



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

November 19th, 2014; Revised September 24, 2015

Submitted to:

Clean Energy Renewable Fuels, LLC

Prepared by

ICF International
75 E. Santa Clara St., Suite 300
San Jose, CA 95113

POC: Jeffrey Rosenfeld; Jeffrey.rosenfeld@icfi.com

Table of Contents

General Information	3
Process Description	4
Data Collection and Process Results	4
LFG Production Plant	4
Transportation to California by Pipeline.....	7
Compression	8
MDU Fuel Pathway Results	9
Appendix A: Summary of CA-GREET Inputs	10
Appendix B: List of Supporting Annexes.....	11

General Information

Montana-Dakota Utilities Co. (MDU) operates a landfill gas (LFG) treatment facility to recover methane from the Billings Regional Landfill in Billings, MT, to recover methane and process landfill gas to pipeline quality natural gas. MDU owns and operates the Billing Regional Landfill, a 800-acre municipal solid waste facility that is currently landfilling a 50-acre area of the permitted facility.

The anaerobic decomposition of organic wastes in landfills results in the generation of a biogas commonly referred to as landfill gas (LFG). [REDACTED]

The MDU treatment facility purifies raw LFG via a series of processes using specifically designed equipment. Two pressure-swing absorption (PSA) beds remove carbon dioxide and nitrogen. The tail gas from the CO₂ PSA is a lower-BTU stream that is combusted in the enclosed flare (thermal oxidizer). The tail gas stream that is generated by the N₂ PSA unit is a higher-BTU stream that is combusted in the open flare (main flare). [REDACTED]

No permit limitation exists to the production of product gas at MDU. The maximum production capacity is the facility's equipment processing capacity and was determined through the EPA Registration process. [REDACTED]

Pipeline grade LFG is transported via pipeline from Montana to California for compression and sale. The following pathway was produced using two (2) years (July 2012 – June 2014) of landfill gas production data¹ and two (2) years (2011-2012) of CNG compression data.²

¹ Please see Annex 2 for MDU Facility Energy Data Analysis

² Please see Annex 4 for CNG Station Electrical Efficiency Data

Process Description

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

The following steps outline the process train for the production of pipeline quality natural gas from MDU³:

- [REDACTED]
- [REDACTED]
- [REDACTED]

[REDACTED]

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

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

[REDACTED]

The MDU facility 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 and when plant is not operating.

TABLE 1 below shows the available data provided by MDU for input biogas, product biogas, biogas consumed on-site and imported electricity from July 2012 to June 2014. [REDACTED]

[REDACTED]

³ This information was taken from Annex 3 RSF Control Union Engineering Report

⁴ Annex 3 MDU RSF Control Union Engineering Report, page 39

⁵ Annex 2, Summary tab, cell K27. 82% is the sales gas (10.85 mmbtu/hour) divided by the landfill gas (13.22 mmbtu/hour)

⁶ Please see Annex 2, Summary tab, cell E21 for the calculation of this figure

⁷ Please see Annex 2, Summary tab, cell E27 for the calculation of this figure

⁸ Please see Annex 2, Summary tab, cell F27 for the calculation of this figure

MDU Engineering Report. The table also shows the provided data converted to GREET model inputs. The MDU pathway utilizes the CA-GREET default values for LFG recovery.

[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. MDU LFG PLANT OPERATING ENERGY AND FLARE CREDIT⁹
 (THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

	July 2012 – June 2014 Hourly 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]	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]

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

⁹ Please see Annex 2, Summary tab for the calculations of the figures presented in this table

¹⁰ Please see Annex 6 for PDFs of gas sales invoices

¹¹ Please see Annex 5 for PDFs of facility electricity bills

¹² Please see Annex 1 for the Modified GREET model referred to in this report

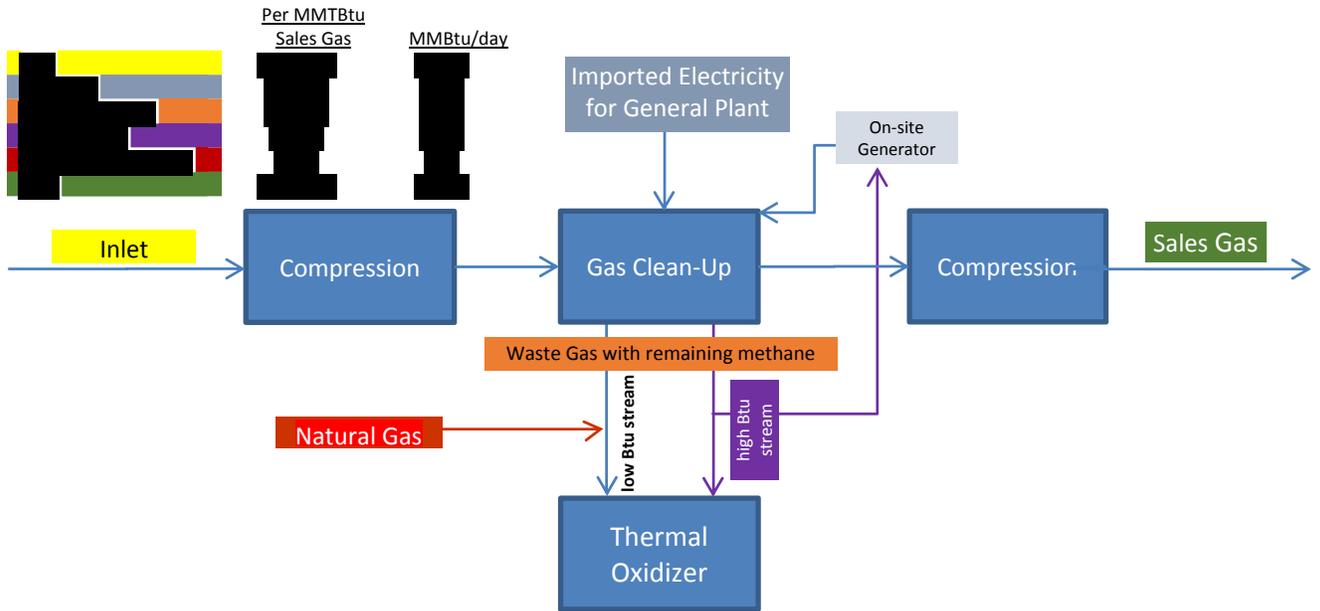


Figure 1. MDU Process per MMBtu and MMBtu/day Energy Flows

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 WECC Northwest (NWPP) Region to represent the 2012 eGRID data for year 2009 where MDU facility is located and this was used for the MDU Pathway. 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 NWPP region) were changed to match the US Average.

TABLE 2. NWPP ELECTRICITY GRID MIX

	eGRID CY 2009 Grid Mix	Marginal Grid Mix	CA-GREET Cell Regional LT Tab
Residual oil	0.48%	0.48%	J83
Natural gas	15.27%	64.24%	J84
Coal	29.83%	29.83%	J85
Nuclear	2.46%	0.00%	J86
Biomass	1.09%	1.09%	J87
Other (renewables)	50.86% (with hydro)	4.36%	J88

This produced the results for LFG to CNG shown in Table 3 below. These values are taken from the NG Tab of the Modified GREET model which can be found in Annex 2 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.¹³

TABLE 3. MDU LFG PLANT GREENHOUSE GAS EMISSIONS

¹³ http://www.arb.ca.gov/fuels/lcfs/022709lcfs_lfg.pdf; page 9.

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

Transport Emissions	MDU LFG Transport
[REDACTED]	[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). [REDACTED]

Table 6 below show the calculation from kWh/GGE to process efficiency and the cells that were changed and the results from cells I151- I157.

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
[REDACTED]	[REDACTED]		
[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]
[REDACTED]	[REDACTED]	[REDACTED]	[REDACTED]

TABLE 6. CNG COMPRESSION GREENHOUSE GAS EMISSIONS
 (THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

Recovery and Processing Emissions	Compression
[REDACTED]	[REDACTED]

¹⁵ Please see Annex 8 for the CNG station Electrical Efficiency Data
¹⁶ 109,772 Btu/GGE default CA-GREET value

MDU 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 G158 – I185 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 Gas¹⁷.

TABLE 7. MDU PATHWAY RESULTS

GHG Emissions (gCO ₂ e/MJ)	MDU LFG Plant to CNG
[REDACTED]	[REDACTED]
gCO ₂ e/MJ WTW	45.24

¹⁷ http://www.arb.ca.gov/fuels/lcfs/022709lcfs_lfg.pdf

Appendix B: List of Supporting Annexes

MDU Pathways Annex 1 - Modified GREET model_LFG to CNG

MDU Pathways Annex 2 - Facility Energy Data & Analysis

MDU Pathways Annex 3 - RSF Control Union Engineering Report

MDU Pathways Annex 4 - Clean Energy – CNG Station Electrical Efficiency Data

MDU Pathways Annex 5 - Electric Invoices – July 2012 to June 2014

MDU Pathways Annex 6 - Gas Sales – July 2012 to June 2014

MDU Pathways Annex 8- Natural Gas Flows