Life-Cycle Assessment of Sauk Hills Landfill Gas to Delivered LNG 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)

The Sauk Trail Hills LFG Plant is located in Canton, Mi, 25 miles West of Detroit. It is owned and operated by Canton Renewables. The Sauk Trail Hills Plant will be processing, cleaning and pressurizing LFG from the Sauk Trail Hills Landfill to be introduced into the pipeline. The plant has a capacity of [redacted] of product gas at [redacted] methane ([redacted] MMBtu/hr). The production rate equals [redacted] standard cubic feet per hour of gas (or [redacted] million SCF/day). The Btu content averages [redacted] Btu (LHV)/SCF[1]. The designed injection capacity to the pipeline will be [redacted] MMBtu/hr. The Canton Renewables gas processing plant utilizes cutting edge technology for the clean-up of LFG to meet stringent pipeline specifications. The gas produced is safe, reliable and chemically equivalent to natural gas, only cleaner. Gas compression, scrubbing, chilling, drying, and polishing technologies are employed for processing. The gas meets local pipeline specifications and in practice substitution will be occurring where the same gas introduced into the pipeline in Canton, MI will not be same used in California for LNG.

Sauk Hills is an NSPS regulated site with a pre-existing LFG collection system. Once a landfill which is either new or has an increase in permitted design capacity after May 30, 1991, then if it is permitted for more than 2.5 million cubic meters design capacity or has more than 2.5 million megagrams of in place waste, it is subject to NSPS rules. Sauk Hills exceeded the above limitations in 1993 to become and NSPS regulated landfill.

An NSPS landfill is required to install a LFG collection system within 30 months after the site reaches an emission of 50 megagrams per year of Non-Methane Organic Compounds (NMOC). Once the landfill is required to have a LFG collection system, specific cells within the landfill are required to have a LFG collection system installed before the waste is 5 years old. Sauk Hills exceeded these limits and were required to have an LFG collection system installed in 1999. The installation of the collection system began in 1997 and was completed within 30 months in 1999.

Process Description

(This Section contains Confidential Business Information)

[redacted] The Process Flow Diagram if the facility is shown in Figure 1. (This figure contains Confidential Business Information)

[1] Values of [redacted] Btu/scf (HHV) and [redacted] Btu/scf LHV were used in the calculations.

[redacted]

SAUK TRAIL HILLS LANDFILL High BTU Gas Project Landfill Gas Treatment Facility	**PROCESS FLOW DIAGRAM** **Sauk Trail Hills Landfill** **Canton, MI.**	Design: JJG Date: 5-10-11	CERF Clean Energy Renewable Fuels

Figure 1 – Sauk Hills LFG Plant Process Flow Diagram (This figure is Confidential Business Information)

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), Liquefaction, and Transportation and Distribution.

LFG Production Plant

(This Section contains Confidential Business Information)

The plant has a product capacity of [redacted] scfm of product gas at [redacted] methane ([redacted] MMBtu/hr). The process has a thermal oxidizer that consumes the waste stream LFG ([redacted] MMBtu/hr) which is [redacted] of the input LFG ([redacted] MMBtu/hr). The Sauk Trail Hills Plant expected load is [redacted] kW ([redacted]) per [redacted] MMBtu of product pipeline gas as shown in Figure 2. The figure shows the maximum demand values when the equipment is expected to be used [redacted] of the time and factors for motor efficiency, power factor, percent (%) of time running, brake Hp, and percent (%) design oversize are multiplied to the full load to determine the expected actual loads. The electric motors operate at [redacted] of their full load ([redacted] kW). This means that operationally, the power draw of the system will be approximately [redacted] kW. Of this [redacted] kW, [redacted] kW or [redacted] % of the power is used in the gas collection system "blowers" for recovery of landfill gas and the balance [redacted] kW is for the LFG processing. The electric motors consume [redacted] kWh per MMBtu of product pipeline gas, [redacted] kWh for recovery ([redacted] of power load) and the balance [redacted] kWh for processing.

The thermal oxidizer operates [redacted] of the time. The unit is designed for low Btu gas with a methane content between [redacted] methane and [redacted] methane. Gas compositions above [redacted] yield high temperatures in the unit and can destroy the catalyst so the TOX system is operated at less than [redacted] methane. A [redacted] methane gas stream has a Btu content of [redacted] Btu (LHV)/SCF. The TOX is rated for a flow of [redacted] SCFM. With [redacted] methane (at [redacted] Btu/SCF) the Btu rating for the TOX would be [redacted] MM Btu/hr. The plant design is for the TOX to operate at [redacted] methane ([redacted] Btu/SCF HHV). This means the normal firing rate for the TOX is [redacted] MM Btu/hr. It has a small pilot of [redacted] scfh natural gas ([redacted] scfm natural gas, [redacted] Btu/hr) during the processing stage. The conversion factor utilized for electricity was [redacted] MJ/kWh. Efficiency is calculated as LFG energy produced divided by the sum of LFG energy produced and total energy consumed in the process, this case is all electricity and landfill gas.

Table 1. Sauk Hill LFG Plant Operating Energy and Flare Credit

(This Table contains Confidential Business Information)

All Units in Btus per MMBtu of LFG	Sauk Trail Hills LFG Plant	Input Value	Changed Cells – NG Tab
LFG Produced	[redacted]		
Recovery Electricity	[redacted]	[redacted]	[redacted]
Recovery Efficiency	[redacted]	[redacted]	[redacted]
Processing Electricity	[redacted]	[redacted]	[redacted]
LFG Used (Processing)	[redacted]	[redacted]	[redacted]
Natural Gas (Processing)	[redacted]	[redacted]	[redacted]
Processing Efficiency	[redacted]	[redacted]	[redacted]
Flare Credit	[redacted]	[redacted]	

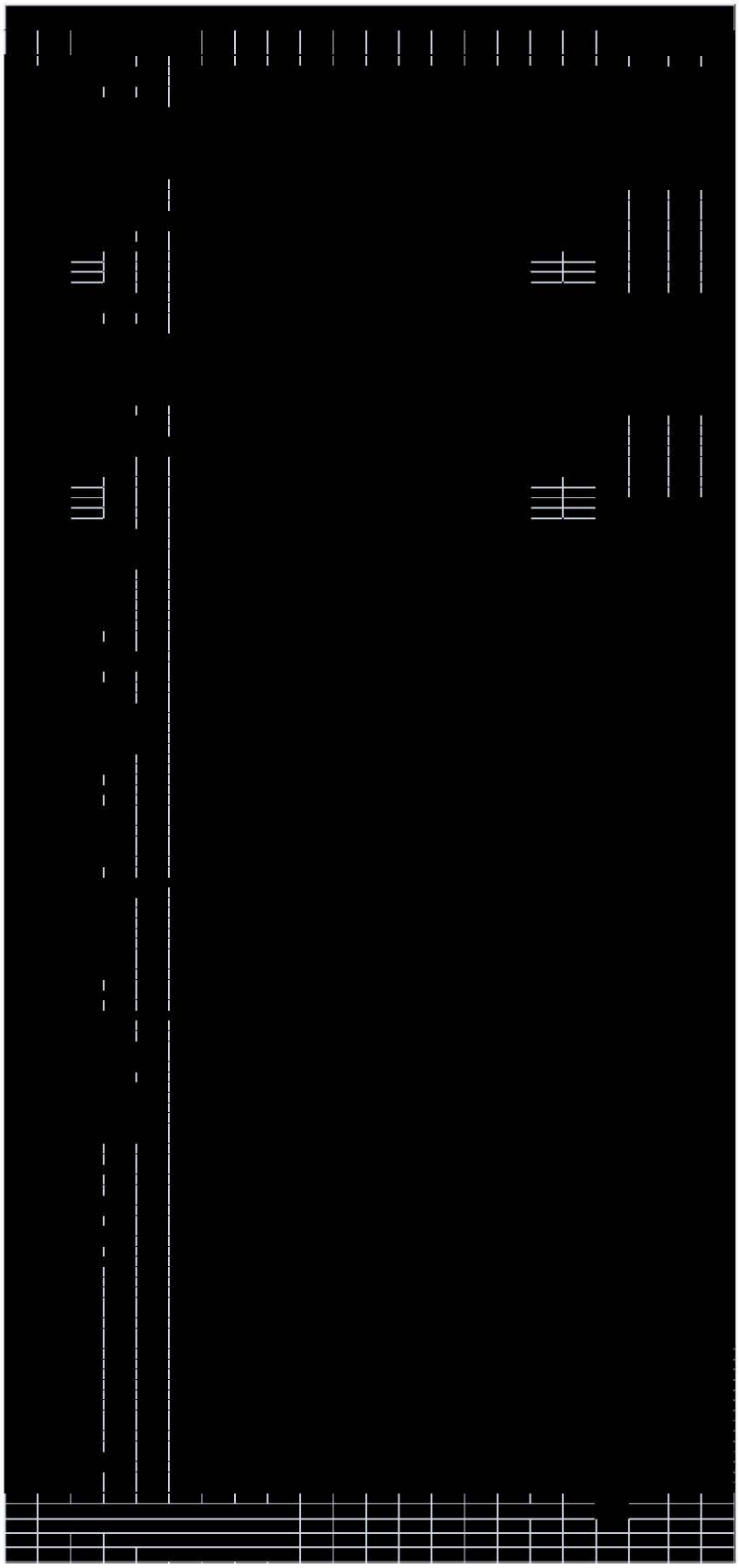

Figure 2 – Sauk Hills Motor Electricity Demand (This figure contains Confidential Business Information)

The GREET model LFG pathway was then modified to adjust efficiency gas and process energy shares as listed in

Table 1. Midwest Region was chosen for Sauk Trail Hills.
This produced the results for LFG to LNG shown in the table below taken from cells on the NG Tab. LNG uses a loss factor (LF) of [redacted](cell [redacted]). Conversion from g/MMBtu to g/MJ was done using the conversion factor of [redacted]MJ/MMBTU as is done in the CA-GREET model.

Table 2. Sauk Hills LFG Plant Greenhouse Gas Emissions

(This Table contains Confidential Business Information)

Recovery and Processing Emissions	Sauk Trail Hills LFG Plant to LNG	CA-GREET Cell NG Tab
gVOC/MMBTU	[redacted]	[redacted]
gCO/MMBTU	[redacted]	[redacted]
gCH4/MMBTU	[redacted]	[redacted]
gN2O/MMBTU	[redacted]	[redacted]
gCO2/MMBTU	[redacted]	[redacted]
gCO2e/MMBTU	[redacted]	[redacted]
gCO2e/MJ	[redacted]	[redacted]
gCO2e/MJ w/LF	[redacted]	[redacted]
gCO2e/MJ Flare Credit	[redacted]	[redacted]
gCO2e/MJ Flare Credit w/LF	[redacted]	[redacted]
gCO2e/MJ Total	[redacted]	[redacted]
gCO2e/MJ Total w/ LF	[redacted]	[redacted]

Transportation to California by Pipeline

The pipeline transport distance was modified to [redacted]miles from Canton, MI to Boron, CA 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 determine by taking the calculated natural gas pipeline emissions for 750 miles from the "T&D" tab and multiplying it by the ratio of [redacted]mi/750 mi. This is the same methodology utilized throughout the natural gas tab for all of the pipeline transport pathways. The table below shows the differences in pipeline transport emissions with the application of the loss factor ([redacted]for LNG) from cells [redacted]on the NG Tab.

Table 3. Sauk Hills LFG Transport Greenhouse Gas Emissions

(This Table contains Confidential Business Information)

Transport Emissions	Sauk Trail Hills LFG Transport
gVOC/MMBTU	[redacted]
gCO/MMBTU	[redacted]
gCH4/MMBTU	[redacted]
gN2O/MMBTU	[redacted]
gCO2/MMBTU	[redacted]
gCO2e/MMBTU	[redacted]
gCO2e/MJ	[redacted]
gCO2e/MJ w/ LF	[redacted]

Liquefaction

(This Section contains Confidential Business Information)

Based on the submitted Confidential Business Information from Clean Energy Fuels, the Boron facility requires [redacted] kWh/gal of LNG for liquefaction ([redacted] kWh/ [redacted] gal LNG = [redacted] kWh/gal LNG). Only electricity is required for the process making the fuel shares [redacted] electricity. Table 4 below shows the calculation from kWh per gallon to process efficiency and the cells that were changed. Table 5 shows the results from cells [redacted] and [redacted].

Table 4. Boron LNG Plant Operating Energy

(This Table contains Confidential Business Information)

All Units in Btus per Gal of LNG	Boron LNG Plant	Input Value	Changed Cells – NG Tab
LNG Produced	[redacted]		
Liquefaction Electricity	[redacted]	[redacted]	[redacted]
Liquefaction Natural Gas	[redacted]	[redacted]	[redacted]
Liquefaction Efficiency	[redacted]	[redacted]	[redacted]

Table 5. Boron LNG Plant Greenhouse Gas Emissions

(This Table contains Confidential Business Information)

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

LNG Transport to Refueling Station

In addition the CA-GREET default LNG transport distance of [redacted] miles was used but the fuel shares were modified to utilize the Westport HPDI trucks consuming [redacted] LNG and [redacted] diesel with an EER of [redacted]. The numbers were inputted in cells [redacted] (% diesel consumption) and [redacted] (% LNG consumption) on the "T&D" tab and the results were taken from cells [redacted] on the "NG" tab.

Table 6. LNG Transport Greenhouse Gas Emissions

(This Table contains Confidential Business Information)

	California LNG Plant – [redacted] miles [redacted] Diesel and [redacted] LNG
gVOC/MMBTU	[redacted]
gCO/MMBTU	[redacted]
gCH4/MMBTU	[redacted]
gN2O/MMBTU	[redacted]
gCO2/MMBTU	[redacted]
gCO2e/MMBTU	[redacted]
gCO2e/MJ	[redacted]

LNG Storage

In addition the CA-GREET default for LNG storage was used. The default values are listed in Table 7 below and yield the results in Table 8 (the results were taken from cells [redacted] on the "NG" tab.).

Table 7. 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	[redacted]	[redacted]	[redacted]	[redacted]
Duration of Storage or Transit: Days	[redacted]	[redacted]	[redacted]	[redacted]
Recovery Rate for Boil-Off Gas	[redacted]	[redacted]	[redacted]	[redacted]

Table 8. LNG Storage Greenhouse Gas Emissions

	LNG Storage
gVOC/MMBTU	[redacted]
gCO/MMBTU	[redacted]
gCH4/MMBTU	[redacted]
gN2O/MMBTU	[redacted]
gCO2/MMBTU	[redacted]
gCO2e/MMBTU	[redacted]
gCO2e/MJ	[redacted]

Sauk Hills 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 the sum of cells [redacted] and [redacted] on the "NG" tab for LNG. The TTW gCO2e/MJ was taken from the Detailed California-Modified GREET Pathway for Liquefied Natural Gas (LNG) from Landfill Gas[2].

Table 9 - Pathway Results

GHG Emissions (gCO2e/MJ)	Sauk Trail Hills LFG Plant to LNG
Landfill Gas Production	[redacted]
Flare Credit	[redacted]
Landfill Gas Transport	[redacted]
Liquefaction	[redacted]
LNG Transport	[redacted]
LNG Storage	[redacted]
gCO2e/MJ WTT	[redacted]
Carbon in Fuel	[redacted]
Vehicle CH4 and N2O	[redacted]
gCO2e/MJ TTW	[redacted]
gCO2e/MJ WTW	30.09

[2] http://www.arb.ca.gov/fuels/lcfs/092309lcfs_lfg_lng.pdf