# Life-Cycle Assessment of Fort Smith Landfill Gas to Delivered CNG in California

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Submitted to:

Shell Energy North America

Prepared by

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

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

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## General Information

Cambrian Energy/Southtex Fort Smith Treaters (CEST) LLC operates a landfill gas (LFG) treatment facility to recover methane from the City of Fort Smith Landfill in Sebastian County, AR.

The anaerobic decomposition of organic wastes in landfills results in the generation of a biogas commonly referred to as landfill gas (LFG). Raw LFG consists primarily of about [redacted] methane and [redacted] carbon dioxide, but also includes other trace compounds and water vapor. A landfill Gas Collection and Control System (GCCS) consisting of 128 vertical extraction wells within the refuse and a series of high density polyethylene lateral and header pipes routes raw LFG to the treatment facility located on the landfill site.

The CEST treatment facility purifies raw LFG via a series of cooling, filtering, and compressing processes using specifically designed equipment. The treatment facility utilizes a previously existing blower/flare at the site. CEST uses purified LFG routed upstream of the meter as pilot fuel for the flare and the thermal oxidizer and purchases electricity from Oklahoma Gas & Electric Company to serve the plant's electrical demand.

No permit limitation exists to the production of product gas at CEST. The maximum production capacity is the facility's equipment processing capacity and was determined through the EPA Registration process. The annual US EPA Actual Peak Capacity (calculated using the lower heating value of methane) is [redacted] million renewable fuel gallon equivalents of purified biogas production per year.

Pipeline grade LFG is transported via pipeline from Arkansas to California for compression and sale. The following pathway was produced using two (2) years (January 2012 – December 2013)[1] of landfill gas production data and two (2) years (2011-2012)[2] of CNG compression data.

## Process Description

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

[1] Please see Annex 5 for CEST electric bills, and Annex 6 and 7 for the facility's gas sales

[2] Please see Annex 4 for CNG station electrical efficiency data

[3] Please see Annex 3 RSF Control Union Engineering Report for additional details

[redacted]

[redacted] The heat content of the gas sold minus the heat content of any propane supplement added reflects the amount of renewable fuel produced (i.e. the heat content of methane recovered) by the treatment facility. This amount is dedicated for transference to downstream commercial customer(s) for qualified end use and RIN generation and are shown in the invoices to Shell and is therefore not included as an input in the analysis presented in this report.

The LFG is primarily utilized by an off-site end user and the flare is only operational at those times when it is not used for its primary purpose.

A landfill gas with a [redacted] molar methane content is processed to [redacted] methane purity, the balance being the inerts of N2 and CO2[4]. Approximately 94% of the methane is recovered in the gas to be sold. The balance is consumed in the flare or thermal oxidizer as the TOX pilot[5]. The purified LFG for the TOX is routed upstream of the meter.

## 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)

Two years (2012-2013) of plant modeling data show an average landfill gas inlet of [redacted] mmscf/day[6] at [redacted] methane which is equivalent to a potential product of [redacted] mmscf/day[7] of biogas at [redacted]%[8] methane. The CEST 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 CEST for input biogas, product biogas, biogas consumed on-site and imported electricity from January 2012 to December 2013. The balance of

[4] Annex 3 RSF Control Union Engineering Report, page 1
[5] Annex 2, Summary, cell K34.
[6] Please see Annex 2, Summary tab, cell K27 for the calculation of this figure
[7] Please see Annex 2, Summary tab, cell F27/10^6 for the calculation of this figure
[8] Please see Annex 2, Summary tab, cell E34 for the calculation of this figure

the biogas consumed in the thermal oxidizer and flare is calculated based on modeling data provided in the CEST Engineering Report (*Annex 3, pages 20 and 23*). The table also shows the provided data converted to GREET model inputs. The CEST pathway utilizes the CA-GREET default values for LFG recovery.

The value of [redacted] MMBtu/hour in **TABLE 1** below is the average amount of product pipeline quality biogas produced per hour. 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. CEST LFG PLANT OPERATING ENERGY AND FLARE CREDIT**[9]
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

| | Jan 2012 – Dec 2013 Average Hourly Data | Btu/MMBtu of Product Gas | Input Value | Changed Cells – NG Tab |
|---|---|---|---|---|
| Product Biogas | [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[11] | |

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 and 7 for PDFs of gas sales invoices
[11] Please see Annex 1 for the Modified GREET model referred to in this report

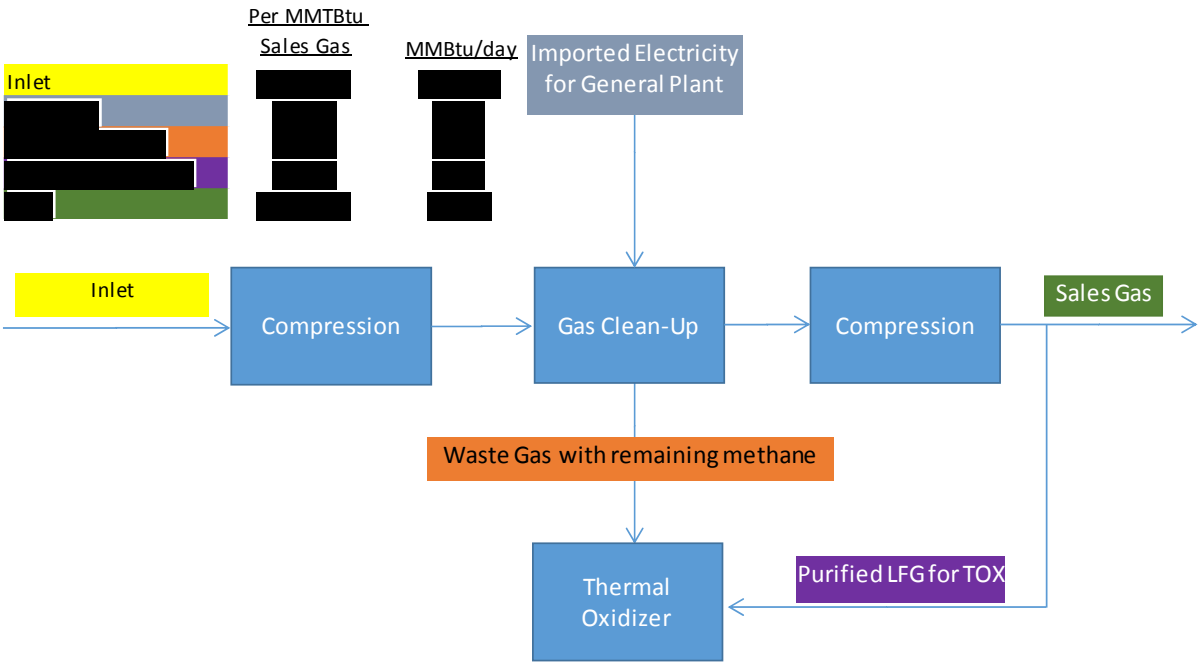


Figure 1. CEST Process per MMBtu and MMBtu/day Energy Flows

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 SPP South (SPSO) Region to represent the 2012 eGRID data for year 2009 (8th Edition[12]) where Fort Smith, AR 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 SPSO region) were changed to match the US Average.

**TABLE 2. SPSO ELECTRICITY GRID MIX**

| | eGRID CY 2009 Grid Mix | Marginal Grid Mix | CA-GREET Cell Regional LT Tab |
|---|---|---|---|
| Residual oil | 0.39% | 0.39% | J83 |
| Natural gas | 33.87% | 39.40% | J84 |
| Coal | 55.23% | 55.23% | J85 |
| Nuclear | 0.00% | 0.00% | J86 |
| Biomass | 1.21% | 1.21% | J87 |
| Other (renewables) | 9.31% (w/ hydro) | 3.78% (w/o hydro) | J88 |

This produced the results for LFG to CNG 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.

[12] 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

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. CEST LFG PLANT GREENHOUSE GAS EMISSIONS**
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

| | Recovery Emissions | CEST LFG Plant | CA-GREET Cell NG Tab |
|---|---|---|---|
| gVOC/MMBTU | [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] |

## Transportation to California by Pipeline

Clean Energy owns, operates or supplies natural gas and biomethane to [redacted]. A single representative transport distance (and carbon intensity) was chosen for all of Clean Energy's stations to allow for fungibility of CEST's biomethane between the CNG stations and require the approval of only one pathway instead of [redacted]. [redacted] Google Maps was used to determine the driving routes with the I-40W route most similar to the pipeline map to Los Angeles and I-40W to I-5N the most similar to the pipeline map to San Francisco.[14] 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.

[13] http://www.arb.ca.gov/fuels/lcfs/022709lcfs_lfg.pdf; page 9.
[14] Please see Annex 3 RSF Control Union Engineering Report, pipeline map on page 120.

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

| Transport Emissions | CEST LFG Transport |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [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). The weighted average energy consumption is [redacted] and has been previously approved in Pathway CNG009_1. Table 5 and 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 |
|---|---|---|---|
| [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] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |

[15] Please see Annex 4 for the CNG station Electrical Efficiency Data
[16] 109,772 Btu/GGE default CA-GREET value

## CEST 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[17].

**TABLE 7. PATHWAY RESULTS**

| GHG Emissions (gCO2e/MJ) | CEST LFG Plant to CNG |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| gCO2e/MJ WTW | 27.66 |

[17] 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 | | | |
| [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] |
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| [redacted] | [redacted] | [redacted] | [redacted] |
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| [redacted] | [redacted] | [redacted] | [redacted] |
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| [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]) |

[18] 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

Annex 3 - RSF Control Union Engineering Report

Annex 4 – Clean Energy – CNG Station Electrical Efficiency Data

Annex 5 - Electric Bills 2012-2013

Annex 6 - Gas Sales 2012

Annex 7 - Gas Sales 2013

# Life-Cycle Assessment of Fort Smith Landfill Gas to Delivered LNG and LCNG in California

October 1st, 2014; Revised August 24th, 2015

Submitted to:

Shell Energy North America

Prepared by

ICF International
75 E. Santa Clara St., Suite 300
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POC: Jeffrey Rosenfeld; Jeffrey.rosenfeld@icfi.com

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## General Information

Cambrian Energy/Southtex Fort Smith Treaters (CEST) LLC operates a landfill gas (LFG) treatment facility to recover methane from the City of Fort Smith Landfill in Sebastian County, AR.

The anaerobic decomposition of organic wastes in landfills results in the generation of a biogas commonly referred to as landfill gas (LFG). Raw LFG consists primarily of about [redacted] methane and [redacted] carbon dioxide, but also includes other trace compounds and water vapor. A landfill Gas Collection and Control System (GCCS) consisting of 128 vertical extraction wells within the refuse and a series of high density polyethylene lateral and header pipes routes raw LFG to the treatment facility located on the landfill site.

The CEST treatment facility purifies raw LFG via a series of cooling, filtering, and compressing processes using specifically designed equipment. The treatment facility utilizes a previously existing blower/flare at the site. CEST uses purified LFG routed upstream of the meter as pilot fuel for the flare and the thermal oxidizer and purchases electricity from Oklahoma Gas & Electric Company to serve the plant's electrical demand.

No permit limitation exists to the production of product gas at CEST. The maximum production capacity is the facility's equipment processing capacity and was determined through the EPA Registration process. The annual US EPA Actual Peak Capacity (calculated using the lower heating value of methane) is [redacted] million renewable fuel gallon equivalents of purified biogas production per year.

Pipeline grade LFG is transported via pipeline from Arkansas to California for liquefaction and sale. The following pathway was produced using two years (January 2012 – December 2013)[1] of landfill gas production data and two (2) years (2011-2012)[2] of liquefaction data.

## Process Description

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

[1] Please see Annex 5 for CEST electric bills, and Annex 6 and 7 for the facility's gas sales

[2] Please see Annex 8 for LNG station electrical efficiency data

[3] Please see Annex 3 RSF Control Union Engineering Report for additional details

[redacted]

[redacted] The heat content of the gas sold minus the heat content of any propane supplement added reflects the amount of renewable fuel produced (i.e. the heat content of methane recovered) by the treatment facility. This amount is dedicated for transference to downstream commercial customer(s) for qualified end use and RIN generation and are shown in the invoices to Shell and is therefore not included as an input in the analysis presented in this report.

The LFG is primarily utilized by an off-site end user and the flare is only operational at those times when it is not used for its primary purpose.

A landfill gas with a [redacted] methane content is processed to [redacted] methane purity, the balance being the inerts of N2 and CO2[4]. Approximately 94% of the methane is recovered in the gas to be sold. The balance is consumed in the flare or thermal oxidizer as the TOX pilot[5]. The purified LFG for the TOX is routed upstream of the meter.
.

## 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 & Distribution.

### LFG Production Plant

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

Two years (2012-2013) of plant modeling data show an average landfill gas inlet of [redacted] mmscf/day[6] at [redacted] methane which is equivalent to a potential product of [redacted] mmscf/day[7] of biogas at [redacted] methane. The CEST 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.

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[4] Annex 3 RSF Control Union Engineering Report, page 1
[5] Annex 2, Summary, cell K34.
[6] Please see Annex 2, Summary tab, cell K27 for the calculation of this figure
[7] Please see Annex 2, Summary tab, cell F27/10^6 for the calculation of this figure
[8] Please see Annex 2, Summary tab, cell E34 for the calculation of this figure

Table 1 below shows the available data provided by CEST for input biogas, product biogas, biogas consumed on-site and imported electricity from January 2012 to December 2013. The balance of the biogas consumed in the thermal oxidizer and flare is calculated based on modeling data provided in the CEST Engineering Report (*Annex 3, pages 20 and 23*). The table also shows the provided data converted to GREET model inputs. The CEST pathway utilizes the CA-GREET default values for LFG recovery. The value of [redacted] MMBtu/hr in Table 1 below is the average amount of product pipeline quality biogas produced per hour. 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. CEST LFG PLANT OPERATING ENERGY AND FLARE CREDIT[9]**
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

| | Jan 2012 – Dec 2013 Average 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] | Calculated w/in GREET[11] | |

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 and 7 for PDFs of gas sales invoices
[11] Please see Annex 9 for the Modified GREET model referred to in this report

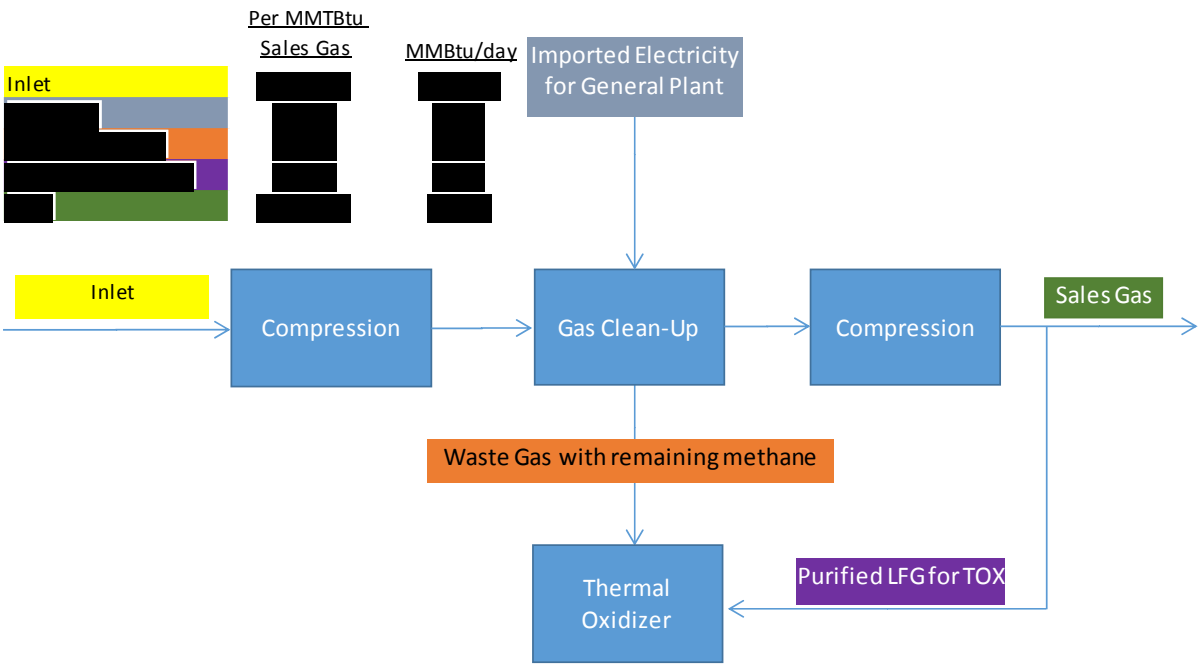


Figure 1. CEST Process per MMBtu and MMBtu/day Energy Flows

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 SPP South (SPSO) Region to represent the 2012 eGRID data for year 2009 (8th Edition[12]) where Fort Smith, AR 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 SPSO region) were changed to match the US Average.

**TABLE 2. SPSO ELECTRICITY GRID MIX**

| | eGRID CY2009 Grid Mix | Marginal Grid Mix | CA-GREET Cell Regional LT Tab |
|---|---|---|---|
| Residual oil | 0.39% | 0.39% | J83 |
| Natural gas | 33.87% | 39.40% | J84 |
| Coal | 55.23% | 55.23% | J85 |
| Nuclear | 0.00% | 0.00% | J86 |
| Biomass | 1.21% | 1.21% | J87 |
| Other (renewables) | 9.31% (w/ hydro) | 3.78% (w/o hydro) | J88 |

This produced the results for LFG to CNG shown in Table 3 below. These values are taken from the NG Tab of the Modifed GREET model which can be found in Annex 9 of the supporting documents

[12] 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

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] The default LFG transport distance of one mile was used since the distance between CEST and the City of Fort Smith Landfill is less than 1 mile, as can be seen in Figure 2 below.

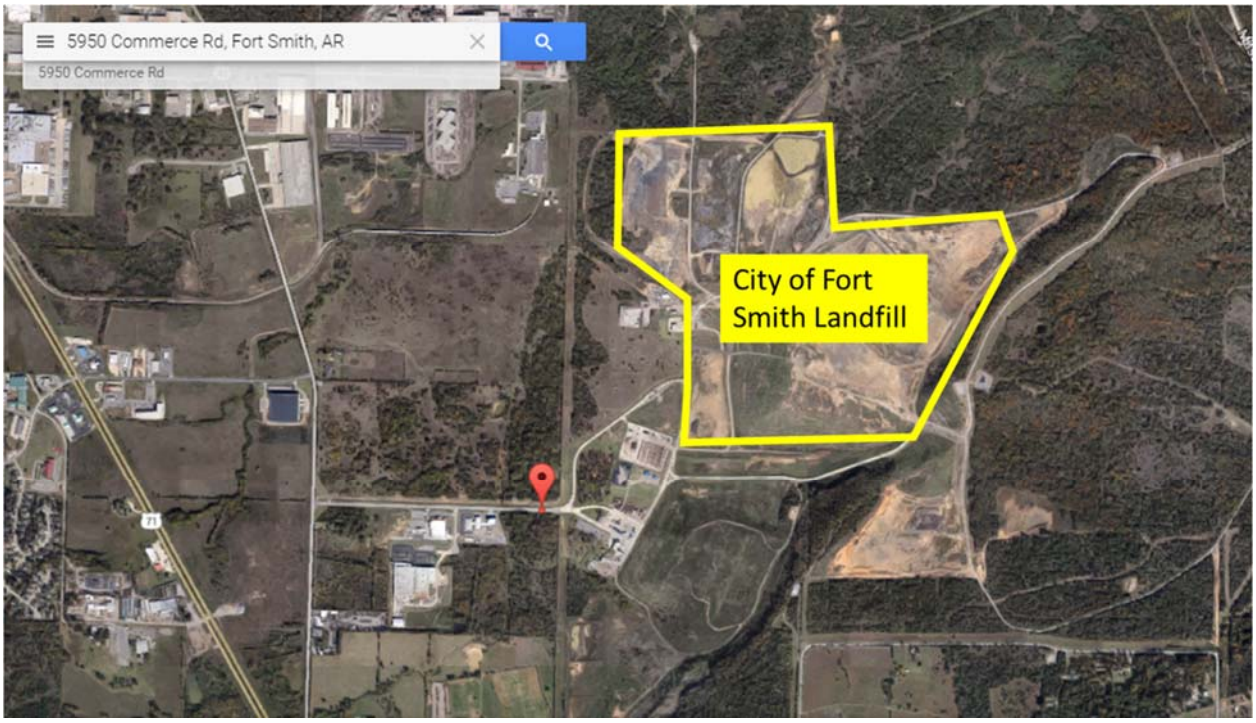


Figure 2. Proximity between CEST (identified location) and the City of Fort Smith Landfill

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

| | Recovery Emissions | CEST LFG Plant | CA-GREET Cell 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] |

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

## Transportation to California by Pipeline

The pipeline transport distance was modified to 1,442 miles from Fort Smith, AR 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.[14] 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. CEST LFG TRANSPORT GREENHOUSE GAS EMISSIONS**
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

| Transport Emissions | CEST LFG Transport |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |

## Liquefaction

(THIS SECTION CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

Based on the submitted Confidential Business Information from Clean Energy Fuels for two (2) years (2011-2012), the Boron facility requires [redacted]. All excess gas that is not converted to LNG is sent to the neighboring natural gas power plant.

Table 5 and

Table 6 below show the calculation from kWh/GGE to process efficiency and the cells that were changed and the results from cells G163- G169.

**TABLE 5. BORON LNG PLANT OPERATING EFFICIENCY[16]**
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

| All Units in Btus per Gal of LNG | Boron LNG Plant | Input Value | Changed Cells – NG Tab |
|---|---|---|---|
| [redacted] | [redacted] | | |
| [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] |

[redacted]

| | | | |
|---|---|---|---|
| [redacted] | [redacted] | [redacted] | [redacted] |

**TABLE 6. BORON LNG PLANT GREENHOUSE GAS EMISSIONS**
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

| Recovery & Processing Emissions | Boron LNG Plant - Liquefaction |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |

## LNG Transport to Refueling Station

In addition the CA-GREET default LNG transport distance of 50 miles was used but the fuel shares were modified to utilize the Westport HPDI trucks consuming 90% LNG and 10% diesel with an EER of 1.0. The numbers were inputted in cells CD95 (% diesel consumption) and CD97 (% LNG consumption) on the "T&D" tab and the results were taken from cells H163-H169 on the "NG" tab. The LNG trucks also have 100% boil-off capture, adjusting "Inputs" Tab cell D179 to 100%.

**TABLE 7. LNG TRANSPORT GREENHOUSE GAS EMISSIONS**
(THIS TABLE CONTAINS CONFIDENTIAL BUSINESS INFORMATION)

| Recovery & Processing Emissions | Boron LNG Plant – Transport |
|---|---|
| gVOC/MMBTU | 0.150 |
| gCO/MMBTU | 0.400 |
| gCH4/MMBTU | 0.710 |
| gN2O/MMBTU | 0.009 |
| gCO2/MMBTU | 289.99 |
| gCO2e/MMBTU | 311.62 |
| gCO2e/MJ | **0.30** |

## LNG Storage

In addition the CA-GREET default for LNG storage was used. The default values are listed in Table 8 below (the results were taken from cells I163-I169 on the "NG" tab).

**TABLE 8. 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 | 0.05 | E171 | 0.1 | F171 |
| Duration of Storage or Transit: Days | 5 | E174 | 0.1 | F174 |
| Recovery Rate for Boil-Off Gas | 80% | E179 | 80% | F179 |

**TABLE 9. 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 re-vaporized and then compressed to cylinder pressure (at about 3000psi). According to ARB default LNG and CNG pathways (as sent to Clean Energy and ICF by ARB Staff):

- Re-gasified to LNG: + 0.75 gCO2e/MJ[17]
- Compressed to CNG: +2.14 gCO2e/MJ[18]
- Total: 2.89 gCO2e/MJ

[17] http://www.arb.ca.gov/fuels/lcfs/092309lcfs_lng.pdf
[18] http://www.arb.ca.gov/fuels/lcfs/022709lcfs_cng.pdf

## CEST 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 Gas[19].

**TABLE 10. PATHWAY RESULTS**

| GHG Emissions (gCO2e/MJ) | CEST LFG Plant to LNG | CEST LFG Plant to L/CNG |
|---|---|---|
| [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] |
| gCO2e/MJ WTW | 32.16 | 34.28 |

[19] 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 | | | |
| [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] | [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] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | | | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] |

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

| | | | |
|---|---|---|---|
| Boil-Off Rate: % per Day | %/day | 0.05 / 0.1 | E171 / F171 |
| Duration of Storage or Transit: Days | Days | 5 / 0.1 | E174 / F174 |
| Recovery Rate for Boil-Off Gas | % | 80% / 80% | E179 / F179 |
| L/CNG | | | NG Tab |
| L/CNG Conversion | gCO2e/MJ | 2.89 | J171 |

## Appendix B: List of Supporting Annexes

Annex 2 - Facility Energy Data & Analysis_070214

Annex 3 - RSF Control Union Eng Report

Annex 5 - Electric Bills 2012-2013

Annex 6 - Gas Sales 2012

Annex 7 - Gas Sales 2013

Annex 8 – Boron LNG Electricity Consumption Data

Annex 9 - Modified GREET model LFG to LNG and LCNG