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

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Submitted to:

Clean Energy Renewable Fuels, LLC

Prepared by

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General Information

(This Section contains Confidential Business Information)

Westside Gas Producers, LLC, operates a landfill gas (LFG) refinery located in Three Rivers, MI. The refinery recovers methane from approximately [redacted] at a Waste Management landfill. The refinery has been operating since May 2001.

The refinery uses the Kryosol process to remove the impurities in the landfill gas and produces commercially saleable natural gas. Westside purchases natural gas from Semco Energy Gas Company to provide startup fuel for the compressor and thermal oxidizer. Westside purchases electricity from Midwest Energy Cooperative to serve the plant's electrical demand.

The inlet capacity for the refinery is [redacted]. There is no stated limitation for production in the refinery permit; thus, peak capacity was based on the production history, [redacted]. During that period, the refinery produced [redacted] (LHV) of purified gas, or [redacted] equivalent renewable fuel gallons. The EPA Actual Peak Capacity (105% of maximum annual production) is [redacted] equivalent renewable fuel gallons.

Based on EPA guidance received, the "contracted volume" of the biogas facility was calculated using the most restrictive contract for sale of biogas for use as transportation fuel. This volume will be used in lieu of the EPA Permitted capacity for purposes of CDX registration. The annual contracted volume was calculated to be [redacted] equivalent gallons renewable fuel which is greater than the EPA Permitted.

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 process train for the production of pipeline quality natural gas from this project includes a gas collection system under a vacuum to collect landfill gas. The landfill gas is transferred to the refinery via pipe and blowers. The biogas is then purified using the Kryosol process:

The landfill gas with [redacted] methane content is processed to approximately [redacted] methane purity, the balance being the inerts of N2 and CO2. Gas not meeting specifications for pipeline natural gas or unable to be accepted by the pipeline may be combusted by flare.

CO2 and other flash gas streams from the purification process are disposed of in a thermal oxidizer while liquid waste is returned to the landfill. Heavy hydrocarbons collected in the process are disposed of as RCRA hazardous waste.

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

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The plant has a stated capacity of [redacted] at [redacted] methane. The peak capacity is [redacted] gallons renewable fuel gallon equivalents of purified biogas production per year. Westside 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. Westside does not have process heaters. [redacted] While the plant is operating, this natural gas is purified gas from the refinery production; when starting up operations, natural gas is purchased from Semco Energy Gas.

The table below shows the available data provided by Westside for input biogas, product biogas, consumed biogas, and imported electricity from January 2012 to December 2013. The balance of the biogas consumed in the thermal oxidizer and flare is calculated. The table also shows the provided data converted to GREET model inputs. The Westside 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]. 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. Westside LFG Plant Operating Energy and Flare Credit

(This Table contains Confidential Business Information)

	January 2012 – December 2013 Data	Btu/MMBtu of Product Gas	Input Value	Changed Cells – NG Tab
LFG Produced	[redacted]	[redacted]		
Imported Electricity	[redacted]	[redacted]	[redacted]	AI79 (via C184)
LFG Consumed (Energy + Flare)	[redacted]	[redacted]	[redacted]	AI75 (via C183)
Imported Natural Gas	[redacted]	[redacted]	[redacted]	AI76 (via C185)
Processing Efficiency	-	[redacted]	[redacted]	AI66 (via C182)
Flare Credit	-	[redacted]	Calculated w/in GREET	

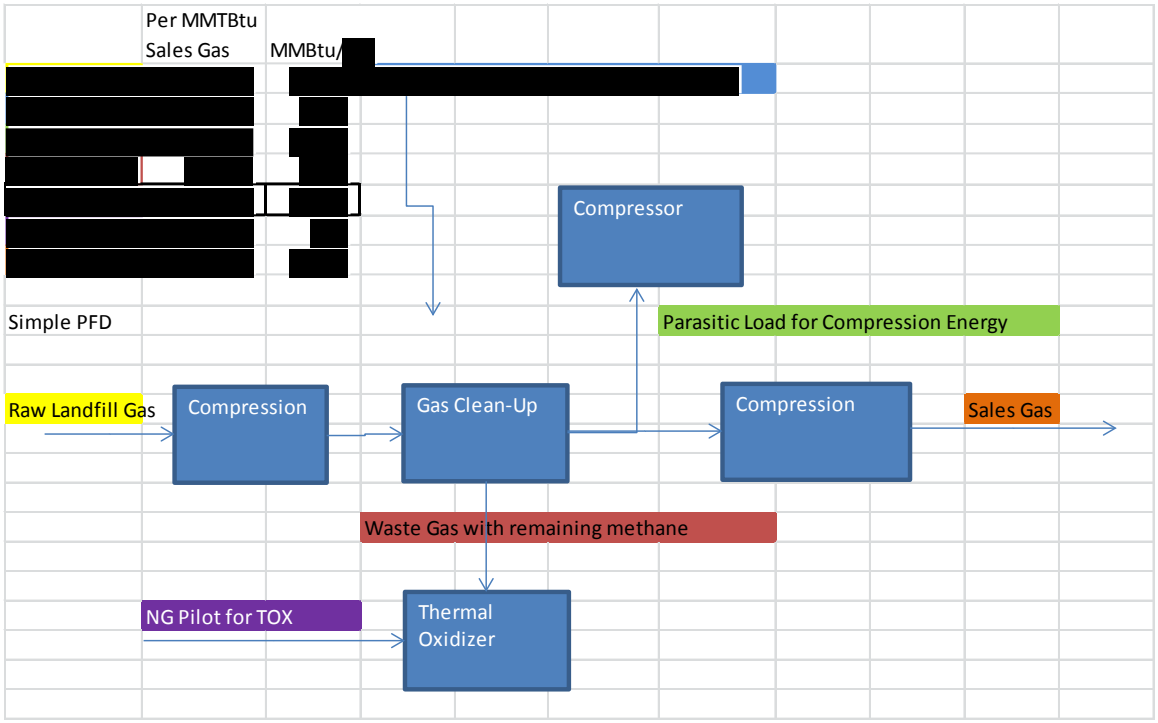

Figure 1. Westside Process per MMBtu and MMBtu/day Energy Flows

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 RFCM Region to represent the eGRID (8th Edition[1]) where Three Rivers is located and this was used for Westside. 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 RFCM Region) were changed to match the US Average.

Table 2. RFCM Electricity Grid Mix

	eGRID Grid Mix	Marginal Grid Mix	CA-GREET Cell Regional LT Tab
Residual oil	1.0%	1.0%	J83
Natural gas	9.5%	24.8%	J84
Coal	72.0%	72.0%	J85
Nuclear	15.3%	0%	J86
Biomass	1.9%	1.9%	J87
Other (renewables)	0.3% (w/ hydro)	0.3% (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 4,621.25 Btu of electricity/MMBtu of landfill gas for recovery and 17.32 Btu electricity/MMBtu for transport.[2]

Table 3. Westside LFG Plant Greenhouse Gas Emissions

(This Table contains Confidential Business Information)

	Recovery Emissions	Westside 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

[1] 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

[2] 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] stations in California and plans to send this gas to upwards of [redacted] stations in California. Shown in the submitted documentation [redacted] stations [redacted] are located in Southern California and Southern California stations consume [redacted] of the gas from 2011-2012. A single representative transport distance (and carbon intensity) was chosen for all of Clean Energy's stations to allow for fungibility of Westside'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 2,242 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. Westside LFG Transport Greenhouse Gas Emissions

(This Table contains Confidential Business Information)

Transport Emissions	Westside 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 [redacted] The weighted average energy consumption is [redacted] kWh/GGE and has been previously approved in Pathway [redacted]. 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	[redacted]		
Compression Electricity	[redacted]	[redacted]	AA79
Compression Natural Gas	[redacted]	[redacted]	AA75
Compression Efficiency	[redacted]	[redacted]	AA66

Table 6. CNG Compression Greenhouse Gas Emissions

(This Table contains Confidential Business Information)

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

Westside 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[4].

[3] 109,772 Btu/GGE default CA-GREET value

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

Table 7 - Pathway Results

GHG Emissions (gCO2e/MJ)	Westside 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	25.62

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[5] (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)
Natural Gas Fuel Share	%	[redacted]	AI76 (via C185)
Electricity	kWh/MMBtu	[redacted]	N/A
Electricity	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AI91)
Natural Gas	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AI85)
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	%	1.0	J83
Natural gas	%	24.8	J84
Coal	%	72.0	J85
Nuclear	%	0	J86
Biomass	%	1.9	J87
Other (renewables)	%	0.3	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)

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