LCFS Life Cycle Fuel Pathway Report
Method 2B Application: Texas Landfill Gas CNG

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Life Cycle Associates, LLC

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1.) Company Overview

GHI Energy, LLC ("GHI") is a natural gas marketing firm that provides pipeline-quality landfill gas to CNG users in California from the Fort Bend Landfill Gas Recovery Project (LGRP) in Texas. Since June 2013, this gas has been purchased under a long-term contract and shipped to California users via existing natural gas pipelines as allowed by the LCFS.

The specific landfill included in this proposal is the Fort Bend Regional Landfill, Needville, Texas, owned by WCA Waste Corporation. The landfill gas processing facility is owned by Fort Bend Power Producers and operated by Morrow Renewables.

This pathway is based on the existing CARB pathway for non-specific North American Landfill Gas to CNG with certain modifications to account for the specific processes and characteristics of gas from the LGRP and the specific pipeline pathway to California. To date, GHI has been delivering gas from Fort Bend using ARB's generic LFG-CNG pathway. This pathway application is for a facility specific pathway; additionally, GHI is also requesting retroactive LCFS treatment for its landfill gas deliveries in California since deliveries began from the Fort Bend landfill in June, 2013.

2.) LGRP Landfill Gas to CNG Pathway

This pathway is based on the existing CARB LCFS pathway for landfill gas to CNG from generic North American sources used in California. Modifications have been made to this pathway to better approximate the lower carbon intensity of landfill gas originating from LGRP due to a.) pipeline distance to California (1,864 miles); b.) the use of more efficient and modern treating equipment and methods; and c.) the consumption of process electricity from Texas. The following four main assumptions were changed from the existing North American LCFS landfill gas to CNG pathway:

- A pipeline distance of 1,864 miles from Needville, Texas to CNG dispensing stations;
- A methane removal efficiency of [redacted] achieved through the use of newer technology and "wet scrubbing" using a Solexol solvent;
- Fuel shares of [redacted] from landfill gas and electricity, respectively for LFG processing;
- Electricity consumption from Texas generation mix.

Unless otherwise noted, no other assumptions were changed from the existing LCFS North American LFG CNG pathway.

Figure 1 shows the land fill gas to fuel system boundary diagram. Land fill gas enters the LGRP processing facility, which is powered using the Texas electric grid and a portion of the land fill gas feedstock. The finished renewable natural gas product enters the pipeline and is transported to CNG distribution stations in California. The gas is compressed into CNG with CA marginal electric grid power and dispensed into vehicles for use. By contrast, the reference system below shows the alternate fate of the land fill gas, which would be flared onsite at the landfill if it were not being used as a feedstock.

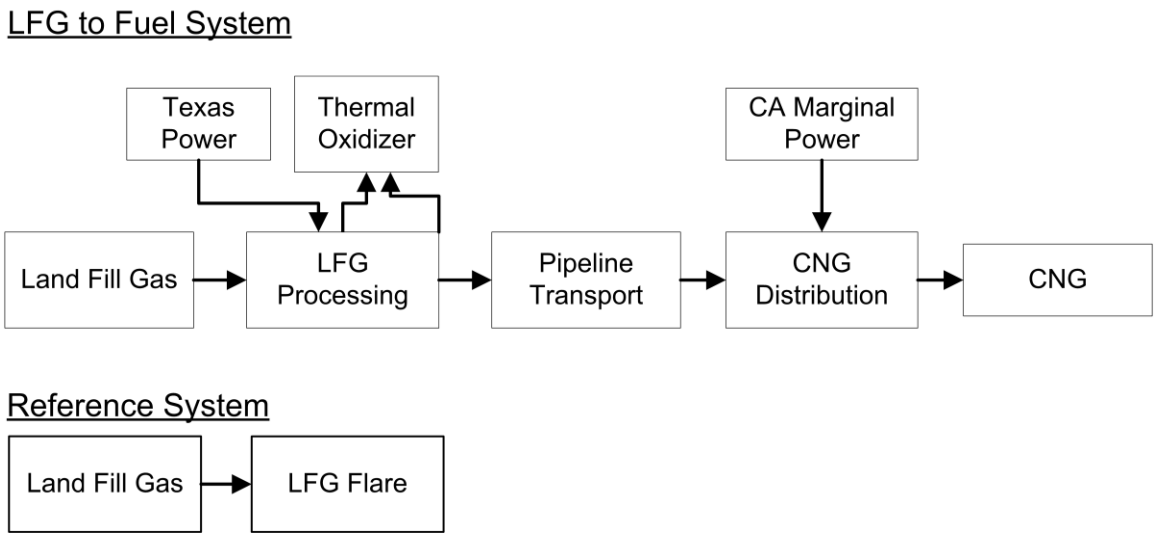


Figure 1. System Boundary Diagram

2.1) Landfill Gas Recovery and Transport to Processing

The pathway begins with the collection of raw landfill gas from wells drilled into the landfill. Gas is collected and then transported approximately one mile to an on-site processing facility via a negative pressure pipeline system, powered by a hermetically sealed electric blower. According to the CA_GREET 1.8b model for the pathway, the life cycle energy necessary for these steps is approximately [redacted] Btu for every 1 million Btu's collected and is provided entirely by electricity from the local grid. Likewise, because only electric blowers are utilized, there are no direct emissions from this process, only upstream emissions associated with grid electricity of [redacted] gCO_2e/MJ.

2.2) Landfill Gas Processing

The next step in the pathway is cleaning the LFG to pipeline quality and pressure, via a compressor feeding the gas through a "wet scrubber" system to separate usable methane from the LFG stream using a constantly recycled solvent stream (Solexol) to strip out CO_2 and heavy hydrocarbons. While the LFG processing data in the existing CARB pathway assumes a membrane process with a stated efficiency of [redacted] based on legacy technology, the more advanced wet scrubber system being used at LGRP is much more efficient and captures [redacted] of all methane in the LFG stream. Any remaining uncaptured landfill gas ([redacted] is combusted in a thermal oxidizer to minimize emissions. The LGRP processing system is designed for a maximum capacity [redacted]

cubic feet of raw landfill gas per day, [redacted] assuming [redacted] methane content used by the industry and the U.S. Environmental Protection Agency. Average operating data indicates a throughput [redacted]. At this throughput, the LGRP system uses approximately [redacted] of grid electricity and the thermal oxidizer uses pre-scrubber LFG at a standard rate of 100 MMBtu/day.

Figure 2 shows an overview of the steps that landfill gas undergoes once it enters the Fort Bend facility. Approximately [redacted] pounds per hour [redacted] methane and carbon dioxide landfill gas are fed into the facility. The gas is then taken from vacuum to [redacted] by blower, cooled, and sulfur treated. The gas is then compressed to [redacted] and routed to a coalescer and pre-absorber, which absorbs the heavy hydrocarbons and water. The hydrocarbons are stripped from the solvent and incinerated and the solvent is reused. The gas is cooled and coalesced and routed to the main absorber, which removes the carbon dioxide and sends it to be vented. The carbon dioxide stripped gas is sent through a carbon filter, and then a platinum catalyst reactor to remove the oxygen. It's then routed to a residue compressed to boost the pressure to that of the sales pipeline. Before entering the pipeline, the remaining trace water is removed with a glycol contactor and coalescer. The process produces about [redacted] per hour of finished biogas per day.

Energy flows from the Ft Bend facility are based on the process flow diagram (PFD) submitted to ARB. The flow rates for the average operation are shown in Appendix B. The PFD indicated the mass flows and energy flows for all of the process units. Total electric power based on 2 years of electricity bills corresponds to [redacted] of pipeline gas produced. Energy consumed in the process corresponds to [redacted] for the VOC incinerator plus [redacted] of fuel gas for the incinerator shown in Appendix B. Fuel gas is derived from post clean up landfill gas prior to compression. These parameters when converted to GREET inputs are shown in Appendix B. GREET recalculates these energy inputs from the fuel shares and efficiency input.

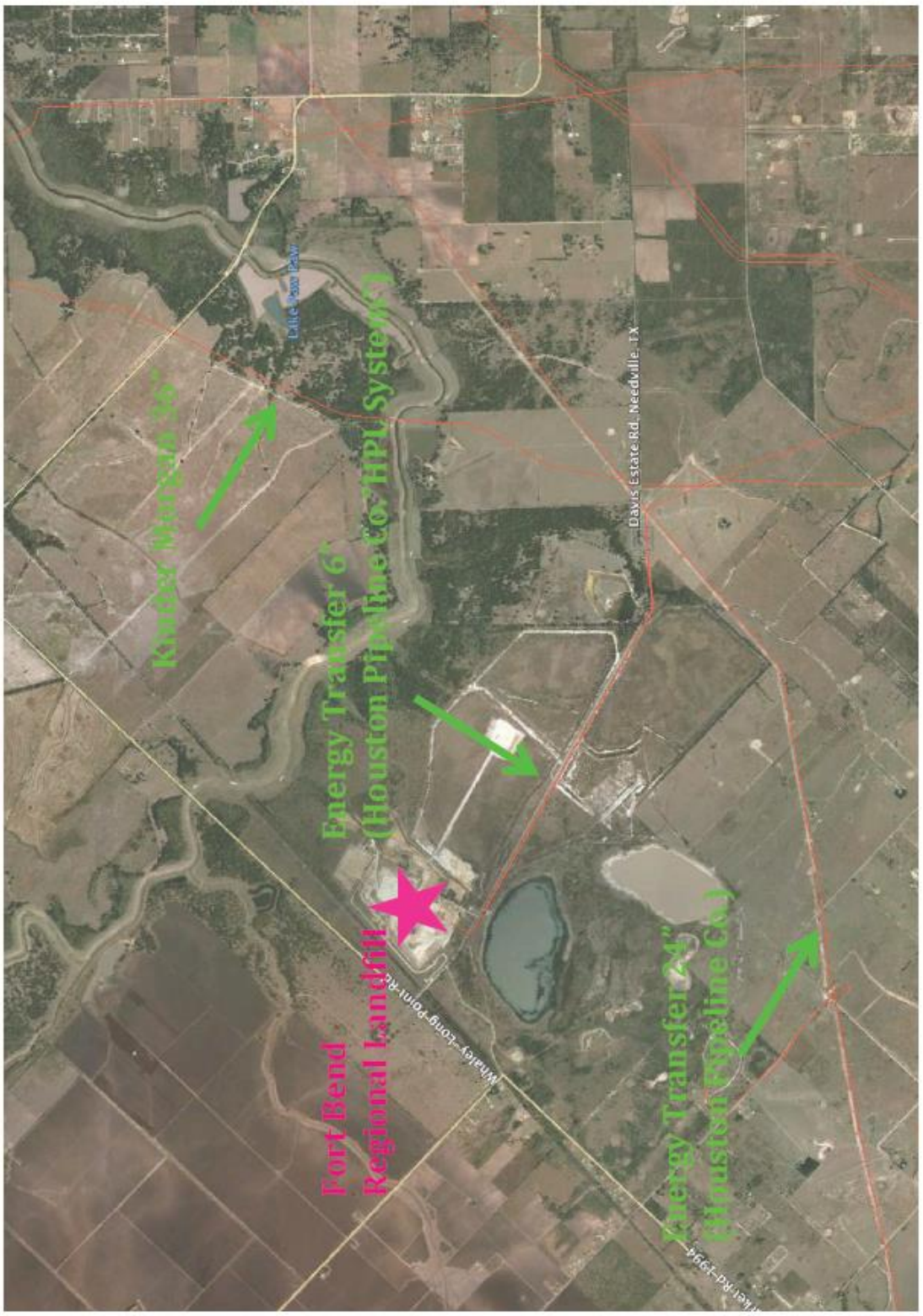


Figure 2. Fort Bend Pipeline Map

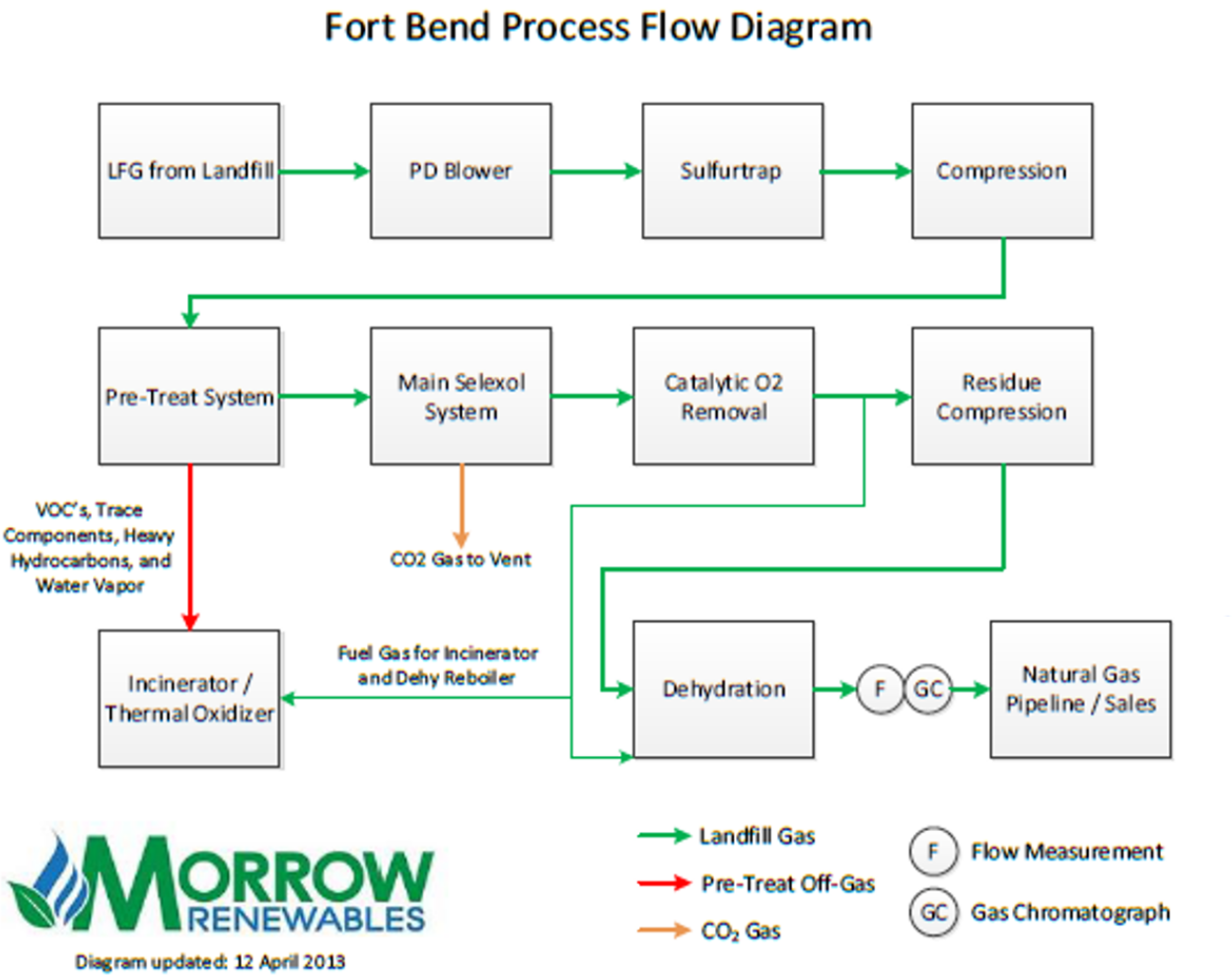


Figure 3. Fort bend Process Flow Block Diagram, Design Basis

2.3) Natural Gas Transport and Distribution

The third step in the pathway is transport and distribution of the natural gas by pipeline from the processing plant to the CNG refueling station in California. For this pathway, it is assumed that the refueling station is located 1,864 miles from the LGRP, which is the distance from Needville, Texas to Visalia, California via pipeline as estimated from an EIA map. The energy consumption for T&D consists of:

- T&D Feedstock Loss
- T&D Pipeline Transport Energy Consumption

- the gas is presumed to travel from Needville, Texas, to the California border at Topock, Arizona, along the following route:

  Houston Pipeline Company → Kinder Morgan Texas Pipeline → El Paso Natural Gas → Socal Gas Company

From the California border, the gas will be transferred to each of the local CNG stations that are using Fort Bend natural gas. Station locations and their driving distance from Needville, TX are shown below. The total pipeline distance was calculated separately as shown in Appendix A, based on an EIA map of U.S. pipelines. A maximum pipeline transport distance of 1,864 miles was assumed in the GREET model.

Based on the assumptions in the CA_GREET1.8b model, plus the change in pipeline distance made above, the transport and distribution stage of the pathway consumes [redacted]

2.4) CNG Compression at the Fueling Station

Once the gas reaches California, the remaining steps in the pathway are identical to the existing CARB LFG-CNG pathway for both in-state and out of state sources.

At the CNG fueling station, the gas is withdrawn from the pipeline and compressed to approximately 3,000 psi (or higher) for dispensing into a natural gas vehicle. The default CA_GREET fueling station compressor efficiency is 98%, and metering measurements from CNG compression stations with Fort Bend renewable CNG sales show compressors to have comparable compression efficiency. Metering data from the 7 station showed a weighted average of [redacted] compression rate (see Table 1). The data collected represented a two month period between May and August of 2015, except for one station, which provided data from September and October of 2014. The compressors are powered by grid electricity, in this case, electricity from the California Marginal Grid Mix. This results in an energy consumption of [redacted] and emissions [redacted] (CARB, 2009; CARB, 2014).

Table 1. CNG Compression Energy

Station Name	Compression Energy (kWh/MMBtu)	Electricity Used (kWh)	CNG Sold (MMBtu)
[redacted]			
[redacted]			
[redacted]			
[redacted]			
[redacted]			
[redacted]			
[redacted]			
Total			
Weighted Average			

3.) Modifications to the Existing CARB Pathway for Landfill Gas to CNG

Five key assumptions within the existing CARB out-of-state landfill gas pathway were changed to better reflect the characteristics of the fuel being produced at the LGRP:

- Instead of the U.S. average electricity grid mix, the model uses the Texas marginal electricity mix based on the current eGRID electricity generation mix for Texas as published by EPA and modified to replace all baseline coal and nuclear sources with natural gas generation as shown in Table 2.

Table 2. Texas Electricity Grid Mix

2009 EPA eGRID Texas Electricity Mix		2009 EPA eGRID Texas Electricity Mix modified for marginal sources	
Residual oil	0.8%	Residual oil	0.8%
Natural gas	45.0%	Natural gas	57.2%
Coal	34.8%	Coal	34.8%
Nuclear	12.0%	Nuclear	0.00%
Biomass	0.1%	Biomass	0.1%
Other (renewables)	7.3%	Other (renewables)	7.1%

Texas marginal electricity is assumed in land fill gas recovery and feedstock processing. The California marginal electricity mix is used for CNG compression since all CNG stations will be located in California.

- The use of a newer "wet scrubber" methane capture system thus resulting in a higher overall efficiency in the processing stage [redacted] as well.

- A shorter pipeline transport distance of 1,864 miles is assumed to move the fuel from the LGRP to the farthest California CNG station.

The changes to the existing CARB North American LFG-CNG pathway are summarized in Table 3.

Table 3. Changes to CA-GREET Assumptions

Model Parameter	GREET Model		Original GREET Values	LGRP Values
	Tab	Cell		
Electricity Distribution Mix	Regional LT	C2	U.S. Mix	Texas Marginal
Electricity Distribution Mix	Regional LT	D83	2.7%	0.8%
Electricity Distribution Mix	Regional LT	D84	18.9%	57.2%
Electricity Distribution Mix	Regional LT	D85	50.7%	34.8%
Electricity Distribution Mix	Regional LT	D86	18.7%	0.00%
Electricity Distribution Mix	Regional LT	D87	1.3%	0.1%
Electricity Distribution Mix	Regional LT	D88	7.7%	7.1%
Selection of Electricity Mix	Inputs	C351	1, US	4, User Defined
Biogas share in LFG processing	NG	AI75	76.8%	[redacted]
Electricity share in LFG processing	NG	AI79	23.8%	[redacted]
Distance from NG plant to CNG fueling station	T&D Flowcharts	F459	750	1,864
Processing Efficiency	Inputs Via FuelProdTS	B455 AR41	82.7%	[redacted]
CNG Compression Electricity Mix	Inputs	C351	1, US	3, CA

4.) Data Sources and Calculations

The changes made to GREET default values are calculated based on metering measurements from the Fort Bend facility and the CNG distribution stations that are purchasing its product.

The conversion efficiency of landfill gas to CNG at the Fort Bend facility was calculated based on electricity meters in the plant and pipeline sales of CNG leaving the plant. LFG processing electricity and pipeline gas produced data were available for 2 years, and pipeline production was verified by two years of audit data. Only the last 23 months are included in efficiency calculations since the plant was not running to scale during the first two months. Flare electricity metering data for the same 23 months was included in the total electricity usage.

LFG input, flared LFG, and fuel gas sent to flare quantities are based on the process flow design. Metered land fill gas input data was not available. Flared gas from the Fort Bend facility includes tail gas from the pre-treatment system as well as fuel gas that is produced from the Solexol process. The process consumes [redacted] based on the product transfer document. This value has a very small effect on the CI because the LFG is burned by thermal oxidizer or alternatively by the flare. In order to test sensitivity of the model to the LFG input volume, we varied the biogas input value by 150%. The overall life cycle carbon intensity was increased by less than 0.1%.

CNG compression data was requested from clients of Fort Bend CNG. One month of data was provided by 8 different CNG stations. The weighted average of all the stations was used as the compression efficiency value, which matched the GREET default.

Table 4 shows the original data used to generate different model inputs.

Table 4. Model Data Sources

Data Source	Input to model
Electricity bills from Ft Bend processing facility	Provides kWh/mmBtu electricity consumed
Eco Engineers review of gas production	Provides mmBtu/day of RNG produced
Process flow diagram and flow sheet	Provides Btu/mmBtu of combusted biogas
Electricity bills for CNG compression	[redacted]
EIA pipeline map, Google map	Provides pipeline transport distance

The plant's operating efficiency is calculated based on the ratio of energy consumed to renewable CNG energy produced. The Fort Bend plant uses [redacted] of electricity and [redacted] per day of land fill gas. The electricity plus unconverted LFG translate into [redacted] of electricity and [redacted] of land fill gas per MMBtu CNG produced, which constitute [redacted] of the total energy consumed in processing, respectively. The ratio of CNG product gas to total processing energy amounts to an overall process efficiency of [redacted]. The flare credit is equal to the amount of energy that was diverted from landfill gas flaring, [redacted] per day [redacted] of CNG produced.

Table 5. Plant Operating Efficiency and Energy Use

	Daily Average	Btu/MMBtu of Product Gas	Input Value	Cell Changed-NG Tab
Renewable CNG Produced	[redacted]	1,000,000	1,000,000	Default
Imported Electricity	[redacted]	[redacted]	[redacted]	NG, AI79
LFG Consumed	[redacted]	[redacted]	[redacted]	NG, AI75
Imported Natural Gas	[redacted]	[redacted]	[redacted]	N/A
Processing Efficiency	[redacted]	[redacted]	[redacted]	Inputs, B455
Flare Credit	[redacted]	[redacted]	[redacted]	N/A

5.) Results from CA-GREET Model

The pathway includes [redacted] When the changes described above are entered into the CA-GREET model, the final result is a pathway CI of 25.19 gCO_2e/MJ, as summarized in Table 6 below.

Cells containing parameters modified from the existing CARB pathway are shaded in Table 6. Note that all other parameters within the CA-GREET model calculation for the existing CARB pathway for out of-state landfill gas to CNG remain unchanged and the existing CARB pathway is hereby incorporated by reference.

Table 6. Results from CA-GREET Model with Modified Assumptions

	Electric Grid Mix	Energy, Btu/MMBtu	GHG, gCO_2e/MJ
Well-to-Tank (WTT)			
Landfill Gas Recovery	TX	[redacted]	[redacted]
Landfill Gas Processing	TX	[redacted]	[redacted]
Flaring Credit		[redacted]	[redacted]
Transport & Distribution		[redacted]	[redacted]
XXXX		[redacted]	[redacted]
Compression at Station in California	CA	[redacted]	[redacted]
Total WTT		[redacted]	[redacted]
Tank-to-Well (TTW)			
Carbon in Fuel		1,000,000	55.20
Vehicle CH_4 and N_2O			2.53
Total TTW		**1,000,000**	**57.73**
Total Well-to-Wheel (WTW)		[redacted]	**25.19**

References

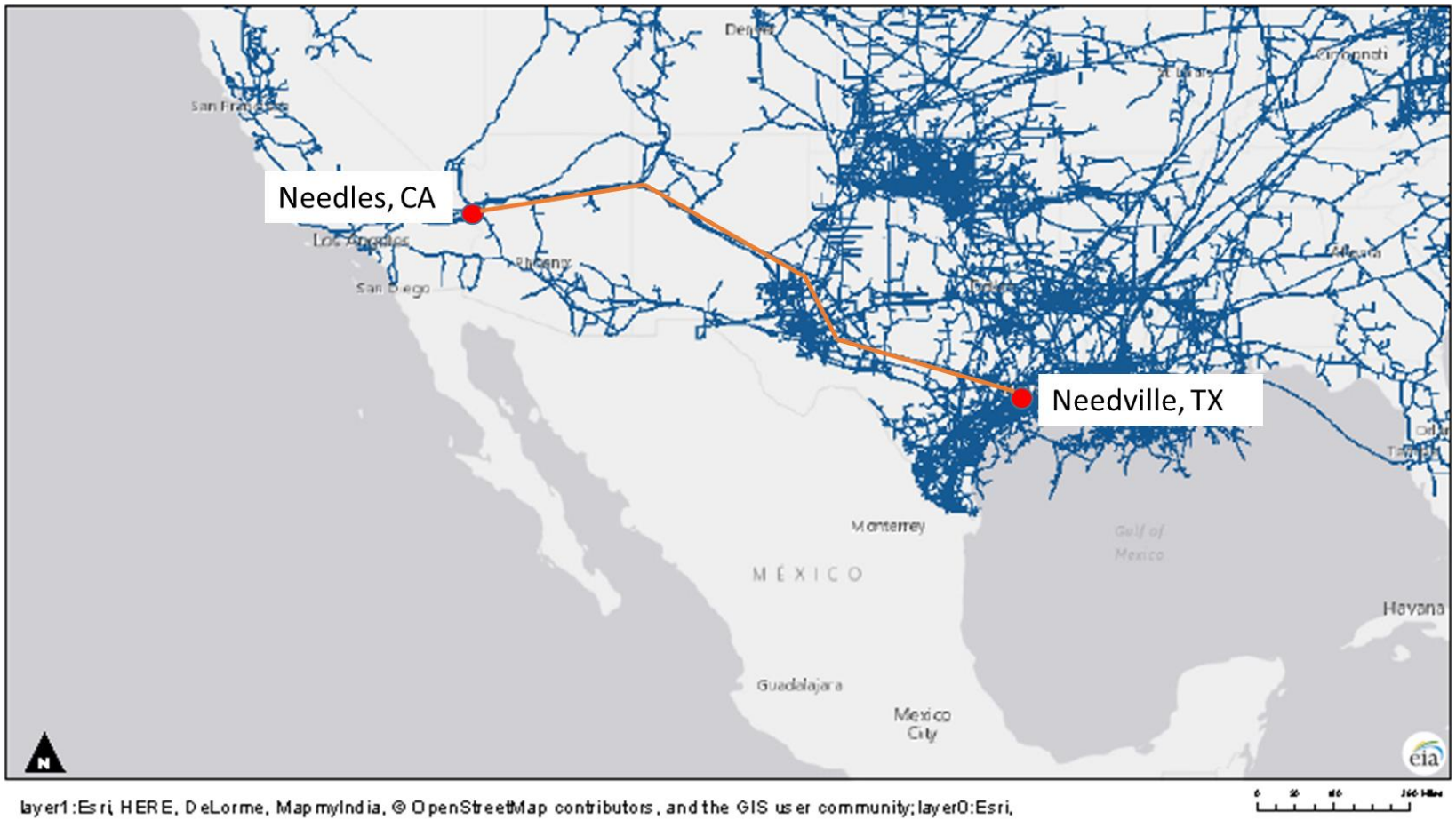
California Air Resources Board. "California-Modified GREET Pathways: North American Landfill Gas to Compressed Natural Gas, Liquefied Natural Gas, and Liquefied-Compressed Natural Gas." Technical Report Version 2.0, 2014.

California Air Resources Board. "Detailed California-Modified GREET Pathway for Compressed Natural Gas (CNG) from North American Natural Gas." Technical Report Version 2.1, 2009.

United States Environmental Protection Agency: *Landfill Methane Outreach Program: "Methane Emissions from Landfills."* 2013, http://www.epa.gov/lmop/basic-info/index.html#a02

Appendix A

The following map shows the estimated travel distance and pipeline route that the Fort Bend bioCNG product will travel between the facility in Needville, TX and Needles, CA. The pipeline map was generated using an Energy Information Administration mapping tool. A travel distance of 1500 miles was generated based on the assume pipeline route, traced in orange. 364 additional miles were calculated to the farthest CNG dispensing station for a total of 1,864.



Source: http://www.eia.gov/state/maps.cfm?v=Natural%20Gas

Appendix B

Table 7. Mass Balance for Fort Bend Processing Facility, Flow Rates for Average Data (VALUES REDACTED)

Stream	LFG	VOCs	Pretreat	Selexol	O_2 Removal	Fuel Gas	Dehydrator	Pipeline
Component								
CH_4								
C_2H_6								
N_2								
CO								
CO_2								
Total								
LHV (Btu/lb)								
average molar weight								
mol "C" per mol gas								
carbon weight %								
Btu/scf (LHV)								
SG								
Density (g/ft3)								
Mass								
Total								
Energy								
mmBtu/h								
Btu/mmBtu NG								

Table 8 displays the numbers used to calculate the LFG processing efficiency. GREET input values are highlighted in grey.

Table 8. Processing Efficiency Calculations

Parameter	**Btu/MMBtu**	**Fuel Share**	**GREET Cell Changed**
Biogas Consumed	[redacted]	[redacted]	NG, AI75
Electricity Consumed	[redacted]	[redacted]	NG, AI79
Total Energy Consumed	[redacted]		N/A
Renewable CNG Produced	1,000,000		N/A
Total Processing Energy	[redacted]		N/A
LFG Processing Efficiency	[redacted]		Inputs, B455