Life-Cycle Assessment of McCarty Landfill Gas to CNG in California – San Diego Metropolitan Transit System

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Submitted to:

BP Natural Gas and Power

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General Information

GSF Energy, LLC owns the McCarty Road LFG Recovery Facility, a gas collection and processing facility located at the McCarty Road Landfill in the city of Houston, Texas. The facility produces high BTU gas for sale to Centerpointe Energy, Inc.

The McCarty Facility uses solvent absorption technology for the removal of moisture, contaminants, and CO2 from the raw landfill gas. Compression, scrubber and radiator engines are operated on the high BTU gas produced in the McCarty Facility. Prior to December 2012, the McCarty Facility purchased electricity from Direct Energy Services to serve the plant's electrical demand. The facility then switched to Champion Energy Services starting on December 21st 2012 and continues to be serviced by this electricity provider.

The McCarty renewable fuel facility permits, which are required to be submitted to EPA, consist of the most recent applicable air permits issued by EPA or by the state pollution control agency (the Texas Commission on Environmental Quality). These air permits include Permit [redacted], issued by the Texas Commission on Environmental Quality (April 27, 2010); and a Minor Revision, permit number [redacted], dated February 28, 2012. These permits do contain limitations on air contaminant emissions rates for the facility, but do not specify a maximum volume output of renewable fuel for the facility.

The McCarty Facility has submitted documents to EPA that demonstrate the facility's actual peak capacity. These documents include a spreadsheet showing the production of high BTU gas at the facility on a daily basis for the five year period from January 1, 2007 through December 31, 2011. The resulting actual peak capacity for the McCarty Facility is [redacted] gallons of renewable fuel per year.

Pipeline grade LFG is transported via pipeline from Texas to San Diego, CA for compression and use as CNG. The following pathway was produced using two years (April 2012 – March 2014)[1] of landfill gas production data and two (2) years (July 2011 – June 2013)[2] of compression data.

Process Description

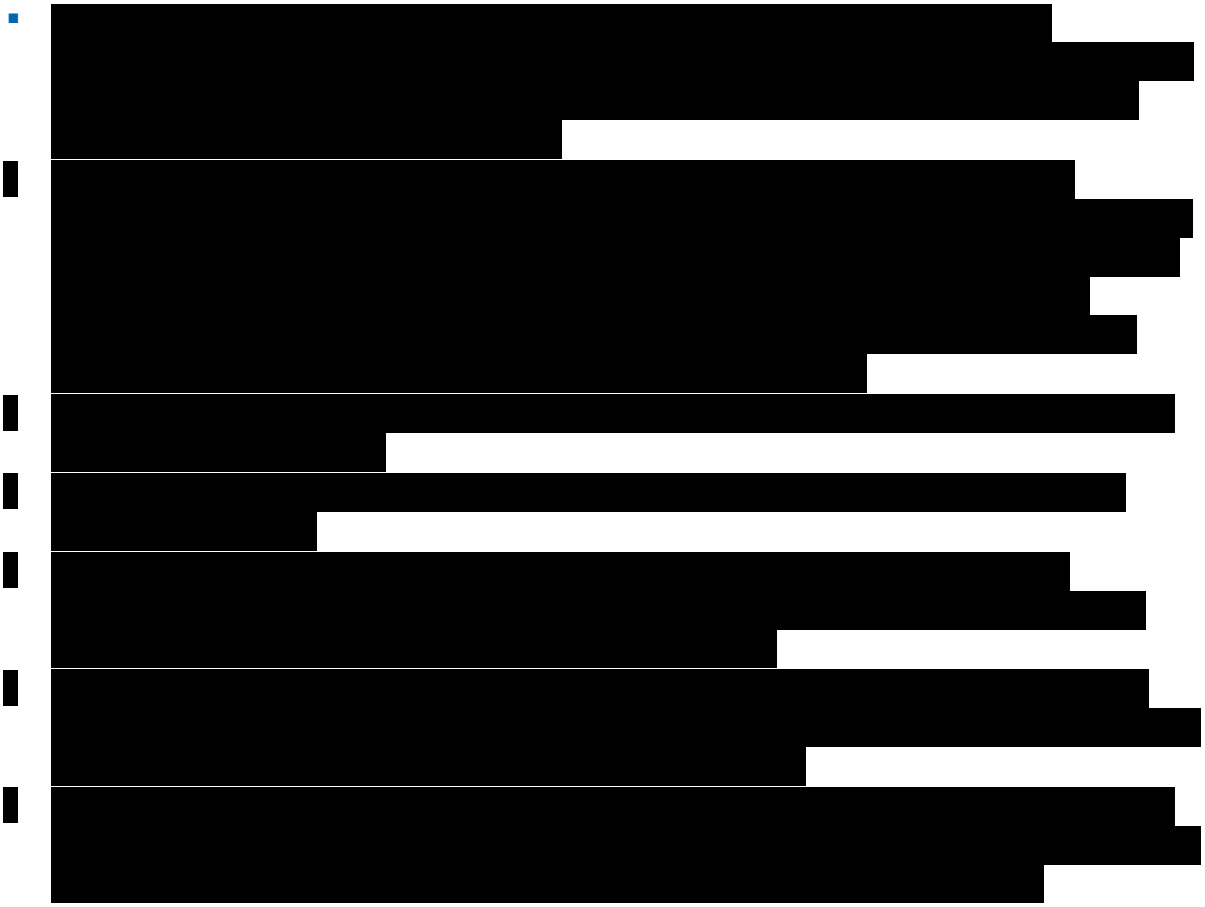
(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

[redacted]

[1] Please see Annex 5 and Annex 6 for MCCARTY electric and gas bills, and Annex 7 for the facility's gas sales; these invoices are summarized in Annex 2

[2] Please see Annex 4 for CNG data from SD Metro.

[3] Please see Annex 3 HR Green Engineering Report for additional details



A landfill gas with a [redacted] molar methane content is processed to on average [redacted] methane purity, the balance being the inerts of N2 and CO2. Approximately [redacted] of the methane is recovered in the gas to be sold. The balance is consumed in the thermal oxidizer.

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 San Diego, CA (Pipeline), and Compression.

LFG Production Plant

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

Two years (April 2012- March 2014) of plant modeling data show an average landfill gas inlet of [redacted] mmscf/day[4] at [redacted] methane and product gas of [redacted] MMBtu/day[5] of biogas at an average [redacted] methane. The McCarty facility imports the necessary electricity to purify the landfill gas and imports natural gas as a pilot for the onsite thermal oxidizer and open flares to

[4] Please see Annex 2, Summary tab, cell C23 for the calculation of this figure
[5] Please see Annex 2, Summary tab, cell L6 for the calculation of this figure
[6] Please see Annex 2, Summary tab, cell D31 for the calculation of this figure

combust off-gases generated during the regeneration steps and when plant is not operating. Natural gas is also imported to fuel compressors.

Table 1 below shows the available data provided by McCarty for input biogas, product biogas, biogas consumed on-site and imported electricity from April 2012 to March 2014. The balance of the biogas consumed in the thermal oxidizer and flare is calculated based on monthly production data provided by McCarty (*Annex 2*) and an assumption of [redacted] methane content of input biogas. The table also shows the provided data converted to GREET model inputs. The McCarty pathway utilizes the CA-GREET default values for LFG recovery. The value of [redacted] MMBtu/day in Table 1 below is the average amount of product pipeline quality biogas produced per day. 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. MCCARTY LFG PLANT OPERATING ENERGY AND FLARE CREDIT[7]
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

	April 2012 – March 2014 Daily 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]	[redacted]	[redacted]	Calculated w/in GREET[9]	

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

[7] Please see Annex 2, Summary tab for the calculations of the figures presented in this table
[8] Please see Annex 7 for PDFs of gas sales invoices
[9] Please see Annex 1 for the Modified GREET model referred to in this report

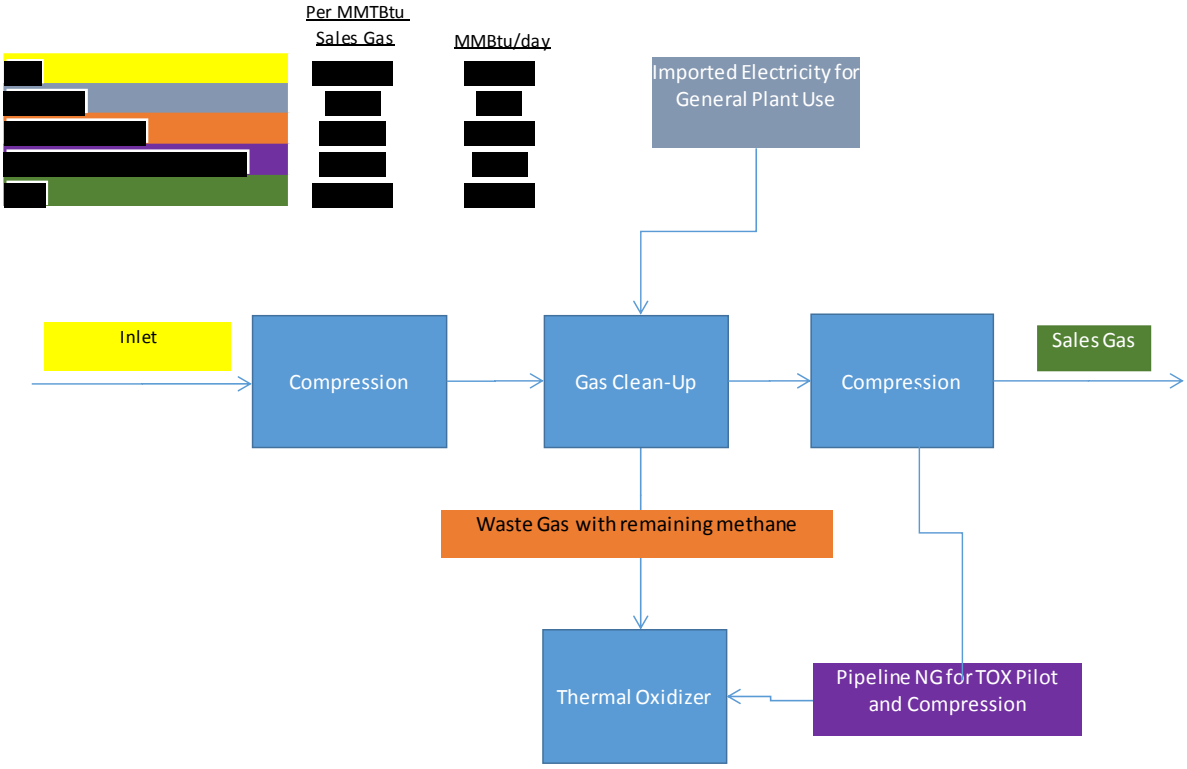


Figure 1. McCarty Process per MMBtu and MMBtu/day Energy Flows

The GREET model LFG pathway was then modified to adjust efficiency gas and process energy shares as listed in Table 2. The Southeast Asia region on the Regional LT tab was changed to the ERCOT All (ERCT) Region to represent the 2012 eGRID data for year 2009 (8th Edition[10]) where Houston, TX is located . The ARB methodology of converting eGRID electricity mix to marginal mix was employed. This changed the electric mix cells of J83-J88 on the Region LT tab to those shown in Table 2. The remaining values from the Southeast Asia Region (now the ERCT region) were changed to match the US Average.

TABLE 2. ERCT ELECTRICITY GRID MIX

	eGRID CY2009 Grid Mix	Marginal Grid Mix	CA-GREET Cell Regional LT Tab
Residual oil	1.2%	1.2%	J83
Natural gas	47.8%	60.4%	J84
Coal	33.0%	33.0%	J85
Nuclear	12.3%	0.00%	J86
Biomass	0.1%	0.1%	J87
Other (renewables)	5.5% (w/ hydro)	5.3% (w/o hydro)	J88

[10] 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

This produced the results for LFG to LNG shown in Table 3 below. These values are taken from the NG Tab of the Modifed 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.[11] The default LFG transport distance of one mile was used since the distance between McCarty Road LFG Facility and the McCarty Road Landfill is less than 1 mile, as can be seen in Figure 2 below.

Figure 2. Proximity between McCarty Road LFG Facility (identified location) and the McCarty Road Landfill

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

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

	Recovery Emissions	MCCARTY LFG Plant	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/C1587
gCO2e/MJ Flare Credit		[redacted]	D157
Total gCO2e/MJ Recovery + Processing		[redacted]	E157

Transportation to California by Pipeline

The pipeline transport distance was modified to 1,468 miles from Houston, TX to San Diego, CA where the gas will be compressed. The distance was 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-10 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 for LFG to CNG, and this same distance will be used for LFG and LNG. The table below shows the pipeline transport emissions from cells F151-F157 on the NG Tab.

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

Transport Emissions	McCarty 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 SD Metro, SD Metro will be submitting for one pathway for their CNG Stations based on two (2) years of data (July 2011-June 2013). The weighted average energy consumption is [redacted] kWh/GGE[12]. Table 5 and

[12] Please see Annex 4 for the CNG station Electrical Efficiency Data

Table 6 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]

[13] 109,772 Btu/GGE default CA-GREET value

MCCARTY 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 H158 which is the sum of cells E158 – G185 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[14].

TABLE 7. PATHWAY RESULTS

GHG Emissions (gCO2e/MJ)	MCCARTY LFG Plant to CNG – SD Metro
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	19.82

[14] 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			
Thermal	Btu/MMBtu	[redacted]	CA-GREET Default (L85)
Electricity	Btu/MMBtu	[redacted]	CA-GREET Default[15] (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 C186)
Electricity	kWh/MMBtu	[redacted]	N/A
Electricity	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AI91)
LFG	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AI87)
Natural Gas	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AI85)
Credit for Not Flaring	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AJ88)
Total Energy	Btu/MMBtu	[redacted]	N/A
ERCT Electricity Grid Mix			Regional LT Tab
Residual oil	%	1.2	J83
Natural gas	%	60.4	J84
Coal	%	33.0	J85
Nuclear	%	0.0	J86
Biomass	%	0.1	J87
Other (renewables)	%	5.3	J88
Natural Gas Transport			T&D Flowcharts Tab (via NG Tab)
Pipeline Distance	mi	1,468	F479 (via E148)
Compression			NG Tab
Electricity	kWh/gal LNG	[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)
Natural Gas	Btu/MMBtu	[redacted]	Calculated in CA-GREET (AA85)

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

Appendix B: List of Supporting Annexes

Annex 1 - Modified GREET model LFG to CNG

Annex 2 - Facility Energy Data & Analysis_070214

Annex 3 – HR Green Eng Report

Annex 4 – SD Metro Calculation Summary File

Annex 5 - McCarty Electric Utility Invoices Apr 2012 - Mar 2014

Annex 6 - McCarty Gas Utility Invoices Apr 2012 - Mar 2014

Annex 7 - McCarty Gas Sales Invoices Apr 2012 - Mar 2014

Annex 8 – SD Metro Invoices