Life-Cycle Assessment of Lachenaie Landfill Gas to Delivered LNG and LCNG in California

January 22nd, 2015; Revised May 26th, 2015 for facility name change

Submitted to:

BP Natural Gas and Power

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General Information

Complexe Enviro Progressive ltee (CEF) operates a landfill gas treatment facility to recover methane from the Lachenaie Landfill site that serves the Montreal Urban Community (MUC) in Quebec, Canada.

The anaerobic decomposition of organic wastes in landfills results in the generation of a biogas commonly referred to as landfill gas (LFG). [redacted] The CEF Landfill is comprised of four main exploitation zones ("fields") among which three (fields #1, #2 and #3) are no longer used for landfill operation while the 4th zone (field #4) is used and expanded for current and future receipts of residual waste. All four fields are equipped with an underground interconnecting vacuum network to capture LFG. [redacted]

A landfill Gas Collection and Control System (GCCS) consisting of extraction wells within the refuse and a series of high density polyethylene pipes routes raw LFG to the treatment facility located on the landfill site. The CEF LFG cleanup technology is a waterwash based scrubbing process provided by Greenlane Biogas North America. [redacted]

The CEF treatment facility purifies raw LFG via a series of seven modular pressure water scrubbing units and three Pressure Swing Absorbers (PSA). Each individual unit is comprised of gas compression, gas upgrading and gas polishing operations. CEF purchases electricity from Hydro Quebec to meet the facility's energy demand. Most of the tail gas from the CO_2 scrubbing units is combusted in a thermal oxidizer (TOX), an enclosed flare that is partially fueled by imported propane. The tail gas stream that is generated by the N_2 PSA units is a higher-BTU stream that is combusted in a dedicated Nitrogen Removal Unit (NRU) flare.

[redacted] This estimate is based on the annual US EPA Actual Peak Capacity calculation using the lower heating value of methane.

Pipeline grade LFG is transported via pipeline from Quebec to California for compression and sale. The following pathway was produced using two and half months (Sept 14th – Nov 30th 2014) of landfill gas production data and two (2) years (2011-2012) of LNG production data.[4]

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[1] CEF Pathways Annex 3 - Engineering Review Report FINAL PE Sealed, pg. 33

[2] The power generation contract will be terminated by 2021, inclusively. Thus this supplemental amount of biogas will be rendered available to generate biomethane as of 2022.

[3] Calculation of sales gas methane content and HHV are shown in Annex 2 - Facility Energy Data Analysis, Gas Sales tab, rows 13-14

[4] Please see Annex 2 for CEF Facility Energy Data Analysis, Annex 7 for gas sales receipts, and Annex 8 for LNG electricity consumption data

Process Description

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

[redacted]

[5] Information is sourced from Annex 3 CEF Engineering Review Report, pg. 43-47

[6] Annex 2, Summary tab, cell K25. 94% is the sales gas (166.15 mmbtu/hour) divided by the landfill gas (176.37 mmbtu/hour)

Data Collection and Process Results

To estimate GHG emissions, the energy and materials necessary for the following processes needs to be determined: LFG Production Plant, Transport of Gas to California (Pipeline), Liquefaction, and Transportation & Distribution.

LFG Production Plant

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

[redacted] The CEF facility imports electricity and propane to purify the landfill gas and uses an onsite thermal oxidizer and open flares to combust off-gases generated during the purification steps and when the plant is not operating.

Table 1 below shows the available data provided by CEF for input biogas, product biogas, biogas consumed on-site, imported electricity and imported propane from September 14th to November 30th 2014. The balance of the biogas consumed in the thermal oxidizer and flare is calculated based on modeling data provided in the CEF Engineering Report. The table also shows the provided data converted to GREET model inputs. The CEF pathway utilizes the CA-GREET default values for LFG recovery.

[redacted] To determine combustion emissions from the consumed natural gas and landfill gas at the landfill gas plant, the GREET default values for natural gas combustion process for natural gas liquefaction (100% natural gas turbine) were chosen since they represent the processes more closely than natural gas compression (100% natural gas engine).

TABLE 1. CEF LFG PLANT OPERATING ENERGY AND FLARE CREDIT[10]

(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

	Sept 14th – Nov 30th 2014 Hourly Data	Btu/MMBtu of Product Gas	Input Value	Changed Cells – NG Tab
[redacted]				

[7] Please see Annex 2, Summary tab, cell E22 for the calculation of this figure
[8] Please see Annex 2, Summary tab, cell E25 for the calculation of this figure
[9] Please see Annex 2, Summary tab, cell F25 for the calculation of this figure
[10] Please see Annex 2, Summary tab for the calculations of the figures presented in this table
[11] Please see Annex 7 for PDFs of gas sales invoices
[12] Please see Annex 5 for PDFs of facility electricity bills

	Sept 14th – Nov 30th 2014 Hourly Data	Btu/MMBtu of Product Gas	Input Value	Changed Cells – NG Tab
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	

Below is a simplified process diagram of the facility that includes the estimated energy flow associated with each step of the LFG recovery process.

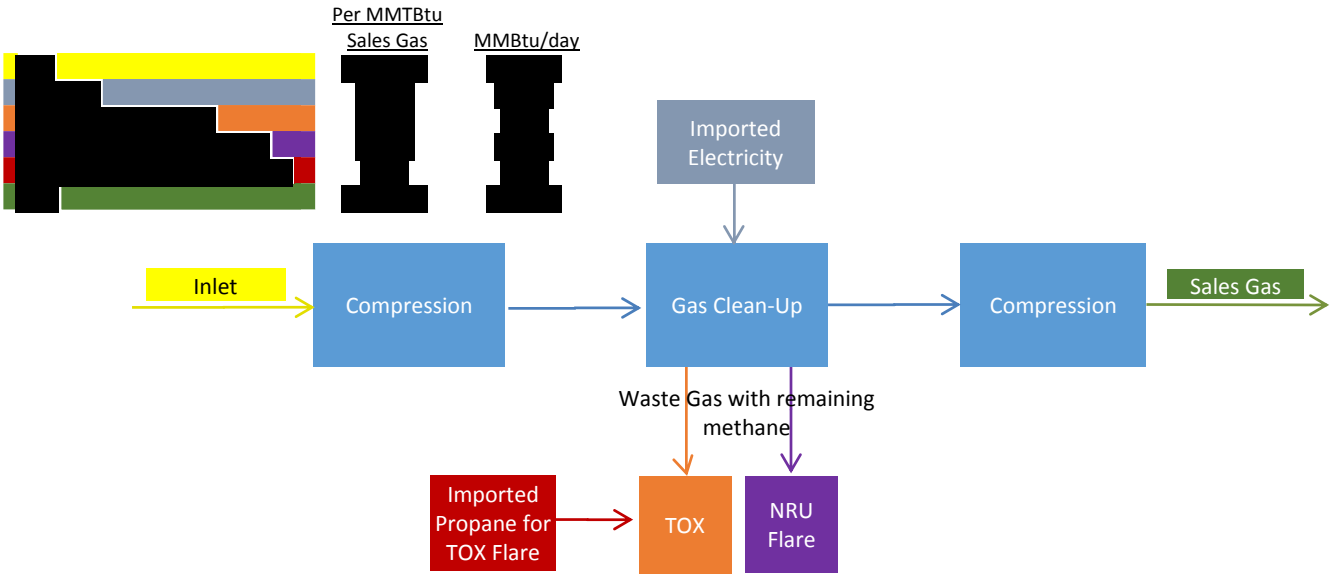

Figure 1. CEF Process per MMBtu and MMBtu/day Energy Flows

[13] Please see Annex 6 for PDFs of facility propane bills
[14] Please see Annex 1 for the Modified GREET model referred to in this report

The GREET model LFG pathway was then modified to adjust efficiency gas and process energy shares as listed in Table 2. The Southeast Asia region on the Regional LT tab was changed to reflect the average electricity grid mix of Hydro-Quebec, the utility that provides electricity the CEF facility. The ARB methodology of converting the average grid electricity mix to marginal mix was not employed because Hydro-Quebec exports 12-15% of their electricity production.[15] Table 2 presents the average Hyrdo-Quebec electricity grid mix for 2012, as published by the Canada National Energy Board in the Energy Future 2013 Market Assessment Report.[16] The allocation of Canadian energy categories to those used in GREET is also shown. To be conservative, the combined biomass, solar and geothermal category in the Quebec grid mix was allocated in total to the biomass category in the GREET model. The remaining values from the Southeast Asia Region were changed to match the US Average grid mix for the electricity consumed during the transport and distribution phase of the CEF LFG pathway.

TABLE 2. HYDRO-QUEBEC ELECTRICITY GRID MIX

Quebec CY 2012 Grid Mix		Allocation to GREET Electricity Categories	CA-GREET Cell Regional LT Tab
Hydro / Wave / Tidal	96.67%	Other (renewables)	J88
Wind	0.75%	Other (renewables)	J88
Biomass / Solar / Geothermal	0.42%	Biomass	J87
Uranium	1.98%	Nuclear	J86
Coal & Coke	0.00%	Coal	J85
Natural Gas	0.07%	Natural Gas	J84
Oil	0.10%	Residual Oil	J83

This produced the results for LFG to pipeline biogas shown in Table 3 below. These values are taken from the NG Tab of the Modified GREET model which can be found in Annex 1 of the supporting documents submitted in conjunction with this report. Conversion from g/MMBtu to g/MJ was done using the conversion factor of 1055.055 MJ/MMBTU as is done in the CA-GREET model.

The recovery energy and emissions are based on ARB LFG pathway defaults of 4621.25 Btu of electricity/MMBtu of landfill gas.[17]

TABLE 3. CEF LFG PLANT GREENHOUSE GAS EMISSIONS
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

	Recovery Emissions	CEF LFG Plant	CA-GREET Cell NG Tab
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

[15] Hydro-Quebec 2013 Annual Report, pg. 2 (1990-2013 data). Retrieved from http://www.hydroquebec.com/publications/en/annual_report/pdf/annual-report-2013.pdf

[16] National Energy Board. Canada's Energy Future 2013: Energy Supply and Demand Projections to 2035, An Energy Market Assessment. Annex Table A5.1 Reference Case Generation by Primary Fuel Type. Retrieved from https://www.neb-one.gc.ca/nrg/ntgrtd/ftr/2013/ppndcs/pxlctrctgnrtn-eng.html

[17] http://www.arb.ca.gov/fuels/lcfs/022709lcfs_lfg.pdf; page 9.

	Recovery Emissions	CEF LFG Plant	CA-GREET Cell NG Tab
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]		[redacted]	[redacted]
[redacted]		[redacted]	[redacted]

Transportation to California by Pipeline

The pipeline transport distance was modified to 2,854 miles from Terrebonne QC to Boron CA, where the gas will be liquefied. The distances were determined by the using the driving route most similar to the pipeline map. Biomethane from the CEF landfill travels from Quebec to California via the TransCanda, Union Gas, Vector, ANR, and Transwestern and SoCal Gas pipelines.[18] Google Maps was used to determine the driving routes with the I-40 route most similar to the pipeline map. The emissions were determined by linked cell E148 on the NG tab to cell F479 on the T&D_Flowcharts tab. The table below shows the pipeline transport emissions from cells F151-F157 on the NG Tab.

TABLE 4. CEF LFG TRANSPORT GREENHOUSE GAS EMISSIONS
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

Transport Emissions	CEF LFG Transport
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

Liquefaction

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

[redacted]

Table 5 and Table 6 below show the calculation from kWh/GGE to process efficiency and the cells that were changed and the results from cells G163- G169.

[18] Please see Annex 3 pg.237 for the CEF to CA pipeline map

TABLE 5. BORON LNG PLANT OPERATING EFFICIENCY[19]
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

All Units in Btus per Gal of LNG	Boron LNG Plant	Input Value	Changed Cells – NG Tab
[redacted]	[redacted]		
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

TABLE 6. BORON LNG PLANT GREENHOUSE GAS EMISSIONS
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

Recovery & Processing Emissions	Boron LNG Plant - Liquefaction
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

LNG Transport to Refueling Station

In addition the CA-GREET default LNG transport distance of 50 miles was used but the fuel shares were modified to utilize the Westport HPDI trucks consuming 90% LNG and 10% diesel with an EER of 1.0. The numbers were inputted in cells CD95 (% diesel consumption) and CD97 (% LNG consumption) on the "T&D" tab and the results were taken from cells H163-H169 on the "NG" tab.

TABLE 7. LNG TRANSPORT GREENHOUSE GAS EMISSIONS
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

Recovery & Processing Emissions	Boron LNG Plant – Transport
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

[19] Please see Annex 7 – Boron LNG Electricity Consumption Data for the calculations of the figures presented in this table

LNG Storage

In addition the CA-GREET default for LNG storage was used. The default values are listed in Table 8 below (the results were taken from cells I163-I169 on the "NG" tab).

TABLE 8. LNG STORAGE CA-GREET DEFAULT VALUES

	Bulk Terminal Storage	CA-GREET Cells Inputs Tab	Distribution	CA-GREET Cells Inputs Tab
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

TABLE 9. LNG STORAGE GREENHOUSE GAS EMISSIONS

	LNG Storage
[redacted]	
[redacted]	
[redacted]	[redacted]
[redacted]	
[redacted]	
[redacted]	[redacted]
[redacted]	[redacted]

L/CNG Conversion

To convert from LNG to CNG, LNG is re-vaporized and then compressed to cylinder pressure (at about 3000psi). According to ARB default LNG and CNG pathways (as sent to Clean Energy and ICF by ARB Staff):

- Re-gasified to LNG: + 0.75 gCO2e/MJ[20]
- Compressed to CNG: +2.14 gCO2e/MJ[21]
- Total: 2.89 gCO2e/MJ

[20] http://www.arb.ca.gov/fuels/lcfs/092309lcfs_lng.pdf
[21] http://www.arb.ca.gov/fuels/lcfs/022709lcfs_cng.pdf

CEF Fuel Pathway Results

When the CA-GREET model is run completely with the modifications listed above, the table below shows the complete pathway results. The WTT pathway gCO2e/MJ results were taken from cell J170 which is the sum of cells E170 – I170 on the "NG" tab for LNG. The TTW gCO2e/MJ was taken from the Detailed California-Modified GREET Pathway for Liquefied Natural Gas (LNG) from Landfill Gas[22].

TABLE 10. CEF PATHWAY RESULTS

GHG Emissions (gCO2e/MJ)	CEF LFG Plant to LNG	CEF LFG Plant to L/CNG
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]		[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
gCO2e/MJ WTW	**11.84**	**13.96**

[22] http://www.arb.ca.gov/fuels/lcfs/022709lcfs_lfg.pdf

Appendix A: Summary of CA-GREET Inputs

Parameter	Unit	Value	CA-GREET Cell Changed
LFG Recovery and Transport			
[redacted]			

[23] http://www.arb.ca.gov/fuels/lcfs/022709lcfs_lfg.pdf, pages 9-10.

[redacted]	[redacted]	[redacted]	[redacted]
[redacted]			[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]			[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

Appendix B: List of Supporting Annexes

CEF Pathways Annex 2 - Facility Energy Data & Analysis

CEF Pathways Annex 3 - Engineering Review Report FINAL PE Sealed

CEF Pathways Annex 5 - Electricity Invoices Hydro-Quebec - Sept 2014 to Nov 2014

CEF Pathways Annex 6 - Propane Invoices - Sept 2014 to Nov 2014

CEF Pathways Annex 7 - Gas Sales - Sept 2014 to Nov 2014

CEF Pathways Annex 8 - Boron LNG Electricity Consumption Data

CEF Pathways Annex 9 - Modified GREET model_LFG to LNG and LCNG