ERC Measurement and Validation Protocol

OPTIGAZ LANDFILL GAS GENERATING STATION
KIRKLAND, QUÉBEC

SUBMITTED TO:

CLEAN AIR CANADA INCORPORATED (CACI)

Cumming Cockburn Limited
Consulting Engineers, Planners and Environmental Scientists
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1.0 Summary

The Optigaz Landfill Gas (LFG) generating station is located in an industrial building adjacent to the Meloche landfill site on the island of Montreal Québec. The generating station reduces emissions of harmful methane and volatile organic compounds from the landfill by collecting and combusting landfill gas in engines and flares.

The generating station was commissioned in June 1998 and is expected to continue operation for up to 25 years or until landfill gas production becomes negligible.

Assuming an average methane concentration of 55 % by volume in the landfill gas, the cumulative total methane produced is 389.6 Million m^3 – CH_4. The expected claimable emission reduction is expected to be 4.01 (M.T.C.E.) Million Metric Tonnes Carbon Equivalent.

This document describes the emission reducing activity at the Optigaz LFG generating station and identifies the sources and magnitudes of the expected emission reductions. It establishes the validity of these reductions for emission credit trade and specifies methodologies for measuring, calculating and verifying the values of emission reductions and credits arising from the activity.

2.0 Source Identification

The Optigaz LFG generating station is located adjacent to the Meloche sanitary landfill site at the west end of the island of Montreal in Kirkland, Québec. The generating plant is housed in an industrial space immediately adjacent to the landfill and the owner/operator may be contacted at:

Optigaz Inc.
(Formerly Société de Cogénération Meloche Inc.)
16789B Hymus Blvd.
Kirkland, Québec
H9H 3L4
Attn: Pascal Brun, President
Phone (514) 694-5550
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The landfill site is owned by La Compagnie Meloche Inc. and was filled with municipal solid waste over a 10-year period ending in 1990. The landfill gas generating station is owned by Optigaz Inc., formerly Société de Cogénération Meloche Inc., and operated by O&M Cogeneration Inc.

3.0 Project Description

This section defines the emission reducing activity.

3.1 Site Description

The Meloche Landfill is an old quarry, approximately 61 m deep and 9 ha in area that was filled with 3,915,000 tons (3.551 Million Tonnes) of municipal solid waste between 1980 and 1990. The waste composition is approximately 40 % residential and 60 % commercial/industrial.

A total of 33 vertical gas vent-wells and a perimeter gas collection system were installed during the operation of the landfill. The purpose of the gas collection system was to prevent the emission of odours and migration of gas to adjacent properties by collecting fugitive gas near the boundaries and surface of the landfill. It was not intended to collect gas generated in the bulk of the landfill. A flare was provided for disposal of the small quantity of vented gas.

The original gas collection system was installed voluntarily by La Compagnie Meloche Inc. and was not required by any provincial regulation or local ordinance.

3.2 Activity Description

The development of a LFG generating station at the Meloche site was proposed by Highland Energy Inc. and resulted in the formation of Société de Cogénération Meloche Inc. in 1997.

As the existing gas collection system did not provide adequate access to the landfill gas for power generation, Société de Cogénération Meloche Inc. installed 12 new slotted gas wells with flow control valves on each wellhead. The gas from these new wells was combined with that from the original gas collection system. The existing flare was retained.

A generating station with two 800 kW Caterpillar G3516Le-SCAC lean-burn engine-generator sets was installed in an industrial property immediately adjacent to the landfill site. Gas is withdrawn from the landfill under vacuum by two cross-connected filter/blower/drier units.

The two 16 cylinder, 1200 RPM diesel engines together draw 1,020 m^3/hour (600 CFM) of landfill gas at full load. This is approximately 35 % of the current total gas production in the landfill. Unused gas is currently retained in the landfill. Gas drawn by the generating station was flared when the engines were not running until the end of 1999; the flares are no longer operational. Caterpillar (1) gives the engine heat rate as 11.08 MJ/kWh at full load and 11.98 MJ/kWh at 50% load when fuelled by landfill gas. The heat rate can be considered linear in this range.

The 1.6 MW plant was commissioned in June 1998 and additional improvements to the gas collection system were completed in September 1998. Société de cogénération Meloche Inc. was acquired by CHI Canada Inc. and Soquip Inc. and renamed Optigaz Inc. in October 2000.

3.3 Emission Reduction Strategy

The emission reduction strategy of the activity is to reduce methane emissions through combustion of landfill gas in engines and flares. Methane is a potent greenhouse gas with 21-times the global warming potential of carbon dioxide on a mass basis over 100 years. Combustion of landfill gas in engines and flares is also effective in reducing VOC emissions.

4.0 Quality of Emission Reductions

This section addresses non-quantitative criteria governing the validity of emission reduction credits.

4.1 Real

The emission reductions from the Meloche Landfill site are real and are solely due to activity of the proponent, i.e. landfill gas combustion in the LFG generating station. The reductions would not occur without the activity and are not a result of the cessation of any activity. A small quantity of landfill gas was being flared at the Meloche Landfill prior to the 1990 Kyoto base year. The emissions baseline has been adjusted downward to reflect this as described in Section 6.

4.2 Surplus

The reduction in emissions is surplus to any legal requirements. There is no requirement to collect or flare landfill gases in the Province of Québec at this time. The Ministère de l'Environnement et de la Faune is considering introducing such requirements in the near future: they advise that new requirements will be modeled on EPA regulations and will only affect new landfill projects. Neither Société de Cogénération Meloche Inc. or Optigaz Inc. has made or registered any undertaking to voluntarily reduce emissions from the Meloche landfill site.

4.3 Owned

An agreement (2) executed between Highland Energy Inc. and La Compagnie Meloche Inc. dated August 4, 1995, specifies Highland Energy Inc.'s exclusive right to:

> *"…use the "landfill gas" in any way that "Highland Energy Inc." deems appropriate for electric power generation <u>or other beneficial use</u> subject to applicable laws and regulations."*

This agreement was assigned to Société de Cogénération Meloche Inc. at the time of that company's formation. Optigaz Inc., the renamed Société de Cogénération Meloche Inc., is therefore is the sole owner of any emission reduction credits from activities at the Meloche landfill site. The term of the agreement is 15 years (to July 1, 2011) and can be extended for ten additional one-year terms.

5.0 Analysis of Baseline Emissions

This section quantifies the expected annual and cumulative pollutant emissions from the Meloche landfill site that are subject to reduction through the activity of the proponent.

5.1 Landfill Gas Production

Organic waste in landfills is anaerobically decomposed into methane and carbon dioxide gases through a succession of microbial processes. The rate of decomposition depends on a host of factors including the age of the landfill, composition and physical arrangement of the waste materials, the temperature, the moisture content and pH of the decomposing mass. Some organic waste, such as food wastes, are decomposed rapidly while others, such as cellulose, are decomposed at a slower rate. Inorganic materials such as glass or stone and some organic materials such as lignins and plastics are not decomposed at all.

For engineering purposes, landfill gas evolution is treated as a first-order kinetic process where the rate of gas evolution is proportional to the amount of organic material remaining that has not yet decomposed. The rate of gas evolution reaches a maximum soon after placement and then declines exponentially over time. As the composition of the waste is generally not known in detail, a single rate constant is assumed for all decomposable organic materials.

5.2 Methodology

The baseline emissions are calculated in accordance with methods and assumptions given in the Intergovernmental Panel on Climate Change manual "Revised 1996 Guidelines on National Greenhouse Gas Inventories" (3) as adopted by Environment Canada. The IPCC methodology assumes that 1) all decomposable organics will eventually be converted to landfill gas, 2) all of the

The cumulative methane gas production prior to the beginning of emission reduction activity on June 30, 1998 is taken to be 255.4 Mm³ using the LandGEM model. Subtracting this from the theoretical lifetime total methane emissions and reducing by 5 % to account for prior activity, the expected total baseline methane emissions during the period of the activity is:

$$0.95*(665.5 \text{ Mm}^3 - 255.4 \text{ Mm}^3) = 389.6 \text{ Mm}^3 \text{- } CH_4$$

6.1 Baseline Gas Composition

The landfill gas composition varies markedly during the early stages of decomposition, being initially high in CO_2, and then stabilizes to 50-60 % CH_4 once fully anaerobic conditions are established. This usually occurs within one to two years following the closing of the landfill.

The gas composition at the Meloche Landfill site was analyzed (5) by an independent laboratory, Bodycote Technitrol Inc. of Pointe-Claire Québec on July 8, 1988. The landfill at this time can be assumed to have a stable gas composition. Samples were taken at the engine inlet (after the scrubber) as the main objective of the analysis was to determine the fuel quality of the gas.

The following results were obtained, expressed on a dry basis at standard conditions (25°C and 101.1 kPa):

Table 5.1
Analysis of Meloche Landfill Gas

Constituent	Abbreviation	Concentration
Methane	CH_4	57.0 % vol.
Carbon dioxide	CO_2	34.0 % vol.
Nitrogen	N_2	3.3 % vol.
Oxygen	O_2	2.0 % vol.
Others (assumed inert)		3.7 % vol.
		100.0 % vol.
Volatile Organic Compounds	VOC	
Total Halogenated Hydrocarbons	TTH	Not detected
Monocyclic Aromatic Hydrocarbons	MAH	89.0 mg/Nm³

Hydrogen, carbon monoxide, hydrogen sulphide and halogenated hydrocarbons were below detection limits. Total organic halides were low (25.1 mg/ Nm³). Only small quantities of other organic compounds (benzene, toluene) were detected in one of the five samples drawn. VOCs appear to occur solely as aromatic hydrocarbons, and so the total VOC concentration is taken to be 89 mg/Nm³ as MAH. This is conservative as it does not include VOC removal in the scrubber.

The lower heating value of this gas is determined by the methane concentration alone and is found to be 19.27 MJ/m³ (517.4 BTU/ft³).

6.2 Summary of Baseline Emissions

The following table summarizes the baseline emissions estimate for the activity by year from 1998 to 2020, and the remaining balance of future emissions. The figures have been reduced 5 % to account for the prior flare system, and 1998 emissions have been prorated to account for the July 1, 1998 start of the activity. Methane density evaluated at 25°C.

Table 5.2

Meloche Landfill – Baseline Emissions Summary

Year	LFG Mm^3	CH_4 Mm^3	M.T.C.E. (Tonnes CO_{2E})
1998	14.631	8.047	110,485
1999	28.120	15.466	212,348
2000	27.015	14.858	204,000
2001	25.944	14.269	195,913
2002	24.942	13.718	188,348
2003	23.957	13.177	180,920
2004	23.025	12.664	173,877
2005	22.109	12.16	166,957
2006	21.245	11.685	160,435
2007	20.416	11.229	154,174
2008	19.622	10.792	148,174
2009	18.845	10.365	142,311
2010	18.102	9.956	136,696
2011	17.394	9.567	131,355
2012	16.713	9.192	126,206
2013	16.058	8.832	121,263
2014	15.428	8.485	116,499
2015	14.823	8.153	111,941
2016	14.243	7.834	107,561
2017	13.683	7.526	103,332
2018	13.148	7.231	99,282
2019	12.632	6.947	95,382
2020	12.136	6.675	91,648
Future	274.122	150.767	2,070,031
Total	**708.353**	**389.595**	**5,349,139**

NOTE: M.T.C.E. = Metric Tonnes Carbon Equivalent = Tonnes CO_{2E}

7.0 Analysis of Emission Reductions

The activity reduces methane emissions by combustion of landfill gas. Assuming the methane concentration averages 55 % by volume, the complete combustion of one cubic meter of landfill gas converts 0.55 m³ of methane to carbon dioxide and water according to the reaction:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

The density of methane converted is found from the ideal gas law, assuming a 25°C gas temperature as recommended by EPA Manual AP-42 (6) :

$$\rho = \frac{PM}{R_o T} = \frac{(1\text{ atm})\ (16\text{ kg/mole})}{(0.08206)(298.15\text{ K})} = 0.6540\text{ kg/m}^3\text{-}CH_4$$

Where R_o is the universal gas constant, 0.08206 m³-atm/kmole-K, T is the absolute temperature in Kelvin (K = °C + 273.15) and M is the molecular weight of methane in kg.

According to the IPCC [7], methane has a global warming potential 21 times that of CO_2 on a mass basis over 100 years. The combustion of 1 m³ of methane is then equivalent to a reduction of :

$$21*(0.6540) = 13.73 \text{ kg } CO_{2E}/m^3\text{- }CH_4$$

Over the period of the activity and assuming a 75 % LFG recovery rate, this accumulates to :

$$0.75 \times \frac{(389.595 \text{ million } m^3\text{- }CH_4)(13.73 \text{ kg } CO_{2E}/m^3\text{- }CH_4)}{(100 \text{ kg/tonne})} = 4.01 \text{ million tonne } CO_{2E}$$

7.1 Summary of GHG Emission Reductions

The following table summarizes the expected GHG emission reductions by year from 1998 to 2010 and the remaining balance of future reductions.

The 1998 reductions in this table are for the period of the activity only, starting on July 1, 1998. A 75 % landfill gas recovery efficiency and complete combustion of methane are assumed. All figures given are the estimated recovered quantities.

Table 5.3

Meloche Landfill – Emission Reduction Summary

Year	LFG Mm³	CH_4 Mm³	M.T.C.E. (Tonnes CO_{2E})
1998	10.973	6.035	82,864
1999	21.090	11.600	159,261
2000	20.261	11.144	153,000
2001	19.458	10.702	146,935
2002	18.707	10.289	141,261
2003	17.968	9.883	135,690
2004	17.269	9.498	130,408
2005	16.582	9.120	125,218
2006	15.934	8.764	120,326
2007	15.312	8.422	115,631
2008	14.717	8.094	111,131
2009	14.134	7.774	106,734
2010	13.577	7.467	102,522
2011	13.046	7.175	98,516
2012	12.535	6.894	94,655
2013	12.044	6.624	90,948
2014	11.571	6.364	87,374
2015	11.117	6.115	83,956
2016	10.682	5.876	80,671
2017	10.262	5.645	77,499
2018	9.861	5.423	74,461
2019	9.474	5.210	71,537
2020	9.102	5.006	68,736
Future	205.592	113.075	1,552,523
Total	**531.265**	**292.196**	**4,011,855**

7.2 Emissions from Methane Combustion

The products of landfill gas combustion include carbon dioxide and water vapour as described above, as well as nitrogen oxides and other species resulting from the technical implementation of the combustion process. The quantity of nitrogen oxide in the exhaust gas is strongly dependent on combustion temperature and can be controlled to a degree.

Environment Canada took samples of all gases at the Meloche site in late-September 1999 [8]. Table 5.4 summarizes the results of their exhaust gas analysis. As part of the test, the engine was adjusted to burn leaner, reducing the combustion temperature by approximately 54°C. This had a dramatic effect on NO_x emissions as indicated in the table. The overall VOC destruction efficiency was found to be 93.7 %.

Table 5.4
Meloche Landfill – Engine Stack Emissions

Pollutant		g/KWh	g/m^3-CH_4
CO		2.78	8.24
SO_2		Not detected	Not detected
NO_X As NO_2	Before adjustment	8.79	26.07
	After adjustment	1.17	2.49
HCl		0.0015	0.0045
HF		0.0062	0.0183
Hexachlorobenzene		Not detected	Not detected
PAHs		5.1×10^{-6}	15×10^{-6}
VOCs		9.67×10^{-6}	28.64×10^{-6}
Particulates		0.0185	0.0548

8.0 Measurement of Emission Reductions

The generating station kWh output is currently metered at two locations: a pair of meters on the engine-generator sets that give the gross electrical output of each, and a single Hydro-Québec meter giving the net output of the station. The difference between meter readings at the two locations is the internal electrical consumption of the station.

Meters on the engine-generators are read and logged daily by the station operator. The Hydro-Québec meter is read monthly by Hydro-Québec personnel. The accuracy of the kWh meters is estimated to be better than ± 1.5 % at a 95 % confidence level.

9.0 Emission Reduction Credit Calculation

The emission calculations begin by determining the volume of landfill gas utilized. The volume of landfill gas consumed by the engines is estimated from the electrical energy production of the plant. As gas is diverted from the engine to the flare when the engines are taken offline, the volume of gas flared should be the same as the engines would have drawn when running. It is discounted however to allow for estimation uncertainty.

Once the landfill gas volume is found, the mass of CH_4 combusted is determined from the known gas composition and the density of methane in the assumed 25°C, 1 atm state. This is converted to CO_2 equivalents using the global warming potential for methane and reduced by 5 % for pre-activity flaring to obtain the emission reduction credits.

9.1 Electricity Generation

This method calculates the volume of landfill gas consumed indirectly from kWh of energy production. It assumes the landfill gas is consumed at 25°C atm pressure.

1. *Gross Generation* – This is taken from the log of station meter readings. The annual average difference between the station log and the net generation reported by Hydro-Québec should be on the order of 3.1 % of the net generation.

2. *Volume of LFG Combusted* – This is calculated from the gross generation using the engine heat rate provided by the engine manufacturer and the most recent calorific value of landfill gas :

$$\text{LFG,m}^3 = \frac{\text{[gross kWh produced] * [genset heat rate, MJ/kWh]}}{\text{[LFG specific calorific value, MJ/m}^3\text{]}}$$

The heat rate is determined for the average engine load during the period. From manufacturer's data, the heat rate for a Caterpillars G3516LE-SCAC engine running on LFG can be estimated from :

$$\text{Genset heat rate, MJ/kWh} = 12.88 - \frac{1.8\ \text{[kWh produced in period]}}{820\ \text{[operating hours in period]}}$$

As an example, for current conditions with a calorific value of 19.27 MJ/m³ and a full-load heat rate of 11.08 MJ/kWh, the LFG volume consumed is:

$$\text{LFG, m}^3 = \text{[gross kWh] * (0.575 m}^3\text{ - LFG/kWh)}$$

9.2 Gas Flaring

Landfill gas was diverted to a flare whenever the engines were forced offline by Hydro-Québec. Until the end of 1999. The offline time periods were recorded by the station operator and confirmed by Hydro-Québec, who provides financial compensation for energy not accepted.

3. *Volume of LFG Flared* – The volume of LFG diverted to the flare is the volume drawn by the engines at full load: 1,020 m³/h. As this volume is currently inferred rather than measured, it is reduced by 15 % for uncertainty (eg. Unknown friction losses in the flare system piping). This gives :

$$\text{LFG, m}^3 = 0.85 \text{ * [flare operation, hours] * (1020 m}^3\text{ - LFG/h)}$$

9.3 Common Calculations

The total volume of LFG combusted is the sum of the volumes obtained form steps 2 and 3 above. The following calculations are independent of the method used to determine the LFG volume consumed:

4. *Mass of Methane Combusted* – The volume of LFG consumed is multiplied by the methane fraction obtained from the most recent gas analysis, and the resulting methane volume is multiplied by the methane density at 25 ;C and 1 atm. pressure :

$$CH_4 \text{ mass, tonnes} = \frac{[CH_4 \text{ fraction}][LFG, m^3][CH_4 \text{ density}, kg/m^3]}{[1000 \text{ kg/tonne}]}$$

The methane density at 25 °X and 1 atm is obtained from the ideal gas law :

$$CH_4 \text{ density} = \frac{PM}{R_o T} = \frac{[1 \text{ atm}][16 \text{ kg/mole}]}{[0.08206 \text{ m}^3\text{-atm/kmole-K}][298.15 \text{ K}]} = 0.6557 \text{ kg/m}^3$$

5. *Greenhouse Gas Emission Credit* – The CO_2 equivalent emission credit for methane is 21 times the mass of methane combusted. This is further reduced by 5 % to 19.95 account for flaring underway prior to 1990 :

   CO_2 –eq, tonnes = 19.95*[CH_4 mass, tonnes]

10.0 Verification Procedure

All emission reduction credits claimed under this protocol shall be independently verified by Cumming Cockburn Limited, and a copy of their ERC Creation Report shall be submitted along with each Notice of Credit Creation. In verifying a credit creation, Cumming Cockburn shall:

- check instrument calibration records
- review Hydro and engine logs and compute mass flows
- verify that all computed values are mutually consistent, adjusting estimates for uncertainty where warranted
- confirm that no changes affecting the validity of the credits have occurred
- compute the appropriate values of emission credits to be claimed.

11.0 Documents Examined

1. Caterpillar Corporation, "G3516 LE SCAC Generator Set Performance" Specification DM0116-00.

2. La Compagnie Meloche Inc. and Highland Energy Inc., "Agreement for the Sale of Landfill Gas and Landfill Gas Production Rights". August 4, 1995.

3. IPCC, *Revised 1996 Guidelines for National Greenhouse Gas Inventories*. Paris, FR : International Energy Agency, 3 vols., 1996. **http://www.iea.org/ipcc/invs1.html**

4. LandGEM 2.1 Software and Manual. Research Triangle Park, NC: US Environmental Protection Agency, February 1998. **http://epa.gov/ttn/catc/products.html#software**

5. Menard, M. and S. Miko, Sampling and Analysis of Biogas from the Meloche Landfill Site in Kirkland". Pointe-Claire, PG: Bodycote Technitrol Inc., August 1998.

6. ----ibid., "Municipal Solid Waste Landfills" in Washington, DC : US Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors Ap-42*, Volume I : Stationary Sources, 1998. **http://www.epa.gov/ttn/chief/ap42.html**

7. IPCC, *Climate Change 1995 : The Science of Climate Change*. Cambridge, UK : Cambridge University Press, 1996.

8. Cianciarelli, D., *Characterization of Emissions from an 812 kW_e Reciprocating Engine Fired with Landfill Gas.* Ottawa, ON : Environment Canada, Emissions Research and Measurement Division Report ERMD 99-05, December 1999 (draft)

12.0 Author's Declaration

This Protocol was prepared by the Energy and Environmental Services Department of Cumming Cockburn Limited and is based on information supplied by Optigaz Inc. The work was performed on a fee-for-service basis. Neither Cumming Cockburn Limited nor any of its employees have any financial interest in the affairs of Optigaz Inc., or in any emission reduction credits that may be produced as a result of their activity at the Meloche Landfill site.