California Environmental Protection Agency

Air Resources Board

Detailed California-Modified GREET Pathway for Liquefied Natural Gas (LNG) from North American and Remote Natural Gas Sources

Stationary Source Division

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The Staff of the Air Resources Board developed this preliminary draft version as part of the Low Carbon Fuel Standard regulatory process

The ARB acknowledges contributions from Life Cycle Associates (under contract with the California Energy Commission) during the development of this document

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These comments will be compiled, reviewed, and posted to the LCFS website in a timely manner.

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SUMMARY

CA-GREET Model Pathway for LNG from North American Natural Gas and Remote Natural Gas

Well-To-Tank (WTT) Life Cycle Analysis of a fuel pathway includes all steps from feedstock recovery to final finished fuel. Tank-To-Wheel (TTW) analysis includes actual combustion of fuel in a motor vehicle for motive power. Together, WTT and TTW analysis are combined to provide a total Well-To-Wheel (WTW) analysis.

A Life Cycle Analysis Model called the **Gr**eenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation (GREET)[1] developed by Argonne National Laboratory forms the core basis of the methodology used in this document. This model was modified by staff with assistance from Life Cycle Associates to create a CA-GREET model. This modified model incorporated California specific factors for emission factors, fuel properties, etc. into the original Argonne model. This pathway document details the energy use and associated Greenhouse Gas (GHG) emissions for the entire Liquefied Natural Gas (LNG) from Natural Gas (NG) pathway. The document includes LNG derived from: natural gas produced in North America and natural gas from remote NG sources (overseas from South East Asia for this document). Figure 1 details the steps for the three scenarios modeled in this document for LNG availability and use in California.

Appendix A1: The left most scenario (Scenario 1) is for NG recovered and processed in North America, transported via pipeline to California, liquefied in California, transported to LNG filling stations in California and used as LNG in a heavy-duty vehicle in California. Complete details for this scenario is provided in Appendix A1.

Appendix A2: The scenario in the middle of Figure 1 (Scenario 2) is for NG recovered, processed, and liquefied from remote sources (assumed from South East Asia), transported via tanker to Baja, re-gasified to NG and pipelined to California where it is liquefied to LNG, transported to LNG filling stations and used as LNG in a heavy-duty vehicle in California. Complete details for this scenario is provided in Appendix A2.

Appendix A3: The rightmost scenario in Figure 1 (Scenario 3) is for NG recovered, processed, and liquefied from remote sources, transported via tanker to Baja, trucked from Baja to California as LNG and used as LNG in a heavy-duty vehicle in California. Complete details for this scenario is provided in Appendix A3.

The summary section details the GHG emissions for the three scenarios with complete details for the scenarios provided in Appendices A1, A2, and A3. Details of all the input values are provided in Appendix B.

Note: Staff is working on surveys for NG production, transmission and distribution in California. Based on the results, staff may update the analysis presented in this document.

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[1] GREET Model: Argonne National Laboratory: http://www.transportation.anl.gov/modeling_simulation/GREET/index.html

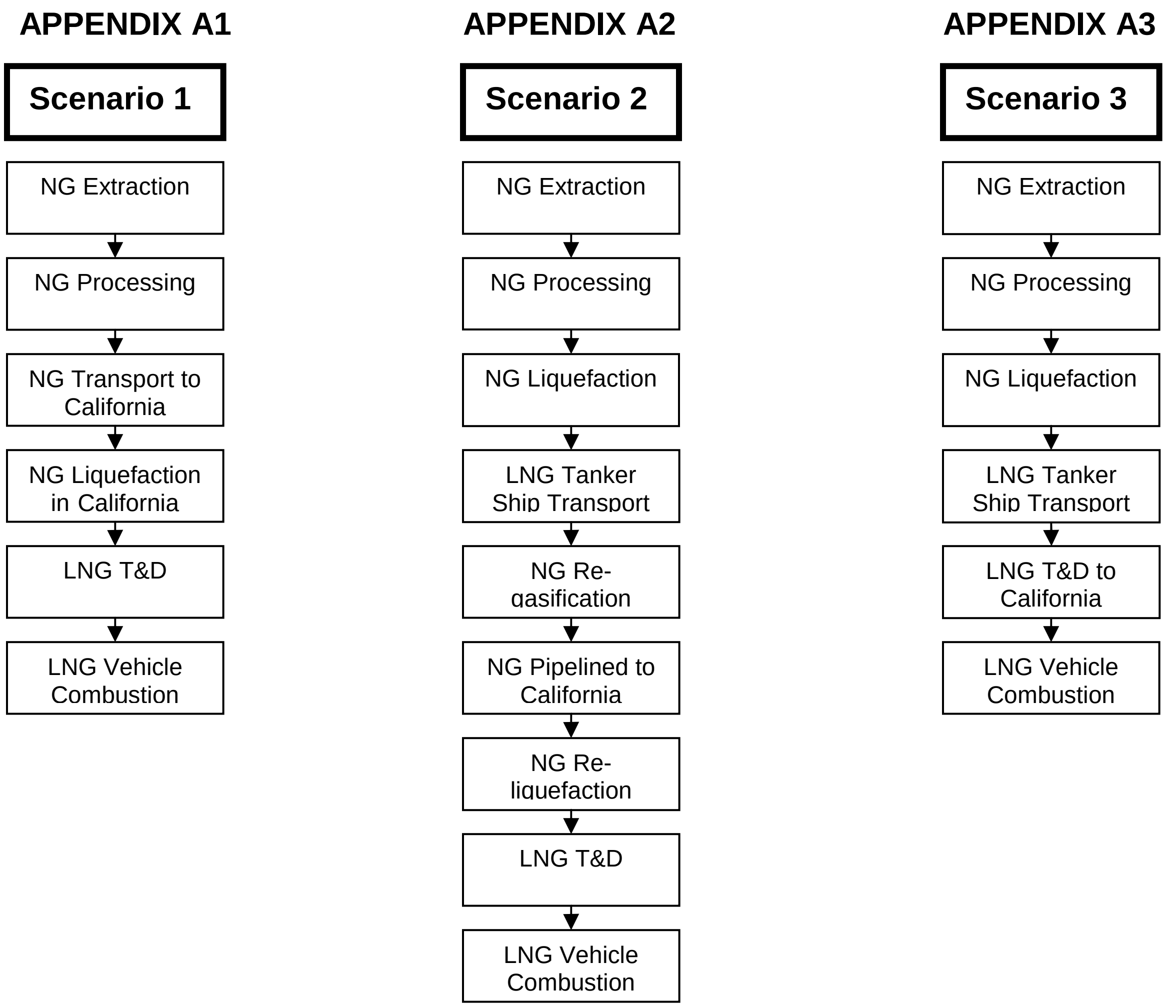

Figure 1. Discrete Components of the Three Natural Gas to LNG Pathways Detailed in this Document

Several general descriptions and clarification of terminology used throughout this document are:

- CA-GREET employs a recursive methodology to calculate energy consumption and emissions. To calculate WTT energy and emissions, the values being calculated are often utilized in the calculation. For example, crude oil is used as a process fuel to recover crude oil. The total crude oil recovery energy consumption includes the direct crude oil consumption and the energy associated with crude recovery (which is the value being calculated).

- Btu/mmBtu is the energy input necessary in Btu to produce or transport one million Btu of a finished (or intermediate) product. This description is used consistently in CA-GREET for all energy calculations. There are 1,055 MJ in one mmBtu of energy, so in order to convert one million Btu into MJ, divide the million Btu by 1,055.

- gCO_2e/MJ provides the total greenhouse gas emissions on a CO_2 equivalent basis per unit of energy (MJ) for a given fuel. Methane (CH_4) and nitrous oxide (N_2O) are converted to a CO_2 equivalent basis using IPCC global warming potential values and included in the total.

- CA-GREET assumes that VOC and CO are converted to CO_2 in the atmosphere and includes these pollutants in the total CO_2 value using ratios of the appropriate molecular weights.

- Process Efficiency for any step in CA-GREET is defined as:

$$\text{Efficiency} = \text{energy output} / (\text{energy output} + \text{energy consumed})$$

Table A below provides a summary of the GHG emissions for all the three scenarios.

Table A. Summary of GHG Emissions for the Three Scenarios Detailed Here

	Appendix A1 Scenario 1	**Appendix A2 Scenario 2**	**Appendix A3 Scenario 3**
	North American NG, Liquefied in CA and used in CA	Overseas LNG shipped to Baja, re-gasified, pipelined to CA, re-liquefied to LNG for use in CA	Overseas LNG, shipped to Baja, then trucked to CA for use in CA
Pathway Components	**gCO_2e/MJ**		
Well-to-Tank			
Natural Gas Recovery	3.49	3.43	3.43
Natural Gas Processing	3.74	4.00	4.00
NG Transport to LNG Plant	0.97	0.45	0.45
Overseas Liquefaction	n/a	7.40	7.40
Transport via Ocean Tanker to CA	n/a	1.65	1.65
Transmission via pipeline	n/a	0.76	n/a
Re-gasification	n/a	0.75	n/a
Liquefaction at LNG Plants	15.79	15.79	n/a
LNG Truck Transport, Distribution and Storage	0.64	0.64	2.07
Total Well-to-Tank GHG Emissions	**24.63**	**34.87**	**19.00**
Tank-to-Wheel			
Carbon in Fuel	56.0	56.0	56.0
Vehicle CH_4 and N_2O	2.50	2.50	2.50
Total Tank-to-Wheel GHG Emissions	**58.50**	**58.50**	**58.50**
Total Well-to-Wheel GHG Emissions (gCO_2e/MJ)	**83.13**	**93.37**	**77.50**

Note: All numerical entries in Table above are in gCO_2e/MJ. Rounding of values has not been performed in several Tables in this document. This is to allow stakeholders executing runs with the CA-GREET model to compare actual output values from the model with values in this document.

APPENDIX A1 (SCENARIO 1)
LNG FROM NORTH AMERICAN NG

SECTION 1. NATURAL GAS RECOVERY

This Appendix details the energy use and GHG emissions for LNG derived from North American Natural Gas. Most of the details provided here for NG is from the NA NG to CNG pathway document published on the Low Carbon Fuel Standard website in February 2009 (http://www.arb.ca.gov/fuels/lcfs/lcfs.htm). The values for NG recovery, processing, and transport to CA are the same as detailed in the NA NG to CNG pathway document published in February 2009 and available from the Low Carbon Fuel Standard website.

1.1 Energy Use for Natural Gas Recovery

Details of the energy use for North American Natural Gas (NA NG) has been provided in the NA NG to CNG pathway document published in February 2009. Table 1.01 provides a summary of the results for energy consumption from recovery of NA NG.

Table 1.01. Total Energy Consumption for NA NG Recovery

Fuel Type	Energy Use
Residual Oil (Btu/mmBtu)	288
Diesel Fuel (Btu/mmBtu)	3,313
Gasoline (Btu/mmBtu)	311
Natural gas (Btu/mmBtu)	23,328
Electricity (Btu/mmBtu)	676
NG Leaks (Btu/mmBtu)	3,290
Total Energy Use for NA NG Recovery (Btu/mmBtu)	**31,207**

Note: See detailed calculations in the NA NG to CNG document published in February 2009 at http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

1.2 GHG Emissions from NA Natural Gas Recovery

The pathway detailed here for NA NG uses the same information for calculating GHG emissions from natural gas recovery. This is available from the NA NG pathway document indicated earlier and the results are summarized in Table 1.02.

Table 1.02. Total GHG Emissions from Natural Gas Recovery

	GHG Species			
Fuel Type	**CO_2**	**CH_4**	**N_2O**	**Total GHG Emissions**
Residual Oil (gCO_2e/mmBtu)	24	0.025	0.000	25
Diesel (gCO_2e/mmBtu)	260	0.292	0.005	269
Gasoline (gCO_2e/mmBtu)	19	0.051	0.001	20
Natural Gas (gCO_2e/mmBtu)	1,366	4.171	0.021	1,477
Electricity (gCO_2e/mmBtu)	56	0.069	0.001	58
NG Leakage (gCO_2e/mmBtu)		72.166		1,804
Total GHG Emissions (gCO_2e/mmBtu)	**1,726**	**4.608**	**0.027**	**1,849**
Total GHG Emissions (gCO_2e/MJ)				**3.49**

SECTION 2. NATURAL GAS PROCESSING

2.1 Energy use for Natural Gas Processing

The energy use is the same as published in the NA NG to CNG pathway document and Table 2.01 provides a summary of the energy use for NG processing.

Table 2.01. Total Energy Consumption for NG Processing

Fuel Type	Energy Use
Diesel Fuel	323
Natural gas	27,889
Electricity	2,172
NG Leaks	1,479
Total Energy Consumption for NG Processing (Btu/mmBtu)	**31,862**

2.2 GHG Emissions from Natural Gas Processing

The GHG emissions for NG processing are the same as detailed in the NA NG to CNG pathway document and Table 2.02 provides a summary of the GHG emissions from natural gas processing.

Table 2.02. Total GHG Emissions from NG Processing

	GHG Species			
Fuel Type	**CO_2**	**CH_4**	**N_2O**	**Total GHG Emissions**
Diesel (gCO_2e/mmBtu)	25	0.028	0.000	26
Natural Gas (gCO_2e/mmBtu)	1,654	0.203	0.025	1,666
Electricity (gCO_2e/mmBtu)	181	0.222	0.002	187
NG Leakage (gCO_2e/mmBtu)	1,253	32.450		811
Non-combustion Processing Emissions (gCO_2e/mmBtu)				1,253
Total GHG Emissions (gCO_2e/mmBtu)	**3,112**	**32.903**	**0.027**	**3,943**
Total GHG Emissions (gCO_2e/MJ)				**3.74**

SECTION 3. NATURAL GAS TRANSPORTATION AND DISTRIBUTION

3.1 Energy Use for NG Transport to LNG Plants in California

The third step in the LNG from NA NG pathway is transport and distribution of the natural gas by pipeline from the processing plant to the LNG refueling station. The energy use is the same as detailed in the NA NG to CNG pathway document. Table 3.01 provides a summary of the energy use for transport of NG to LNG plants in California.

Table 3.01. Energy Use for NG Transport to LNG Plants in CA

Total Energy Use = 9,348 Btu/mmBtu

3.2 GHG Emissions from Natural Gas Transport to LNG Plants in California

GHG emissions from transporting NG to California is the same as detailed in the NA NG to CNG pathway document and is summarized in Table 3.02.

Table 3.02. Total GHG Emissions Associated with NG Transport to California LNG Plants

	GHG Species			
	CO_2	**CH_4**	**N_2O**	**GHG Emissions**
GHG Emissions (g/mmBtu)	**532**	**19.640**	**0.015**	
Total GHG Emissions (gCO_2e/mmBtu)				**1,028**
Total GHG Emissions (gCO_2e/MJ)				**0.97**

SECTION 4. NATURAL GAS LIQUEFACTION TO LNG

4.1 LNG Liquefaction Energy Use

The next step is liquefaction of NG at LNG plants in California. LNG is produced by the compression and cooling of natural gas and expansion through several stages in an LNG plant. LNG is stored near atmospheric pressure at -162°C (-260°F).

LNG plants are generally supplied by pipeline gas with supply pressures ranging from 800 to 1000 psi. The feed gas for LNG is free of components that freeze at cryogenic temperatures including CO_2 and high molecular weight hydrocarbons (C6 and greater). If LNG is produced from pipeline gas in the U.S., it is assumed that the gas meets pipeline specifications.

Medium and small scale LNG facilities operate with typical efficiencies between 76 and 92% using a simple cascade cycle (Kunert 2008)[2]. For the analysis conducted here, only small scale systems (about 5,000 metric ton/year) have been considered based on the systems likely to be used in California. For such systems, the liquefaction efficiencies are likely to be in the lower range of values indicated above. Therefore, for this analysis a liquefaction efficiency of 80% was assumed. Details of the assumptions for efficiency and fuel shares is provided in Table 4.01.

Table 4.01. Energy Efficiency for Natural Gas Liquefaction.

Liquefier Type	Efficiency	Fuel Shares
Small Scale CA	80%, excluding gas processing, which is calculated separately	100% Natural Gas (CA-GREET Default)

North American NG is liquefied at a central facility and distributed by heavy duty LNG trucks. NG liquefaction in California is done by pressure let down or electromagnetic liquefaction and is all electric. Liquefaction in California is assumed to be 100% natural gas- at central facilities, with an average efficiency of 80%. The main parameters for NA liquefaction modeling are:

- Region: California (average crude)
- Liquefaction efficiency (80%)
- Process fuel shares (100% NG, CA-GREET default)
- LNG storage leakage rate (0.05% day, IPCC value)
- LNG storage duration (5 days, CA-GREET default)
- Recovery rate of LNG boil-off (100%)

[2] Kunert (2008). "Small is Beautiful - MiniLNG Concept: A Very Small LNG Production Plant for the Potential Use of Bio-Energy for Future Energy Supply". "The Potential of Bioenergy for Future Energy Supply" Conference, Leipzig, Germany.

The liquefaction efficiency assumed here (80%) implies that 250,000 Btu of direct NG is required to liquefy 1 mmBtu of NG 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. Table 4.02 provides the direct energy use for liquefaction.

Table 4.02. Direct Energy Use by Process Fuel for Liquefaction in California

Process Fuel	Fuel Share	Formula	Direct Energy Use
Natural Gas (Btu/mmBtu)	100%	10^6*(1/0.80 – 1)	250,000
Total Direct Energy Use (Btu/mmBtu)			**250,000**

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 extraction and processing. Total energy use is shown in Table 4.03.

Table 4.03. Total Energy Use by Process Fuel for Liquefaction in California

Fuel	Direct Energy	Upstream Energy	Total Energy Use
Natural Gas (Btu/mmBtu)	10^6*(1/80%)*100% = 250,000	250,000*(31,144 + 31,321)/10^6 = 15,616	265,616
Total Energy Use (Btu/mmBtu)			**265,616**

Note: The values used in this table are from the NA NG to CNG pathway document.

4.2 GHG Emissions from Natural Gas Liquefaction to LNG in California

The analysis in this document considers all liquefaction energy to come from 100% NG with a liquefaction efficiency of 80%. Results for GHG emissions are similar to the energy calculations in the previous section. The pathway assumes zero methane emissions from leaks because typically all NG is either recaptured and re-liquefied or used as a fuel in the process. Table 4.04 summarizes the results where CO and VOC emissions are converted to CO_2eq.

Table 4.04. Total Emissions (Direct + Upstream) Emissions for Liquefaction in California

GHG Species	**GHG Emissions** (g/mmBtu)
VOC	1.707
CO	8.590
CH_4	32.906
N_2O	0.389
CO_2	15,717
GHG Emissions (gCO_2e/mmBtu)	16,655
Total GHG Emissions (gCO_2e/MJ)	**15.79**

SECTION 5. LNG TRANSPORT, DISTRIBUTION, AND STORAGE

5.1 LNG Truck Transport Summary

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 32,000 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 this analysis.

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.

5.2 LNG Truck Transport Energy Consumption

Heavy duty trucks distribute the LNG from the liquefaction facility to the LNG station. The energy results are calculated using a 50 mile transport distance from a LNG plant in California. The main transport inputs are shown below. All inputs except for distances are CA-GREET default values.

- Region: CA (CA marginal electricity, CA average crude)
- Capacity (15 tons)
- Fuel economy (5 mi/gal)
- Fuel used (diesel)
- Fugitive emissions during storage (0.1% loss/day, CA-GREET default)
- Fugitive emission recovery rate (80% industry practice)
- Distance (50 mi, CA-GREET default)

The calculations for heavy duty truck energy consumption are based on truck energy intensity in Btu/ton-mi. The energy intensity is calculated as follows:

Btu/ton-mi = ((128,450 Btu/gal Diesel LHV)/(5 mi/gal))/capacity in tons. The calculation for energy intensity is shown below and direct, upstream and total energy results are presented in Table 5.01.

Energy Intensity for Trip to Destination and Return Trip:
(128,450 Btu/gal)/(5 mi/gal)/15 tons = 1,713 Btu/ton-mi
Direct Diesel Energy

$$\left[\frac{10^6 \times 1{,}724 g/gal}{80{,}968 Btu/gal \times 454 g/lb \times 2{,}000 lbs/ton}\right] \times 50 miles \times 1{,}713 \times 2 \frac{Btu}{ton-mile} =$$

4,016 Btu/mmBtu

Upstream Diesel Energy

$$\left[\frac{10^6 \times 1{,}724 g/gal}{80{,}968 Btu/gal \times 454 g/lb \times 2{,}000 lbs/ton}\right] \times 50 miles \times 1{,}713 \times 2 \frac{Btu}{ton-mile} \times 0.165 Btu/Btu =$$

663 Btu/mmBtu

(where 0.165 Btu/Btu is Btu energy of diesel consumption per Btu of diesel transported - upstream)

Table 5.01. Direct, Upstream and Total Energy Use for Heavy-Duty Diesel Truck Delivering LNG from LNG Plants to Refueling Stations in California

Energy Source	**Energy Use** (Btu/mmBtu)
Direct Energy	**4,016**
Upstream Energy	663
Total Energy (Btu/mmBtu)	4,679

5.3 GHG Emissions from Truck Transport of LNG

Upstream and direct emissions from LNG transport by truck from the LNG plants are shown in Table 5.02 below. Table 5.03 below summarizes the total GHG emissions for LNG transport inclusive of methane losses.

Table 5.02. Upstream and Direct Emissions for Heavy-Duty Diesel Truck Transport of LNG from LNG Plants to Refueling Stations in California

	GHG Species (g/mmBtu)		
Fuels	**CO_2**	**CH_4**	**N_2O**
Upstream Diesel Emissions	64	0.4524	0.001
Direct Diesel Emissions	313	0.006	0.008
Total Emissions (g/mmBtu)	**378**	**0.453**	**0.009**

Example of calculation CO_2 shown above:

Upstream Diesel CO_2:

$$\left[\frac{1{,}724 g/gal}{80{,}968 Btu/gal \times 454 g/lb \times 2{,}000 lbs/ton}\right] \times 50 miles \times 15{,}813 g/mmBtu \times 1{,}713 \times 2 \frac{Btu}{ton-mile} =$$

64 g/mmBtu

where 15,813 g/mmBtu is the upstream CO_2 emissions associated with diesel production (calculated in the "*Petroleum"* sheet of the CA-GREET model)

Direct Diesel CO_2

$$\left[\frac{1{,}724 g/gal}{80{,}968 Btu/gal \times 454 g/lb \times 2{,}000 lbs/ton}\right] \times 50 miles \times (77{,}809 + 77{,}912) g/mmBtu \times 1{,}713 \frac{Btu}{ton-mile}$$

= **313 g/mmBtu CO_2**

Total: **378 g/mmBtu CO_2** where 77,809 g/mmBtu and 77,912 g/mmBtu are the emission factors from the *EF* sheet of CA-GREET.

Fugitive emissions from truck transport are modeled based on 0.1% boil-off/day and 80% recovery. These are CA-GREET default parameters.

Table 5.03. Total GHG Emissions for LNG Transport in CA

Fuel	GHG Species			
	CO_2	**CH_4**	**N_2O**	**GHG Emissions**
Diesel (g/mmBtu)	378	0.453	0.009	392
Methane Losses (g/mmBtu)		0.426		11
Total Emissions (gCO_2e/mmBtu)	**378**	**0.879**	**0.009**	**403**
Total GHG Emissions (gCO_2e/MJ)				**0.38**

5.4 GHG Emissions from Storage of LNG

Fugitive methane emissions occur during LNG storage. The net emissions are a function of the methane boil-off and recovery rates. There are 6 key inputs determining the fugitive methane emissions, shown below in Table 5.04.

Table 5.04. LNG Storage Emissions

Description	Bulk Terminal	Distribution
Daily Boil-Off Rate (%)	0.05%	0.1%
Duration (Days)	5	0.1
Boil-Off Recovery Rate (%)	80%	80%
Net Methane Emissions (g/mmBtu)	10.7	0.4
Net Methane Emissions (gCO_2e/mmBtu)	267	10.6
Net Methane Emissions (gCO_2e/MJ)	0.25	0.01
Total GHG Emissions (gCO_2e/MJ)	**0.26**	

Calculation of the net fugitive emissions based on the inputs is shown below:

Net Boil-Off Emissions:
[(0.05% bulk terminal boil-off/day)*(5 days)/(1-(0.05% bulk terminal boil-off/day)*(5 days))*(1-80% recovery) + [(0.1% distribution boil-off/day)*(0.1 days)/(1-(0.1% distribution boil-off/day)*(5 days))*(1-80% recovery)]*10^6/(80,968 Btu/gal)*(1,724 g/gal) = **11.1** g CH_4/mmBtu

Converting to gCO_2e/MJ: (11.1 g CH_4/mmBtu)*25/(1055 MJ/mmBtu) = **0.26** g CO_2e/MJ

SECTION 6. GHG EMISSIONS FROM VEHICLES

6.1 LNG Composition

LNG composition affects the inputs to its life cycle analysis in two ways. First, the composition determines the product fuel's carbon content which can range from 74.7 to 76.1% corresponding to a range of 55.4 to 56.8 g/MJ (as CO_2) when calculated from the individual LNG composition. The range in carbon content for LNG is relatively small as it contains low levels of nitrogen and no CO_2. A carbon content of 75.7% was selected as the CA-GREET input based on the average of a range of LNG compositions. The CA-GREET inputs for heating value and density were also changed to reflect LNG compositional data that was consistent with data and the carbon content in g/MJ.

6.2 GHG Emissions from Vehicles

Vehicle GHG emissions consist of:

- Tailpipe CO_2 (combusted CH_4)
- Tailpipe N_2O (combustion product)
- Tailpipe CH_4 (product of incomplete combustion, evaporative losses)

In this analysis, heavy duty trucks use LNG. The CO_2 is calculated from the carbon content of the fuel, minus the tailpipe methane emissions. CO_2 emissions therefore depend on the fuel heating value (LHV), density (g/gal) and carbon content (% C by weight).

(1,724 g-LNG/gal)*(0.757 g-C/g-NG)*(1/80,968 Btu/gal)*(44 g-CO_2/12 g-C)*(Btu/1.055 kJ)*(1,000 kJ/MJ) = **56.0** g CO_2/MJ

In the above equations 1,724 is the density of LNG (CA-GREET default), 0.757 is the Carbon in LNG (Ca-GREET default) and the LHV of LNG is 80,968 Btu/gal.

The same vehicle CH_4 and N_2O emissions are assumed for LNG vehicles as CNG vehicles which is 2.5 g CO_2e/MJ, (see NA NG to CNG fuel pathway document on the LCFS website at http://www.arb.ca.gov/fuels/lcfs/lcfs.htm for complete details).

Table 6.01. LNG Tailpipe Emissions.

Tailpipe Emissions	CO_2	CH_4 and N_2O	Total
Total GHG Emissions (gCO_2e/MJ)	56.0	2.5	**58.5**

APPENDIX A2 (SCENARIO 2)
LNG FROM REMOTE SOURCES, SHIPPED TO BAJA, RE-GASIFIED, PIPELINED TO CA, LIQUEFIED IN CA

This Appendix details the energy use and GHG emissions for LNG produced from remote NG (overseas modeled here as being South East Asia), shipped to Baja, Mexico, re-gasified, pipelined to CA, liquefied in CA and transported for use in CA. Some of the details provided here for NG are from the NA NG to CNG pathway document published on the Low Carbon Fuel Standard website in February 2009 (http://www.arb.ca.gov/fuels/lcfs/lcfs.htm). Other details are from Appendix A1 of this document. This scenario differs from scenario 1 presented in Appendix A1 in the following areas:

a) NG recovery and processing uses South East Asia Electricity mix compared to U. S. Average mix for scenario 1.
b) Liquefaction efficiency is 90% for this compared to 80% for scenario 1.
c) LNG is transported via ocean tanker which does not exist in scenario 1.
d) LNG is re-gasified for this scenario but not for scenario 1.
e) NG is pipelined from Baja, Mexico, to CA for this scenario but NG is transported from average U. S. sources of NG for scenario 1.
f) There is liquefaction in California for scenario 2 which is the same for scenario 1.

Table A2.1 below provides a summary of the GHG emissions calculated for scenario 2. Details of the calculations are presented in the following sections.

Table A2.1. Summary of GHG Emissions for Scenario 2

Pathway Component	**GHG Emissions**
NG Recovery (gCO_2e/MJ)	3.43
NG Processing (gCO_2e/MJ)	4.00
NG Transp. to LNG Plant (gCO_2e/MJ)	0.45
NG Liquefaction (Overseas) (gCO_2e/MJ)	7.40
LNG Transport via Ocean Tanker (gCO_2e/MJ)	1.65
NG Pipeline Transmission (gCO_2e/MJ)	0.76
Re-gasification (gCO_2e/MJ)	0.75
NG Liquefaction (CA) (gCO_2e/MJ)	15.79
LNG/Diesel Truck Transport and Storage (gCO_2e/MJ)	0.64
WTT GHG Emissions (gCO_2e/MJ)	**34.87**
Carbon in Fuel (gCO_2e/MJ)	56.00
Tailpipe Emissions (non-CO_2 ,gCO_2e/MJ)	2.50
TTW GHG Emissions (gCO_2e/MJ)	**58.50**
Total WTW GHG Emissions (gCO_2e/MJ)	**93.37**

The basic assumptions for the calculations above are summarized in Table A2.2.

Table A2.2. Basis Assumptions for Remote Sourced LNG for Scenario 2

Description	**Value/Assumption**
NG Transport from field to Remote LNG plants (mi)	50
Liquefaction Efficiency	90% for remote liquefaction and 80% for California liquefaction
LNG Transport from remote source via Ocean Tanker (mi)	8,769
LNG Truck Transport (mi)	50
Electricity Mix for remote source	S. E. Asia Average
Electricity Mix for CA process	CA Marginal

SECTION 1. REMOTE NATURAL GAS RECOVERY, PROCESSING AND TRANSPORT TO LNG PLANT

1.1 Remote NG Recovery and Processing

For NG recovery and processing, the same assumptions and inputs are assumed for NG produced at a remote site as that for NA NG. Hence the results are similar to those provided in Sections 1 and 2 in Appendix A1. The small differences are related to the average electricity mix used for South East Asia (Residual oil 19.3%, NG 33.5%, Coal 36.3%, Biomass 2.2% and other renewables 8.6%) being different compared to the U.S. Average electricity mix used in the calculations for the recovery and processing of NA NG. The values for GHG emissions for recovery and processing are shown in Table A in the summary section and the total emissions are 3.43 (recovery) and 4.0 (processing) for a total of **7.43 gCO_2e/MJ** for the recovery and processing of remote natural gas.

SECTION 2. REMOTE NATURAL GAS LIQUEFACTION TO LNG

2.1 Liquefaction Energy Use

Liquefaction at the remote site is modeled as being produced in a large scale (over 4 million tonne/year) liquefier. A detailed description of the processing requirements for LNG is provided in a report by the International Gas Union (Rahal 2006[3]). The conversion efficiency for LNG ranges from 89% to 93% for large scale facilities. The inputs for the analysis used here are based on the Argonne GREET inputs with data from a 1999 article (Kikkawa 1999[4]).

The energy for liquefaction is generated with turbines at the LNG plant. 2% of the energy input is purchased power to operate facility controls based on the CA-GREET default with the balance from NG. The inputs and breakdown of the energy used are shown in Table 2.01. The calculation methodology is similar to the one presented for liquefaction in California in Appendix A1.

Table 2.01. Total Energy Inputs for Overseas LNG Liquefaction Systems

Parameter	Energy or Other Value
Liquefaction Inputs	
Natural Gas (Btu/mmBtu)	108,889
Electric Power (Btu/mmBtu)	2,222
Total (Btu/mmBtu)	**111,111**
Liquefaction Efficiency	90%
Fuel Shares	
Natural Gas	98%
Electric Power	2%

[3] Rahal, C. (2006). "Liquefied Natural Gas". Report of Programme Committee D, Triennium 2003-2006, 23rd World Gas Conference, International Gas Union.

[4] Kikkawa, Y. and I Aoki, 199, "Gas to Liquid of 21st Century," AIChE meeting, Houston, TX, March 1999

2.2 GHG Emissions from Natural Gas Liquefaction to LNG

For this document, liquefaction energy comes from the resource mix described in the previous section. The GHG emissions correspond to the natural gas and electricity use. The pathway assumes zero methane emissions from leaks because typically all NG is either recaptured and re-liquefied or used as a fuel in the process. Table 2.02 summarizes the results where CO and VOC emissions are converted to CO_2 eq. The calculations are similar to the ones presented for liquefaction in California in Appendix A1.

Table 2.02. Total Emissions (Direct + Upstream) Emissions for Remote Liquefaction of NG

GHG Species	**GHG Emissions** (g/mmBtu)
VOC	0.796
CO	4.135
CH_4	15.003
N_2O	0.175
CO_2	7,381
Total GHG Emissions (gCO_2e/mmBtu)	7,808
Total GHG Emissions (gCO_2e/MJ)	**7.4**

SECTION 3. LNG TRANSPORT TO CALIFORNIA, DISTRIBUTION, RE-GASIFICATION, TRANSPORT, AND STORAGE WITHIN CALIFORNIA

3.1 LNG Transport via Ocean Tanker

LNG is transported in large cryogenic tanks aboard LNG tanker ships. Standard LNG carriers range in size from 120,000 to 155 000 m^3. A few small purpose built ships and large LNG carriers 210,000 m^3 have also been built (Rahal 2006[5]). Most LNG tankers operate on a combination of LNG and bunker fuel. Some very large LNG tankers operate on only bunker fuel and use an on-board re-liquefaction system to capture boil off. The analysis here is based on 53% NG ship fuel share, including the LNG from boil off (0.15%/day) and 47% residual oil as fuel.

LNG Tanker Ship Energy Consumption

The parameters for modeling LNG tanker ship transport energy are shown below. All inputs except for distances are CA-GREET default values.

- Region: Southeast Asia (U.S. Average Crude, South East Asia electricity)
- Capacity (65,000 tons)
- Average speed (19 mph)
- Energy consumption for transport and return trip (4,620 and 4,691 Btu/hphr)
- Fuel shares (47% residual oil, 53% natural gas)
- Load factor for transport and return trip (80% and 70%)
- Distance (8,769 miles)

The calculations for energy tanker ship energy consumption are based on the ship energy intensity (in Btu/ton-mile). The calculations for energy intensity are below:

Trip to Destination:
(4,620 Btu/hphr)*(15,635 hp required)*(80% load factor)/(65,000 tons)(19 mph average speed) = **48 Btu/ton-mi**

Return Trip:
(4,691 Btu/hphr)*(15,635 hp required)*(70% load factor)/(65,000 tons)(19 mph average speed) = **43 Btu/ton-mi**

The ships boil off approximately 0.15%/day of the LNG, which is used as ship fuel. 100% recovery is assumed in GREET, since there are no fugitive emissions and the boil-off determines the loss factor.

[5] Rahal, C. (2006). "Liquefied Natural Gas". Report of Programme Committee D, Triennium 2003-2006, 23rd World Gas Conference, International Gas Union.

The ship distance shown in Table 3.01 was estimated using an online shipping calculator tool (Eship 2008[6]).

Table 3.01. Transport Distance for LNG Shipment via Ocean Tanker from Remote Source to Baja

Pathway Scenario	LNG Source	Destination Port	Distance (mi)
2	South East Asia	Baja (Mexico)	8,769

Ocean tanker transport energy is calculated the same way as energy for all transport modes. The calculations for ocean tanker transport from South East Asia to Baja, Mexico are shown below in Table 3.02.

Table 3.02. Direct, Upstream and Total Energy Use for Transport via Ocean Tanker to Baja

Fuel (Btu/mmBtu)	**Direct Energy Use**	**Upstream Energy Use**	**Total Energy Use**
Residual Oil	8,769	1,008	9,777
NG	9,871	3,490	13,360
Total Energy Use (Btu/mmBtu)			**23,137**

Direct Residual Oil Energy (South East Asia to Baja)
Direct energy = 10^6 Btu/(80,968 Btu/gal)*(1,724 g/gal)/(454 g/lb)/(2,000 lbs/ton)*(8,769 mi)*(48 Btu/ton-mi + 43 Btu/ton-mi)*(47%) = **8,769 Btu/mmBtu**

Upstream Residual Oil Energy
10^6 Btu/(80,968 Btu/gal)*(1,724 g/gal)/(454 g/lb)/(2,000 lbs/ton)*(8,769 mi)*(48 Btu/ton-mi + 43 Btu/ton-mi)*(0.115 Btu/Btu)(47%) = **1,008 Btu/mmBtu**

The direct and upstream energy for the natural gas component is calculated in the same manner as detailed for residual oil. The total energy for both residual oil and NG is shown in Table 3.02 and is **23,137 Btu/mmBtu**.

GHG Emissions from Transport via Ocean Tanker

Ocean tanker transport emissions is calculated the same way as emissions for all transport modes. The total GHG emissions, including ship combustion and upstream emissions for scenario 2 is shown in Tables 3.03 and Table 3.04.

[6] Eship. (2008). "Sea Distances - Voyage Calculator." Retrieved September 1, 2008, from http://www.e-ships.net/dist.htm.

Table 3.03. Total Emissions (Direct + Upstream) for Ocean Tanker Transport of LNG from Remote Source to Baja

	GHG Species				
Fuel(g/mmBtu)	**CO_2**	**VOC**	**CO**	**CH_4**	**N_2O**
Residual Oil	825	0.777	1.810	0.876	0.019
Natural Gas	799	0.905	1.192	2.723	0.025
Total GHG Emissions (g/mmBtu)	**1,625**	**1.682**	**3.002**	**3.599**	**0.043**

Table 3.04. Total GHG Emissions for Ocean Tanker Transport of LNG from Remote Source to Baja

	GHG Species			Emissions
Fuel (g/mmBtu)	**CO_2**	**CH_4**	**N_2O**	
Residual Oil	830	0.876	0.019	
Natural gas	804	2.723	0.025	
Total GHG Emissions (gCO_2e/mmBtu)				1,737
Total GHG Emissions (gCO_2e/MJ)				**1.65**

3.2 Re-gasification

Scenario 2 requires that LNG gas be re-gasified to natural gas for pipeline transmission. This includes heating the gas to ambient temperature and raising the pressure to pipeline pressures of 800 psi. Several methods are used for the re-gasification or vaporization process. LNG is pumped into a heat exchanger and the source of heat could be sea water, combustion of the vaporized gas, or ambient air. Some systems also aim to make use of the latent heat energy from LNG to produce useful work. The energy required for re-gasification ranges from 0.5% to 3% (Heede 2006[7], Rahal 2006[8]). An average re-gasification energy requirement of 1.0% was assumed for this document.

Energy Consumption from LNG Re-gasification

The equipment used for re-gasification is similar to a NG boiler or steam generator. Direct energy for LNG re-gasification is based on the share of the feedstock stream (LNG) used for re-gasification:

(1.0%)*(1,000,000 Btu LNG) = 10,000 Btu NG/mmBtu LNG throughput

[7]Heede, R. (2006). "LNG Supply Chain Greenhouse Gas Emissions from the Cabrillo Deepwater Port: Natural Gas from Australia to California", Climate Mitigation Services.
[8]Rahal, C. (2006). "Liquefied Natural Gas". Report of Programme Committee D, Triennium 2003-2006, 23rd World Gas Conference, International Gas Union.

The upstream energy component consists of the total energy required to generate the LNG delivered by tanker ship (just prior to re-gasification). This includes energy for extraction, transport to LNG facility, processing, liquefaction, storage and LNG tanker ship transport. The total energy (direct + upstream) for Scenario 2 that includes re-gasification is shown below in Table 3.05.

Table 3.05. Total Energy (Direct + Upstream) for LNG Re-gasification

Description	**Energy** (Btu/mmBtu)
Direct Energy	10,000
Upstream Energy	2,959
Total Energy Use (Btu/mmBtu)	**12,959**

GHG Emissions from LNG Re-gasification

The NG process fuel input (10,000 Btu/mmBtu) and the NG fuel properties (lower heating value, % carbon in fuel and density) determine the direct CO_2 emissions from re-gasification and equipment-specific emission factors (in g/mmBtu fuel burned) dictate the other emission species. Since CA-GREET does not model LNG re-gasification and emission factor data for re-gasifiers is not readily available, this analysis uses CA-GREET default emission factors for large (> 100 mmBtu/hr) NG utility boilers to calculate direct emissions (shown below in Table 3.06).

Table 3.06. Emission Factors for Large (> 100 mmBtu/hr) NG Boiler

Species	**Emissions**
CO_2 (g/mmBtu fuel burned)	58,198
VOC (g/mmBtu fuel burned)	1.557
CO (g/mmBtu fuel burned)	16.419
CH_4 (g/mmBtu fuel burned)	1.100
N_2O (g/mmBtu fuel burned)	0.315

The total greenhouse gas calculations are based on the direct energy input (10,000 Btu/mmBtu) with emission factors shown in Table 3.06. Table 3.07 below presents the total (direct + upstream) emissions for re-gasification for Scenario 2 considered here. Since 1.0% of the LNG is consumed for re-gasification, this step contributes a 1.0% feed loss to the process steps upstream of re-gasification. This is equivalent to applying a 1.01 loss factor to the upstream process energy and emission results.

Table 3.07. Total GHG Emissions from LNG Re-gasification

	GHG Species			**Emissions**
	CO_2	**CH_4**	**N_2O**	
Re-gasification Emissions (g/mmBtu)	777	0.511	0.007	
Total GHG Emissions (gCO_2e/mmBtu)				792
Total GHG Emissions (gCO2e/MJ)				**0.75**

3.3 Pipeline Transport to CA under Scenario 2

NG Pipeline Transmission Energy

The main input parameters for modeling pipeline energy are the energy intensity and equipment shares for turbines, engines for pressurizing the gas, pipeline distance and % loss factor. Using details for transporting NG as shown in Appendix A1, for this scenario using 250 mile transport from Baja, Mexico to California, the direct and upstream . NG energy calculations for pipeline transport to California (scenario 2) are shown as an example:

Direct Energy (NG) (Scenario 2)

$$\left[\frac{10^6 \times 20.4g/ft^3}{930Btu/ft^3 \times 454g/lb \times 2{,}000lbs/ton}\right] \times 250miles \times 405\frac{Btu}{ton-mile} \times (0.069\frac{Btu}{Btu} \times 94\%)$$

= 190 Btu/mmBtu

Upstream Energy (NG and electricity) (Scenario 2)

$$\left[\frac{10^6 \times 20.4g/ft^3}{930Btu/ft^3 \times 454g/lb \times 2{,}000lbs/ton}\right] \times 250miles \times 405\frac{Btu}{ton-mile} \times (0.069 \times 94\% + 1.997 \times 6\%)$$

= **542 Btu/mmBtu**

Where:

0.069 Btu/Btu: energy consumption from transportation of NG (CA-GREET calculated in cell D170, "*T&D"* tab)
1.997 Btu/Btu: energy consumption from transmission of electricity (CA-GREET calculated in cell R170, "*T&D"* tab)

Table 3.08 provides a summary of the total energy use for pipeline transport of NG from Baja, Mexico to CA for Scenario 2.

Table 3.08. Total Energy Use for Transport of Re-gasified NG from Baja, Mexico

	Energy Use (Btu/mmBtu)
Direct Energy Use	190
Upstream Energy Use	542
Total Energy Use (Btu/mmBtu)	732

GHG Emissions from NG Pipeline Transmission

Greenhouse gas emissions resulting from NG pipeline transmission are presented here. Direct and upstream emissions are calculated using the same equations shown in the NA NG to CNG document. The total process fuel emissions are shown below in Table 3.09.

Table 3.09. Total GHG Emissions for Pipeline Transmission from Baja, Mexico

	GHG Species			**GHG Emissions**
	CO_2	**CH_4**	**N_2O**	
Fuels	(g/mmBtu)			(gCO_2e/mmBtu)
Natural Gas	289	1.315	0.010	325
Electricity	31	0.064	0.001	33
Methane Losses		17.548		439
Total GHG Emissions (gCO_2e/mmBtu)				796
Total GHG Emissions (gCO_2e/MJ)				**0.76**

3.4 Liquefaction in California

For Scenario 2 where liquefaction occurs in California, the process has been described earlier in Appendix A1. The emissions for this step in the pathway is **15.79 gCO_2e/MJ**.

3.5 LNG Transport and Storage in California

This section is the same as presented in Appendix A1. The GHG emissions from LNG transport and storage in CA are 0.38 + 0.26 = **0.64 g CO_2e/MJ**.

SECTION 4. GHG EMISSIONS FROM VEHICLES

4.1 Tank To Wheel (TTW) GHG Emissions

GHG emissions are the same as detailed in Appendix A1 and the total GHG emissions are **58.5 gCO_2e/MJ**.

APPENDIX A3 (SCENARIO 3)
LNG FROM REMOTE SOURCES, SHIPPED TO BAJA, TRUCKED TO CA

This Appendix details the energy use and GHG emissions for LNG produced from remote NG (overseas modeled here as being South East Asia), shipped to Baja, Mexico, trucked to CA and use in CA. Some of the details provided here for NG are from the NA NG to CNG pathway document published on the Low Carbon Fuel Standard website (http://www.arb.ca.gov/fuels/lcfs/lcfs.htm) in February 2009. Other details are from Appendices A1 and A2 of this document. This scenario differs from scenarios 1 and 2 presented in Appendices A1 and A2 in the following areas:

a) NG recovery and processing uses South East Asia Electricity mix which is the same for scenario 2 while for scenario 1, the mix is U. S. Average mix.
b) Liquefaction efficiency is 90% for this and scenario 2 compared to 80% for scenario 1.
c) LNG is transported via ocean tanker for this scenario and scenario 2 which does not exist in scenario 1.
d) LNG is not re-gasified for this scenario and scenario 1 but is for scenario 2.
e) NG is not pipelined from Baja, Mexico, to California for this scenario but is for scenario 2 and for scenario 1, NG is transported from average U. S. sources to California.
f) There is liquefaction in California for scenario 2 which is the same for scenario 1 but does not happen for scenario 3.
g) LNG is transported from Baja, Mexico, for this scenario but does not happen for scenarios 1 and 2.

Table A3.1 below provides a summary of GHG emissions calculated for scenario 3. Details of the calculations are presented in the following sections.

Table A3.1. Summary of GHG Emissions for Scenario 3

Pathway Component	**GHG Emissions (gCO_2e/MJ)**
NG Recovery (gCO_2e/MJ)	3.43
NG Processing (gCO_2e/MJ)	4.00
NG Transp. to LNG Plant (gCO_2e/MJ)	0.45
NG Liquefaction (Overseas) (gCO_2e/MJ)	7.40
LNG Transport via Ocean Tanker (gCO_2e/MJ)	1.65
LNG/Diesel Truck Transport and Storage (gCO_2e/MJ)	2.07
WTT GHG Emissions (gCO_2e/MJ)	**19.00**
Carbon in Fuel (gCO_2e/MJ)	56.00
Tailpipe Emissions (non-CO_2, gCO_2e/MJ)	2.50
TTW (gCO_2e/MJ)	**58.50**
Total WTW GHG Emissions (gCO_2e/MJ)	**77.50**

The basic assumptions for the calculations above are summarized in Table A3.2.

Table A3.2. Basis Assumptions for Remote Sourced LNG

Description	**Value/Assumption**
NG Transport from field to Remote LNG plants (mi)	50
Liquefaction Efficiency	90% for remote liquefaction
LNG Transport from remote source via Ocean Tanker (mi)	8,769
LNG Truck Transport (mi)	250
Electricity Mix for remote source	South East Asia Average
Electricity Mix for CA process	CA Marginal

SECTION 1. REMOTE NATURAL GAS RECOVERY, PROCESSING AND TRANSPORT TO LNG PLANT

1.1 Remote NG Recovery and Processing

As detailed in scenario 2 and shown in Appendix A2, the results are **3.43** g/CO_2e/MJ for NG recovery and **4.0** g/CO_2e/MJ for NG processing.

SECTION 2. REMOTE NATURAL GAS LIQUEFACTION TO LNG

2.1 Liquefaction Energy Use

As presented in scenario 2 and shown in Appendix A2, the energy use for overseas liquefaction is **111,111** Btu/mmBtu.

2.2 GHG Emissions from Natural Gas Liquefaction to LNG

As presented in scenario 2 and shown in Appendix A2, the GHG emissions from overseas liquefaction are **7.4** g/CO_2e/MJ.

SECTION 3. LNG TRANSPORT TO BAJA, THEN TRUCKED AND STORAGE WITHIN CALIFORNIA

3.1 LNG Transport via Ocean Tanker

As presented in scenario 2 and shown in Appendix A2, transport of LNG from remote sources (modeled here as being from South East Asia) via ocean tanker requires 23,137 Btu/mmBtu of energy and **1.65** gCO_2e/MJ of GHG emissions are generated during the transport process.

3.2 LNG Transport and Storage to California from Baja, Mexico to California

The calculations are the same as presented in section 5 of Appendix A1, but with a transport distance of 250 miles from Baja, Mexico to California. The total energy use is **4,679** Btu/mmBtu (Table 5.01 of Appendix A1). The GHG emissions are calculated to be **1.81** gCO_2e/MJ of truck transport which has to be combined with **0.26** gCO_2e/MJ of emissions from LNG storage (see Appendix A2 for LNG storage emission details) for a total of **2.07** gCO_2e/MJ GHG emissions and is shown in Table A in the summary section.

SECTION 4. GHG EMISSIONS FROM VEHICLES

4.1 Tank To Wheel (TTW) GHG Emissions

GHG emissions are the same as detailed in section 6 of Appendix A1 and the total emissions are **58.5** gCO_2e/MJ.

APPENDIX B

LIQUEFIED NATURAL GAS (LNG) FROM NORTH AMERICAN AND REMOTE NATURAL GAS SOURCES PATHWAY INPUT VALUES

Parameters	Units	Values	Note
GHG Equivalent			
CO_2		1	CA-GREET Default
CH_4		25	CA-GREET Default
N_2O		298	CA-GREET Default
VOC		3.1	CA-GREET Default
CO		1.6	CA-GREET Default
Natural Gas Recovery			
Process Efficiency		97.2%	CA-GREET Default
Natural Gas Leak Rate		0.35%	CA-GREET Default
Fuel Shares			
Residual Oil		0.9%	CA-GREET Default
Conventional Diesel		9.8%	CA-GREET Default
Conventional Gasoline		0.9%	CA-GREET Default
Natural Gas		76.2%	CA-GREET Default
Electricity		0.9%	CA-GREET Default
Feed Loss (Leak)		11.4%	CA-GREET Default
Equipment Shares			
Small Boiler - Residual Oil		100%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	85,049	CA-GREET Default
Commercial Boiler - Diesel		25%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	78,167	CA-GREET Default
Stationary Reciprocating Eng. - Diesel		50%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	77,349	CA-GREET Default
Turbine - Diesel		25%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	78,179	CA-GREET Default
Stationary Reciprocating Eng. - Gasoline			
CO_2 Emission Factor	gCO_2/mmBtu	50,480	CA-GREET Default
Small Boiler - NG		50%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	58,215	CA-GREET Default
Stationary Reciprocating Eng. - NG		50%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	56,388	CA-GREET Default
Natural Gas Processing			
Process Efficiency		97.2%	CA-GREET Default
Natural Gas Leak Rate		0.15%	CA-GREET Default
Fuel Shares			
Conventional Diesel		0.9%	CA-GREET Default
Natural Gas		91.1%	CA-GREET Default
Electricity		2.8%	CA-GREET Default
Feed Loss (Leak)		5.1%	CA-GREET Default
Equipment Shares			
Commercial Boiler - Diesel		33%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	78,167	CA-GREET Default
Stationary Reciprocating Eng. - Diesel		33%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	77,349	CA-GREET Default
Turbine - Diesel		34%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	78,179	CA-GREET Default
Large Boiler - NG		50%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	58,215	CA-GREET Default

Parameters	Units	Values	Note
Large Turbine - NG		50%	CA-GREET Default
CO_2 Emission Factor	gCO_2/mmBtu	58,196	CA-GREET Default
Feed Loss		1.001	CA-GREET Default
NG Liquefaction			
NG Liquefaction Efficiency in CA		80%	CA-GREET Default
Process Fuels Shares			
Natural Gas		98%	CA-GREET Default
Electricity		2%	CA-GREET Default
Remote NG Processing Efficiency		90%	Excluding gas processing
Process Fuels Shares			Assumed the same as NA NG
Natural Gas Pipeline Transmission			
Natural Gas Use		94%	CA-GREET Default
Electricity Use		6%	CA-GREET Default
Distance travel	Miles	1,400	For NA NG to California
LNG Truck Transport			
Tanker Truck Size	ton	15	fueled by diesel or LNG
Distance travel	Miles	50	from LNG plants in CA to CA filling stations
		250	from LNG plants in Baja to CA filling stations
Fuel Economy	Mi/gal	5	
Fugitive Emissions During Storage	%/day	0.1%/day	CA-GREET default
Fugitive Emissions Recovery Rate		80%	Industry Practice
Vehicle Emissions			
Carbon in NG	grams C/gram NG	72.4	CA-GREET default
Fuels Properties	**LHV (Btu/gal)**	**Density (g/gal)**	
Crude	129,670	3,205	CA-GREET Default
Residual Oil	140,353	3,752	CA-GREET Default
Conventional Diesel	128,450	3,167	CA-GREET Default
Conventional Gasoline	116,090	2,819	CA-GREET Default
CaRFG	111,289	2,828	CA-GREET Default
CARBOB	113,300	2,767	CA-GREET Default
Natural Gas	83,686	2,651	NG Liquids
Natural Gas			NG gaseous: 930 Btu/scf