



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

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Submitted to:

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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 9635, issued by the Texas Commission on Environmental Quality (April 27, 2010); and a Minor Revision, permit number O1512, 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 Topock, AZ for liquefaction and sale in California. The following pathway was produced using two years (April 2012 – March 2014)¹ of landfill gas production data and two (2) years (2011-2012)² of liquefaction data.

Process Description

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

The process train for the production of pipeline quality natural gas from this project includes a gas collection system that consists of a series of wells and header pipes on the landfill adjacent to the renewable fuel facility. A blower applies vacuum to this system and draws the landfill gas toward the renewable fuel facility. The biogas is then purified and compressed using the following processes³:

- [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 8 for LNG and LCNG data used to develop ARB approved LNG011 CNG015 pathways

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



A landfill gas with a █% molar methane content is processed to on average █% methane purity, the balance being the inerts of N2 and CO2. Approximately █% 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 Arizona (Pipeline), Liquefaction, and Transportation & Distribution within California.

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 █ mmscf/day⁴ at █% methane and product gas of █ MMBtu/day⁵ of biogas at an average █%⁶ 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 █% 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 2,785 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 CREDIT⁷
 (THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

	April 2012 – March 2014 Daily Data	Btu/MMBtu of Product Gas	Input Value	Changed Cells – NG Tab
Product Biogas	█ MMBtu/day	1,000,000		
Imported Electricity	█ kWh	= █ █ Btu	= █ █	AI79 (via C184)
TOX	█ MMBtu /day	= █ █ Btu	= █ █	AI75 (via C183)
Natural Gas	█ MMBtu/day	= █ █ Btu	= █ █	AI76 (via C186)
Processing Efficiency	-	█ █	█	AI66 (via C182)
Flare Credit	-	█ Btu	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 9 for the Modified GREET model referred to in this report

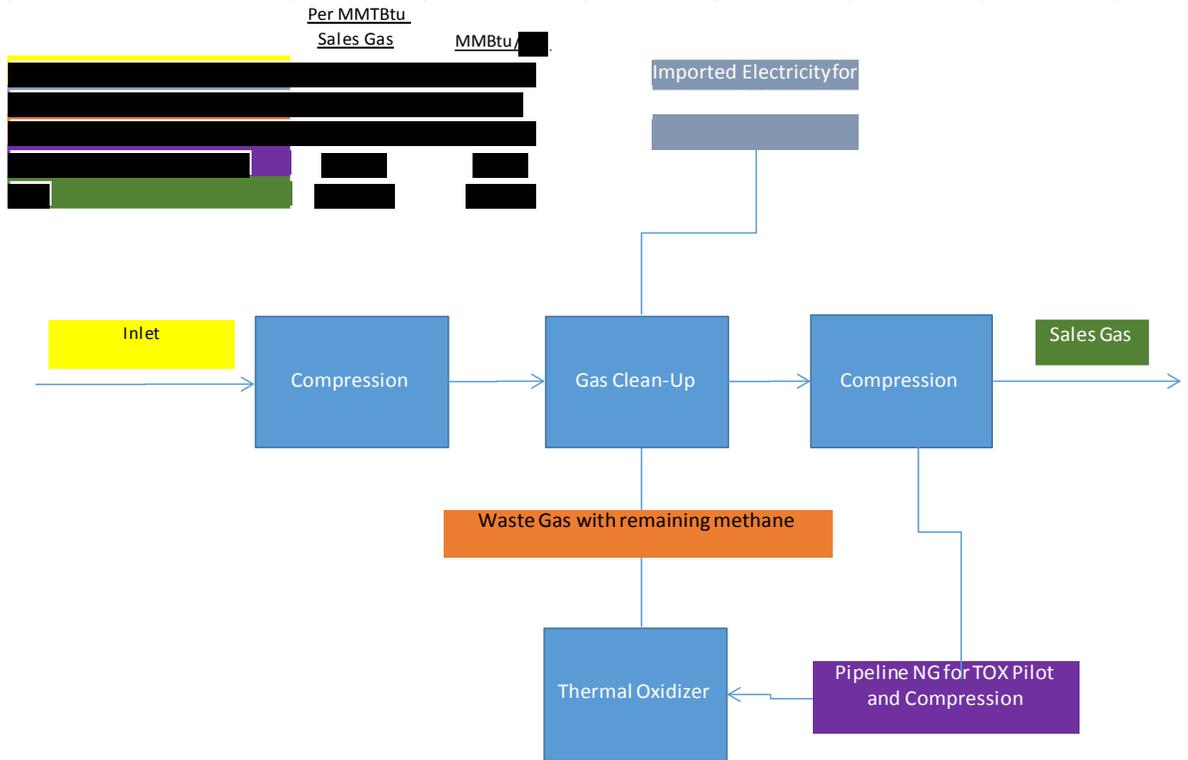


Figure 1. McCarty Process per MMBtu and MMBtu/day Energy Flows

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 Edition¹⁰) 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 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.¹¹

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	████	████	B163/C163
gCO/MMBTU	████	████	B164/C164
gCH4/MMBTU	████	████	B165/C165
gN2O/MMBTU	████	████	B166/C166
gCO2/MMBTU	████	████	B167/C167
gCO2e/MMBTU	████	████	B168/C168
gCO2e/MJ	████	████	B169/C169
gCO2e/MJ Flare Credit		████	D169
Total gCO2e/MJ Recovery + Processing		████	E169

Transportation to Arizona by Pipeline

The pipeline transport distance was modified to 1,365 miles from Houston, TX to Topock, AZ where the gas will be liquefied. 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-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 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	████
gCO/MMBTU	████
gCH4/MMBTU	████
gN2O/MMBTU	████
gCO2/MMBTU	████
gCO2e/MMBTU	████
gCO2e/MJ	████

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

Liquefaction

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

Based on the submitted Confidential Business Information from Applied Natural Gas for two (2) years (2011-2012), the Topock facility requires [REDACTED] kWh electricity and [REDACTED] Btu natural gas per gallon of LNG for liquefaction [REDACTED] kWh/gal LNG; [REDACTED] Btu/gal LNG)¹². For the Topock LNG facility, a portion of the feed gas is used as process fuel and the remaining is product LNG gas. 80,968 Btu is the energy content of one gallon of LNG.

Table 5 shows the calculation from kWh/GGE to process efficiency and the cells that were changed.

TABLE 5. TOPOCK LNG PLANT OPERATING EFFICIENCY¹³

(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

All Units in Btus per Gal of LNG	Topock LNG Plant	Input Value	Changed Cells – NG Tab
Feed Gas	[REDACTED]		
Liquefaction Electricity	[REDACTED] tu	[REDACTED]	AD79 (via C178)
Liquefaction Natural Gas	[REDACTED] Btu	[REDACTED] %	AD75 (via C177)
Liquefaction Efficiency	[REDACTED] %	[REDACTED] %	AD66 (via C175)

For the liquefaction phase, the Southeast Asia region on the Regional LT tab was changed to the WECC Southwest (AZNM) Region to represent the 2012 eGRID data for year 2009 (8th Edition¹⁴) where Topock, AZ 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 6. The remaining values from the Southeast Asia Region (now the AZNM region) were changed to match the US Average. The greet model was modified to include a drop down menu in cell H174 of the NG tab to go between the AZNM and ERCT subregions.

¹² Please see Annex 8

¹³ Please see Annex 8

¹⁴ 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

TABLE 6. AZNM 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

Table 7 below show the results from cells G163- G169.

TABLE 7. TOPOCK LNG PLANT GREENHOUSE GAS EMISSIONS

(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

Recovery & Processing Emissions	Topock LNG Plant - Liquefaction
gVOC/MMBTU	
gCO/MMBTU	
gCH4/MMBTU	
gN2O/MMBTU	
gCO2/MMBTU	
gCO2e/MMBTU	
gCO2e/MJ	

LNG Transport to Refueling Station

Based on the data provided in Annex 8 and Annex 9, trucks from Applied Natural Gas vehicles travel an average of [REDACTED] miles round-trip (Annex 8, L-CNG tab, cell D28) and have an aggregate fuel consumption is [REDACTED] % diesel and [REDACTED] % LNG (Annex 9, Metrics tab, cells T45-T46). The distance of [REDACTED] miles (the one-way distance, [REDACTED] was inputted in cell CD93 and fuel consumption numbers were inputted in cells CD95 (% diesel consumption) and CD97 (% LNG consumption) on the “T&D” tab. The results were taken from cells H163-H169 on the “NG” tab.

TABLE 8. LNG TRANSPORT GREENHOUSE GAS EMISSIONS

(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

Recovery & Processing Emissions	Topock LNG Plant – Transport
gVOC/MMBTU	
gCO/MMBTU	
gCH4/MMBTU	
gN2O/MMBTU	
gCO2/MMBTU	
gCO2e/MMBTU	
gCO2e/MJ	

LNG Storage

In addition the CA-GREET default for LNG storage was used. The default values are listed in Table 9 below (the results were taken from cells I163-I169 on the “NG” tab).

TABLE 9. LNG STORAGE CA-GREET DEFAULT VALUES

	Bulk Terminal Storage	CA-GREET Cells Inputs Tab	Distribution	CA-GREET Cells Inputs Tab
Boil-Off Rate: % per Day	█	E171	█	F171
Duration of Storage or Transit: Days	█	E174	█	F174
Recovery Rate for Boil-Off Gas	█	E179	█	F179

TABLE 10. LNG STORAGE GREENHOUSE GAS EMISSIONS

	LNG Storage
gVOC/MMBTU	
gCO/MMBTU	
gCH4/MMBTU	11.10
gN2O/MMBTU	
gCO2/MMBTU	
gCO2e/MMBTU	277.47
gCO2e/MJ	0.26

L/CNG Conversion

To convert from LNG to CNG, LNG is compressed and vaporized to cylinder pressure (at about 3000psi). According to Applied Natural Gas’ approved pathway CNG015¹⁵, the additional energy requirement results in an additional █ g/MJ (Annex 8).

¹⁵ <http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/angf-rpt-101813.pdf>, page 4

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 J170 which is the sum of cells E170 – I170 on the “NG” tab for CNG. The TTW gCO₂e/MJ was taken from the Detailed California-Modified GREET Pathway for Liquefied Natural Gas (LNG) from Landfill Gas¹⁶.

TABLE 11. PATHWAY RESULTS

GHG Emissions (gCO ₂ e/MJ)	MCCARTY LFG Plant to LNG	MCCARTY LFG Plant to L/CNG
Landfill Gas Recovery	█	█
Landfill Gas Processing	█	█
Flare Credit	█	█
Landfill Gas Transport	█	█
Liquefaction	█	█
LNG Transport	█	█
LNG Storage	█	█
L/CNG Conversion		█
gCO ₂ e/MJ WTT	█	█
Carbon in Fuel	█	█
Vehicle CH ₄ and N ₂ O	█	█
gCO ₂ e/MJ TTW	█	█
gCO ₂ e/MJ WTW	27.45	27.85

¹⁶ 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	█	CA-GREET Default (L85)
Electricity	Btu/MMBtu	█	CA-GREET Default ¹⁷ (L91)
Total Energy	Btu/MMBtu	█	N/A
LFG Plant		NG Tab	
LFG Processing Efficiency	%	█	AI66 (via C182)
Electricity Fuel Share	%	█	AI79 (via C184)
LFG Fuel Share	%	█	AI75 (via C183)
Natural Gas Fuel Share	%	█	AI76 (via C186)
Electricity	kWh/MMBtu	█	N/A
Electricity	Btu/MMBtu	█	Calculated in CA-GREET (AI91)
LFG	Btu/MMBtu	█	Calculated in CA-GREET (AI87)
Natural Gas	Btu/MMBtu	█	Calculated in CA-GREET (AI85)
Credit for Not Flaring	Btu/MMBtu	█	Calculated in CA-GREET (AJ88)
Total Energy	Btu/MMBtu	█	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
AZNM Electricity Grid Mix		Regional LT Tab	
Residual oil	%	0.1	J83
Natural gas	%	58.2	J84
Coal	%	39.6	J85
Nuclear	%	0.0	J86
Biomass	%	0.3	J87
Other (renewables)	%	2.8	J88
Natural Gas Transport		T&D Flowcharts Tab (via NG Tab)	
Pipeline Distance	mi	1,365	F479 (via E148)
Liquefaction		NG Tab	
Electricity	kWh/gal LNG	█	N/A

¹⁷ http://www.arb.ca.gov/fuels/lcfs/022709lcfs_lfg.pdf, pages 9-10.

Natural Gas	Btu/gal LNG		N/A
Liquefaction Efficiency	%		AD66
Electricity Fuel Share	%		AD79
Natural Gas Fuel Share	%		AD75
Electricity	Btu/MMBtu		Calculated in CA-GREET (AD91)
Natural Gas	Btu/MMBtu		Calculated in CA-GREET (AD85)
LNG Transport			T&D Tab
Transport Distance	miles		CD93
Truck LNG Fuel Share	%		CD97
Truck Diesel Fuel Share	%		CD95
LNG Storage			Inputs Tab
Boil-Off Rate: % per Day	%/day	0.05 / 0.1	E171 / F171
Duration of Storage or Transit: Days	Days		E174 / F174
Recovery Rate for Boil-Off Gas	%		E179 / F179
L/CNG			NG Tab
L/CNG Conversion	gCO2e/MJ		J171

Appendix B: List of Supporting Annexes

Annex 1 - Modified GREET model LFG to LNG and LCNG

Annex 2 - Facility Energy Data & Analysis_070214

Annex 3 – HR Green Eng Report

Annex 4 – McCarty Road - ALT Transportation Metrics 2014

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 - LNG and L-CNG CI calculation for ANGF v4 FINAL