Life-Cycle Assessment of Kansas City Landfill Gas to Delivered CNG in California

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BP Natural Gas and Power

Prepared by

ICF International
75 E. Santa Clara St., Suite 300
San Jose, CA 95113

POC: Jeffrey Rosenfeld; Jeffrey.rosenfeld@icfi.com

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General Information

(This Section contains Confidential Business Information)

EIF KC Landfill Gas LLC operates a landfill gas (LFG) refinery at Johnson County Landfill in Shawnee, Kansas. The refinery recovers methane from the landfill operated by Deffenbaugh Industries, Inc.

The refinery removes sulfur compounds, moisture, carbon dioxide, and hydrocarbons to produce a methane rich gas stream that meets pipeline specifications. KC purchases electricity from Westar Energy to serve the plant's electrical demand. The facility also uses LFG to provide startup fuel for the flare and thermal oxidizer (called the "incinerator" in the RIN application). The gas produced is delivered into the KS Pipeline which is connected to the interstate pipeline system and downstream delivery points. [redacted]. The propane used to increase btu/scf is not included in the following technical report because the Green Gas (gas from LFG) is separated on the gas sales invoices from Brown Gas which includes natural gas and propane. The following technical report only takes into account the Green Gas.

The stated capacity of the KC refinery is [redacted] MMBtu per day. The permit places on restrictions on the maximum quantity or rate of gas that can be treated at the refinery. The peak capacity of plant is determined based on production from January – December 2013. The net production during the period is equivalent to [redacted] renewable gallons. The actual peak capacity is 105% of the maximum annual at [redacted] renewable gallons. Conversions were made using an LHV and HHV Btu content of methane of 909.4 Btu (LHV)/SCF and 1010 Btu (HHV)/SCF[1]. (See Attachment F of the EPA RIN Application, *EIF KC Landfill Gas - EPA Eng Report Sealed 20140116.pdf*).

EIF KC Landfill Gas LLC has contracted to sell up to [redacted] MMBtu/day of production from the facility to BP Energy and BP has contracted with Clean Energy for up to [redacted] MMBtu/day. The following pathway was produced using two (2) years (January 2012 – December 2013) of landfill gas production data and two (2) years (2011 – 2012) of compression data.

Process Description

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The LFG is collected from wells at the landfill under vacuum and fed into a series of units listed below to remove the identified compounds:

- [redacted]

[1] Methane Lower Heat Value = 909.4 Btu/scf (Source: ASTM D3588 "Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels")

The product gas is sampled every 5 minutes to determine composition and heating value. Propane is added to the product gas in the event the heat value is not high enough. Propane used for this purpose is excluded from the following technical report because the Green Gas (gas from LFG) is separated on the gas sales invoices from Brown Gas which includes natural gas and propane. The following technical report only takes into account the Green Gas. The flare can also be used to burn gas not meeting the specifications or in the event the pipeline cannot accept gas.

There are no fired process heaters in the refinery. LFG is used to increase heat content of gas for the incinerator. There is no generation of electricity onsite.

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), and Compression.

LFG Production Plant

(This Section contains Confidential Business Information)

The plant has a stated capacity of [redacted] MMBtu per day. The permit places restrictions on the maximum quantity or rate of gas that can be treated at the refinery. The peak capacity of plant is determined based on production from January – December 2013. The net production during the period is equivalent to [redacted] renewable gallons. The actual peak capacity is 105% of the maximum annual at [redacted] renewable gallons. KC imports the necessary electricity to purify the landfill gas and uses an onsite thermal oxidizer and open flares to combust off-gases generated during the regeneration steps and when the plant is not operating. KC does not have process heaters. The refinery uses propane to add heating value to product gas when necessary. The refinery uses LFG to power the thermal oxidizer (incinerator) and flare pilot.

The table below shows the available data provided by KC for input biogas, product biogas, consumed biogas (including waste gas and LFG as a pilot in the incinerator and flare), and imported electricity from January 2012 to December 2013. The balance of the biogas is consumed in the thermal oxidizer and flare. The table also shows the provided data converted to GREET model inputs. The KC pathway utilizes the CA-GREET default values for LFG recovery. After the table is a simplified process diagram of the facility. The value of [redacted] in Table 1 below is the amount of product pipeline quality biogas produced. All supporting data and calculations for Table 1 and Figure 1 below can be found in [redacted] *.xls* spreadsheet on the

"Summary" tab. 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. KC LFG Plant Operating Energy and Flare Credit

(This Table contains Confidential Business Information)

	2012-2013 Data	Btu/MMBtu of Product Gas	Input Value	Changed Cells – NG Tab
LFG Produced	[redacted]	1,000,000		
Imported Electricity	[redacted]	[redacted]	[redacted]	[redacted]
LFG Consumed (TOX)	[redacted]	[redacted]	[redacted]	
LFG as Pilot Gas for Flare/TOX	[redacted]	[redacted]	[redacted]	
Total LFG Used	[redacted]	[redacted]	[redacted]	[redacted]
Processing Efficiency	-	[redacted]	[redacted]	[redacted]
Flare Credit	-	[redacted]	[redacted]	

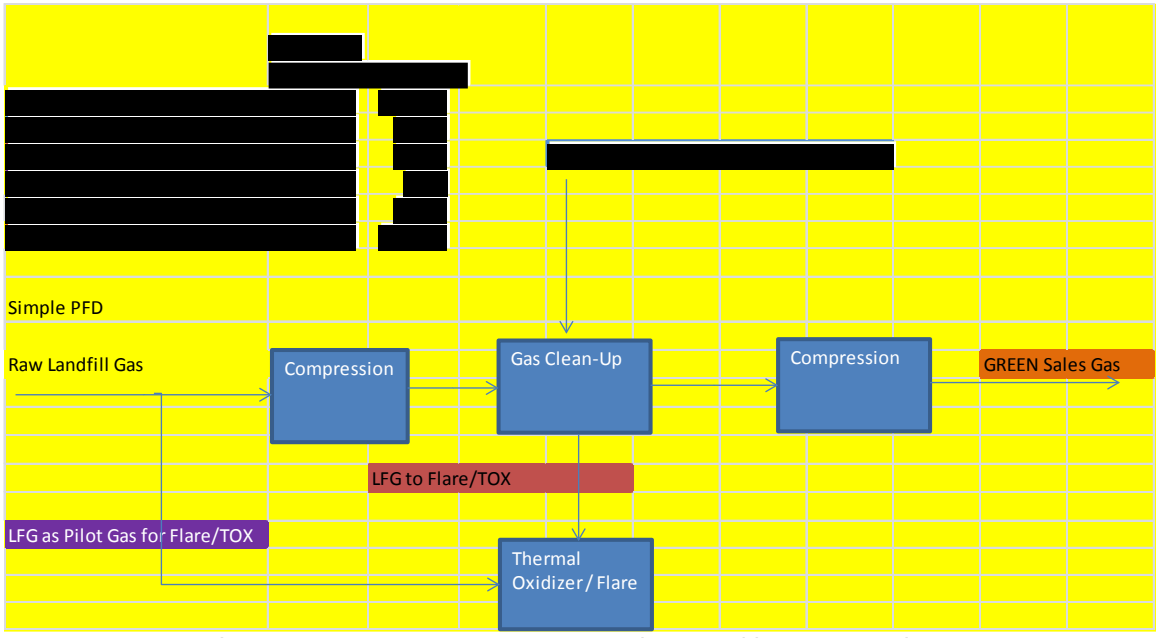

Figure 1. KC Process per MMBtu and MMBtu/day Energy Flows

The GREET model LFG pathway was then modified to adjust efficiency gas and process energy shares as listed in Table 1. The Southeast Asia region on the Regional LT tab was changed to the SPNO Region to represent the eGRID (8th Edition[2]) where Shawnee is located and this was used for KC. The ARB methodology of converting eGRID electricity mix to marginal mix was employed. This changed the electric mix cells of J83-J88 on the Regional LT tab to those shown in Table 2. The remaining values from the Southeast Asia Region (now the SPNO Region) were changed to match the US Average.

Table 2. SPNO Electricity Grid Mix

	eGRID Grid Mix	Marginal Grid Mix	CA-GREET Cell Regional LT Tab
Residual oil	1.3%	0.3%	J83
Natural gas	7.81%	21.4%	J84
Coal	73.8%	73.8%	J85
Nuclear	13.5%	0%	J86
Biomass	0.03%	0%	J87
Other (renewables)	4.5% (w/ hydro)	4.4% (w/o hydro)	J88

This produced the results for LFG to biomethane shown in the table below taken from cells on the NG Tab. Conversion from g/MMBtu to g/MJ was done using the conversion factor of 1,055.055 MJ/MMBTU as is done in the CA-GREET model.

The recovery energy and emissions are based on ARB LFG pathway defaults of [redacted] Btu of electricity/MMBtu of landfill gas.[3]

Table 3. KC LFG Plant Greenhouse Gas Emissions

(This Table contains Confidential Business Information)

	Recovery Emissions	KC LFG Processing	CA-GREET Cell NG Tab
gVOC/MMBTU	[redacted]	[redacted]	B151/C151
gCO/MMBTU	[redacted]	[redacted]	B152/C152
gCH4/MMBTU	[redacted]	[redacted]	B153/C153
gN2O/MMBTU	[redacted]	[redacted]	B154/C154
gCO2/MMBTU	[redacted]	[redacted]	B155/C155
gCO2e/MMBTU	[redacted]	[redacted]	B156/C156
gCO2e/MJ	[redacted]	[redacted]	B157/C157
gCO2e/MJ Flare Credit		[redacted]	D157
Total gCO2e/MJ Recovery + Processing		[redacted]	E157

[2] eGrid 8th Edition Version 1.0, Year 2009 Summary Tables, created May 2012. www.epa.gov/cleanenergy/documents/egridzips/eGRID_8th_edition_V1-0_year_2009_Summary_Tables.pdf

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

Transportation to California by Pipeline

Clean Energy owns, operates or supplies natural gas and biomethane to [redacted] hown in the submitted documentation (*Clean Energy – CNG Station Electrical Efficiency Data - KC.xls),* [redacted] A single representative transport distance (and carbon intensity) was chosen for all of Clean Energy's stations to allow for fungibility of KC's biomethane between the CNG stations and require the approval of only one pathway instead of [redacted] individual pathways. A weighted average pipeline distance was determined of 1,682 mi [redacted] The distances were determined by the using the driving route most similar to the pipeline map. Google Maps was used to determine the driving routes with the I-40W route most similar to the pipeline map to Los Angeles and I-40W to I-5N the most similar to the pipeline map to San Francisco. The emissions were determined by linked cell E148 on the NG tab to cell F479 on the T&D_Flowcharts tab for LFG to CNG. The table below shows the pipeline transport emissions from cells F151-F157 on the NG Tab.

Table 4. KC LFG Transport Greenhouse Gas Emissions

(This Table contains Confidential Business Information)

Transport Emissions	KC LFG Transport
gVOC/MMBTU	[redacted]
gCO/MMBTU	[redacted]
gCH4/MMBTU	[redacted]
gN2O/MMBTU	[redacted]
gCO2/MMBTU	[redacted]
gCO2e/MMBTU	[redacted]
gCO2e/MJ	[redacted]

Compression

(This Section contains Confidential Business Information)

Based on the submitted Confidential Business Information from Clean Energy Fuels, Clean Energy will be submitting for one pathway for their CNG Stations based on two (2) years of data (2011-2012) found in *Clean Energy – CNG Station Electrical Efficiency Data - KC.xls*. The weighted average energy consumption [redacted] and has been previously approved in Pathway CNG009_1. The tables below show the calculation from kWh/GGE to process efficiency and the cells that were changed and the results from cells G151- G157.

Table 5. CNG Station Plant Operating Efficiency

(This Table contains Confidential Business Information)

All Units in Btus per GGE	Compression	Input Value	Changed Cells – NG Tab
CNG Produced			
Compression Electricity			AA79
Compression Natural Gas			AA75
Compression Efficiency			AA66

Table 6. CNG Compression Greenhouse Gas Emissions

(This Table contains Confidential Business Information)

Recovery and Processing Emissions	Compression
gVOC/MMBTU	
gCO/MMBTU	
gCH4/MMBTU	
gN2O/MMBTU	
gCO2/MMBTU	
gCO2e/MMBTU	
gCO2e/MJ	

KC 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 J158 which is the sum of cells E158 – I158 on the "NG" tab for CNG. The TTW gCO2e/MJ was taken from the Detailed California-Modified GREET Pathway for Compressed Natural Gas (CNG) from Landfill Gas[5].

[4] 109,772 Btu/GGE default CA-GREET value

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

Table 7 - Pathway Results

GHG Emissions (gCO2e/MJ)	KC LFG Plant to CNG
Landfill Gas Recovery	[redacted]
Landfill Gas Processing	[redacted]
Flare Credit	[redacted]
Landfill Gas Transport	[redacted]
Compression	[redacted]
gCO2e/MJ WTT	[redacted]
Carbon in Fuel	[redacted]
Vehicle CH4 and N2O	[redacted]
gCO2e/MJ TTW	[redacted]
gCO2e/MJ WTW	26.38

Appendix A: Summary of CA-GREET Inputs

Parameter	Unit	Value	CA-GREET Cell Changed
LFG Recovery and Transport			
Thermal	Btu/MMBtu	[redacted]	CA-GREET Default (L85)
Electricity	Btu/MMBtu	[redacted]	CA-GREET Default[6] (L91)
Total Energy	Btu/MMBtu	[redacted]	N/A
LFG Plant			NG Tab
LFG Processing Efficiency	%	[redacted]	AI66 (via C182)
Electricity Fuel Share	%	[redacted]	AI79 (via C184)
LFG Fuel Share	%	[redacted]	AI75 (via C183)
Electricity	kWh/MMBtu	[redacted]	N/A
Electricity	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AI91)
LFG	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AI87)
Credit for Not Flaring	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AJ88)
Total Energy	Btu/MMBtu	[redacted]	N/A
Electricity Grid Mix			Regional LT Tab
Residual oil	%	0.3	J83
Natural gas	%	21.4	J84
Coal	%	73.8	J85
Nuclear	%	0.0	J86
Biomass	%	0.0	J87
Other (renewables)	%	4.4	J88
Natural Gas Transport			T&D Flowcharts Tab (via NG Tab)
Pipeline Distance	mi	[redacted]	F479 (via E148)
Compression			NG Tab
Electricity	kWh/GGE	[redacted]	N/A
Compression Efficiency	%	[redacted]	AA66
Electricity Fuel Share	%	[redacted]	AA79
Natural Gas Fuel Share	%	[redacted]	AA75
Electricity	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AA91)

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