**LCFS Life Cycle Fuel Pathway Report**
**Method 2B Application: Out of State Landfill Gas to LNG for LNG and LCNG vehicle use**

**Applied Natural Gas Fuels**

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## 1.) Company Overview

Applied Natural Gas Fuels, Inc. (ANGF) operates a Liquefied Natural Gas (LNG) plant in Topock, Arizona. ANGF has recently entered into agreements to procure landfill gas from facilities around the United States to be shipped to ANGF's plant and converted to LNG, then delivered to California for LNG and LCNG[1] transportation use.

This pathway is intended to describe a generic North American landfill gas to LNG pathway that may be applied to any landfill gas to pipeline facility in the United States shipping pipeline biogas to ANGF's Topock facility. It is based on both the existing ARB Method 1 pathway for out of state landfill gas to CNG and a natural gas to LNG pathway that was previously submitted by ANGF and posted by ARB in September of 2012. It should be noted that this pathway is a true blend of the two existing pathways: the upstream LFG gathering, processing, and pipeline transportation portions are exactly identical to the exiting out of state LFG-CNG pathway, and the portions downstream from the LNG plant are exactly identical to the existing ANGF LNG pathway, with an additional modification for re-vaporization and subsequent compression for use in CNG vehicles. Because this pathway presumes that landfill gas itself is used as process fuel at the LNG plant, the liquefaction stage of this pathway has been modified to reflect the use of LFG as process fuel rather then North American natural gas.

Furthermore, ANGF is requesting that as part of this pathway, similar guidelines be applied to the mixing of natural gas feedstocks as has been previously approved for the mixing of feedstocks for other biofuels such as renewable diesel and ethanol[2], wherein the proportion of different carbon intensities in a finished batch of fuel is assumed to be equal to the proportion of the different feedstocks input at the beginning of the fuel manufacturing process. Stated another way, if X% of the natural gas feedstock in a given time period is from a specific source, then X% of the finished LNG is considered to be made from than same source and have a specific carbon intensity different and distinct from the rest of the fuel, and, so long as appropriate accounting records are kept and cargoes adequately tracked, the finished volume of may be divided and shipped as desired.

## 2.) Generic Landfill Gas to LNG Pathway

As stated above, this pathway is based on a combination of the Method 1 ARB out of state landfill gas to CNG pathway and ANGF's previously approved natural gas to LNG Method 2B pathway.

[1] L-CNG (Liquefied-to-Compressed Natural Gas) is produced by vaporizing the LNG and using the resulting gas to charge CNG tanks. The fuel from these tanks is used in CNG-powered vehicles.
[2] California Air Resources Board, *Mixed Feedstock Bio- and Renewable Diesel Guidance: Low Carbon Fuel Standard*, December 3, 2012

The upstream portion of the ARB out of state LFG-CNG ARB makes certain assumptions, that are duplicated in this pathway, to better approximate the higher carbon intensity of landfill gas originating from out of state sources that may a.) be further away from California and thus require a higher energy input for pipeline transportation over a greater number of miles; b.) utilize older equipment that is less efficient compared to contemporary standards; and c.) be located in states with a local electricity generation mix that uses power sources with higher carbon intensities than that of the California marginal mix used in the original ARB in-state pathway. To meet these criteria for a higher CI out of state pathway, the following five main assumptions differ from existing ARB in-state landfill gas pathways

- A pipeline distance of 3,600 miles from out of state sources to California versus 50 miles from an in-state landfill to fueling station.
- LFG processing is at 77.2% efficiency with processing fuels shares of 76.2% LFG and 23.8% electricity usage.
- A methane removal efficiency of 84% versus 90% achieved from newer technology.
- Electricity provided from a fuel mix that is 100% generated from coal compared to the much less carbon intensive California marginal mix used in the existing LFG pathway assumptions.
- The use of "US Average" crude oil recovery values in the Cal GREET model (as opposed to the California values used for in state sources).
- Reverting back to the GREET model default assumption of 0.15% T&D leakage rather than the 0.08% assumption used for California in-state pipeline systems.

### 2.1) Landfill Gas Recovery and Transport to Processing

This 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 Cal GREET model for the ARB out of state LFG-CNG pathway, the energy necessary for these steps is approximately 15,082 Btu's 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 1.59 $gCO_2e/MJ$.

### 2.2) Landfill Gas Processing

The next step in this pathway is cleaning the LFG to pipeline quality and pressure, via a compressor system feeding the gas through a membrane to separate usable methane from the LFG stream. In order to make the out of state LFG pathway as conservative as possible, it presumes a less advanced membrane with only an 84% efficiency. Any remaining uncleaned landfill gas (approximately 16%) is combusted in a thermal oxidizer to minimize emissions. Per the existing LCFS pathway, a typical LFG recovery system draws 2,570 MMBtu/day of LFG from the landfill and requires 1.8 MW of grid electricity. The thermal oxidizer uses pre-membrane LFG at a rate of 72 MMBtu/day.

With 2,570 MMBtu/day drawn from the landfill and 72 being used as fuel in the thermal oxidizer, 2,498 MMBtu/day is fed to the membrane where 84% (2,098 MMBtu/day) is sent to the pipeline.

The remaining 16% (400 MMBtu/day) is sent to the thermal oxidizer. 1.8 MW (147.41 MMBtu/day) is used as the process energy. Therefore, the overall efficiency of the LFG gas cleaning process is 2,098/(2,570+147.41) = 77.2%. Because the lower overall process efficiency removes less methane from the gas stream, the energy process share between landfill gas and electricity consumption is larger than in the original ARB in-state LFG-CNG pathway (76.2% and 23.8% versus 68.6% and 31.4%, respectively).

Using the 77.2% efficiency factor and the reallocated energy process shares between landfill gas and electricity, plus a flaring credit for all energy that is captured and would otherwise be flared to the atmosphere, the total energy consumed during the processing stage of this pathway is -783,680 Btu/MMBtu of energy captured and the total emissions are -32.73 gCO2e/MJ. Note that the flaring credit is higher here than the in-state pathway due to the lower overall efficiency of the process, which results in less methane being captured in the energy stream and thus more methane being consumed in the processing stage.

### 2.3) Natural Gas Transport and Distribution

The third step in this pathway is transport and distribution of the natural gas by pipeline from the processing plant to the LNG manufacturing plant It is assumed that the refueling station is located 3,600 miles from the LFG processing plant. The energy consumption for T&D consists of:

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

This pathway relies on out of state pipeline systems and therefore uses a more conservative default GREET assumption of 0.15%.

Based on the current assumptions in the GREET model, plus the two changes in pipeline distance and leakage assumptions made above, the transport and distribution stage of this pathway consumes 43,126 Btu/MMBtu with emissions of 3.37 gCO2e/MJ.

### 2.4) LNG Liquefaction

LNG is produced by the compression and cooling of natural gas and expansion through several stages in an LNG plant. LNG is stored at around 15 psi at -162°C (-260°F).

The Topock LNG plant is supplied by mainline pipeline gas with supply pressure of approximately 650 psi. The feed gas for LNG is free of components that freeze at cryogenic temperatures including CO2 and high molecular weight hydrocarbons (C6 and greater). Because the refined landfill gas is delivered to the plant via a common carrier natural gas pipeline, it is assumed that the gas meets pipeline specifications.

The Topock LNG plant operates with an efficiency of [redacted], which implies that [redacted] Btu of LFG input is required to liquefy 1MMBtu of LNG fuel. A natural gas turbine is used for liquefaction energy. Unlike NG extraction and processing, CA-GREET models feed loss (Btu/MMBtu) based directly on the methane boil-off rather than using a fuel share for feed loss. However, zero percent feed loss is assumed because typically LNG facilities recapture boil off and re-liquefy the NG or use it as fuel.

Total energy for liquefaction is based on the direct energy input plus the upstream energy for that fuel and is calculated in the same way as total energy for landfill gas gathering. According to the ARB out of state LFG-CNG pathway, total energy used for landfill gas gathering is 15,084 Btu/MMBtu and total energy used for landfill gas production, including a flaring credit, is 783, 680 Btu/MMBtu. Additionally, per the existing ANGF LNG pathway, grid electricity usage at the LNG fueling station is approximately [redacted] Btu/MMBtu of finished fuel dispensed. Total energy for liquefaction is therefore [redacted] btu/MMbtu and total emissions are 14.58 gCO2e/MJ.

## 2.5) LNG Truck Transport

LNG is distributed by heavy-duty truck (HDT) from the bulk terminal in California to end-user. The 80,000 lb GVW limit for tanker trucks carrying liquid fuels sets the theoretical upper weight limit for LNG (or any liquid fuel) cargo. The cargo capacity for gasoline tanker trucks is 54,000 lbs, or 9,000 gallons of gasoline. Since the density of LNG is slightly more than half of the density of gasoline, the practical LNG cargo capacity is limited by volume rather than weight. The 9,000 gallon capacity of a tanker truck translates into approximately 35,000 lbs (16 tons) LNG cargo capacity, or ~60% of the cargo weight limit. The Argonne GREET model default of 15 tons is close to this and used in both the ARB LNG pathway and the ANGF LNG pathway.

Heavy-duty tanker trucks transfer LNG by passing a small amount of LNG into a heat exchanger to increase the pressure in the tanker truck and force the liquid into the receiver tank. After transferring the vapors, the LNG tank on the truck is purged. Life cycle energy includes the direct and upstream diesel energy used to operate the truck and the fuel lost to boil off methane emissions (which contributes to the loss factor). Emissions include direct and upstream emissions for diesel fuel in a HDT and the fugitive methane boil-off emissions.

According to the ANGF LNG pathway document, [redacted]% of the LNG is transported by HD diesel trucks to two company-operated refueling stations (Barstow and Ontario) and to other LNG transportation customers in California. The remaining [redacted]% is transported by the one LNG truck in the fleet. Total energy is [redacted] Btu/MMBtu. The carbon intensity is estimated to be 3.87 g/MJ of LNG produced.

## 2.6) LNG Storage

At the final destination, some CH4 is released or "boiled off" to keep the cargo cool while stored. The GREET model for the existing ANGF pathway uses different boil-off rates for different locations: [redacted]%/day at the storage plant [redacted]%/day during transportation and during refueling station storage. ANGF's Barstow station is equipped with a methane boil-off recovery system. Using the values originally presented in the ANGF pathway, total energy in this stage is [redacted] Btu/MMBtu and the carbon intensity is calculated to be 0.66 g/MJ.

**Table 2: Results from CA-GREET Model(s) with Modified Assumptions**

| | Energy, Btu/MMBtu | GHG, gCO2e/MJ |
|---|---|---|
| **Well-to-Tank (WTT)** | | |
| Landfill Gas Recovery and Transport[3] | 15,084 | 1.59 |
| Landfill Gas Processing[4] | -783,680 | -32.73 |
| Transport & Distribution[5] | 43,126 | 3.37 |
| LNG Production[6] | [redacted] | 14.58 |
| LNG Transportation and Distribution[7] | [redacted] | 3.87 |
| LNG Storage[8] | [redacted] | 0.66 |
| **Total WTT** | [redacted] | **-8.66** |
| | | |
| **Tank-to-Well (TTW)** | | |
| Carbon in Fuel[9] | 1,000,000 | 56 |
| Vehicle CH4 and N2O[10] | | 2.5 |
| **Total TTW** | **1,000,000** | **58.5** |
| | | |
| **Total Well-to-Wheel (WTW)** | [redacted] | **49.84** |

## 2.7) Re-vaporization and Compression for Use as LCNG

While many customers consume LNG in its liquid form, some customers consume the LNG in a CNG vehicle. In this case the LNG is re-vaporized and then compressed to CNG cylinder pressure (~3000-3600 psi) and dispensed into CNG vehicles. This step is identical to the existing CNG pathways previously approved by CARB. The energy usage is 40,748 Btu/MMBtu and carbon intensity of this step is calculated to be 2.14 g/MJ as shown in Table 3.

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[3] Equal to values found in existing ARB Method 1 pathway for out of state LFG-CNG
[4] Equal to values found in existing ARB Method 1 pathway for out of state LFG-CNG
[5] Equal to values found in existing ARB Method 1 pathway for out of state LFG-CNG
[6] Calculated using upstream LFG-CNG values within previously published calculations used in the existing ANGF North American LNG Method 2B pathway
[7] Equal to values found in existing ANGF North American LNG Method 2B pathway
[8] Equal to values found in existing ANGF North American LNG Method 2B pathway
[9] Equal to values found in existing ANGF North American LNG Method 2B pathway
[10] Equal to values found in existing ANGF North American LNG Method 2B pathway

**Table 3: Results from CA-GREET Model(s) with Modified Assumptions**

| | Energy, Btu/MMBtu | GHG, gCO2e/MJ |
|---|---|---|
| **Well-to-Tank (WTT)** | | |
| Landfill Gas Recovery and Transport[11] | 15,084 | 1.59 |
| Landfill Gas Processing[12] | -783,680 | -32.73 |
| Transport & Distribution[13] | 43,126 | 3.37 |
| LNG Production[14] | [redacted] | 14.58 |
| LNG Transportation and Distribution[15] | [redacted] | 3.87 |
| LNG Storage[16] | [redacted] | 0.66 |
| Re-vaporization and Compression to CNG | 40,748 | 2.14 |
| **Total WTT** | [redacted] | **-6.52** |
| | | |
| **Tank-to-Well (TTW)** | | |
| Carbon in Fuel[17] | 1,000,000 | 55.2 |
| Vehicle CH4 and N2O[18] | | 2.5 |
| **Total TTW** | **1,000,000** | **57.5** |
| | | |
| **Total Well-to-Wheel (WTW)** | [redacted] | **50.98** |

[11] Equal to values found in existing ARB Method 1 pathway for out of state LFG-CNG
[12] Equal to values found in existing ARB Method 1 pathway for out of state LFG-CNG
[13] Equal to values found in existing ARB Method 1 pathway for out of state LFG-CNG
[14] Calculated using upstream LFG-CNG values within previously published calculations used in the existing ANGF North American LNG Method 2B pathway
[15] Equal to values found in existing ANGF North American LNG Method 2B pathway
[16] Equal to values found in existing ANGF North American LNG Method 2B pathway
[17] Equal to values found in existing ANGF North American LNG Method 2B pathway
[18] Equal to values found in existing ANGF North American LNG Method 2B pathway

## References

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

California Air Resources Board . "MAXCOAL-CNG pathway for Out of State Landfill Gas to CNG" Technical Report, 2013.

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Applied Natural Gas Fuels, Inc. "Method 2A application for Liquefied Natural Gas from Topock Arizona" Technical Submission, 2012.