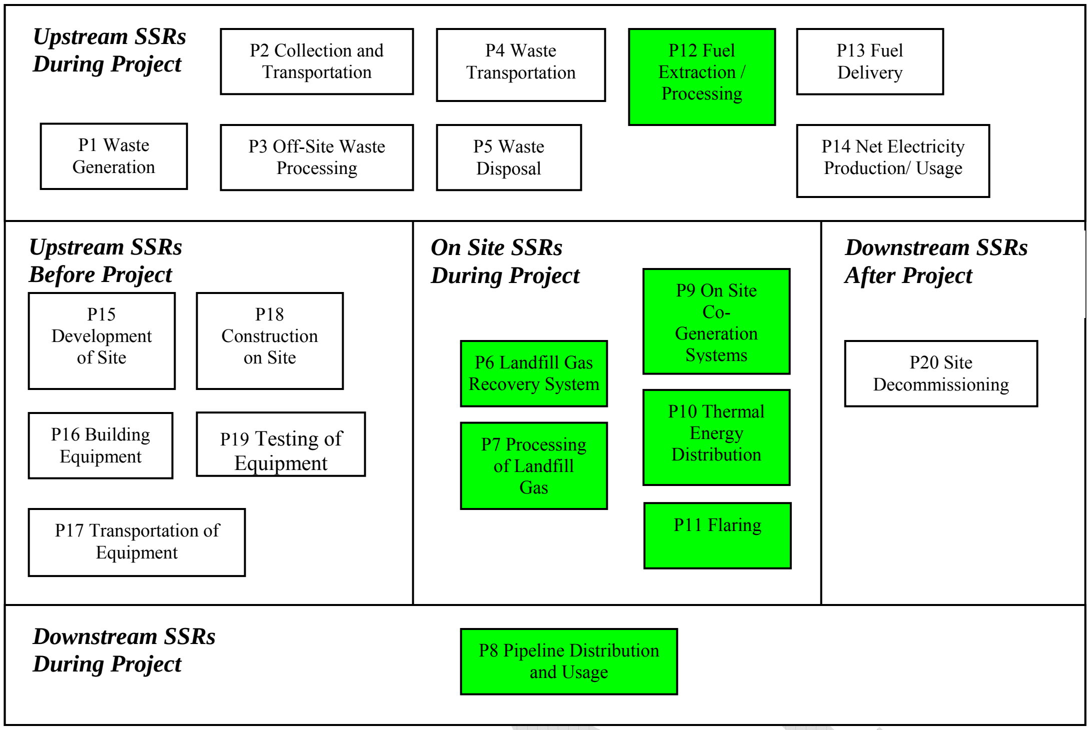
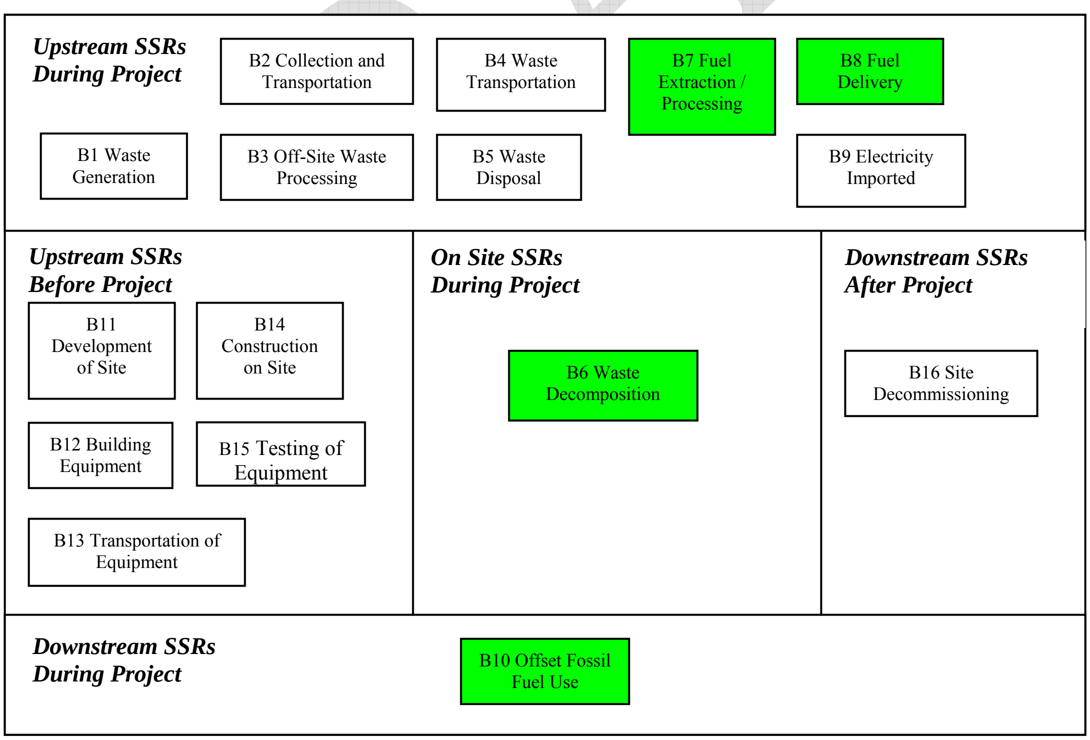


FIGURE 1.2: Baseline Element Life Cycle Chart



* Sources, sinks and reservoirs selected for measurement and monitoring under this protocol are highlighted.

This protocol does not attempt to estimate or quantify the total GHG emissions from a landfill. The GHG reduction calculation is based on the measurement of the volume of LFG collected and the assumption that all of the LFG collected would have been released in the absence of an LFG collection system. Thus the calculation of the total volume of methane generated in the landfill, using modeling or other calculation methods, is not required under this protocol.

To demonstrate that a project meets the requirements under this protocol, the project proponent must supply sufficient evidence to demonstrate that:

1. The combustion is carried out under controlled conditions as demonstrated by a description of the LFG end use and specifications of the combustion device in use;
2. The LFG is not vented directly to atmosphere under the project condition once it is gathered as demonstrated by operational records and/or an attestation by the project proponent;
3. Metering of gas volumes takes place upstream within a reasonable distance of either the combustion device or point of inclusion in the off-site pipeline network such that the meter to address the potential for fugitive emissions as demonstrated by a project schematics; and
4. The quantification of reductions achieved by the project is based on actual measurement and monitoring (except where indicated in this protocol) as indicated by the proper application of this protocol.

Flexibility in applying the quantification protocol is provided to project developers in the following ways:

1. Project proponents may use alternative monitoring methodologies and/or equipment rather than the methodologies and/or equipment described in this protocol. The proponent must justify that the chosen methodology and/or equipment provides equivalent or more conservative data than the specified equipment;
2. Where the LFG is included within a shared pipeline network, and the end-use of the LFG cannot be directly attributed, it is reasonable to assume that the end use is complete combustion at destruction efficiencies meeting the assumptions of the emission factors underlying Environment Canada's factors, as listed in the annual inventory of national emissions. In such circumstances, the most conservative emission factors for natural gas should be used for the downstream use of the LFG;
3. Site specific emission factors may be substituted for the generic emission factors indicated in this protocol document. The methodology for generation of these emission factors must be sufficiently robust as to ensure reasonable accuracy;
4. This protocol may be used to quantify emission reductions from an upgrade of an open flare to a controlled combustion device even if the open flare. For the purposes of this protocol, the efficiency of an open flare is assumed to be 25%. As such, the baseline condition for conversion from an open flare to controlled combustion would be the same as conversion from no flare to controlled

combustion with a corresponding discount of 25% applied to all volumes of LFG combusted or included into the pipeline; and

5. Project proponents may use a site-specific flare efficiency for an open flare, provided there is sufficient data to support the efficiency chosen.

If applicable, the proponent must indicate and justify why flexibility provisions have been used.

2.0 Quantification of Identified Sources, Sinks and Reservoirs

Quantification of the reductions, removals and reversals for the sources, sinks and reservoirs selected for measurement and monitoring under this protocol will be completed using the methodologies outlined in **TABLE 2.1**, below. These calculation methodologies serve to complete the following three equations for calculating the emission reductions from the comparison of the baseline and project conditions.

$$\text{Emission Reduction} = \text{Emissions}_{\text{Baseline}} - \text{Emissions}_{\text{Project}}$$

$$\text{Emissions}_{\text{Baseline}} = \text{Emissions}_{\text{Fuel Extraction / Processing}} + \text{Emissions}_{\text{Electricity Production}} + \text{Emissions}_{\text{Waste Decomposition}} + \text{Emissions}_{\text{Offset Fossil Fuel Use}}$$

$$\text{Emissions}_{\text{Project}} = \text{Emissions}_{\text{Fuel Extraction / Processing}} + \text{Emissions}_{\text{Recovery System}} + \text{Emissions}_{\text{Processing of Landfill Gas}} + \text{Emissions}_{\text{Onsite Co-generation}} + \text{Emissions}_{\text{Thermal Energy}} + \text{Emissions}_{\text{Flaring}} + \text{Emissions}_{\text{Pipeline distribution}}$$

TABLE 2.1: Quantification Procedures

1. Project/Baseline SSR	2. Parameter / Variable	3. Unit
Project SSRs		
P12 Fuel Extraction and Processing	$\text{Emissions}_{\text{Fuel Extraction / Processing}} = \sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CO2})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CH4})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ N2O})$	
	$\text{Emissions}_{\text{Fuel Extraction / Processing}}$	kg of CO2e
	Volume of Fossil Fuel Combusted for P6 to P11 / Vol_{Fuel}	m^3
	CO_2 Emissions Factor for Fuel Including Production and Processing / EF Fuel_{CO2}	kg CO_2 per m^3
	CH_4 Emissions Factor for Fuel Including Production and Processing / EF Fuel_{CH4}	kg CH_4 per m^3
	N_20 Emissions Factor for Fuel Including Production and Processing / EF Fuel_{N2O}	kg N2O per m^3
P6 Landfill Gas Recovery System Operation	$\text{Emissions}_{\text{LFG System}} = (\text{Vol. LFG Consumed} * \%\ CH_4 * \text{EF LFG}_{CH4})$; $(\text{Vol. LFG Consumed} * \%\ CH_4 * \text{EF LFG}_{N2O})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CO2})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CH4})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ N2O})$	
	$\text{Emissions}_{\text{LFG System}}$	kg of CO_2 ; CH_4 ; N_2O
	Volume of Landfill Gas Consumed / Vol. LFG Consumed	m^3
	Methane Composition in Landfill Gas / % CH_4	-
	CH_4 Emissions Factor for Landfill Gas / EF LFG_{CH4}	kg CH_4 per m^3
	N_20 Emissions Factor for Landfill Gas / EF LFG_{N2O}	kg N_2O per L / m^3 / other
	Volume of Each Type of Fuel used / Vol Fuel_{i}	L / m^3 / other
	CO_2 Emissions Factor for Each Type of Fuel / $\text{EF Fuel}_{i\ CO2}$	kg CO_2 per L / m^3 / other
	CH_4 Emissions Factor for Each Type of Fuel / $\text{EF Fuel}_{i\ CH4}$	kg CH_4 per L / m^3 / other
	N_20 Emissions Factor for Each Type of Fuel / $\text{EF Fuel}_{i\ N2O}$	kg N_2O per L / m^3 / other
P7 Processing of Landfill Gas	$\text{Emissions}_{\text{Process LFG}} = (\text{Vol. LFG Consumed} * \%\ CH_4 * \text{EF LFG}_{CH4})$; $(\text{Vol. LFG Flared} * \%\ CH_4 * \text{EF LFG}_{N2O})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CO2})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CH4})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ N2O})$	
	$\text{Emissions}_{\text{Process LFG}}$	kg of CO_2; CH_4; N_2O
P8 Pipeline Distribution and Usage	$\text{Emissions}_{\text{Pipeline}} = (\text{Vol. LFG Consumed} * \%\ CH_4 * \text{EF LFG}_{CH4})$; $(\text{Vol. LFG Consumed} * \%\ CH_4 * \text{EF LFG}_{N2O})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CO2})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CH4})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ N2O})$	
	$\text{Emissions}_{\text{Pipeline}}$	kg of CO_2 ; CH_4 ; N_2O
P9 On Site Co-Generation Systems	$\text{Emissions}_{\text{Co-Gen}} = (\text{Vol. LFG Consumed} * \%\ CH_4 * \text{EF LFG}_{CH4})$; $(\text{Vol. LFG Consumed} * \%\ CH_4 * \text{EF LFG}_{N2O})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CO2})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CH4})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ N2O})$	
	$\text{Emissions}_{\text{Co-Gen}}$	kg of CO_2 ; CH_4 ; N_2O
P10 Thermal Energy Distribution	$\text{Emissions}_{\text{Heat Dist}} = (\text{Vol. LFG Consumed} * \%\ CH_4 * \text{EF LFG}_{CH4})$; $(\text{Vol. LFG Consumed} * \%\ CH_4 * \text{EF LFG}_{N2O})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CO2})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CH4})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ N2O})$	
	$\text{Emissions}_{\text{Heat Dist}}$	kg of CO_2 ; CH_4 ; N_2O
P11 Flaring	$\text{Emissions}_{\text{Flaring}} = (\text{Vol. LFG Flared} * \%\ CH_4 * \text{EF LFG}_{CH4})$; $(\text{Vol. LFG Flared} * \%\ CH_4 * \text{EF LFG}_{N2O})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CO2})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ CH4})$; $\sum (\text{Vol. Fuel}_{i} * \text{EF Fuel}_{i\ N2O})$	
	$\text{Emissions}_{\text{Flaring}}$	kg of CO_2 ; CH_4 ; N_2O
	Volume of Landfill Gas Flared / Vol. LFG Flared	m^3

Baseline SSRs		
B7 Fuel Extraction and Processing	$Emissions_{Fuel\ Extraction\ /\ Processing} = \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CO2})\ ;\ \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CH4})\ ;\ \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ N2O})$	
	Emissions $_{Fuel\ Extraction\ /\ Processing}$	kg of CO2e
	Volume of Fossil Fuel Combusted for B10 / Vol Fuel	m^3
B9 Electricity Imported	$Emissions_{Electricity} = Electricity * EF_{Elec}$	
	Emissions $_{Electricity}$	kg of CO2e
	Incremental Electricity Exported from the Site / Electricity	kWh
	Emissions Factor for Electricity / EF $_{Elec}$	kg of CO2e per kWh
B6 Waste Decomposition	$Emissions_{Waste\ Decomp} = Vol_{LFG\ Consumed} * \%\ CH_4 * \rho\ CH_4$	
	Emissions $_{Waste\ Decomp}$	kg of CH_4
	Density of Methane	kg / m^3
B10 Offset Fossil Fuel Use	$Emissions_{Fuel\ Offset} = \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CO2});\ \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CH4})\ ;\ \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ N20})$	
	Emissions $_{Fuel\ Offset}$	kg of CO_2 ; CH_4 ; N_2O
	Volume of Each Type of Fuel Offset by Landfill Gas / Vol Fuel $_i$	m^3

APPENDIX A: Glossary of New Terms

Bioreactor Landfill:	A landfill cell that is specifically engineered to enhance the decomposition of wastes through careful manipulation of site conditions.
Controlled Conditions:	Specific conditions in terms of temperature, residence time and air intake taking place in an enclosed space to optimize the combustion of methane.
Landfill:	A defined area of land or excavation that receives or has previously received waste that may include household waste, commercial solid waste, non hazardous sludge and industrial solid waste.
Landfill Gas:	Gas resulting from the decomposition of wastes placed in a landfill typically comprised primarily of methane, carbon dioxide and other trace compounds.
Landfill Gas Project:	Installation of infrastructure that in operating causes a decrease in GHG emissions through combustion of the methane component of LFG.