LCFS Life Cycle Fuel Pathway Report
North-American Landfill Gas to Compressed Natural Gas

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1.) Overview

This pathway is intended to describe a generic North-American landfill gas to CNG pathway that may be applied to any landfill gas to pipeline facility in the United States. It is based on the existing ARB pathway for California Landfill Gas to CNG (ARB, 2009) with certain modifications to account for the processing facility being located outside of California and using less up-to-date technology than that assumed in the existing ARB pathway.

2.) North American Landfill Gas to CNG Pathway Description

The North-American LFG-to-CNG pathway is based on the existing ARB LCFS pathway for landfill gas to CNG from in-state sources in California. Modifications have been made to 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 pathway. To meet these criteria for a higher CI out of state pathway, the following five main assumptions were changed from the existing LCFS landfill gas to CNG pathway:

- 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.
- A methane removal efficiency of 84% versus 90% achieved from newer technology.
- LFG processing is at 77.2% efficiency with processing fuels shares of 76.2% LFG and 23.8% electricity usage.
- Electricity provided from electricity that is 100% generated from coal compared to the much less carbon intensive California marginal mix used in the existing pathway.
- The use of “US Average” crude oil recovery values in the CA-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.

Unless otherwise noted, no other assumptions were changed from the existing LCFS in-state LFG CNG pathway.

2.1) Landfill Gas Recovery and Transport to Processing

The North American LFG-to-CNG 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 model, 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 gCO2e/MJ.

2.2) Landfill Gas Processing

The next step 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. The LFG processing data in the existing CARB pathway assumes a membrane efficiency of 90%, based on advanced contemporary technology. In order to make the 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 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 the pathway is -768,198 Btu/MMBtu of energy captured and the total emissions are -32.19 gCO_2e/MJ. Note that the flaring credit is higher 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 (T&D)

The third step in the CNG from LFG 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 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

Although the existing ARB pathway assumes a T&D leakage rate of 0.08% based on data provided by PG&E and Socal Gas (which are entirely inside of California), the pathway relies on out of state pipeline systems and therefore reverts back to the 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 o 43,825 Btu/MMBtu with emissions of 3.73 gCO2e/MJ.

2.4) CNG Compression at the Fueling Station

Once the gas reaches California, the remaining steps are identical to the existing ARB LFG-to-CNG pathway.

At the CNG fueling station, the gas is withdrawn from the pipeline and compressed to approximately 3,000 psi (or higher) for dispersal into a natural gas vehicle. Fueling station compressors are assumed to be 97% efficient and powered by grid electricity, in this case, electricity from the relatively low carbon California Marginal Mix. This results in an energy consumption of 40,746 Btu/MMBtu and emissions of 2.15 gCO2e/MJ.

The gas is shipped via the existing natural gas pipeline grid to a CNG fueling station.

The gas is compressed (~3,000 psi) and dispensed into a CNG vehicle and subsequently combusted as fuel as described in the existing ARB LFG-to-CNG document (ARB, 2009).

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

A key presumption within the administration of the LCFS is that a fuel may not utilize a pathway that results in a reported carbon intensity that is less than its actual CI. Accordingly, three key assumptions within the existing ARB California landfill gas pathway were changed to better reflect the characteristics of the fuel being produced out of state and to calculate a hypothetical maximum carbon intensity pathway that could be applicable to landfill gas produced anywhere in the United States:

- 100% landfill processing energy from electricity produced from coal having average United States characteristics for heating value and carbon content (note that downstream compression to CNG continues to be provided by California marginal electricity);

- The use of older, less efficient methane recovery membranes still in place at older landfill gas processing facilities, thus resulting in a lower overall efficiency in the processing stage. This change in overall processing efficiency subsequently affects the respective energy process shares of landfill gas and electricity as well.

- A much longer pipeline transportation distance necessary to move the fuel from out of state sources onto the California intrastate pipeline system. For the purposes of this exercise, the gas is presumed to travel from Augusta, Maine, to the California border at Topock, Arizona, along the following route:

  Maritime and Northeast Pipeline → Algonquin Gas Transmission → Texas Eastern Pipeline → Trunkline Gas → Sabine Pipeline → Kinder Morgan Texas Pipeline → El Paso Natural Gas → Socal Gas Company

It should be noted that this pathway is not intended to represent any specific landfill in any specific location. Augusta, Maine, was chosen as the hypothetical source of the landfill gas solely because of its maximal pipeline distance from California relative to any other location in the United States.

The changes to the existing ARB pathway are summarized in the table below:

Table 1: Changes to CA-GREET Assumptions

Model Parameter	Existing CARB Pathway for In-State Landfill Gas to CNG	Modified Assumption for New Pathway for Out of State Landfill Gas to CNG	GREET Model Cell References
Electricity Mix at LFG processing facility	California Marginal Mix	100% from coal	Regional LT!C83:C88
Coal Fuel Properties	N/A	Set to "U.S. Average" values	Regional LT!C192:C195
Crude Recovery Fuel Shares	N/A	Set to "U.S. Average" values	Regional LT!C13:C22
Methane Membrane Efficiency	90%	84%	N/A
Total Processing Efficiency	82.7%	77.2%	NG!AI66
LFG process share (due to membrane)	68.6%	76.2%	NG!AI75
Electricity process share (due to membrane)	31.4%	23.8%	NG!!AI79
Pipeline Leakage	0.08%	0.15%	NG!X118
Pipeline Distance	50 miles	3,600 miles	T&D!BR93 T&D_Flowcarts! AE478

4.) Results From CA-GREET Model

When the changes described in Table 1 above are entered into the CA-GREET model, the final result is a pathway CI of 33.02 gCO_2e/MJ, as summarized in Table 2 below.

Cells containing parameters modified from the existing ARB pathway are shaded in Table 2 below. Note that all other parameters within the CA-GREET model calculation for the existing ARB pathway for in-state landfill gas to CNG remain unchanged and the existing ARB pathway is hereby incorporated by reference.

Table 2: Results from CA-GREET Model with Modified Assumptions

	Energy, Btu/MMBtu	**GHG, gCO_2e/MJ**
Well-to-Tank (WTT)		
Landfill Gas Recovery and Transport	15,072	1.59
Landfill Gas Processing	-768,198	-32.19
Transport & Distribution	43,826	3.73
Compression at Station in California	40,748	2.15
Total WTT	**-668,570**	**-24.71**
Tank-to-Well (TTW)		
Carbon in Fuel	1,000,000	55.20
Vehicle CH4 and N2O		2.53
Total TTW	**1,000,000**	**57.73**
Total Well-to-Wheel (WTW)	**331,430**	**33.02**

References

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