# Proposed Tacoma Liquefied Natural Gas Project

## Draft Supplemental Environmental Impact Statement


October 8, 2018

Prepared for:

**Puget Sound Clean Air Agency**

1904 Third Avenue, Suite 105
Seattle, Washington 98101

pscleanair.org
Puget Sound Clean Air Agency

Prepared by:

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# SEPA Fact Sheet

| | |
|---|---|
| **Name of Proposal** | Tacoma Liquefied Natural Gas (LNG) Facility. |

**Description of Proposal**

The Proposed Action is to construct and operate an LNG liquefaction, storage, and marine bunkering facility. The Proposed Action would include construction and operation of an LNG facility to fuel marine vessels and provide LNG fuel to various customers in the Puget Sound area. The liquefaction facility would cool natural gas into a liquid state at -260 degrees Fahrenheit (cryogenic) for on-site storage. The facility would also have the capability to vaporize LNG back to its gaseous state for injection into the Puget Sound Energy (PSE) Natural Gas Distribution System during periods of high demand (referred to as peak shaving). The Proposed Action would consist of the following main components:

- *Tacoma LNG Facility*: Liquefies natural gas, stores LNG, and includes facilities to transfer LNG to the adjacent Totem Ocean Trailer Express (TOTE) Marine Vessel LNG Fueling System, bunkering barges in the Blair Waterway, or tanker trucks on site. It also includes facilities to re-gasify stored LNG and inject natural gas into the PSE Natural Gas Distribution System.
- *TOTE Marine Vessel LNG Fueling System:* Conveys LNG by cryogenic pipeline from the Tacoma LNG Facility to the TOTE site. Includes transfer facilities and an in-water trestle and loading platform in the Blair Waterway to fuel vessels or load bunker barges.
- *PSE Natural Gas Distribution System*: Conveys natural gas to and from the Tacoma LNG Facility. However, this system will require upgrades, including two new distribution pipeline segments with a total length of 5.0 miles, a new limit station (Golden Given Limit Station), and an upgrade to the existing Frederickson Gate Station.

The Tacoma LNG Facility and TOTE Marine Vessel LNG Fueling System would be located in the Port of Tacoma within the City of Tacoma. Two new distribution pipeline segments would be constructed in the City of Tacoma, and the City of Fife (Pipeline Segment A) and unincorporated Pierce County (Pipeline Segment B). The new pipeline segments would be constructed within the dedicated road rights-of-way currently used for vehicular traffic. In addition, the Golden Given Limit Station would be constructed on a developed parcel owned by PSE in unincorporated Pierce County, and modifications to the Frederickson Gate Station would also be located in unincorporated Pierce County.

**Location**

The Tacoma LNG Facility would be generally located north of East 11th Street, east of Alexander Avenue, south of Commencement Bay, and on the west shoreline of the Hylebos Waterway. The site is in an area zoned as Port Maritime Industrial. The site is composed of four separate parcels owned by the Port of Tacoma: Pierce County tax parcels 2275200502, 2275200532, 5000350021, and 5000350040.

The boundaries for these parcels comprise a total area of approximately 30 acres.

**Alternatives**

The *No Action Alternative* and the *Proposed Action* are evaluated in this Draft Supplemental Environmental Impact Statement (DSEIS); the analysis herein is focused exclusively on life-cycle GHG emissions. Key elements of each alternative include the following:

*No Action Alternative:* Construction of the Tacoma LNG Facility, including upgrading of the natural gas distribution system, would not occur. Existing levels of maritime petroleum fuels use would continue.

*Proposed Action:* The Tacoma LNG Facility would be constructed and produce between approximately 250,000 and 500,000 gallons of LNG per day, for use by marine customers, including TOTE, as well as regasification into the PSE natural gas distribution system for peak-shaving purposes. Additional uses would include providing LNG to other industries or merchants, such as fuel for high-horsepower trucks used in long-haul trucking or other marine transportation uses. The Tacoma LNG Facility would operate and be staffed with approximately 16 to 18 full-time employees 24 hours per day, 365 days a year.

The *Proposed Action* would also include the construction of segments of the PSE natural gas distribution system in the City of Tacoma, the City of Fife, and unincorporated Pierce County. This would include the installation of new pipe, a new limit station, and modifications to the Fredrickson Gate Station.

**Proponent**

Puget Sound Energy
10885 NE 4TH Street PSE-095
Bellevue, WA 98009-9734

**SEPA Lead Agency**

Puget Sound Clean Air Agency
1904 Third Avenue, Suite 105
Seattle WA 98101
Telephone: (800) 552-3565

**SEPA Responsible Official**[1] Carole J. Cenci

**DSEIS Contact Person** Betsy Wheelock
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**Required Approvals and/or Permits**

The federal, state, and local approvals, licenses, and permits required for construction and operation of the Proposed Action are listed in the table below. The approval associated with the analysis in this DSEIS is Puget Sound Clean Air Agency's (PSCAA's) Order of Approval.

| AGENCIES | APPROVAL, LICENSE, or PERMIT |
|---|---|
| **FEDERAL** | |
| United States Department of Transportation/Pipeline and Hazardous Materials Safety Administration | Delegated to Washington Utilities and Transportation Commission for approval of design elements consistent with federal standards |
| United States Department of the Army Corps of Engineers (USACE), Seattle District | Section 10 Permit (Rivers and Harbors Act) |
| | Section 404 Permit (Clean Water Act [CWA]) |
| | Section 106 Consultation (National Historic Preservation Act) with applicable tribes (Puyallup Tribe of Indians and the Muckleshoot Tribe). |
| United States Coast Guard | Waterway Suitability Analysis Addresses requirements of 33 Code of Federal Regulations (CFR) Part 127: Coast Guard assessment of LNG Marine Operations |
| | Permission to establish Aids to Navigation required under 33 CFR Part 66 |
| | Letter of Intent (33 CFR Part 127) recommendation to operator and develops operation plans (OPLAN) at sea ports. |
| National Marine Fisheries Service (NMFS) | Section 7 of Endangered Species Act |
| | Essential Fish Habitat (EFH), Magnuson-Stevens Fishery Management and Conservation Act |

[1] The Responsible Official is the designated person that is responsible for compliance with the SEPA lead agency procedural responsibilities.

| AGENCIES | APPROVAL, LICENSE, or PERMIT |
|---|---|
| | Marine Mammal Protection Act Level B harassment authorization |
| **STATE** | |
| Washington State Department of Ecology (WDOE) | National Pollutant Discharge Elimination System (NPDES) – Construction Stormwater General Permit |
| | NPDES Industrial Stormwater General Permit |
| | Coastal Zone Consistency Determination |
| | 401 Water Quality Certification (CWA) |
| | Spill Prevention and Spill Response Plan (CWA) |
| | Hazardous Chemical Inventory Reporting Requirements |
| Washington Department of Fish and Wildlife (WDFW) | Hydraulic Project Approval |
| Washington State Department of Transportation (WSDOT) | State Highway Crossing Permit |
| Washington Department of Archaeology and Historic Preservation (DAHP) | Section 106 Consultation (NHPA) in coordination with lead federal agency (USACE) |
| **LOCAL JURISDICTIONS** | |
| City of Tacoma | Shoreline Substantial Development Permit |
| | Wetland/Stream/Fish and Wildlife Habitat Area Permit |
| | Floodplain Development Permit |
| | Clear and Grade Permit/Demolition Permit |
| | Building Permit |
| | Street Use or Right-of-Way Use Permit |
| Pierce County | Street use or Right-of-Way Use Permit<br>Conditional Use Permit |
| | Construction (Clear & Grade) Permit |
| | Building Permit |
| | Critical Areas Review |
| City of Fife | Right-of-Way permit Utility permit |
| | Flood permit |
| | Critical Areas Review |
| Port of Tacoma | Tenant Improvement Procedure |

| AGENCIES | APPROVAL, LICENSE, or PERMIT |
|---|---|
| **TRIBAL** | |
| Puyallup Tribe of Indians | Section 106 Consultation in coordination with USACE |
| Muckleshoot Tribe | Section 106 Consultation in coordination with USACE |
| **REGIONAL AGENCIES** | |
| Puget Sound Clean Air Agency | Order of Approval |

**Authors and Principal Contributors**

This DSEIS has been prepared under the direction of the PSCAA. Research and analysis associated with this DSEIS were provided by the following consulting firms:

- **Ecology and Environment, Inc.** – DSEIS research, analysis, and document preparation
- **Life Cycle Associates, LLC** – GHG life-cycle analysis for the Proposed Action and No Action alternatives

For a complete list of individual contributors, see Appendix A of the DSEIS.

**Date of Issuance of this DSEIS**

October 8, 2018

**DSEIS Comment Period**

October 8, 2018 through November 21, 2018

**DSEIS Public Hearing**

- Date of the public hearing: October 30, 2018
- Time of the public hearing: 2:00 to 5:00 p.m. and 6:30 to 10:00 p.m.
- Hearing location: Rialto Theater, 310 South 9th Street, Tacoma, Washington 98402

The purpose of the public hearing is to provide an opportunity for agencies, organizations, and individuals to present comments regarding the DSEIS—in addition to submittal of written comments.

Comments may be submitted in writing to the PSCAA using the address above, by facsimile to (206) 343-7522, or to the following email address: publiccomment@pscleanair.org

**PSCAA Final Actions**

- Approval of the Final SEIS for the Tacoma LNG Facility as a document that is adequate for Washington State Environmental Policy Act (SEPA) compliance, including any proposed mitigation;
- Decision regarding a final Order of Approval for the Proposed Action.

| | |
|---|---|
| **Type of Supplemental Environmental Impact Statement** | This document supplements the Final Environmental Impact Statement (FEIS) for the Tacoma LNG Facility issued by the City of Tacoma in November 2015. This DSEIS evaluates greenhouse gas (GHG) emissions impacts associated with the construction and operation of an LNG liquefaction and marine bunkering facility within the City of Tacoma on land leased from the Port of Tacoma, and construction of segments of a natural gas pipeline in the City of Fife and unincorporated areas of Pierce County. This DSEIS fulfills the need for the PSCAA to evaluate the life-cycle GHG emissions from the Proposed Action. |
| **Phased Environmental Review** | No additional SEPA review will be required for site-specific development that is proposed to the PSCAA within the scope of the Proposed Action described in this DSEIS. |
| **Location of Background Data** | Puget Sound Clean Air Agency<br>1904 Third Avenue, Suite 105<br>Seattle WA 98101<br>Telephone: (800) 552-3565 |
| **Availability of this DSEIS** | Hard copies of the DSEIS can be viewed at the PSCAA office and at the following locations:<br>• Any Tacoma Public Library (all eight branches)<br>• Center at Norpoint, 4818 Nassau Avenue Northeast, Tacoma, Washington 98422<br>The DSEIS can also be reviewed online at: www.pscleanair.org/PSELNGPermit. In addition, a limited number of complimentary hardcopies or CDs of the DSEIS will be made available (while the supply lasts) at the PSCAA office.<br>The PSCAA is open 8 a.m. to 4:30 p.m. Monday through Friday. |

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**Appendices**

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# Acronyms and Abbreviations

| Term | Definition |
|---|---|
| API | American Petroleum Institute |
| BOG | boil-off gas |
| CFR | Code of Federal Regulations |
| CI | carbon intensity |
| $CO_2$ | carbon dioxide |
| $CO_2e$ | carbon dioxide equivalent |
| CWA | Clean Water Act |
| DEIS | Draft Environmental Impact Statement |
| DSEIS | Draft Supplemental Environmental Impact Statement |
| ECA | (North American) Emission Control Area |
| Ecology | Washington State Department of Ecology |
| EIS | environmental impact statement |
| EPA | United States Environmental Protection Agency |
| FEIS | Final Environmental Impact Statement |
| GHG | greenhouse gas |
| gpd | gallons per day |
| gpm | gallons per minute |
| GREET | Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation |
| GWP | global warming potential |
| $H_2S$ | hydrogen sulfide |
| kWh | kilowatt hours |
| LNG | liquefied natural gas |
| MDO | marine diesel oil |
| MMBtu | million British thermal units |
| MVFS | marine vessel LNG fueling system |
| NOC | Notice of Construction |
| NPDES | National Pollutant Discharge Elimination System |
| OPGEE | Oil Production Greenhouse Gas Emission Estimator |
| Proposed Action | Construction, operation, and decommissioning of the Tacoma LNG Project |
| PSCAA | Puget Sound Clean Air Agency |
| PSD | Prevention of Significant Deterioration |
| PSE | Puget Sound Energy |
| psig | pounds per square inch gauge |
| RCW | Revised Code of Washington |

| | |
|---|---|
| SEIS | Supplemental Environmental Impact Statement |
| SEPA | Washington State Environmental Policy Act |
| TOTE | Totem Ocean Trailer Express |
| tpy | tons per year |
| USACE | United States Department of the Army Corps of Engineers |
| WAC | Washington Administrative Code |

# Executive Summary

## ES.1 Introduction and Background

The City of Tacoma initiated an environmental review of the Tacoma Liquefied Natural Gas (LNG) Project (referred to herein as the Proposed Action) proposed by Puget Sound Energy (PSE) at the Port of Tacoma in September 2014. The Proposed Action would include on-site LNG liquefaction, storage for bunkering marine fuel, a truck loading facility, and the capability to re-gasify to meet peak natural gas demand. To supply the LNG facility, the Proposed Action also includes the construction of two new segments of pipeline connecting the LNG facility to PSE's existing natural gas distribution system. The construction, operation, and decommissioning of the Proposed Action is referred to herein as the Proposed Action.

This environmental review process, performed under the authority of Revised Code of Washington chapter 43.21C (Washington State Environmental Policy Act [SEPA]), was triggered when PSE formally applied for a Shoreline Substantial Development Permit with the City of Tacoma. On September 12, 2014, the City of Tacoma issued a SEPA Determination of Significance, indicating the City's intention to require an Environmental Impact Statement (EIS) to assess the environmental impacts of the Proposed Action at the Port of Tacoma and the surrounding area.

On September 12, 2014, the City of Tacoma began a SEPA scoping process to solicit input from the public on the issues to address in the environmental review. The City issued a Draft EIS (DEIS) on July 7, 2015. The City accepted comments on the DEIS through August 6, 2015. After consideration of comments on the DEIS and making appropriate changes, the City issued a Final EIS (FEIS) on November 9, 2015.

Following issuance of the FEIS, PSE submitted a Notice of Construction (NOC) permit application to the Puget Sound Clean Air Agency (PSCAA) for the Tacoma LNG Facility. During PSCAA's review of the NOC permit application, the agency determined that an analysis of greenhouse gas (GHG) emissions and impacts in the FEIS included quantitative emissions for the Tacoma LNG Facility site, but did not account for "upstream" GHG emissions associated with natural gas extraction and transmission. In addition, PSCAA determined that the Washington State Department of Ecology guidance document for identification and evaluation of GHGs, which the FEIS analysis relied upon, had been withdrawn for revision after completion of the FEIS.

Accordingly, PSCAA initiated this Supplemental EIS (SEIS) to address Sections 3.2 and 3.13 of the FEIS. Specifically, PSCAA concluded that a "life-cycle" approach to characterizing GHG emissions and impacts was needed in the SEIS. The life-cycle analysis identifies and quantifies all GHG emissions associated with natural gas extraction and transmission, on-site LNG production and storage, and "downstream" end-uses of the LNG. To contrast the GHG emissions and impacts from the Proposed Action, a life-cycle analysis was performed for the No Action Alternative (i.e., the current situation) for this SEIS. The life-cycle analysis and SEIS will inform PSCAA's decision-making process for processing the NOC permit application for the facility. The life-cycle analysis forms the basis for the analysis and conclusions in this SEIS. The methodology used and results of the life-cycle analysis are documented in reports contained in Appendices B and C, respectively, of this document.

This SEIS is an informational and evaluative tool. It does not mandate approval or disapproval of the Proposed Action, but informs the public and decision-makers of the Proposed Action's potential impacts related to the emission of GHGs and, as appropriate, mitigation measures to avoid or reduce potential significant impacts.

This SEIS is organized as follows:

- **Chapter 1** describes the purpose and need of the Proposed Action in the context of the analyses conducted by PSCAA to comply with SEPA.
- **Chapter 2** describes the Proposed Action components and construction procedures.
- **Chapter 3** describes the No Action Alternative and related assumptions.
- **Chapter 4** evaluates the affected environment, and the Proposed Action's potential environmental consequences associated with GHG emissions on the surrounding region.

# ES.2 SEIS Objectives, Purpose, and Need

The purpose of the Proposed Action is to receive natural gas from PSE's distribution system, chill natural gas to produce approximately 250,000 to 500,000 gallons of LNG daily, and store up to 8 million gallons of LNG on site. LNG would be distributed for use as marine transportation fuel by Totem Ocean Trailer Express (TOTE) at its Port of Tacoma facility, along with other potential future regional LNG marine vessel customers. During times of peak gas demand, 85,000 dekatherms of LNG would be re-gasified and re-injected into PSE's distribution system. In addition, PSE is also proposing to load LNG onto trucks or barges for use by other regional markets seeking a cleaner fuel source.

The Proposed Action would address a need for new peak-day resources as identified through PSE's 2013 biennial integrated resource plan. PSE determined that the most cost effective way of meeting its resource needs would be the combination of additional regional underground storage; the Tacoma LNG Facility; and refurbishment of an existing, on-system, peak-day resource.

In addition to meeting long-term resource needs, the Proposed Action would enable TOTE to meet new fuel standards for maritime vessels in response to the North American Emission Control Area (ECA), which established more stringent emission standards within 200 miles of the United States and Canadian coasts. A significant portion of the LNG to be produced at the Tacoma LNG Facility would be consumed by TOTE. However, additional fuel switching by other companies from petroleum products to LNG in response to ECA would provide further demand for LNG in the region.

# ES.3 SEIS Alternatives and Review

This document evaluates two alternatives: the Proposed Alternative and the No Action Alternative, consistent with alternatives evaluated in the City of Tacoma's DEIS and FEIS.

This SEIS addresses direct and indirect Proposed Action GHG emissions impacts, as well as supplements the analysis of cumulative impacts of GHGs evaluated in the FEIS. It also evaluates potential GHG emissions impacts of the Proposed Action that would result from its construction, operation and maintenance, and decommissioning at the end of its design life.

# ES.4 Major Conclusions

Based on the analyses presented in this SEIS, the following major conclusions have been drawn:

- The use of LNG produced by the Proposed Action, instead of petroleum-based fuels for marine vessels, trucks, and peak shaving is predicted to result in an overall decrease in GHG emissions in the Puget Sound region, a net beneficial impact compared to the No Action Alternative. As demonstrated by the range of potential impacts from the Proposed Action and No Action alternatives based on an LNG capacity of 250,000 to 500,000 gallons per day, the greater the replacement of other petroleum-based fuels with LNG, the greater the overall reductions in GHG emissions.

- The conclusion regarding the overall reductions in GHG emissions stated above is dependent upon the assumption that the sole source of natural gas supply to the facility is from British Columbia. The analysis supports the recommendation that the facility's air permit include the condition regarding the sole source of the natural gas from British Columbia as a requirement so the analysis and this conclusion is consistent with the proponent's project description.

# 1 Purpose, Need, and Alternatives Considered

This chapter presents the purpose of the Proposed Action set forth by the proponent, Puget Sound Energy (PSE), the need for the Proposed Action, and the alternatives considered, consisting of the Proposed Action and the No Action Alternative. Throughout this Draft Supplemental Environmental Impact Statement (DSEIS), the term “Proposed Action” refers to the construction, operation, and decommissioning of the Tacoma Liquefied Natural Gas (LNG) Project.

The focus of this SEIS is on impacts associated with air quality, specifically emissions of greenhouse gases (GHGs) from the alternatives. This SEIS does not address the other Washington State Environmental Policy Act (SEPA) elements of the environment (e.g., environmental health/public safety, shoreline use, etc.) as these topics were addressed in the Final EIS (FEIS).

## 1.1 Purpose and Need

The purpose of the Proposed Action as described in the FEIS is to produce LNG for use as a maritime fuel for Totem Ocean Trailer Express (TOTE) vessels and other future regional LNG marine fuel customers, to re-gasify the LNG to meet peak-shaving needs, and for loading on trucks or barges for other regional markets seeking a cleaner fuel. Some of the LNG loaded on trucks could support resupplying the proponent’s LNG storage facility in Gig Harbor.

The stated need for the Proposed Action has two categories: cleaner fuel for maritime or other transportation uses and peak-day resource support for natural gas customers. The cleaner fuel need for maritime use includes the contract PSE has with TOTE to provide LNG to TOTE at the Port of Tacoma for TOTE’s vessels that operate between Tacoma and Anchorage, Alaska. This PSE contract with TOTE was reached, in part, to meet the International Convention for the Prevention of Pollution from Ship emissions limits for nitrogen oxide and sulfur oxide in the Emission Control Areas along the United States and Canadian coasts. In addition to TOTE, the proposed facility would be able to support other transportation cleaner fuel needs, not limited solely to maritime use. A second stated need is during peak-energy demand periods, PSE would be able to meet that demand through the use of the LNG as an alternative to other market driven alternatives to meeting customer supply requirements.

## 1.2 Alternatives Considered

Under Washington Administrative Code (WAC) 197-11-620(1) SEISs are to be prepared in the same way and format as the draft and final EISs. The SEIS is intended to evaluate the same alternatives as the FEIS—new alternatives are not required. Therefore, this SEIS analyzes the Proposed Action and the No Action alternatives, which are summarized below.

### 1.2.1 Proposed Action

The Proposed Action for the purposes of the SEIS is to construct the Tacoma LNG Facility to produce 250,000 to 500,000 gallons per day (gpd) of LNG to be used as a marine fuel and provide LNG to various customers in the Puget Sound area via LNG bunkering barges and tanker trucks, replacing the use of marine diesel oil (MDO) and diesel fuel. The Tacoma LNG Facility would also have the capability of vaporizing LNG back to its gaseous state for injection into the PSE natural gas distribution system during periods of high demand, referred to as “peak shaving.” The area of the Proposed Action is shown in Figure 1-1. The Proposed Action would consist of the following main components:

- **Tacoma LNG Facility**: Liquefies natural gas, stores up to 8 million gallons of LNG, and includes facilities to transfer LNG to the TOTE Marine Vessel LNG Fueling System (described below), bunkering barges in the Blair Waterway, or tanker trucks on site. It also includes facilities to re-gasify stored LNG and inject natural gas into the PSE Natural Gas Distribution System. This facility would be located in the Port of Tacoma within the City of Tacoma.

- **TOTE Marine Vessel LNG Fueling System:** Conveys LNG by cryogenic pipeline from the Tacoma LNG Facility to the TOTE site and includes transfer facilities and an in-water trestle and loading platform over the Blair Waterway to fuel vessels or load bunker barges. The locations of these components are shown in Figure 1-2.
- **PSE Natural Gas Distribution System**: Conveys natural gas to and from the Tacoma LNG Facility. It includes two new distribution pipeline segments (Pipeline Segment A and Pipeline Segment B), a new limit station (Golden Given Limit Station), and an upgrade to the existing Frederickson Gate Station. Pipeline Segment A would be located in the City of Tacoma and the City of Fife. Pipeline Segment B would be located in unincorporated Pierce County. In addition, the Golden Given Limit Station and Fredrickson Gate Station would be located in unincorporated Pierce County.

### 1.2.2 No Action Alternative

Under the No Action Alternative, the existing land uses would continue at the proposed Tacoma LNG Facility site, which is zoned Port Maritime Industrial. LNG would not be produced or stored at the Tacoma LNG Facility site and would not be available to replace MDO for fuel marine vessels or other customers in the Puget Sound area. To assess the potential changes from the Proposed Action's operation and supplying LNG, it is assumed that the equivalent amount of MDO and diesel fuel would continue to be used. Additionally, some LNG would be re-gasified and injected into the PSE natural gas pipeline system during periods of peak demand. The Gig Harbor LNG storage facility would continue to be supplied by truck from Canada. Under the No Action Alternative, the economic and employment impacts of the Proposed Action would not occur. However, the No Action Alternative would require TOTE to seek another source of LNG or other means to reduce their emissions to meet International Maritime Organization requirements.

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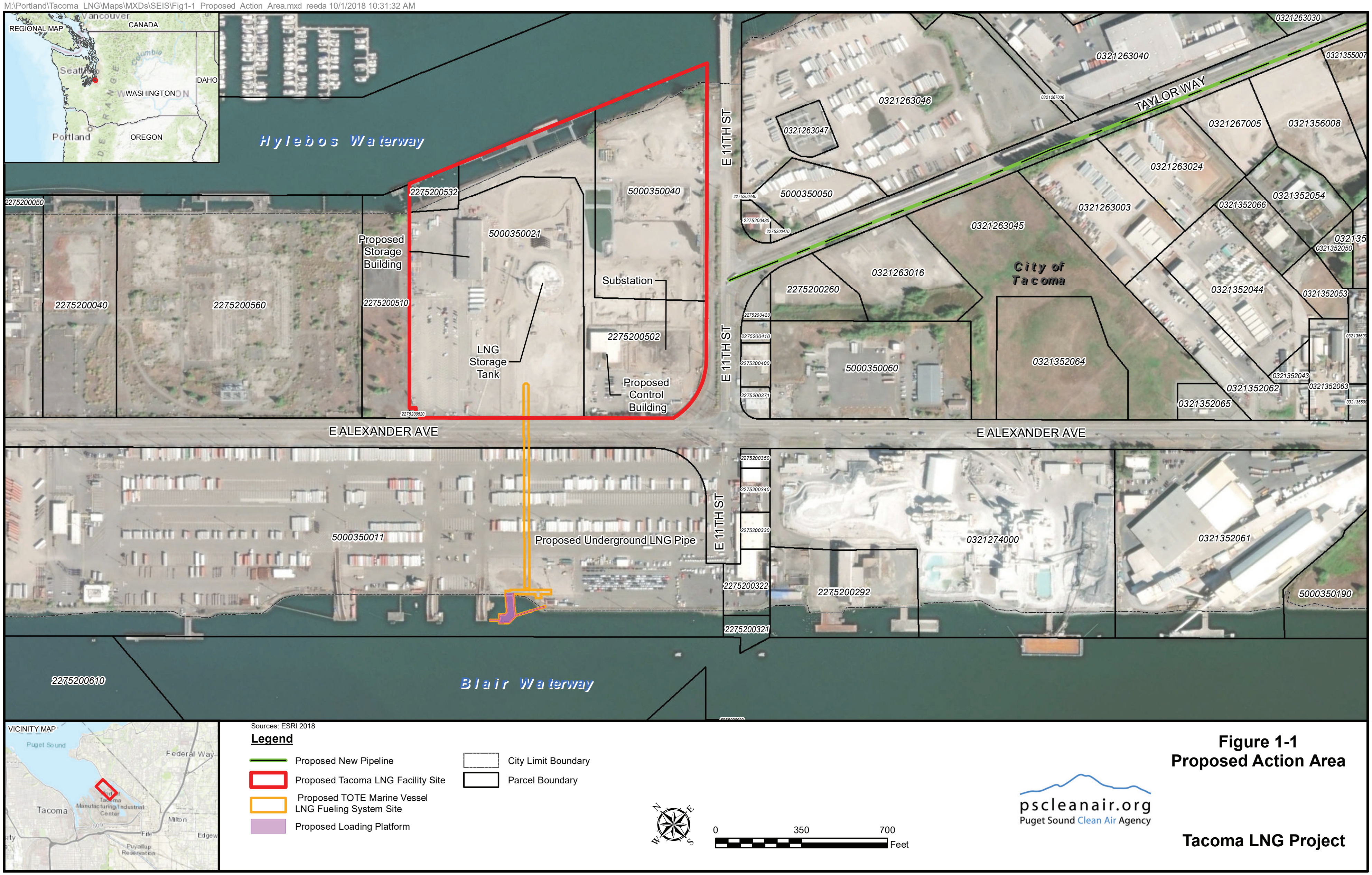


**Figure 1-1**
**Proposed Action Area**

**Tacoma LNG Project**

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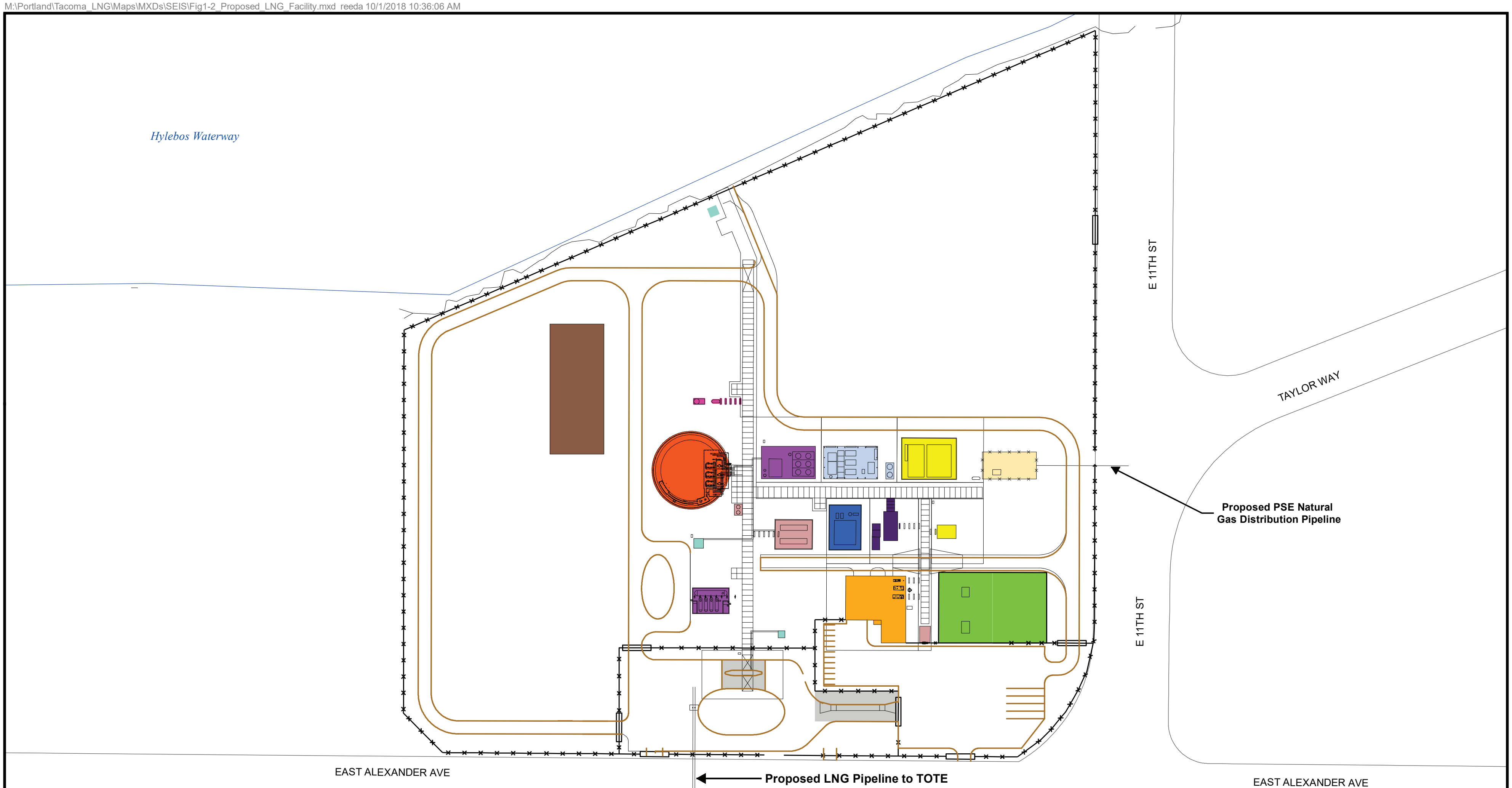
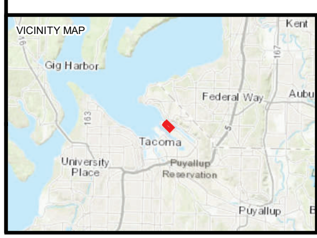



Sources: ESRI 2018

**Legend**

- Metering and Odorization
- Pretreatment
- Compressor Building
- Liquefaction
- LNG Storage Tank
- Truck Loading Station
- Vaporization
- Sumps
- Enclosed Ground Flare System
- Facility Cooling Water System
- Power Distribution Center
- Electrical Substation
- Control Building
- Storage Building
- Equipment
- Roads
- Fence
- Hylebos Waterway
- Pipe Rack

0 200 Feet

pscleanair.org
Puget Sound Clean Air Agency

**Figure 1-2**
**Proposed LNG Facility Layout**

**Tacoma LNG Project**

# 2 Description of the Proposed Action

## 2.1 Introduction

The Tacoma LNG Facility components and operational details are fully described in the FEIS. As summarized in Chapter 1 (Purpose, Need, and Alternatives Considered), the Proposed Action for the purposes of the DSEIS is to construct the Tacoma LNG Facility to produce 250,000 to 500,000 gpd of LNG to be used as a marine fuel and provide LNG to various customers in the Puget Sound area via LNG bunkering barges and tanker trucks, replacing the use of MDO and diesel fuel. The Tacoma LNG Facility would also have the capability of vaporizing LNG back to its gaseous state for injection into the PSE Natural Gas Distribution System during periods of high demand, referred to as "peak shaving."

As the nature of the Tacoma LNG Facility or its intended uses has not changed since the FEIS, and pursuant to the Notice of SEIS issued by the Puget Sound Clean Air Agency (PSCAA) on January 24, 2018, this chapter only examines the components relevant to the GHG life-cycle analysis.

Life-cycle emissions include not only the direct emissions associated with production of LNG, but also include emissions associated with extraction, refining, and transport of each fuel used in production and emissions associated with end use (combustion in marine engines and heavy duty trucks and peak shaving). Upstream life-cycle or well to tank emissions are the emissions associated with production and transport of fuel used at the LNG production plant: natural gas feedstock, natural gas fuel, diesel fuel, and electricity. For natural gas, upstream life-cycle emissions include emissions due to natural gas extraction and transport to the facility. For on-site diesel, upstream life-cycle emissions are those associated with crude oil recovery, transport to the refinery, refining, and finished product transport to end use. For electricity, upstream life-cycle emissions include recovery, and processing and transport of each fuel type to the electricity generating plants (generally a mix of coal, nuclear, natural gas, oil, hydro and other renewables). Direct emissions from the Proposed Action include all fuel combustion emissions, as well as fugitive emissions at the plant. End use emissions refer to the final combustion of LNG for vessel/truck transportation and peak shaving applications.

Appendix B contains the methodology employed for the GHG life-cycle analysis. Appendix C provides the detailed results of the GHG life-cycle analysis.

In the life-cycle analysis, there are references to a "Scenario A" and "Scenario B." The Scenario A analysis is based on a facility LNG production rate of 250,000 gpd. The Scenario B analysis is based on a production rate of 500,000 gpd. The FEIS stated the facility would produce between 250,000 and 500,000 gpd. The information originally provided by PSE for this life-cycle analysis reflected a facility design for 250,000 gpd production, which also matches the capacity of the facility described in the Notice of Construction (NOC) application. That air permit action is still pending, waiting for the completion of this SEIS review. Both scenarios have been evaluated and included in these analyses to reflect the Proposed Action that PSE is currently seeking and the full capacity of the facility that was referenced in the FEIS.

## 2.2 Upstream (Well to Tank)

### 2.2.1 Natural Gas Extraction and Transportation

The gas supply for the LNG Facility would come exclusively from British Columbia. No natural gas would be obtained from other regions for the Tacoma LNG Facility (PSE 2018). British Columbia has adopted comprehensive drilling and production regulations that are intended to reduce methane emissions. The Canadian national government has recently adopted new regulations that require companies to control methane leaks from equipment and the release of methane from compressors starting on January 1, 2020. However the life-cycle analysis presented in this document takes into account only those British Columbia regulations currently in effect and does not consider the additional emissions reductions that will result from the new national regulations adopted by the Canadian government in April 2018.

The gas supply for the LNG Facility would be transported from British Columbia by way of Westcoast Pipeline (Duke Energy) to the Huntingdon/Sumas export/import point located near the United States and Canadian border. Gas received at the Huntingdon/Sumas export/import point would be transported approximately 145 miles on Northwest Pipeline (Williams Company) to the Frederickson Meter Station, Southeast of Tacoma. PSE has acquired pipeline capacity on the Northwest Pipeline that would be dedicated to this purpose. (PSE 2018)

The bulk of gas receipts into the PSE system for the LNG Facility are anticipated at Frederickson. Under certain conditions, some gas may enter the PSE system at the North Tacoma Meter Station, approximately 131 miles from the Huntingdon/Sumas hub. However, the longer transmission distance of 145 miles is assumed for all gas transmission between the Huntingdon/Sumas hub and the PSE's pipeline system. (PSE 2018)

### 2.2.2 Petroleum Upstream

Under the Proposed Action, diesel fuel would continue to be used in small quantities. See Section 3.2 (Upstream Emissions) for further discussion of petroleum related upstream emissions.

### 2.2.3 Electric Power Generation

For each gallon of LNG produced, the LNG Facility would consume 1.35 kilowatt hours (kWh) of grid power to meet its electricity requirements.

The electric power generation mix affects the GHG emissions associated with purchased power. Power would be delivered to the Tacoma LNG Facility through the Tacoma Power electrical system. Although the majority of electricity is generated by hydro-electric, nuclear, and non-hydroelectric renewables, some is generated using natural gas (US EIA 2018). The Washington State Average Mix, which is a similar mix to Tacoma Power that would supply the Tacoma LNG Facility, with an average emission rate of 18 g/kWh carbon dioxide equivalent ($CO_2e$), was used to estimate upstream electricity emissions (State Energy Office at the Washington Department of Commerce 2017). GHG emissions are calculated with the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) (ANL 2015) model upstream emission factors. Refer to Appendix C for more information on emissions assumptions for electric power generation.

## 2.3 LNG Processing Facility

Direct GHG emissions from the Proposed Action include combustion and fugitive emissions from various processing operations. Natural gas would enter the LNG Facility through a metering station connected to a new underground pipeline and upgrades to the existing distribution system originating at Frederickson. Natural gas entering the LNG Facility would be routed to an inlet filter separator to remove small particles and liquid droplets to protect the downstream boost compression and the pre-treatment systems. In order to convert the natural gas to a liquid, the feed gas would be boosted in pressure to approximately 525 pounds per square inch gauge (psig) by an electric motor-driven, two-stage, integrally-geared centrifugal compressor. Once cooled to a temperature of -260 degrees Fahrenheit, the pressure is decreased to approximately 3 psig. Fugitive leakage from the feed gas compressor's seals would be captured and sent to the enclosed ground flare. The LNG would then be pumped into an 8 million gallon double-walled storage tank.

LNG would be pumped out from the storage tank for either vaporization and reintroduction into the local distribution system, or use as a marine vessel or surface vehicle fuel. LNG would be removed from the storage tank by way of submerged motor in-tank pumps. The submerged motor LNG pumps would be contained within the enclosed LNG tank and therefore are not a source of fugitive emissions.

## 2.3.1 Natural Gas Pretreatment Systems

### 2.3.1.1 Amine Pretreatment System

Natural gas entering the Tacoma LNG Facility through the dedicated pipeline would be composed primarily of methane, but would also contain other non-methane hydrocarbons. In addition, quantities of nitrogen, carbon dioxide ($CO_2$), sulfur compounds (hydrogen sulfide [$H_2S$] and odorants), and water would be present in the feed gas stream entering the plant. (PSE 2018)

$CO_2$ and water would freeze within the liquefaction process and must be removed to sufficient levels to allow optimal performance of the heat exchangers. $CO_2$, water, some sulfur-based components, and trace contaminants would be removed from the feed gas by an Amine Pretreatment System designed to treat up to 26 million standard cubic feet per day of inlet gas with an average of 2 percent $CO_2$ concentration so as not to limit the capacity of the liquefaction system. (PSE 2018)

For purposes of determining GHG emissions from the Tacoma LNG Facility, the Amine Pretreatment System generates GHGs from two components of the process. First, there is an 18.0 million British thermal units (MMBtu) per hour natural gas fired Water Propylene Glycol heater that would generate combustion emissions. Second, an aqueous amine solution would absorb $CO_2$ and $H_2S$ from the natural gas through a chemical reaction, resulting in a “sweet” gas with less than 50 parts per million of $CO_2$ and a “rich” amine solution that contains the $CO_2$ and $H_2S$. The “rich” aqueous amine solution would then be heated in a 3.2 MMBtu/hour regenerator to remove the $CO_2$ and $H_2S$, resulting in a “lean” amine solution that would be reused in the process. The exhaust from the amine regenerator would be routed to the enclosed ground flare, which would oxidize $H_2S$, odorants and volatile organic compounds at high temperature into water, $CO_2$, and $SO_2$. (PSE 2018)

### 2.3.1.2 Non-methane Hydrocarbon Removal

After pretreatment, but prior to liquefaction of the natural gas, non-methane hydrocarbons that may freeze at the cryogenic temperatures encountered downstream would be removed by partial refrigeration. Nitrogen would be used to purge the truck loading hoses and facilitate liquid draining and then be routed to the enclosed ground flare. The remainder of the removed hydrocarbons would be disposed of via the enclosed ground flare. Flash gases from the non-methane hydrocarbon storage vessel would be sent to the enclosed ground flare. These uses are taken into account in the life-cycle analysis. (PSE 2018)

## 2.3.2 Liquefaction

After the non-methane hydrocarbon removal process, the natural gas would be mixed with compressed boil-off gas (BOG) from the storage tank and condensed to a liquid by cooling the gas to approximately -260 degrees Fahrenheit using a mixed refrigerant (composed of methane, ethylene, propane, isopentane, and nitrogen). Seal leakage from the compressor would be captured and sent to an enclosed ground flare. Liquefaction is expected to typically occur during 51 weeks of the year. Up to 10 days per year, the Tacoma LNG Facility is expected to operate in a holding mode while LNG is vaporized. (PSE 2018)

## 2.3.3 LNG Storage

The LNG would be stored in an 8-million-gallon, low-pressure LNG storage tank at less than 3 psig. The LNG storage tank would be a full containment structure consisting of a steel inner tank and a pre-stressed concrete outer tank. The storage tank would be vapor- and liquid-tight without losses to the environment. Insulating material would be placed between the inner and outer tanks to minimize heat gain and boil-off. (PSE 2018)

To maintain the natural gas in a liquid state, an auto-refrigeration process would be used to keep the temperature of the LNG below -260 degrees Fahrenheit (PSE 2018). Inside the tank, vapor pressure above the liquid is kept constant so the temperature is maintained. When LNG temperature increases, vapors, referred to as BOG, are created. In order to avoid pressure build-up within the tank, BOG is collected in a recovery system (PSE 2018). The BOG Recovery System warms the gas and boosts the pressure for either re-liquefaction and return to the storage tank or reinjection into the distribution system as natural gas (PSE 2018). In a situation where the process is disrupted, excess LNG vapors would vent to the enclosed ground flare (PSE 2018). GHG emissions would also occur from fugitive losses that occur from valves associated with the LNG storage tank.

### 2.3.4 LNG Vaporization for Peak Shaving

The LNG vaporization system consists of a pump and vaporizer. The vaporization pump would be external to the LNG storage tank and would boost the pressure to a sufficient level for vaporization and reinjection into the PSE Natural Gas Distribution System pipeline. The vaporizer would consist of a warm water bath that heats the LNG to a gaseous state suitable for use in the pipeline. The vaporization system would have the capacity to deliver 66 million standard cubic feet per day of natural gas at the standard distribution pipeline pressure. The gas sent out to the natural gas pipeline would be metered and odorized. Only one pipeline would convey natural gas to and from the Tacoma LNG Facility. Thus, when the vaporization and reinjection system is operating, the LNG liquefaction system would not operate. (PSE 2018)

Fugitive GHG emissions would occur during the regasification process for peak shaving, and would primarily originate from valves and associated piping connections. GHG emissions would also occur during combustion of the natural gas in the power generation facility associated with peak shaving.

### 2.3.5 LNG Delivery to TOTE and Other Vessels

LNG would be conveyed via cryogenic pipeline to the TOTE marine vessel LNG fueling system (MVFS). The LNG pipeline would extend 1,200 feet from the Tacoma LNG Facility storage tank, pass through a tunnel below the Alexander Avenue right-of-way, then above ground near the Blair Waterway shoreline and extend through a below ground trench to the TOTE terminal access trestle, ending at a loading arm on a bunkering platform. Ship bunkering would typically occur twice per week, for a period of 4 hours each, or a total of 8 hours per week. (PSE 2018)

Marine vessels would be bunkered with LNG for fuel using a dedicated marine bunkering arm equipped with a piggyback vapor return line. The arm is hydraulically maneuvered and includes swivel joints that would be swept with nitrogen to prevent ingress of moisture that could freeze and impede arm movement. When connected to the receiving vessel, the LNG bunkering arm and connected piping would be purged with nitrogen, which would be routed back to the enclosed ground flare. Once the system is purged, LNG would be bunkered onto the receiving vessel at a maximum design rate of 2,640 gpm. Once bunkering is complete, the liquid in the bunkering arm and in the adjacent piping would be drained back to the LNG storage tank. After draining, the arm and connected piping would be purged with nitrogen again. The nitrogen purge would be routed back to the enclosed ground flare and the arm piping depressurized prior to disconnection (PSE 2018).

Fugitive GHG emissions would occur from valves and piping associated with transfer of LNG to TOTE’s ships, and from LNG loading to other marine vessels. During bunkering transfer operations, GHG emissions would occur from BOGs.

LNG may also be supplied to bunker vessels for subsequent transfer to ships. In this process, the bunker vessel would load LNG via the MVFS. The bunker vessel would then transit to the LNG-fueled marine vessel, anchor alongside the vessel, and conduct ship-to-ship transfer of the LNG. This is the process typically used for fuel oil. Because the current situation (i.e., the No Action Alternative) involves bunker barge operations using fuel oil, no additional LNG emissions were evaluated for LNG bunker barge operations beyond methane emissions associated with the ship-to-ship transfer process. (PSE 2018)

### 2.3.6 LNG Truck Loading Facilities

Two loading bays on the west side of the Tacoma LNG Facility would have the capacity to load LNG into 10,000-gallon capacity tanker trucks. The loading bays would be designed to fill a tanker truck at a rate of

300 gpm. Truck loading can be functionally undertaken concurrently with liquefaction, marine loading, or to the pipeline (PSE 2018).

Each truck bay would have an LNG supply and vapor return hose. The hoses would be 3 inches in diameter and 20 feet long and made from corrugated braided stainless steel with connections designed for LNG trailers. After truck loading, the LNG hose would be drained to a common, closed truck station sump connected to the Tacoma LNG Facility vapor handling system where it would be allowed to boil off and be re-liquefied or sent to the pipeline. Nitrogen would be used to purge the hoses and facilitate liquid draining and then routed to the enclosed ground flare. (PSE 2018)

Fugitive GHG emissions would occur from valves associated with truck transfer activities.

### 2.3.7 TOTE Marine Vessel LNG Fueling System

The TOTE MVFS would be located on the TOTE site on the Blair Waterway. The TOTE site is primarily a paved parking area for trailers, other vehicles, and equipment and includes some small buildings and structures.

The TOTE MVFS would consist of an access trestle and LNG loading platform with the LNG pipeline ending at a loading arm or hose on the loading platform that would transfer LNG to the TOTE vessel, or other barges and bunker ships. The loading arm or hose would have emergency release couplings at the outboard of the arm or hose.

The shoreline along the Blair Waterway is developed with berths and armored slopes containing riprap, concrete and asphalt pieces. The slope and armoring of the section of shoreline for the MVFS would remain unchanged. In-water structures in the Blair Waterway associated with existing TOTE operations include a timber T-pier, three concrete piers, and one concrete breasting dolphin.

New construction would include a concrete, steel pile-supported access trestle extending from shore to the LNG loading platform. This 81-foot-long by 33-foot-wide (2,673 square feet) trestle would be constructed adjacent to the existing aft loading platform for the TOTE vessels. It would provide a roadway section for fire truck access to the loading platform, a pipeway, a utility corridor for all required piping and utilities, and a walkway for personnel. Twelve 30-inch-diameter steel pipe piles would support the trestle. A concrete spillway installed along the trestle below the LNG pipeline would convey any accidental release of LNG into a purpose-built containment sump located onshore.

PSE’s LNG delivery system would terminate at the loading flange on TOTE’s ship.

### 2.3.8 Other Process Facilities

The process facilities would include other specific components, such as a meter station, odorizor, BOG recovery system, and flare system. The life-cycle analysis assumed that GHG fugitive emissions would be occur from several of these facility components (see Section 2.3.9 [Fugitive Emissions]).

### 2.3.9 Fugitive Emissions

Fugitive methane emissions can occur from leaks in valves, pump seals, flanges, connectors, and compressor seals. There are multiple fugitive minimization features inherent in the Tacoma LNG Facility design. For example, all of the proposed pumps, with the exception of the hydrocarbon liquid pump, would be submerged inside enclosed liquid storage tanks. In addition, leaks from the feed gas compressor seals would also be captured and vented to the enclosed ground flare. However, the BOG would have fugitive methane emissions. In addition, there are several valves, relief valves, and flanged connectors for conveyance of various process fluids that have the potential for fugitive methane leaks. LNG bunkering of ships at the TOTE terminal would not produce any fugitive emissions. However, there are four swivel joints that have seals with the potential to leak methane. The analysis assumes that the leak rate of the swivel joints would be similar to that of the pump seals. (PSE 2018)

## 2.4 End Use Emissions

The life-cycle analysis assumes that all fuel distributed from the facility would be combusted to power on-road trucking, TOTE marine vessels, truck-to-ship bunkering, or other marine vessels. The volume and type of use vary slightly depending on the daily capacity (see Table 2-1). TOTE marine vessel fuel use is estimated to remain the same for both the 250,000 gpd and 500,000 gpd production level scenarios. The balance of the 500,000 gallons of LNG per day has been attributed to supply fuel to the Gig Harbor LNG facility, on road trucking, truck-to-ship bunkering, and other marine vessels.

**Table 2-1 LNG End Use Volume, Proposed Action**

| | Scenario A | | | Scenario B | | |
|---|---|---|---|---|---|---|
| **LNG Production** | **End Use Share** | **gallons/ day** | **MGal/ year** | **End Use Share** | **gallons/ day** | **MGal/ year** |
| **Total** | **100.0%** | **250,000** | **88.75** | **100.00%** | **500,000** | **177.50** |
| Peak Shaving | 11.0% | 27,397 | 9.73 | 5.48% | 27,397 | 9.73 |
| Gig Harbor LNG Supply | 0.0% | 0 | - | 1.00% | 5,000 | 1.78 |
| On-road Trucking | 0.0% | 0 | - | 2.00% | 10,000 | 3.55 |
| TOTE Marine | 42.7% | 106,849 | 37.93 | 21.37% | 106,849 | 37.93 |
| Truck-to-Ship Bunkering | 0.0% | 0 | - | 1.00% | 5,000 | 1.78 |
| Other Marine (by Bunker Barge) | 46.3% | 115,753 | 41.09 | 69.15% | 345,753 | 122.74 |

Key:
LNG = liquefied natural gas
MGal = million gallons
TOTE = Totem Ocean Trailer Express

## 2.5 Construction Emissions

Direct construction GHG emissions result from the combustion of fuel in construction equipment. Upstream emissions consist of electric power for construction as well as those emissions generated in the production of gasoline and diesel fuel. Construction equipment emissions correspond to the fuel use combined with emission factors for diesel and gasoline during the construction time of about three and a half years. Another portion of construction emissions consists of vehicle trips (workers and heavy-duty trucks). Equipment use was estimated based on construction activities defined in the FEIS (see Section 2.3 [Construction Procedures] of the FEIS). Material manufacturing emissions include the energy inputs and associated GHG emissions in the production of raw materials, and manufacturing processes to produce building materials for the LNG Facility, such as steel and concrete.

GHG emissions were calculated for the following:

- Construction equipment fuel use
- Construction equipment power
- Material delivery
- Material manufacturing for the Tacoma LNG Facility

### 2.5.1 Upstream Construction

Upstream emissions for construction activity include the production of diesel and gasoline for construction equipment, generation of power and upstream fuel production for construction equipment, and manufacturing of materials.

### 2.5.2 Direct Construction Emissions

Direct GHG emissions from construction correspond to the fuel combusted from cranes, dozers, compressors, and other construction equipment, and employee vehicle (i.e., commuter) trips.

# 3 Description of the No Action Alternative

## 3.1 Introduction

Under the No Action Alternative, the Proposed Action would not be implemented. It is assumed that existing land uses would continue at the proposed Tacoma LNG Facility site, which is zoned for maritime industrial operations. Table 3-1 shows the activities and fuel types that occur in the No Action Alternative that would be displaced in the Proposed Action.

**Table 3-1 Key Parameters Affecting Life-Cycle Greenhouse Gas Emissions**

| Displaced Activity | Fuel | Equipment Type |
|---|---|---|
| Diesel Dual Fuel Peak Shaving | Diesel | Dual Fuel Gas Turbine |
| Gig Harbor Peak Shaving | LNG | LNG for NG Peak Shaving |
| On-road Trucking | Diesel | Diesel Truck |
| TOTE Marine | MDO | Marine Engine |
| Truck-to-Ship Bunkering | MDO | Marine Engine |
| Other Marine by Bunker Barge | MDO | Marine Engine |

Key:
LNG = liquefied natural gas
MDO = marine diesel oil
NG = natural gas
TOTE = Totem Ocean Trailer Express

Absent the Tacoma LNG Facility, MDO and diesel fuels would continue to provide the source of energy for the fuel use applications targeted by the Proposed Action. LNG would not be produced or stored at the Tacoma LNG Facility site and would not replace MDO for fuel marine vessels or other users in the Puget Sound area. To assess the potential changes from the Proposed Action's operation and supply LNG, it is assumed that the equivalent amount of MDO and diesel fuel would continue to be used.

Additionally, LNG would not be stored on site for regasification and injected into the PSE natural gas pipeline system during periods of peak demand. During peak demand, natural gas would be diverted to use for industrial and residential customers and dual-fuel turbines generating electricity would convert to using diesel oil during peak periods. The Gig Harbor LNG storage facility would continue to be supplied by truck from Canada.

Life-cycle GHG emissions from the No Action Alternative consist of upstream and end use activities only. No direct emissions have been included in the No Action Alternative analysis. Upstream life-cycle emissions under the No Action Alternative are associated with extraction, refining, and transport of natural gas fuel, MDO, diesel fuel, and electricity. Natural gas and electricity upstream life-cycle activities are described in Chapter 2 (Description of the Proposed Action). For MDO, and diesel fuel, upstream life-cycle emissions are those associated with crude oil recovery, transport of crude oil to the refinery, refining, and finished product transport to end use. End use emissions include peak shaving and transportation related combustion activities. Values from the combustion of MDO and diesel fuel have been estimated based on baseline uses for the TOTE marine vessels, truck transportation, and peak shaving. In addition, the analysis of the No Action Alternative quantifies the emissions from MDO combustion that is projected to be replaced in other vessels with the balance of the 250,000 or 500,000 gpd LNG capacity that would be created by the Proposed Action.

## 3.2 Upstream Emissions

Upstream life-cycle GHG emissions for petroleum fuels including diesel, bunker fuel, and gasoline, were calculated based on the regional resource mix for Washington. Inputs for the life-cycle of petroleum fuels include the location of crude oil resources and how it is extracted, Transportation distance and mode, and the American Petroleum Institute (API) gravity of the crude oil and the carbon intensity (CI) of the final products. These inputs were applied to the GREET analysis of crude oil refining. GHG emissions were based on the more detailed regionally specific Oil Production Greenhouse Gas Emission Estimator (OPGEE) analysis published by the California Air Resources Board (California ARB 2018; El-Houjeiri et al. 2018).

### 3.2.1 Crude Oil Extraction

Crude oil is produced and transported from a variety of resources and regions in the world. GHG emissions from petroleum production depend on the crude oil type and the extraction method, as well as oil refinery configuration, with about a 10 percent range in life-cycle emissions from different crude oil types (Gordon et al. 2015; Keesom, Blieszner, & Unnasch 2012) The life-cycle analysis of petroleum production in the GREET model takes into account the upstream emissions for crude oil production as well as the energy intensity to refine different products. The GREET inputs for petroleum product refining are based on a linear programming analysis of United States refineries, and were used in this analysis (Elgowainy et al. 2014).

### 3.2.2 Transport of Crude Oil

Washington State receives crude oil by vessel, pipeline, and rail. Assessments by the United States Energy Information Administration provide the quantity of oil as well as corresponding API gravity—the measure of petroleum liquid's density relative to water—and sulfur content for all crude oil imported from foreign countries to the United States (US EIA 2018).

The Washington State Department of Ecology (Ecology) tracks and publishes quarterly reports (Ecology 2018) on all foreign and domestic crude oil receipts via rail car, pipeline, and other vessel transport modes. These data help determine the quantity of Alaska and North Dakota crude oil received and help determine the split between different transport modes for Canadian crude oil.

Table 3-2 presents a summary of the sources of Washington's crude oil. As of 2017, transport of crude oil from Canada, North Dakota, and Alaska's North Slope represents 94 percent of Washington's crude oil influx.

**Table 3-2 Summary of 2017 Crude Oil Influx to Washington State**

| Origin | Quantity (1,000 barrels) | Percentage (%) | Transport Mode |
|---|---|---|---|
| Brazil | 5,855 | 3% | Vessel |
| Brunei | 245 | 0% | Vessel |
| Canada | 66,780 | 31% | Mixed |
| Ecuador | 690 | 0% | Vessel |
| Mexico | 451 | 0.2% | Vessel |
| Russia | 2,480 | 1.2% | Vessel |
| Saudi Arabia | 1,297 | 0.6% | Vessel |
| Trinidad & Tobago | 1,367 | 1% | Vessel |
| North Dakota | 49,715 | 23% | Rail |
| Alaska NS | 84,278 | 40% | Mixed |
| Total Crude | 213,159 | N/A | N/A |
| Total Capacity | 231,301 | N/A | N/A |

Source: Appendix C, Table B.10

#### 3.2.2.1 Pipeline from Canada

The majority of Washington State's foreign crude oil is imported from Canada. Canadian crude oil can be derived from oil sands and upgraded before introducing it to a pipeline or it can be conventional crude oil. Data specifying the share of oil sands-derived versus conventional crude exported to each of the five Petroleum Administration for Defense Districts within the United States is no longer available. Instead, the Canada National Energy Board simply distinguishes between light and heavy crude. For Petroleum Administration for Defense District 5, where Washington State is located, the National Energy Board data indicate that 58 percent of the crude is light and 42 percent is heavy (and assumed to be derived from oil sands)(Natural Resources Canada 2015).

Modeled emissions for the No Action Alternative account for the additional mileage that the oil sands-derived crude is transported from Calgary to Edmonton and then to British Columbia. Shipments from Saskatchewan are assumed to be transported from Saskatoon to Edmonton and then to British Columbia.

#### 3.2.2.2 Tanker from Alaska and Unit Train from North Dakota

In addition to Canadian imports, the most significant sources of crude oil used in Washington are from the Alaska North Slope (via pipeline to Valdez and vessel to the west coast ports) and from North Dakota on rail cars.

The emissions model for the No Action Alternative accounts for the transport of crude oil through the Trans-Alaska pipeline system and its subsequent loading and transport via tanker to Washington State, 1,500 miles of crude oil transport from North Dakota prior before to its entry into eastern Washington near Spokane.

### 3.2.3 Crude Oil Storage, Refining, and Distribution

Petroleum refineries convert crude oil primarily into transportation fuels. There are five refineries in Washington State with a combined refining capacity of over 230 million barrels per year. Although the state is a net exporter of refined product, gasoline and diesel are imported from Montana and Utah into eastern Washington. The most recent available pipeline transfer data (Adelsman 2014) indicated that 6 percent of diesel consumed in Washington is refined in Montana and transported to Washington via the Yellowstone pipeline and 10 percent is refined in Utah and transported via the Tesoro pipeline. In the No Action Alternative, the balance (84 percent of diesel) is assumed to be refined in Washington State. We assume that all residual oil/marine diesel consumed is refined in-state. Crude oil storage GHG emissions values are included in the life-cycle analysis modeling. Crude is processed from various locations and production methods and transported by tanker ship, pipeline, or rail car. GHG emissions from petroleum products also depend upon its sulfur content and density (represented by API gravity), on the energy intensity of the refining process and CI of the final products. The energy inputs and emissions are described in Appendix C.

The California Air Resources Board utilizes the OPGEE model to quantify the CI of the crude oil recovery and transport portion of petroleum fuel pathways. For this analysis we utilize the 2016 CI values developed for California using OPGEE (California ARB 2017). The CI from refining and finished fuel (gasoline, diesel and residual oil) were calculated with the GREET model for each refining location (i.e., Washington, Montana, and Utah). The GREET model adjusts refining energy inputs based on correlations between crude location and both sulfur content at API degree. We have also customized the model to use state average electricity grid mixes at each of the refining locations. Details regarding the energy inputs and emission factors are described in Appendix C.

### 3.2.4 Other Upstream Activities

The majority of upstream GHG emissions under the No Action Alternative would come from MDO and diesel fuel use. Some upstream emissions would result from natural gas and electricity use, but this is considered marginal and has not been quantified.

## 3.3 End Use Emissions

The life-cycle analysis under the No Action Alternative assumes that the equivalent amount of MDO and diesel fuel would not be displaced by LNG. These fuels would continue to be combusted to power on-road trucking, TOTE marine vessels, truck-to-ship bunkering, or other marine vessels. The volume and type of use vary slightly depending on the daily capacity (see Table 3-3). As in the LNG estimates, TOTE marine vessel fuel use is estimated to remain the same for both the 250,000 gpd and 500,000 gpd production level scenarios. Under the 500,000 gpd capacity scenario, the increased capacity replaces diesel and MDO for peak shaving, on road trucking, truck-to-ship bunkering, and other marine vessels.

**Table 3-3 Fuel End Use Volumes, No Action Alternative**

| LNG Production | Scenario A | | | Scenario B | | |
|---|---|---|---|---|---|---|
| | End Use Share | MGal/ year | GBtu/ year | End Use Share | MGal/ year | GBtu/ year |
| **Total** | **100.00%** | **50.6** | **7,022** | **100.00%** | **101** | **14,018** |
| Peak Shaving | 10.68% | 5.89 | 750 | 5.35% | 6 | 750 |
| Gig Harbor LNG | 0.00% | - | - | 0.98% | 1.78 | 137 |
| On-road Trucking | 0.00% | - | - | 1.76% | 1.93 | 247 |
| TOTE Marine | 42.92% | 21.48 | 3,014 | 21.50% | 21.48 | 3,014 |
| Truck-to-Ship Bunkering | 0.00% | - | - | 1.01% | 1.01 | 141 |
| Other Marine (by Bunker Barge) | 46.38% | 23.21 | 3,257 | 69.40% | 69.32 | 9,729 |

Key:
GBtu = giga British thermal units
LNG = liquefied natural gas
MGal = million gallons
TOTE = Totem Ocean Trailer Express

### 3.3.1 Peak Shaving

Peak shaving power generation facilities provide electricity for the grid when demand is too high for base load electrical power. For the purposes of analyzing the No Action Alternative, it is assumed that all peak shaving would be accomplished with diesel fuel. The quantity of diesel fuel assumed corresponds to the same kWh of electric power that would be generated by the dual-fuel generators operating on natural gas. It is assumed that 5.89 million gallons of diesel fuel per year would be used for peak shaving under the No Action Alternative.

### 3.3.2 Diesel for On Road Trucking and Truck-to-Ship Bunkering

Under the No Action Alternative, diesel fuel would continue to be used for on-road trucking and by ships that currently use diesel fuel. The amount of diesel displaced by LNG used to estimate diesel from on-road trucking is based on the mileage using the displaced LNG in the Proposed Action, or approximately 1.9 million gallons of diesel for on-road trucking and approximately 1 million gallons of diesel for truck-to-ship bunkering.

### 3.3.3 Use of Marine Diesel Oil as a Marine Fuel

Under the No Action Alternative, marine engines would continue to operate on MDO. Under the 250,000 gpd capacity scenario, the Proposed Action would displace 21.48 million gallons of MDO used by TOTE marine vessels, and would provide additional capacity to replace another 23.21 million gallons of MDO used by other marine vessels. Under the 500,000 gpd scenario, the expanded capacity would also displace 21.48 million gallons of MDO used by TOTE marine vessels, and would provide additional capacity to replace up to 69.32 million gallons of MDO used by other marine vessels.

# 4 Affected Environment, Environmental Consequences, and Mitigation

This chapter describes the regulatory framework for GHG emissions, the methodology of the GHG life-cycle analysis; the existing GHG emissions in the Proposed Action area; the potential change in GHG emissions and associated impacts resulting from the construction, operation, and decommissioning of the Tacoma LNG Facility compared to the No Action Alternative.

## 4.1 Regulatory Framework

This section provides an overview of the federal, state, and local agencies with jurisdiction over GHG emissions from the Proposed Action and the Proposed Action area, and a summary of specific regulations that apply to aspects of GHG emissions from construction and operation of the proposed Tacoma LNG Facility.

### 4.1.1 Agency Jurisdiction

Three agencies have jurisdiction over GHG emissions for the areas of the Port of Tacoma, cities of Tacoma and Fife, and Pierce County: the United States Environmental Protection Agency (EPA), Ecology, and PSCAA. PSCAA is the primary regulatory agency responsible for air quality permitting and compliance within King, Kitsap, Pierce, and Snohomish counties.

### 4.1.2 Federal GHG Policy and Regulations

On April 2, 2007, the United States Supreme Court (Massachusetts v. EPA) decided that GHGs were considered "air pollution" covered by the federal Clean Air Act. That decision indicated that if EPA did not choose to regulate GHGs through that authority, it needed to be based on a scientific determination that there was no endangerment from the emissions or any identified cause for those emissions. On December 7, 2009, EPA determined that the presence of six GHGs in the atmosphere endangers public health and public welfare and included them as contributors to air pollution: $CO_2$, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride (EPA 2009a). That led to regulations developed by EPA to address the emissions of GHGs.

On November 8, 2010, EPA finalized reporting requirements for the petroleum and natural gas industry under 40 Code of Federal Regulations Part 98 Subpart W. This subpart was then amended on December 23, 2011. Subpart W requires petroleum and natural gas facilities that emit 25,000 metric tons or more of $CO_2e$ per year to report annual emissions of specified GHGs from various processes within the facility.

EPA also addressed the relationship of GHG emissions for stationary source permitting programs. Currently, sources that are already Title V major emission sources can be considered major GHG emission sources. GHG emissions thresholds for permitting of stationary sources are an increase of 75,000 tons per year (tpy) of $CO_2e$ at existing major sources and facility-wide emissions of 100,000 tpy of $CO_2e$ for a new source or a modification of an existing minor source. The 100,000 tpy of $CO_2e$ threshold defines a major GHG source for both construction (Prevention of Significant Deterioration [PSD]) and operating (Title V) permitting, respectively. (EPA 2009b)

### 4.1.3 State GHG Policies and Regulations

Washington State has had both policies, statutes, and regulations that address GHG emissions and their impacts for many years. Some of these include:

- Revised Code of Washington (RCW) 80.70 Carbon Dioxide Mitigation (2004)
- RCW 80.80 GHG Emissions – Baseload Electric Generation Performance Standard (2007)

- Washington Administrative Code (WAC) 173-407 GHG Mitigation Requirements & Emission Standards for Power Plants (Ecology 2005)
- WAC 173-441 Reporting of GHG Emissions (2011)
- WAC 173-442 Clean Air Rule (2016) *[on hold, litigation pending]*
- WAC 173-485 Petroleum Refinery GHG Emission Requirements (2014)

Washington State's *Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy* (Ecology 2012) was published to describe the risks of climate change to the state and identify the state's priorities in addressing these risks.

In 2009, the Washington State Legislature approved the State Agency Climate Leadership Act E2SSB 5560, which established GHG emissions reduction limits for state agencies in law (RCW 70.235.050 and RCW 70.235.060) and directed state agencies to quantify GHG emissions, report on actions taken to reduce GHG emissions, and develop a strategy to meet the GHG reduction targets. Washington State has established the following GHG reduction targets to reduce overall emissions (RCW 70.235.020):

- By 2020, reduce overall emissions of GHGs in the state to 1990 levels;
- By 2035, reduce overall emissions of GHGs in the state to 25 percent below 1990 levels; and
- By 2050, the state will do its part to reach global climate stabilization levels by reducing overall emissions to 50 percent below 1990 levels, or 70 percent below the state's expected emissions that year. (Ecology 2016)

In June 2017, Washington Governor Jay Inslee formed the United States Climate Alliance with the governors of New York and California to commit to reducing emissions by 26 to 28 percent from 2005 levels in order to meet or exceed targets of the federal Clean Power Plan (United States Climate Alliance 2018).

The document titled *Guidance for Ecology Including Greenhouse Gas Emissions in SEPA Reviews* (Ecology 2011) was prepared for Ecology staff use as guidance for SEPA review work and indicated as guidance, decisions on impacts were to be made on a case-by-case basis. Prior to the decision to prepare this SEIS for a life-cycle GHG emissions review, Ecology withdrew the 2011 guidance and replacement guidance has not been published. The 2011 guidance indicated that for projects emitting more than 25,000 metric tons per year, a quantitative disclosure of GHG emissions is required under SEPA. The FEIS cited this document and indicated that the direct, operational emissions from the Tacoma LNG Facility site were less than that 25,000 metric tons per year. According to the 2011 guidance, a quantitative analysis should include GHG emissions from all aspects of the Proposed Action, including Scope 1 emissions (project direct), Scope 2 emissions (associated with purchased electricity), and Scope 3 emissions (which include construction emissions as well as new, ongoing transportation emissions associated with the project).

### 4.1.4 PSCAA GHG Policies and Regulations

PSCAA supports, and in some circumstances, has helped implement the state's policies and requirements for GHG emissions. While the agency has engaged on climate action in a variety of capacities for over the last 15 years, a key part of this has been the agency's role in relation to project proposals as presented through SEPA reviews. PSCAA's SEPA checklist requires identification and consideration of GHGs (see PSCAA Reg. I, Section 2.06 Environmental Checklist). GHGs are considered "air contaminants" under the definition of the Washington Clean Air Act (RCW 70.94.030). The agency has requested and established mitigation conditions for GHG impacts through SEPA in the past.

### 4.1.5 Air Quality Permitting Requirements

The air quality permitting requirement for this proposed facility includes the Notice of Construction (NOC) application and the issuance of an Order of Approval. The NOC application has been submitted (NOC No.

11386) and is under review for the Proposed Action. NOC review has several detailed requirements, and will address criteria pollutants, air toxic contaminants, and compliance with any identified applicable air quality standards. A review of GHG emissions and impacts is primarily addressed for a proposal through the SEPA process, which is the exclusive scope of this SEIS analysis.

Among the air quality standards that may apply to the LNG Facility (to be addressed in the NOC review process), it is anticipated that the Ecology rule for GHG emission reporting (WAC 173-441) will apply. That is a reporting rule alone and does not establish any substantive emission limitations. The Ecology Clean Air Rule (WAC 173-442) may also apply and could have some emission reduction/offset obligations as part of that program. While that will be noted in the NOC permit application review documents, that rule has been stayed by the courts and is subject to ongoing litigation. Thus, no emission reductions/offsets are assumed or included in the consideration at this time as the final status of that regulation is uncertain.

### 4.1.6 Regional and State Greenhouse Gas Emissions

EPA and Washington State have a number of programs designed to collect and analyze GHG emissions to better understand the sources of GHGs in the state. These programs help the state design policies to reduce GHG emissions and track its progress towards meeting the state's statutory GHG reduction limits.

EPA collects and reports nationally GHG emissions in the *Annual Inventory of U.S. Greenhouse Gas Emissions and Sinks*. The State of Washington's anthropogenic GHG emissions for the period from 1990 to 2013 (see Table 4-1) were developed using a set of generally accepted principles and guidelines for state GHG emission inventories, with adjustments for Washington-specific data and context, as appropriate—including the addition of military aircraft. The most recent inventory was published in October 2016 (Ecology 2016). Data are available from EPA on the county level; however, these data do not include military aircraft operations.

**Table 4-1 Washington State Annual Greenhouse Gas Air Emissions Inventory**

| Million Metric Tons $CO_2e$ | 1990 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|
| ***Electricity, Net Consumption-based*** | ***16.9*** | ***20.7*** | ***15.7*** | ***15.2*** | ***18.2*** |
| Coal | 16.8 | 15.8 | 12.8 | 12.1 | 13.3 |
| Natural Gas | 0.1 | 4.8 | 2.8 | 3.0 | 4.8 |
| Petroleum | - | 0.1 | 0.1 | 0.1 | 0.07 |
| ***Residential/Commercial/Industrial*** | ***18.6*** | ***19.7*** | ***20.8*** | ***20.5*** | ***21.9*** |
| ***Transportation*** | ***37.5*** | ***42.2*** | ***41.9*** | ***42.5*** | ***40.4*** |
| Onroad Gasoline | 20.4 | 21.9 | 21.3 | 21.2 | 21.7 |
| Onroad Diesel | 4.1 | 8.0 | 8.0 | 7.4 | 7.0 |
| Marine Vessels | 2.6 | 3.0 | 3.3 | 4.1 | 3.4 |
| Jet Fuel and Aviation Gasoline | 9.1 | 8.1 | 7.6 | 8.0 | 6.6 |
| ***Natural Gas Industry*** | ***0.5*** | ***0.8*** | ***0.8*** | ***0.8*** | ***0.8*** |
| ***Industrial Process*** | ***7.0*** | ***4.5*** | ***4.6*** | ***4.6*** | ***4.8*** |
| ***Waste Management*** | ***1.5*** | ***3.1*** | ***3.1*** | ***3.2*** | ***3.3*** |
| ***Agriculture*** | ***6.4*** | ***6.2*** | ***6.5*** | ***6.6*** | ***5.9*** |
| ***Total Gross Emissions*** | ***88.4*** | ***97.2*** | ***93.7*** | ***93.6*** | ***94.4*** |

Source: Ecology 2016
Note:
Bold values are included in the total gross emissions; all other rows and values included are subsets of the category above.
2010-2012 data have been revised based on values contained in the new International Panel on Climate Change Fourth Assessment Report for Global Warming Potential.
Key:
$CO_2e$ = carbon dioxide equivalent

### 4.1.7 GHG Life-Cycle Analysis

The Tacoma LNG Facility would produce LNG that would be used as a fuel for marine and on-road transportation applications, as well as for supplementing natural gas supply in the winter when demand is high (peak shaving). The life-cycle analysis examines the GHG emissions from the Proposed Action and compares these emissions to the alternative of not implementing the Proposed Action, which is the conventional use of distillate fuels in marine and trucking and applications involving pipeline natural gas and diesel fuel use for peak shaving.

In the life-cycle analysis, there are references to a “Scenario A” and “Scenario B.” Scenario A is based on a facility LNG production rate of 250,000 gpd, and Scenario B is based on a production rate of 500,000 gpd. The FEIS stated the facility would produce 250,000-500,000 gpd. Both scenarios have been evaluated and included in these analyses to reflect the Proposed Action that PSE is currently seeking and the full capacity of the facility that was referenced in the FEIS.

Overall, Proposed Action emissions are quantified on a life-cycle basis for each use of LNG with overall life-cycle results weighted by the gallons of LNG consumed by each end use. For the Proposed Action, life-cycle emissions include not only the direct emissions associated with production of LNG, but also the following:

- Upstream life-cycle emissions associated with production and transport of fuels used at the LNG Facility: natural gas feedstock, natural gas fuel, diesel fuel, and electricity;
    - Natural gas: emissions due to natural gas recovery**,** processing and transport to the facility;
    - Diesel: emissions due to crude oil recovery, transport to the refinery, refining, and finished product transport end use;

  - Electricity: emissions include recovery, processing, and transport of each fuel type to the electric power plants (generally a mix of coal, nuclear, natural gas, oil, hydro and other renewables); and
  - Upstream emissions are calculated on a life-cycle basis using the Greenhouse Gases, GREET model from Argonne National Laboratory.
- Direct emissions from LNG production include all fuel combustion emissions in addition to fugitive emissions at the plant. Estimates of direct emissions are based on inputs provided by the proponent and verified with a carbon balance such that the carbon in the natural gas feedstock is equal to the carbon in LNG produced plus emissions from LNG production.
- End use emissions from the Proposed Action are calculated based on the capacity to provide 250,000 or 500,000 gpd for 355 days in a year, and end use emissions from the No Action Alterative are estimated based on the amount of marine diesel, on-road diesel, and natural gas that would be replaced by the Proposed Action.

Emissions of nitrous oxide, methane, and $CO_2$ are quantified and reported on a $CO_2$ equivalent basis by applying global warming potential (GWP) factors from Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC 2007), which is the currently accepted international reporting standard and the method for State of Washington GHG reporting. Refer to Appendix C for detailed explanations of methodology and assumptions.

# 4.2 Affected Environment

Increased GHG emissions are the primary cause of climate change, and therefore efforts to reduce GHG emissions are considered the best way to reduce the potential impacts of climate change. The State of Washington has also established goals to minimize climate change impacts and reduce GHG emissions.

Global climate change threatens ecosystems, water resources, coastal regions, crop and livestock production, and human health. The continuing increase in GHG concentrations in the earth's atmosphere will likely result in a continuing increase in global annual average temperature and climate change effects. Global, federal, and state initiatives to reduce GHG emissions have been implemented to reduce the severity of climate change impacts in the future (EPA 2016). Regardless, climate change impacts would occur under both alternatives.

The potential effects of climate change and GHG emissions are, by nature, global and cumulative impacts. While individual sources of GHG emissions are not large enough to have an appreciable effect on climate change, the global accumulation of GHG emissions is resulting in global and local impacts on the climate.

As discussed above, EPA and Washington State have a number of programs designed to collect and analyze GHG emissions to better understand the sources of GHGs in the state. These programs, in addition to state permitting reporting requirements, help the state design policies to reduce GHG emissions and track its progress towards meeting the state's statutory GHG reduction limits.

GHGs are ranked by their GWP. GWP is based on the ability of a GHG to absorb solar radiation, as well as its residence time in the atmosphere, compared to $CO_2$. Applying GWP factors from the Intergovernmental Panel on Climate Change AR4, $CO_2$ has a GWP of 1, methane has a GWP of 25, and $N_2O$ has a GWP of 298. Emissions of GHGs are typically estimated as $CO_2e$. Estimates of individual GHGs are converted to $CO_2e$ by multiplying each pollutant by its GWP relative to $CO_2$.

## 4.2.1 Existing Sources of GHG Emissions in the Proposed Action Area

The Port of Tacoma is a major center for container cargo, bulk, breakbulk, autos, and heavy-lift cargo. Existing sources of GHG emissions in the area associated with the transportation of cargo are on-road and non-road sources. On-road emissions include emissions from vehicles, such as cars and trucks, with nearby

Interstate 5 being a significant contributor. Non-road sources of emissions include emissions from sources such as marine vessels (including ocean freighters and harbor vessels such as tugs), cargo handling equipment, railroad locomotive operations, and heavy-duty, off-road vehicles. GHG emissions from these on-road and non-road sources include emissions from the combustion of fossil fuels and from fugitive releases.

Vessel emissions from sources within the vicinity of the Tacoma LNG Facility and TOTE Marine Vessel LNG Fueling System include the existing TOTE Terminal and the Washington United Terminal. Also in the vicinity of the Proposed Action are a refinery, U.S. Oil & Refining Company; a Kraft pulp mill, formerly known as Simpson Tacoma Kraft Company, LLC, but now operated by WestRock Company; and other industrial facilities that generate GHG emissions from the combustion of fossil fuels, most commonly in boilers and heaters.

The Tacoma LNG Facility site itself covers approximately 34.7 acres consisting of four separate parcels. The parcels currently contain a gravel pad and an empty naval building that is sometimes used for freight container storage. Current emissions from the site result from mobile sources used to move the freight containers; these emissions are relatively minor and sporadic in nature.

## 4.3 Potential Impacts of the Proposed Action

For a detailed description of the Proposed Action, refer to Chapter 2 (Description of the Proposed Action) and the 2015 FEIS. The overall stated purpose of the Proposed Action is, in part, to construct and operate a facility with the capability to supply fuel for marine, land transportation, and other potential industries in the Pacific Northwest, that is cleaner (i.e., has fewer air emissions) than traditional fuels used by these industries. The scope of this SEIS is to provide a GHG emissions life-cycle analysis of the alternatives developed in the FEIS. The life-cycle analysis for the Proposed Action evaluates the upstream, direct, and end use GHG emissions, and the change in these emissions compared to the No Action Alternative.

When evaluating direct, upstream, and end use GHG emissions, replacing a diesel propulsion engine with a pure LNG propulsion engine results in reduced life-cycle GHG emissions. The use of LNG produced by the Proposed Action, instead of other fuels for marine vessels, trucks, and peak shaving, is expected to result in an overall decrease in GHG emissions in the Puget Sound region, where this fuel would eventually be combusted. As demonstrated by the range of potential impacts from the Proposed Action and No Action alternatives based on an LNG capacity of 250,000 to 500,000 gpd, the greater the replacement of other fuels with LNG, the greater the overall reductions in GHG emissions.

### 4.3.1 Construction Impacts

Construction of the Tacoma LNG Facility would generate air emissions temporarily from construction activities over a four-year period. Upstream electric power and direct (end use) construction emissions have been quantified for the 4 years of construction, while upstream life-cycle construction material emissions are estimated based on the volume of material used and the full life-cycle emissions of the products. Total emissions associated with construction are then averaged over the 40-year lifespan of the Tacoma LNG Facility.

**Table 4-2 GHG Emissions from the Tacoma LNG Facility Construction**

| | GHG Emissions | GHG Emissions | Total GHG Emissions (tonnes) |
|---|---|---|---|
| | tonnes/year (based on 40 year average) | % of total annual life-cycle analysis emissions | |
| **Total Construction** | **1,581** | **0.19%** | **63,232** |
| Direct (Equipment) | 182 | | 7,289 |
| Upstream Life-Cycle (Equipment) | 20 | | 812 |
| Upstream Life-Cycle (Power) | 57 | | 2,262 |
| Upstream Life-Cycle (Material) | 1,322 | | 52,869 |

Key:
GHG = greenhouse gas
LNG = liquefied natural gas
tonne = metric ton

## 4.3.2 Operations Impacts

As discussed above, life-cycle GHG emissions from the Proposed Action include not only the direct emissions associated with production of LNG, but also emissions associated with upstream and end use operations. Operational conditions, parameters, and assumptions to complete the life-cycle analysis were detailed in the 2018 Puget Sound Energy Background Information Document (PSE 2018). The life-cycle analysis provides a range of GHG emissions impacts, based on the potential LNG capacity of 250,000 to 500,000 gpd. Appendix C, the PSE Tacoma LNG Project GHG Analysis Report, provides additional details on the operational assumptions used to estimate GHG emissions.

The life-cycle GHG emissions for the Tacoma LNG Facility and TOTE Marine Vessel LNG Fueling System are presented in Table 4-3.

**Table 4-3 Proposed Action Life-Cycle Analysis Annual Fuel Use Volume and GHG Emissions, Based on 250,000 gpd (Scenario A) to 500,000 gpd (Scenario B) Capacity**

| Life-Cycle Step | Fuel throughput MGal/year | | Fuel throughput GBtu/year | | GHG Emissions (tonnes/year) | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| Construction Emissions | | | | | | |
| **Total Construction** | | | | | **1,581** | **1,581** |
| Direct (Equipment) | | | | | 182 | **182** |
| Upstream Life-Cycle (Equipment) | | | | | 20 | **20** |
| Upstream Life-Cycle (Power) | | | | | 57 | **57** |
| Upstream Life-Cycle (Material) | | | | | 1,322 | **1,322** |
| Operational Emissions | | | | | | |
| **Upstream Life-Cycle** | | | | | **103,949** | **207,844** |
| Natural Gas | | | | | 77,208 | 154,504 |
| Power LNG Production | | | | | 25,739 | 51,477 |
| Diesel Emergency | | | | | 143 | 143 |
| Power LNG Vaporizer - Peak Shaving | | | | | 859 | 1,718 |
| Gig Harbor Diesel truck fuel | | | | | 0 | 1.2 |
| **Direct LNG Plant** | | | | | **52,251** | **108,997** |
| LNG Production | | | | | 46,715 | 94,333 |
| Vaporizer - Peak Shaving | | | | | 942 | 942 |
| Marine Vessel Bunkering Methane | | | | | 4,595 | 13,722 |
| **End Use LNG** | **89** | **177.50** | **6,848** | **13,695** | **529,859** | **1,068,092** |
| Diesel Peak Shaving | 9.73 | 9.73 | 750 | 750 | 43,854 | 43,854 |
| Gig Harbor LNG | 0 | 1.78 | 0 | 137 | 0 | 8,129 |
| On-road Trucking | 0 | 3.55 | 0 | 274 | 0 | 17,862 |
| TOTE Marine Vessels | 37.93 | 37.93 | 2,927 | 2,927 | 225,993 | 225,993 |
| TOTE Marine Diesel Pilot fuel | | | | | 7,611 | 7,611 |
| Truck-to-Ship Bunkering | 0 | 1.78 | 0 | 137 | 0 | 10,575 |
| Truck-to-Ship Bunkering Pilot Fuel | | | | | 0 | 356 |
| Other Marine Vessels LNG (by Bunker Barge) | 41.09 | 122.74 | 3,171 | 9,470 | 244,185 | 729,376 |
| Other Marine Diesel Pilot Fuel | | | | | 8,216 | 24,335 |
| **Total Emissions, Proposed Action** | | | | | **687,639** | **1,386,514** |

Key:
GBtu = Giga British thermal units
GHG = greenhouse gas
gpd = gallons per day
LNG = liquefied natural gas
MGal = million gallons
tonne = metric ton
TOTE = Totem Ocean Trailer Express

The Proposed Action would emit more than an estimated 10,000 metrics tons of $CO_2e$ per year and thus would be subject to GHG reporting requirements, per WAC 173-441. An annual GHG report must be submitted to Ecology each year even if the source does not meet applicability requirements in WAC 173-441-030(1) or (2) in a future year.

### 4.3.3 Decommissioning Impacts

Decommissioning of the Tacoma LNG Facility and TOTE Marine Vessel LNG Fueling System at the end of its useful life would generate impacts similar to those discussed in Section 4.4.1 (Construction Impacts), except without the associated construction material GHG emissions. These emissions are assumed to be below the 1 percent cut-off criteria. The GHG emissions from decommissioning would be temporary and are not anticipated to have any long-term impacts.

## 4.4 Impacts of the No Action Alternative

Under the No Action Alternative, the Proposed Action would not be implemented. As discussed in Chapter 3 (Description of the No Action Alternative), MDO and diesel fuels would continue to provide the source of energy for the fuel use applications that would be displaced under the Proposed Action. LNG would not be produced or stored at the Tacoma LNG Facility site and would not replace MDO for fuel marine vessels or other customers in the Puget Sound area.

### 4.4.1 Construction Impacts

There are no construction impacts associated with the No Action Alternative.

### 4.4.2 Operations Impacts

Direct emissions under the No Action Alternative are negligible; life-cycle GHG emissions consist of upstream and end use activities only. To assess the potential changes from the Proposed Action's operation and supply LNG, it is assumed that the equivalent amount of MDO and diesel fuel would continue to be used. With a capacity to provide 500,000 LNG gallons per day (gpd), the Proposed Action would produce 177.5 million gallons of LNG annually, replacing 89 million gallons of MDO, 8.8 million gallons of diesel fuel, and natural gas in the equivalent of 1.78 million gallons of LNG.

The life-cycle analysis provides a range of GHG emissions impacts, based on the Proposed Action's potential LNG capacity of 250,000 to 500,000 gpd, referred to as "Scenario A" and "Scenario B," respectively, throughout. Appendix B describes the methodology used to create the life-cycle analysis. Appendix C, the PSE Tacoma LNG Project GHG Analysis Report, provides additional detail on the operational assumptions used to estimate GHG emissions.

The life-cycle GHG emissions for the No Action Alternative are presented in Table 4-4.

**Table 4-4 No Action Alternative Life-Cycle Analysis Annual Fuel Use Volume and GHG Emissions, Based on Replacement by 250,000 gpd (Scenario A) to 500,000 gpd (Scenario B) LNG Capacity**

| Life-Cycle Step | Fuel throughput MGal/year | | Fuel throughput GBtu/year | | GHG Emissions (tonnes/year) | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| **Total Upstream Emissions** | | | | | **125,245** | **247,772** |
| No Peak Shaving - Diesel Dual Fuel | | | | | 16,127 | 16,127 |
| Gig Harbor LNG | | | | | 0 | 2,174 |
| On-road trucking | | | | | 0 | 5,297 |
| TOTE Marine Diesel | | | | | 52,448 | 52,448 |
| Truck-to-Ship Bunkering | | | | | 0 | 2,454 |
| Other Marine Diesel (by Bunker Barge) | | | | | 56,670 | 169,272 |
| **Total End Use Diesel /Fuel Oil/LNG** | **50.6** | **101.4** | **7,022** | **14,018** | **602,291** | **1,195,447** |
| Diesel Peak Shaving for Power | 5.89 | 5.89 | 750 | 750 | 58,891 | 58,891 |
| Gig Harbor LNG | 0 | 1.78 | 0 | 137 | 0 | 8,168 |
| On-road Trucking | 0 | 1.93 | 0 | 247 | 0 | 19,316 |
| TOTE Marine Diesel | 21.48 | 21.48 | 3,014 | 3,014 | 261,325 | 261,325 |
| Truck-to-Ship Bunkering | 0 | 1.01 | 0 | 141 | 0 | 12,229 |
| Other Marine Diesel (by Bunker Barge) | 23.21 | 69.32 | 3,257 | 9,729 | 282,076 | 835,519 |
| **Total Emissions (No Action Alternative)** | | | | | **727,536** | **1,443,219** |

Key:
GBtu = Giga British thermal units
GHG = greenhouse gas
LNG = liquefied natural gas
MGal = million gallons
tonne = metric ton
TOTE = Totem Ocean Trailer Express

While marine vessels represent a smaller percentage of State wide GHG emissions, like other transportation related emissions, they have increased in since 1990. As demonstrated by the range of potential impacts from the Proposed Action and No Action Alternatives based on an LNG capacity of 250,000 to 500,000 gpd, the greater the replacement of other fuels with LNG, the greater the overall reductions in GHG emissions.

## 4.5 Summary of Impacts

When evaluating direct, upstream and end use GHG emissions, the Proposed Action would result in a reduction of GHG emissions compared to the No Action Alternative, under both 250,000 gpd and 500,000 gpd capacity scenarios (see Figure 4.2). Generally, this is because replacing a diesel propulsion engine with a pure LNG propulsion engine results in reduced life-cycle GHG emissions. The use of LNG produced by the Proposed Action, instead the use of other fuels for marine vessels, trucks, and peak shaving is expected to result in an overall decrease in GHG emissions in the Puget Sound region. As demonstrated by the range of potential impacts from the Proposed Action and No Action alternatives based on an LNG capacity of 250,000 to 500,000 gpd, the greater the replacement of other fuels with LNG, the greater the overall reductions in

GHG emissions (See Figure 4.2). Table 4-5 provides a comparison of the potential range of emissions from the Proposed Action and the No Action Alternative and the change in emissions.

In the life-cycle analyses, various assumptions needed to be made in order to complete the analysis. Those assumptions are documented in Appendices B and C. One key assumption is that the source of the gas that supplies the plant is identified by PSE as being exclusively sourced from British Columbia, Canada. The life-cycle analysis report indicates that GHG emission factors for natural gas production in the United States may be as much as five times higher than those for Canada. Additional recent research has indicated that the actual realized fugitive emissions from natural gas production in the United States appear to be 60 percent higher than published fugitive emission factors (Alvarez et al. 2018). The combination of the differences in published emission factors for the two sources of gas (United States vs Canada) along with this recent reported research could lead to an upstream natural gas operation emission rate that may be eight times higher than shown if the gas were not exclusively sourced from Canada. The net effect of these higher emission rates, if realized as part of the Proposed Action, would be an increase in GHG emissions through the life-cycle analysis rather than the decreases shown in Table 4-5. Thus, the source of the natural gas is an important factor to this analysis and its conclusions.

**Table 4-5 Comparison of Proposed Action and the No Action Alternative Life-Cycle Analysis GHG Emissions**

| Life-Cycle Step | Proposed Action GHG Emissions (tonnes/year) | | No Action Alternative GHG Emissions (tonnes/year) | | Change GHG Emissions (tonnes/year) | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| Construction Emissions | **1,581** | **1,581** | **0** | **0** | **1,581** | **1,581** |
| Operational Emissions | | | | | | |
| **Upstream Life-Cycle** | **103,949** | **207,844** | **125,245** | **247,772** | **-21,296** | **-39,928** |
| Natural Gas | 77,208 | 154,504 | | | 77,208 | 154,504 |
| Electricity | 25,739 | 51,477 | | | 25,739 | 51,477 |
| Peak Shaving | 143 | 143 | 16,127 | 18,301 | -15,984 | -18,158 |
| Trucking | 859 | 1,718 | 0 | 7,751 | 859 | -6,033 |
| TOTE Marine Vessels | 0 | 1 | 52,448 | 52,448 | -52,448 | -52,447 |
| Other Marine Vessels | | | 56,670 | 169,272 | -56,670 | -169,272 |
| **Direct LNG Plant** | **52,251** | **108,997** | **0** | **0** | **52,251** | **108,997** |
| LNG Production | 46,715 | 94,333 | 0 | 0 | 46,715 | 94,333 |
| Vaporizer - Peak Shaving | 942 | 942 | 0 | 0 | 942 | 942 |
| Marine vessel bunkering methane | 4,595 | 13,722 | | | 4,595 | 13,722 |
| **End Use** | **529,859** | **1,068,092** | **602,291** | **1,195,447** | **-72,432** | **-127,355** |
| Peak Shaving | 43,854 | 43,854 | 58,891 | 58,891 | -15,037 | -15,037 |
| Gig Harbor LNG | 0 | 8,129 | 0 | 8,168 | 0 | -39 |
| On-road Trucking | 0 | 17,862 | 0 | 19,316 | 0 | -1,454 |
| TOTE Marine | 225,993 | 225,993 | 261,325 | 261,325 | -35,332 | -35,332 |
| TOTE Marine Diesel Pilot fuel | 7,611 | 7,611 | | | 7,611 | 7,611 |
| Truck-to-Ship Bunkering | 0 | 10,575 | 0 | 12,229 | 0 | -1,653 |
| Truck-to-Ship Bunkering Pilot Fuel | 0 | 356 | | | 0 | 356 |
| Other Marine LNG (by Bunker Barge) | 244,185 | 729,376 | 282,076 | 835,519 | -37,891 | -106,143 |
| Other Marine Diesel Pilot Fuel | 8,216 | 24,335 | | | 8,216 | 24,335 |
| **Total Emissions** | **687,639** | **1,386,514** | **727,536** | **1,443,219** | **-39,896** | **-56,705** |

Key:
GHG = greenhouse gas
LNG = liquefied natural gas
tonne = metric ton
TOTE = Totem Ocean Trailer Express

# 4.6 Cumulative Impacts

The potential effects of climate change and GHG emissions are, by nature, global and cumulative impacts. While individual sources of GHG emissions are not large enough to have an appreciable effect on climate change, the global accumulation of GHG emissions is resulting in global and local impacts on the climate.

In Section 3.13 (Cumulative Impacts) of the FEIS, GHGs were referenced twice. The GHG emissions for the LNG facility were identified at 20,751 metric tons $CO_2e$ per year in Table 3.13-1 and the socioeconomic discussion on page 3.13-18 stated that "*the substitution of diesel and marine fuels with cleaner-burning LNG could reduce annual greenhouse emissions (including carbon dioxide, nitrogen oxide, sulfur oxide, and particulate emissions), which annually generates approximately $5.7 million in social benefits.*" The SEIS' analysis has shown that the direct onsite GHG emissions for the LNG plant are now estimated to be between 52,272 and 108,998 metric tons $CO_2e$ per year. However, the analysis predicts a net GHG reduction would occur with the Proposed Action, contingent upon the source of the natural gas. The SEIS did not reevaluate other projects in the area, but given the net GHG reduction, contingent on the source of the natural gas, the conclusion is that the first portion of the statement on page 3.13-18 appears to be reasonable. No analysis of the *approximately $5.7 million* in social benefits was included in the scope of the SEIS.

# 4.7 Avoidance, Minimization, and Mitigation

The approach to the analysis in the SEIS has been the life-cycle evaluation for GHGs for the Proposed Action in comparison with the No Action (no project) Alternative. This considered the two options on an equivalent basis. The GHG emissions for the Proposed Action are high enough to trigger some regulatory requirements, and they are high enough to have warranted a more thorough evaluation of the GHG emissions from the Proposed Action on a quantitative basis. The life-cycle analysis shows that the Proposed Action (compared to the No Action Alternative) would produce a net reduction in annual GHG emissions provided that the natural gas source for the plant was British Columbia. This is an important assumption, as discussed previously in this document, and as such, it is recommended that the source of the gas be a required condition for an NOC Order of Approval. Specifically, the NOC process should establish the requirement that the source of natural gas supply to the facility be solely from British Columbia and that specific permit terms and conditions will specify how compliance with this requirement will be demonstrated on a continuous basis. If this recommendation for a conditional requirement is not adopted, the conclusion that the Proposed Action would produce a net reduction of GHG emissions on a life-cycle basis would no longer be valid.

# 4.8 Conclusion

When evaluating direct, upstream, and end use GHG emissions, replacing a diesel propulsion engine with a pure LNG propulsion engine results in reduced life-cycle GHG emissions. The use of LNG produced by the Proposed Action, instead of other fuels for marine vessels, trucks, and peak shaving is predicted to result in an overall decrease in GHG emissions in the Puget Sound region, where this fuel would eventually be combusted. As demonstrated by the range of potential impacts from the Proposed Action and No Action Alternatives based on an LNG capacity of 250,000 to 500,000 gpd, the greater the replacement of other fuels with LNG, the greater the overall reductions in GHG emissions. This conclusion is contingent on the sole source of the natural gas supplied to the facility being from British Columbia. As described above, that condition is a recommended requirement for an NOC Order of Approval so this analysis and conclusion is consistent with the proponent's project description.

**Figure 4-1 Change in GHG Emissions (tonnes/year) Proposed Action Compared to the No Action Alternative**

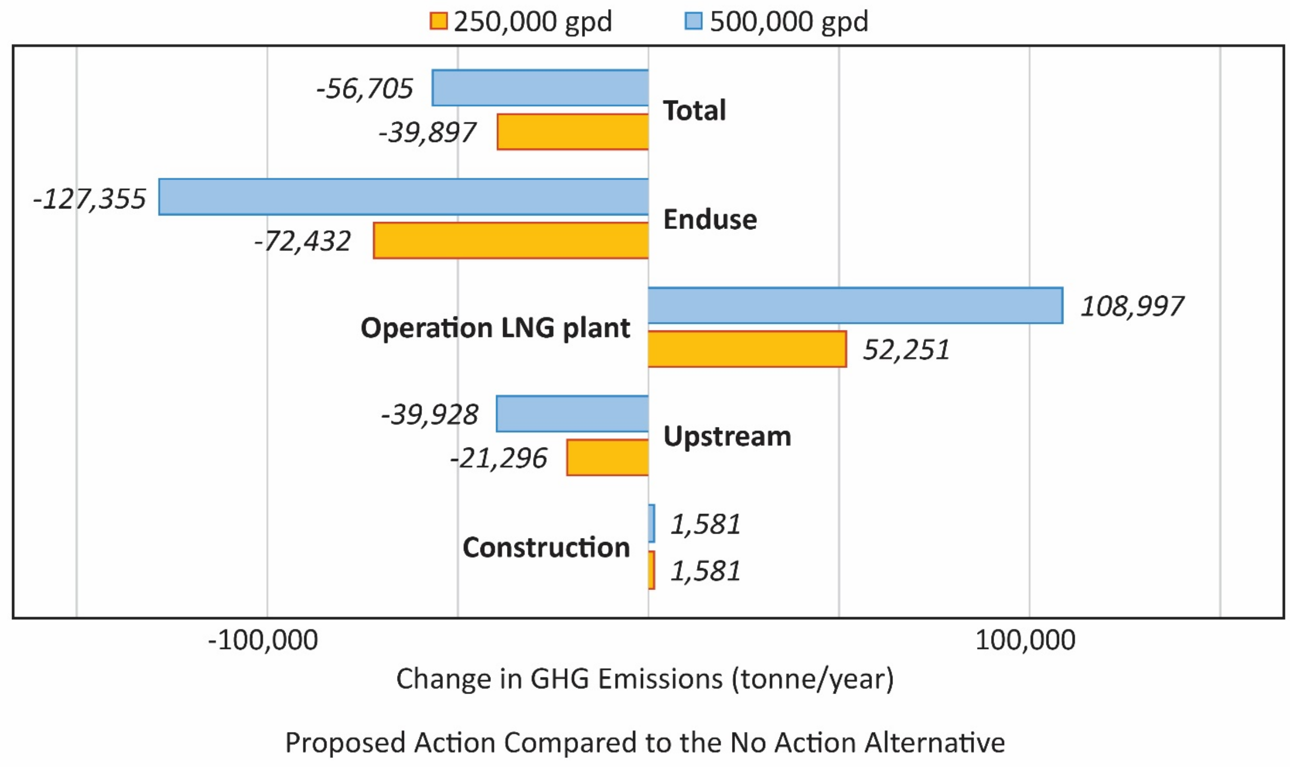
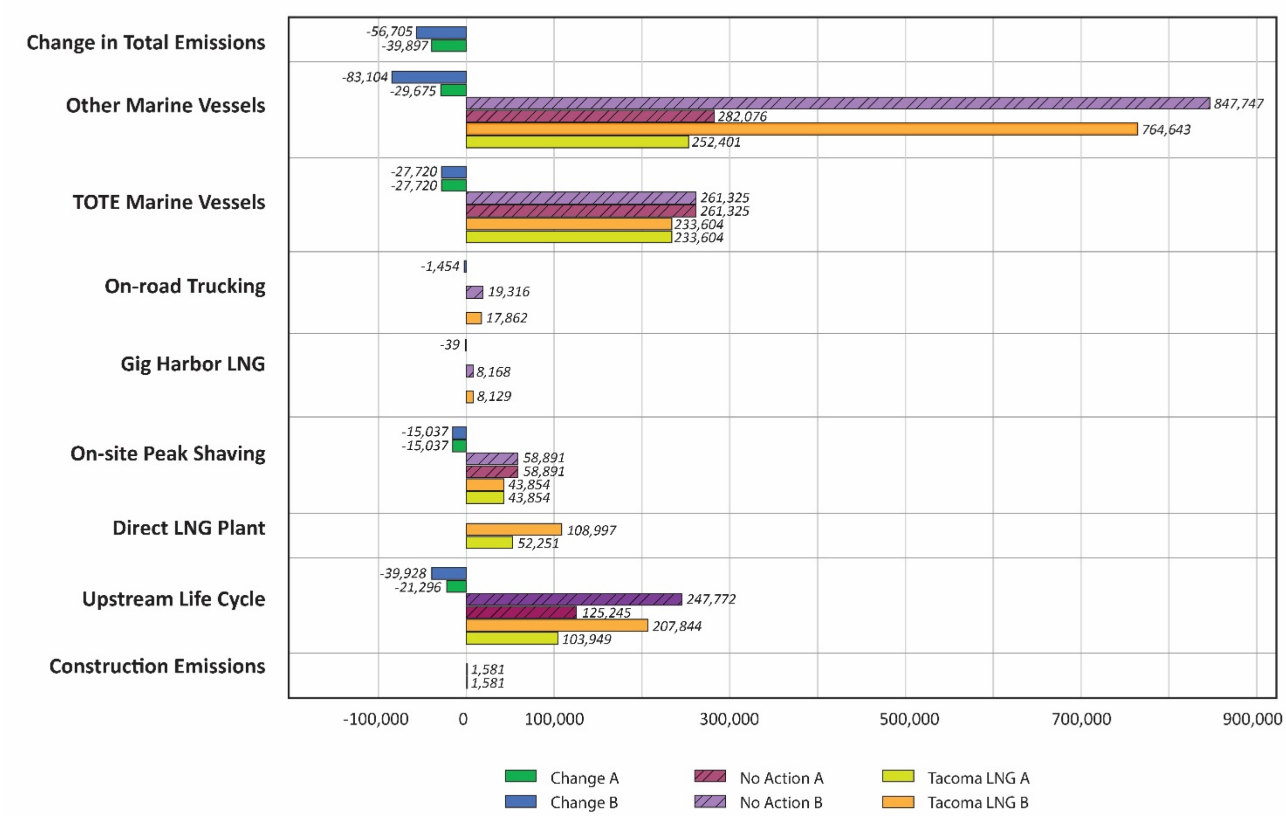


**Figure 4-2 GHG Emissions from Proposed Action vs. No Action Alternative, 250,000 gpd Capacity (Scenario A) and 500,000 gpd Capacity (Scenario B)**



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# APPENDIX A

## List of Preparers

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# APPENDIX B

## PSE Tacoma LNG Project
## GHG Analysis Final Study Methodology

# PSE Tacoma LNG Project GHG Analysis Final Study Methodology

**Prepared for Ecology and Environment, Inc. and**
**Puget Sound Clean Air Agency**
**Under Subcontract 1009806.0001**

LCA.8117.189a.2018

Prepared by
Stefan Unnasch
Love Goyal
Jennifer Pont

July 6, 2018

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# TERMS AND ABBREVIATIONS

| | |
|---|---|
| ALCA | Attributional Life Cycle Analysis |
| ANL | Argonne National Laboratory |
| ARB | California Air Resources Board |
| CA | California |
| CA-GREET | The standard GREET model modified for use in CA LCFS |
| $CH_4$ | Methane |
| CI | Carbon intensity |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| DOE | U.S. Department of Energy |
| EMFAC | EPA's Emission Factors Model |
| EPA | U.S. Environmental Protection Agency |
| g $CO_2e$ | Grams of carbon dioxide equivalent |
| GHG | Greenhouse Gas |
| GHGenius | An LCA model based on LEM that was developed for Natural Resources Canada |
| GREET | The Greenhouse gas, Regulated Emissions, and Energy use in Transportation model |
| GWP | Global Warming Potential |
| HC | Hydrocarbon |
| HHV | Higher Heating Value |
| IPCC | Intergovernmental Panel on Climate Change |
| JRC | Joint Research Centre, JRC/EUCAR/CONCAWE |
| ISO | International Standards Organization |
| JRC | Joint Research Centre |
| LCA | Life Cycle Analysis or Life Cycle Assessment |
| LCFS | Low Carbon Fuel Standard |
| LHV | Lower Heating Value |
| LNG | Liquefied Natural Gas |
| $N_2O$ | Nitrous oxide |
| NETL | National Energy Technology Laboratory |
| NG | Natural Gas |
| NOx | Oxides of nitrogen |
| RPS | Renewable Portfolio Standard |
| UN | United Nations |
| VOC | Volatile Organic Compound |
| WTG | Well-To-Gate |
| WTT | Well-To-Tank |
| WTW | Well-To-Wake |

# SUMMARY

The Tacoma LNG project will produce liquefied natural gas (LNG) that will be used as a fuel for marine and on-road transportation applications as well as for supplementing natural gas supply in the winter when demand is high (peak shaving). This study will examine the greenhouse gas (GHG) emissions from the project and compare these emissions to the alternative of not completing the project, which is the conventional use of distillate fuels in marine and trucking and applications in conjunction with pipeline natural gas use for peak shaving.

Overall project emissions will be quantified on a life cycle basis for each use of LNG with overall life cycle results weighted by the gallons of LNG consumed by each end use. For Tacoma LNG, life cycle emissions include not only the direct emissions associated with production of LNG, but also include emissions associated with recovery, refining and transport of each fuel used in production and emissions associated with end use (combustion in marine engines and heavy duty trucks and peak shaving). Life cycle GHG emissions are composed of upstream life cycle, direct, and end use emissions. Upstream life cycle or well to tank (WTT)[1] emissions are the emissions associated with production and transport of fuel used at the LNG production plant: natural gas feedstock, natural gas fuel, diesel fuel, and electricity. For natural gas, WTT include emissions due to natural gas recovery, processing and transport to the facility. For on-site diesel, WTT emissions are those associated with crude oil recovery, transport to the refinery, refining and finished product transport to end use. For electricity, WTT emissions include recovery, processing and transport of each fuel type to the electricity generating plants (generally a mix of coal, nuclear, natural gas, oil, hydro and other renewables). WTT emissions are calculated on a life cycle basis using the GREET model from Argonne National Laboratory.

Direct emissions from LNG production include all fuel combustion emissions as well as fugitive emissions at the plant. Estimates of direct emissions will be based on inputs provided by the project applicant and verified with a carbon balance such that the carbon in the natural gas feedstock is equal to the carbon in LNG produced plus emissions from LNG production.

End use emissions will be calculated for the amount of LNG required to displace marine diesel, on-road diesel, and peak shaving applications.

Finally, the emissions from the Tacoma LNG project will be compared with life cycle emissions from the alternative action or fuel that is displaced by the project (diesel for marine engines, diesel for onroad applications, and fuel for peak shaving). Emissions of nitrous oxide ($N_2O$), methane ($CH_4$) and carbon dioxide ($CO_2$) will be quantified and reported on a $CO_2$ equivalent basis by applying global warming potential (GWP) factors from IPCC AR4, which is the currently accepted international reporting standard and the method for State of Washington GHG reporting.

[1] The GREET model refers to upstream life cycle emissions as the WTT phase. The term upstream is still used in this study to refer to activities that are upstream of the fuel processing facility.

# 1. INTRODUCTION

## 1.1 Effect of Tacoma LNG Project

The Tacoma LNG project will affect several energy use applications including marine diesel, on-road trucking, and natural gas peak shaving. Currently, marine diesel and on-road diesel fuel are produced in Washington oil refineries. Underground storage caverns are used for natural gas peak shaving. Puget Sound Energy (PSE) forecasts that additional natural gas storage will be required to meet future wintertime peak demand; stored LNG can be re-gasified and introduced to the pipeline to meet peak demand. The Tacoma LNG project will displace a portion of the fuels currently used for marine diesel and on-road diesel applications as well as other sources of natural gas peak shaving.

## 1.2 Life Cycle Analysis Background

The following provides background on life cycle analysis (LCA) for fuel applications. Since the effect of GHG emissions occur over a long duration, the life cycle and total global emissions are considered the relevant metric[2].

LCA is a technique used to model the environmental impacts associated with the production of a good. The product assessed can be anything manmade, from breakfast cereals to sneakers to drop in renewable jet fuel. LCA models assess environmental impacts upon a range of categories, including energy consumption, GHG emissions, criteria air pollution, eutrophication, acidification, water use, land use, and others. This is done by taking a full inventory of all the inputs and outputs involved in a product's life cycle. Environmental impacts may be generated whenever a material flow enters or exits the product system and affects the environment.

Most LCA models used for transportation fuels are spreadsheet-based and use a life cycle inventory (LCI) database to calculate the environmental impacts associated with the material flows and inputs to a fuel value chain. Additionally, LCA has been used to support fuel regulatory and/or legislative initiatives for renewable fuel targets, such as targets for GHG emission reductions. The phases of an LCA are outlined below.

a) The goal and scope definition phase: during this phase the study objective is defined, the system boundaries are determined, and modeling approaches are decided upon.

b) The inventory analysis phase: during this phase, inventory data regarding the life cycle inputs and outputs is collected and analyzed.

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[2] For example, consider electric cars with zero emissions during driving. The life cycle emissions including upstream emissions provide the relevant basis for comparison with other transportation options.

c) The impact assessment phase: during this phase, life cycle inventory data and impacts results are scrutinized for further accuracy and insight. This often involves sensitivity analysis and can lead to additional data collection and inventory modeling.
d) The interpretation phase: during this phase, results are interpreted, summarized, and discussed. (ISO, 2006)

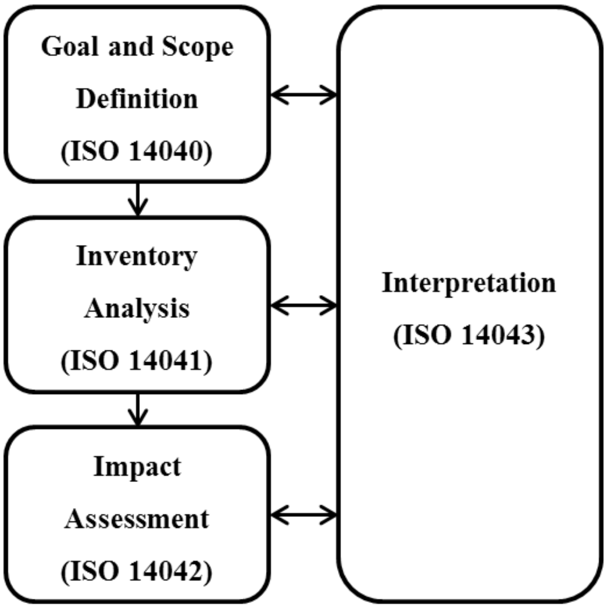


**Figure 1.1.** Process Framework for Life Cycle Assessment

Life cycle emissions are generally considered to cover the full life cycle from resource extraction to end use or the cradle to grave. Life cycle assessments are generally limited to construction and operation. However, the scope can also extend to facility decommissioning and indirect land use conversion (ILUC) effects. A preliminary calculation shows that life cycle decommissioning emissions will be less than 1 percent of total and therefore lower than the cutoff criteria defined for this study. Moreover, ILUC captures emissions associated with diverting crops from one use to another; because this project does not include land cover change from crops or significant vegetation, there are no ILUC emissions. An LCA includes the WTT emissions for inputs to a process. In most cases, WTT emissions occur in the production of WTT inputs. For example, producing fuel used for electric power, an upstream component of LNG production, requires WTT energy inputs.

Because finished fuels are used in recovery of feedstocks (e.g. diesel fuel is used to recover crude oil to produce diesel), determining life cycle emissions for all inputs requires an iterative analysis. Several LCA models perform these calculations for fuels and materials as shown in Table 1.1. All of the models include life cycle data for LNG production. Fuel LCA models provide WTT emissions for all of the energy inputs considered in this analysis which includes natural gas, electric power, diesel fuel, and marine fuel. The GREET and GHGenius models have the most regionally specific detail for the U.S. and Canada. These models also contain a WTT analysis for generic natural gas to LNG and are publicly available. The National Energy Technology Laboratory (NETL) also completed a series of LCA studies that examined the life cycle of natural gas for use in power applications, which provides insight on WTT emissions.

**Table 1.1.** Life Cycle Models and Databases

| Primary Author | Year | Organization | Location of Use | Scope of Products | Model/ Database | Citation |
|---|---|---|---|---|---|---|
| Wang | 2017<br>2013 | ANL | USA | Fuel<br>Vehicles | GREET1<br>GREET2 | (ANL, 2017) |
| O'Conner | 2016 | $(S\&T)^2$ | Canada | Fuels | GHGenius | ((S&T)2, 2013) |
| Delucchi | 1998 | UC Davis | USA | Fuels | LEM | (Delucchi, 2003) |
| JRC | 2011 | JRC | Europe | Fuels | JRC/ LBST Database | (JEC - Joint Research Centre-EUCAR-CONCAWE collaboration, 2014) |
| Neeft | 2012 | Intelligent Energy Europe | Europe | Fuels | BioGrace | (JRC, 2012) |
| ThinkStep | 2016 | ThinkStep | Global | All Materials | GaBi TS | (Thinkstep, 2017) |
| Wernet | 2013 | Swiss Centre for Life Cycle Inventories. | Global | All Materials | EcoInvent | (Weidema et al., 2013) |
| NREL | 2005 | NREL | USA | All Materials | USLCI Database | (NREL, 2012) |
| Skone | 2014 | NETL | USA | Fuels | Studies of NG and Coal | (Skone, 2012) |

Several LCA models and databases also include LCI data on materials of construction for LNG facilities and marine vessels. The GaBi TS, EcoInvent, and USLCI databases contain life cycle analysis results for materials such as steel and concrete, which are used in facility construction. The GREET2 model also calculates life cycle emissions for materials of construction used in vehicles.

The GREET and GHGenius models are publicly available and provide complete transparency to calculations. These models will provide the basis for WTT LCI data in this study.

# 2. METHODS

This study examines the GHG emissions from the Puget Sound Energy Liquefied Natural Gas (Tacoma LNG) facility on a life cycle basis. The life cycle emissions from the Tacoma LNG (including end use) are compared to displaced emissions (e.g., diesel operations) on a life cycle basis. This section describes the system boundary for the analysis, approach for calculating life cycle emissions, scenarios considered in the analysis, and data sources. The discussion of the approach describes a summary of the activity in each step of the life cycle and calculation methods.

For Tacoma LNG, the life cycle analysis will calculate the energy inputs and emissions with each step of the Tacoma LNG process. Each energy input will include a direct and WTT fuel cycle component. The end use of emissions will then be calculated for the volume of fuel used in each LNG application. The life cycle emissions for the alterative use of LNG (No action alternative) will also be calculated. These emissions will include the direct emissions and upstream fuel cycle or WTT emission. The net difference between the Tacoma LNG project and alternative energy use will be reported on an annual basis.

Emissions to be reviewed:

- Upstream:
    - Power generation for electricity used at the facility
    - Manufacturing of the materials used to construct the facility
    - Production, processing and transport of the natural gas used as a feedstock
    - Leaks of natural gas from the equipment used to transport, handle and process the natural gas
    - Upstream production, processing and transport of diesel fuel for emergency equipment
- Direct:
    - Combustion of natural gas and natural gas liquids at the facility in the revaporizer and flare
    - Leaks of natural gas and LNG from the equipment at the facility
    - Loading (bunkering) of LNG into TOTE vessels
    - Loading of LNG into trucks and barges
    - Truck transport of LNG
    - Vaporization of LNG for peak shaving
- End Use:
    - Use of LNG in Totem Ocean Trailer Express, Inc. (TOTE) Marine vessels
    - Use of LNG that is delivered by barge to other (non-TOTE[3]) marine vessels
    - Use of LNG that is delivered by truck to other marine vessels
    - Use of LNG in on-road trucks
    - Use of LNG for on-site peak shaving
    - Use of LNG trucked to Gig Harbor for peak shaving

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- Use of natural gas liquids that are trucked off site as a substitute for propane

For the no-action alternative (use of traditional fuels in marine vessels and trucks and use of diesel fuel for peak shaving) the emissions to be reviewed include:

- Upstream Life Cycle (WTT):
  - Production, processing and transport of diesel and marine fuel
  - Production, processing and transport of natural gas
  - Power generation for electricity used to load and transfer diesel and marine fuel
- Direct:
  - The Tacoma LNG facility effectively provides LNG as a form of energy storage. The alternative distillate fuels result in only minor emissions for storage.
- End Use:
  - Use of marine diesel fuel in TOTE Marine vessels
  - Use of marine diesel fuel for other (non-TOTE[4]) marine vessels
  - Use of diesel in on-road trucks
  - Use diesel fuel to power fuel flexible turbines when natural gas customers are curtailed

The methods used to calculate GHG emissions for the Tacoma LNG project and the no action alternative activities include the following:

- Upstream Life cycle (WTT):
  - GREET model for power generation for electricity used at the facility
  - Project specific and literature data on $CH_4$ leaks as inputs to GREET and GHGenius
  - GREET2 model for manufacturing of metals used to construct the facility
  - USLCI database for concrete, aggregate, and asphalt materials used in site development and facility construction
- Direct and end use:
  - GREET emission factors for combustion of fuels
  - Emission data from the applicant
  - Combustion emission factors for LNG and natural gas based on fuel properties
  - Loading LNG into barges, trucks and TOTE vessels
  - Transporting LNG by truck
  - Energy consumption data for LNG and alternative equipment
  - Leakage rate from the applicant and literature sources

## 2.1 Scope of the Life Cycle Analysis

Life cycle GHG emissions will be quantified for production of LNG and four different end uses:

a) in Totem Ocean Trailer Express, Inc. (TOTE) marine engines for cargo hauling between Tacoma and Anchorage;

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b) transfer to LNG bunkering barges which will fuel other marine engines;
c) transfer to tanker trucks which will fuel heavy duty vehicles;
d) and returning the LNG to the pipeline for peak shaving.

Life cycle emissions include WTT, direct and end use emissions. WTT emissions include natural gas feedstock extraction, processing and transmission as well as emissions associated with production of imported grid power. Direct emissions from LNG production include fuel combustion (emergency generator, process heater and flaring) and fugitive emissions. For the TOTE end use, the life cycle emissions include crude oil recovery, refining, transport and combustion in a marine engine. For other end use emissions include also transfer to end use as either fuel or peak shaving and corresponding combustion emissions.

Once quantified, life cycle emissions for the four end uses are then compared to life cycle emissions of the practices that are displaced. The overall analysis is summarized Figure 2.1.

The analysis is performed on a life cycle basis; so, the emissions associated with fuel production for power generation, natural gas production, and diesel and marine diesel are also counted. Activities associated with Tacoma LNG displace the no action case. The alternative of the Tacoma LNG project is no action by the applicant. So, the same scope of analysis is applied to the displaced emissions.

GHG emissions associated with construction activities and materials of construction are also included in the analysis for Tacoma LNG.

### *Definition of Functional Unit*

The functional unit provides the reference to which all other data in a life cycle assessment are normalized and is use as a reference unit. To define the analyzed system, it is necessary to start with a quantified description of the performance requirements that the product system fulfils. This quantified description is called the “functional unit” of the product system.

The functional unit for this analysis is the LNG produced and used in operation in one year of continuous operation. The life cycle emissions from the Tacoma LNG and displaced emissions are analyzed over this functional unit. The emissions and displaced emissions are also reported per tonne of LNG produced over a 40-year facility life. Current natural gas liquefaction plants are planned with a 30-year technical life time. An analysis about the possibility of extending the life of LNG assets, carried by DNG GL, showed that many existing plants have been running for more than 40 years. Based on this information we defined a lifetime of 40 years for the Tacoma LNG project (Tronskar, 2016).

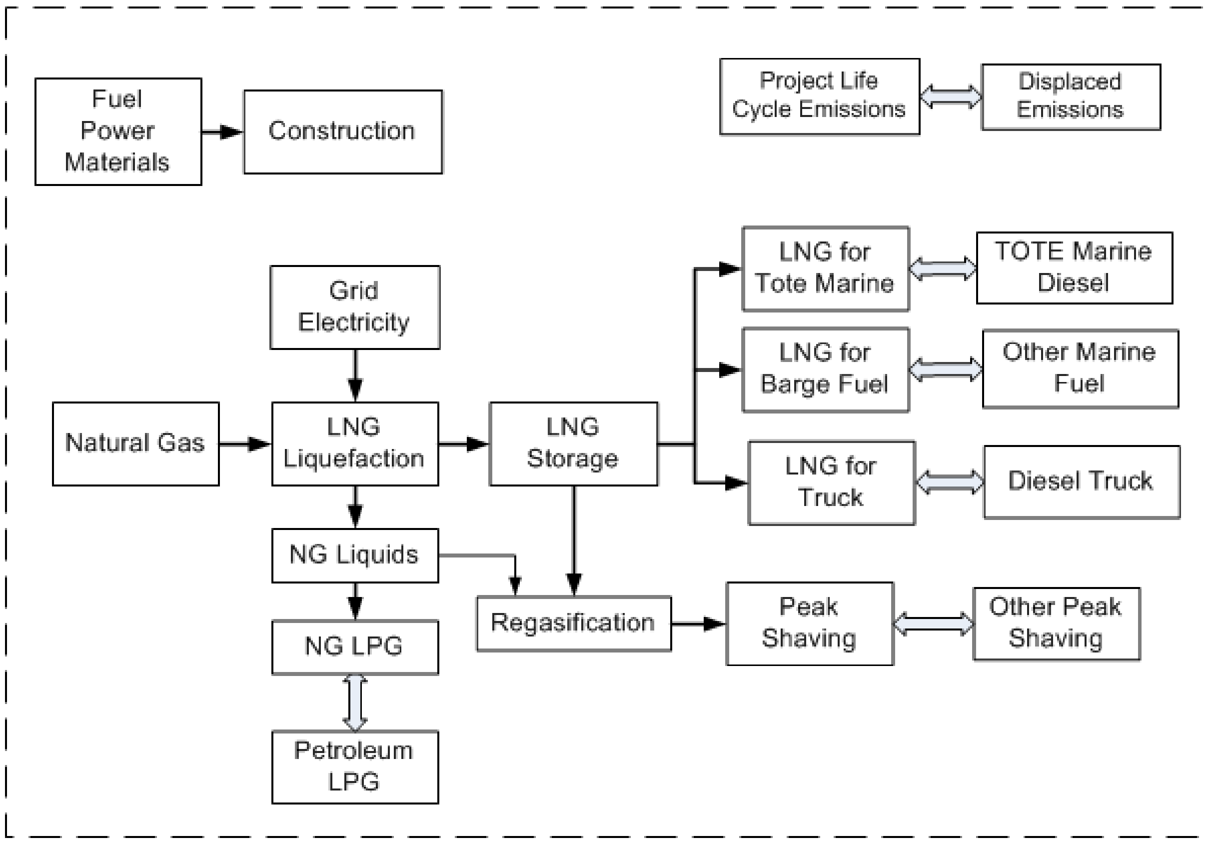


**Figure 2.1.** System Boundary Diagram for Tacoma LNG Life Cycle Analysis and No Action Alternative. WTT emissions are defined in Figure 2.2 and Figure 2.3. Double arrows represent effect of alternative activity.

### *Greenhouse gases (GHGs) used as Life Cycle Criteria*

The study determines the GHG emissions from fuel combustion and fugitive emissions including $CO_2$, $CH_4$, and $N_2O$. These emissions also include fugitive LNG from facility operations and product transfer.

Greenhouse gases (GHGs) warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space; they act like a blanket insulating the Earth. Different GHGs can have different effects on the Earth's warming. Two key ways in which these gases differ from each other are their ability to absorb energy (their "radiative efficiency"), and how long they stay in the atmosphere (also known as their "lifetime")(US EPA, 2018).

The Global Warming Potential (GWP) allows for the weighted summation of greenhouse gases. Specifically, it is a measure of how much energy the emissions of 1 tonne of a gas will absorb over a given period of time, relative to the emissions of 1 tonne of carbon dioxide ($CO_2$). The larger the GWP, the more that a given gas warms the Earth compared to $CO_2$ over that time period. The 100 year time horizon for GWPs will be the basis for weighting GHG emissions.

The GWP was introduced in the IPCC First Assessment Report, where it was also used to illustrate the difficulties in comparing components with differing physical properties using a single metric. The 100-year GWP (GWP100) was adopted by the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol and is now used widely as the default metric. Global Warming Potential (GWP) values have been updated in successive IPCC reports; the AR5 GWP100 values are different from those adopted for the Kyoto Protocol's First Commitment Period. The following table shows how the global warming potential of $CH_4$ has been increased by 17% and that of $N_2O$ has decreased by 11% from the 4$^{th}$ to the 5$^{th}$ Assessment Report (IPCC, 2007; Myhre et al., 2013).

**Table 2.1.** Global Warming Potential of GHG Pollutants

| IPCC Assessment | AR5 | AR4 |
|---|---|---|
| Time Horizon | 100 | 100 |
| $CO_2$ | 1 | 1 |
| $CH_4$ | 30 | 25 |
| $N_2O$ | 265 | 298 |

GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases.

The 100-year GWP is consistent with the time horizons for the Tacoma LNG project. The project will have a duration of about 40 years and the consequences of the emissions will remain in the atmosphere for the lifetime of the long-lived $CO_2$ emissions. The 100-year GWP is also consistent with the policy targets of the Paris Climate Agreement (United Nations/Framework Convention on Climate Change, 2015) which sets targets with the objective to "reduce aggregate greenhouse gas emission levels in 2025 and 2030" such that temperature increases of 2˚C or greater are avoided.

GHG emissions are weighted based on the 100-year time horizon from the United Nations Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007), which is consistent with the State Environmental Policy Act (SEPA) guidelines and Washington GHG inventory protocols as well as other GHG policy initiatives. The 100-year time horizon is also consistent with the long-term goals of the Paris agreement.

### *Cut Off Criteria*

The study tracks GHG emissions based on the energy input for Tacoma LNG combined with life cycle GHG models. Emission categories (e.g. construction, operation, decommissioning) that emit less than 1% of the $CO_2$e from the direct Tacoma LNG plus WTT and downstream emissions are identified as under the threshold of significance. The 1% threshold is based on the experience of the study team in assessing the variability of life cycle GHG emissions. The analysis will attempt to identify all sources of GHG emissions and screen if they fall within this threshold.

### *Operational Basis*

The analysis is based on the continuous operation of the facility to allow for a comparison with alternative sources of energy. GHG emissions are calculated on the expected operational basis (for example 500,000 gallons of LNG production per day over 360 days per year[5]). The life cycle GHG emissions from the Tacoma LNG project will be compared with diesel production where the life cycle emissions data are also on a continuous operation basis. Similarly, LNG used for peak shaving will be compared with conventional natural gas storage.

## 2.2 Activities Included and Approach to Life Cycle Analysis

The GHG analysis encompasses the emissions associated with Tacoma LNG construction and operation and the alternative to not construct the project, which would be the life cycle effect of not producing LNG and using conventional sources of diesel fuel for marine and transportation applications. The alternative case for the option would also include conventional natural gas storage for peak shaving. The life cycle analysis of Tacoma LNG follows the steps outlined in Table 2.2. For each step, the emissions include direct plus WTT emissions and end use emissions. The table shows the life cycle steps, a and the section of this report that contains the description of the activities for each step, emission factors, energy inputs, WTT emissions, life cycle results.

[5] We are requesting data on the throughput.

**Table 2.2.** Life Cycle Steps and Location of Data Sources and Results (Sections with Data TBD)

| | | Report Section for Description of Inputs and Emissions | | | | |
|---|---|---|---|---|---|---|
| **Life Cycle Step** | **Description** | **Activity** | **Direct Emission Factors** | **Energy /Use Rates** | **WTT Emissions** | **Life Cycle Analysis** |
| Construction | Construction equipment, dredging, materials of construction | 2.2.2 | 2.2.1 | TBD | TBD | TBD |
| Operational Emissions | | | | | | |
| Tacoma LNG Upstream | Natural gas, electric power, diesel fuel production [b] | 2.2.3 | 2.2.1 [a] | | 2.2.1 | |
| Tacoma LNG Direct | Boiler, plant operation | 2.2.3 | 2.4.2 | | TBD | |
| Tacoma LNG End Use | LNG fueled marine and truck operation<br>LNG vaporization for peak shaving and gas use | TBD | | | | |
| Displaced Emissions | | | | | | |
| Alternative Upstream | Crude oil production<br>Natural gas production<br>Marine diesel and diesel fuel refining, Electric Power | TBD | | | | |
| Alternative Direct Emission[6] | Diesel filling operations<br>Other Natural Gas peak shaving | TBD | | | | |
| Alternative End Use | Marine diesel and diesel fueled marine and truck operation<br>Stored NG gas use | TBD | | | | |
| Life Cycle Assessment | Cumulative and Step Total Emissions, Comparison of Tacoma LNG to Alternative | 2.1, 2.3 | N/A | N/A | N/A | TBD |

[a] GREET and GHGenius models include similar emission factors for direct combustion as described in Section 2.4.1
[b] Small amounts of diesel for emergency equipment are used by the Tacoma LNG project which result in both direct and WTT emissions

The activities in the life cycle and approach to GHG calculations is first discussed followed by a description of data and inputs for each step.

[6] The Tacoma LNG project would displace current marine diesel operations, which are the no action or alternative case.

*The life cycle analysis will be presented in future reports.*

*Section 2.4 will provide a succinct description of the data and sources once the data are received.*

### 2.2.1 Life Cycle Analysis - General Approach

Life cycle emissions generally consist of direct and WTT emissions. This study uses the GREET framework to calculate emissions from cradle to gate as described in Section 1.2 (ANL 2017). Emissions for each step in the life cycle analysis includes a direct and WTT life cycle emission rate ($\mathbf{E}_u$)[7] component. WTT life cycle emissions include a variety of energy inputs and emissions including natural gas, petroleum fuels, and electric power. WTT emission rates ($\mathbf{E}_i$)[8] for each step in the lifecycle are calculated from the specific energy ($S_i$), direct emission factor ($\mathbf{EF}_i$), and WTT emission rate for the step such that:

$$\mathbf{E}_i = S_i \times (\mathbf{EF}_i + \mathbf{E}_{ui}) \qquad (1)$$ [9]

Where:

$\mathbf{E}_i$ = WTT emission rate for Step i
$\mathbf{EF}_i$ = Direct emission factor for Step i, for each type of equipment and fuel
$S_i$ = Specific energy or use rate for step i
$\mathbf{E}_{ui}$ = WTT emission rate for fuel i

For example, the units for natural gas combustion would include ($S_i$ in Btu/gal LNG × (g $CO_2$/mmBtu direct emissions + g $CO_2$/mmBtu of WTT emissions) where both the emission factor and WTT factor have the same units.

The terms **EF** and **E** represent a data array of emission factors or emission rates that includes $CO_2$, $CH_4$ and $N_2O$ emissions. These arrays are in units of g/mmBtu, LHV basis. The term **EF** refers to a specific direct emission factor for a type of equipment and fuel. The term **E** refers to the WTT emission rate  or upstream life cycle emission rate. Typically, GHG calculations are tracked on a specific energy basis. For example, the term $S_i$ for natural gas use is represented in mmBtu/gallon of LNG in this Study. The emission factor (**EF**) depends upon the carbon content of fuel as well as $CH_4$ and $N_2O$ emissions for the type of equipment. For electric power and

---

[7] Emission rates indicated in **bold** are an array of pollutants in the GREET model including $CO_2$, $CH_4$, and $N_2O$. The life cycle analysis includes the cumulative summation of direct and upstream emissions over all of the energy inputs and displaced emission for the Tacoma LNG project. The WTT results also include direct and WTT components. Emission rates are not referred to as emission factors because they are the result on analysis inputs and vary with each scenario.

[8] The emissions for a process could also be upstream life cycle emissions. For example, the upstream life cycle emissions of natural gas include a term for the upstream life cycle emissions of natural gas.

[9] The units for each term depend on the step in the life cycle. For most situations, the specific energy is in Btu/gal of combusted LNG (or Btu/day) and the emission factors are a data array in g/mmBtu. The nomenclature used here is intended to identify the source of information no not detail all unit conversions in the calculations.

construction materials, the term EF is zero but WTT emissions are calculated using the same principles defined in Equation 1 and includes only WTT emissions

WTT emission rates ($\mathbf{E}_u$) depend on the energy inputs and emissions for each fuel or material and are calculated in the same manner as shown in Equation 1. The same principle for Equation 1 also applies to the calculation of WTT emissions. The WTT emission rates for this study are calculated using the GREET model with inputs that will be developed in the study. The GHGenius model provides an alternative data source for British Columbia natural gas. Other sources of WTT data will also be examined.

### 2.2.2 Construction Emissions

Construction activities consist of development of the Tacoma LNG site, construction of equipment, and storage tanks. Construction activities would include operation of earth moving equipment, cranes, trucks, pile drivers, compressors, pumps, and other equipment. Employee commute traffic for construction workers would also generate GHG emissions[10].

Construction emissions consist of diesel burned in construction equipment, imported power. Construction emissions also include emissions from power used and other sources of emissions generated in the production of the construction materials. Life cycle construction emissions were calculated based on the following:

$$\mathbf{G}_C = \Sigma(U_{DC} \times (\mathbf{EF}_D + \mathbf{E}_D)) + T + U_{eC} \times \mathbf{E}_e + \Sigma(U_m \times \mathbf{E}_m) \qquad (2)$$ [11]

Where:

$\mathbf{G}_C$ = Tacoma LNG Construction GHG emissions in total tonnes
$\Sigma$ refers to summation of inputs for each specific energy input or material input
$U_{DC}$ = Use rate for diesel fuel use for each type of equipment
$\mathbf{EF}_D$ = Emission factor for diesel equipment
$\mathbf{E}_D$ = WTT emission rate from diesel fuel
T = Construction employee commute emissions
$U_{eC}$ = Use rate for electric power used during constructions
$\mathbf{E}_e$ = WTT emission rate for imported electric power
$U_m$ = Use rate for materials used in construction
$\mathbf{E}_m$ = WTT emission rate for materials of construction

[10] It is unclear if employee transportation creates a new source of GHG emissions since the employees would be driving to work with or without construction of the PSEL. These emissions are calculated nonetheless.
[11] The nomenclature assumes appropriate unit conversions such as grams to tonnes or Btu to mmBtu. For example, gallons of diesel fuel use × Btu/gal diesel × (diesel equipment emission factor in g/mmBtu + upstream diesel emission factor from GREET in g/mmBtu) for each pollutant $CO_2$, $CH_4$, and $N_2O$. Similarly, for construction materials tons of steel × g/ton of steel.

Emissions from diesel equipment will be summed over the totally fuel use for each type of construction equipment. Similarly, emissions from construction materials are summed over all the materials used for the Tacoma LNG. Inputs, emission factors, and WTT emission data are described in Section 2.4 and the construction emission results will be examined. WTT emission rates for fuels will be obtained from the GREET1_2017 model. Upstream life cycle emission rates for materials or construction will be obtained from the GREET2 model as well as the USLCI database (NREL, 2012) and other sources.

### 2.2.3 Operational Emissions

Emissions during plant operation include WTT emission rates from natural gas production and transport and power generation, as well as emissions from direct facility operation including fuel combustion on site, and emissions from end use fuel transfer for transfer operations[12] and fuel combustion. The emissions are grouped according to upstream, direct project, and end use. All of these emissions have WTT components such that the product of LNG use rate $U_{TLNG}$ and total emission rate per gallon of LNG, $\mathbf{E}_{TLNG}$ correspond to the total GHG emissions $\mathbf{G}_{LNG}$ via the following:

$$\mathbf{G}_{LNG} = U_{TLNG} \times \mathbf{E}_{TLNG} = U_{TLNG} \times [S_{NG} \times \mathbf{E}_{N} + S_{e} \times \mathbf{E}_{e} + V_{TLNG} + \Sigma(S_{i} \times \mathbf{EF}_{i})] + \Sigma[U_{k} \times (\mathbf{EF}_{L} + V_{O})] + U_{PS} \times (S_{NPS} \times \mathbf{EF}_{PS}) + \Sigma[U_{t} \times (\mathbf{EF}_{D} + \mathbf{E}_{D})] \quad (3)$$

Where:

$U_{TLNG}$ = Total LNG use rate for Tacoma LNG = LNG produced
$\mathbf{E}_{TLNG}$ =Average WTT emission rate for Tacoma LNG
$S_{NG}$ = Specific energy of natural gas feedstock (Btu/mmBtu LNG) for Tacoma LNG
$\mathbf{E}_{N}$ = WTT natural gas emission rate
$S_{e}$ = Specific Energy of electric power consumed per unit of LNG (kWh/gal)
$\mathbf{E}_{e}$ = WTT emission rate for electric power
$V_{TLNG}$ = Tacoma LNG fugitive emission rate (g/gal)
$S_{i}$ = Specific energy for Tacoma LNG combustion emissions and process emissions for LNG production
$\mathbf{EF}_{i}$ = Emission factor for combustion equipment for each fuel type (natural gas, light hydrocarbons, etc.)
$U_{k}$ = Use rate of LNG for marine vessel and diesel truck combustion
$\mathbf{EF}_{L}$ = Emission factor for LNG Marine vessel and diesel truck combustion as well as natural gas for stationary power
$V_{O}$ = Fugitive emission rate from LNG operations in marine and truck operations
$U_{PS}$ = Use rate of LNG for peak shaving
$S_{NPS}$ = Specific energy of fuel uses for vaporization in peak shaving
$\mathbf{EF}_{PS}$ = Emission factor for fuel fired in peak shaving vaporizer (LNG or light hydrocarbons)

[12] The fuel transfer emissions will be tracked for each type of fuel transfer activity including filling TOTE ships, barges, and trucks. The fuel transfer hardware for trucks will be different than that for ships.

$U_t$ = Diesel use rate for LNG transport to peak shaving and bunkering
$\mathbf{EF_D}$ = Emission factor for diesel trucks
$\mathbf{E_D}$ = WTT emission rate for diesel

| |
|---|
| Example Calculation of emissions for 20 million gallons of LNG<br><br>$U_{TLNG} \times [\mathbf{S_N} \times \mathbf{E_N} + \mathbf{S_e} \times \mathbf{E_e} + V_{TLNG}]$: 20 million gallons ×[(1,060,000 Btu NG/mmBtu LNG × 11,000 g $CO_2$/mmBtu NG WTT)+ (1.35 kWh/gal LNG × 200 g $CO_2$/kWh power) + 10 g $CH_4$/gal LNG] ×76,000 Btu/gal LNG +<br><br>$U_{TLNG} \times \Sigma(S_i \times \mathbf{EF_i})$: +20 million gal × (200 Btu NG liquids fired/gal LNG × 65,000 g $CO_2$/mmBtu NGL) + (800 Btu NG fired/gal LNG× 56,000 g $CO_2$/mmBtu NG) × 76,000 Btu/gal LNG +<br><br>$U_k \times (\mathbf{E_{FL}} + V_O)$: + 15 million gallons LNG for TOTE engines × 76,000 Btu/gal × (55,000 g $CO_2$/mmBtu LNG + 0.1 g $CH_4$/gal boil off loss/gal LNG)<br><br>$\mathbf{E_{NL}}$ + 5 million gallons LNG for peak shaving × 76,000 Btu/gal × 55,000 g $CO_2$/mmBtu NG from LNG<br><br>Note: All values are illustrative. Data on fuel compositions has been requested |

$S_{NG}$ is a representative value for all of the natural gas to the Tacoma LNG during normal operation. The term $E_{TLNG}$ represents emissions from both the combustion of natural gas as well as combustion of process gas from the separation unit. Each emission factor is based on the equipment type and design of the LNG production system. The term $S_L$ includes LNG used in all applications with unique value for each application. The LNG provided for peak shaving (one of the $S_L$ terms) will have a slightly different composition than conventional natural gas from underground storage wells.

### *Upstream Natural Gas Production, Separation and Transport Emissions*

Natural gas produced in regions such as British Columbia and the Rocky Mountains will be the feedstock for the Tacoma LNG. The source of natural gas has been requested.

A range of GHG emission estimate correspond to natural gas production based on the energy inputs for production as well as fugitive methane releases. The analysis will examine the range of GHG estimates in the GREET model and scientific literature. The source of natural gas for the Tacoma LNG facility has also been requested and the effect of different natural gas production sources will be examined.

GHG emissions from natural gas production are associated with well operation, separation of light hydrocarbons, transport, and fugitive emissions. The energy inputs for production are expressed as extraction efficiency in the GREET model[13]. The GREET model also includes estimates of fugitive $CO_2$ from gas processing as well as flared natural gas. The study calculations will be based on the GREET inputs for extraction, processing and transport with a sensitivity analysis bases on a range in fugitive methane emissions.

Natural gas is transported by pipeline at pressure of about 800 psi. Natural gas fuel compressor engines compress and move gas along the pipeline network. The GREET model calculates energy inputs for transport based on a transport distance in Btu/ton-mi. Data on gas transport distances has been requested. The GREET model also calculates distribution fugitive emissions. Since the natural gas for the Tacoma LNG project will be connected directly to a transmission pipeline, the fugitive emissions associated with transmission lines will be attributed to Tacoma LNG emissions, but the local delivery or distribution portion will be estimated as zero.

NG is primarily composed of methane ($CH_4$), with small amounts of light hydrocarbons ($C_2$ to $C_4$) and inert gases ($N_2$ and $CO_2$). The composition of the gas affects its carbon factor discussed in Section 2.4.1. Releases of $CO_2$ from the amine separation system will occur at the Tacoma LNG facility, which lowers the amount of carbon species available to be condensed into LNG, making the carbon factor for LNG lower than that of pipeline natural gas. The bulk of the light hydrocarbons are separated to avoid condensation during transportation. These condensates are used on-site or transported to appropriate markets. $C_3$ and $C_4$ hydrocarbons are a feedstock for LPG or as chemical feedstocks. The condensates will affect the LCA depending on the following:

- Captured and sold condensate will be treated as a co-product with a credit of petroleum LPG (shown in Figure 2.1). Information on this has been requested. If condensate is sold the figure will be modified. LPG from the project could be treated as yet another energy product, just like LNG. In this case, the emissions from LPG end use would be compared with emissions of other sources of LPG[14].
- Condensate burned on site will generate emissions that will be counted as project emissions and effect the overall energy input of project (for example condensate could be used as fuel for peak shaving vaporization)
- Condensate burned on site with no energy value will generate emissions that will be included in the analysis

The total WTT life cycle emissions will be calculated in the GREET model. Figure 2.2 shows the system boundary diagram for natural gas in the GREET model. The model calculates WTT emissions from natural gas pathways including LNG as well as fuel for applications such as power plants and oil refineries. The pathway for natural gas consists of extraction, processing, and transmission. The key inputs are energy inputs and fugitive emissions for each step. Energy inputs are represented as Btu of fuel used to process each million Btu of natural gas in each

[13] The GREET estimates for energy inputs for natural gas extraction, processing, and transmission will provide the primary estimate of upstream life cycle energy inputs for natural gas.
[14] The difference between represented as a co-product or energy product only affects the presentation of emission results. The co-product credit will be part of the operating emissions.

step. These include the GREET model default assumptions on extraction efficiency, processing efficiency, mix of process fuels, and flared gas per mmBtu of produced gas. This Study will focus on the range of fugitive methane emissions from these activities. Other data from natural gas production will also be examined.

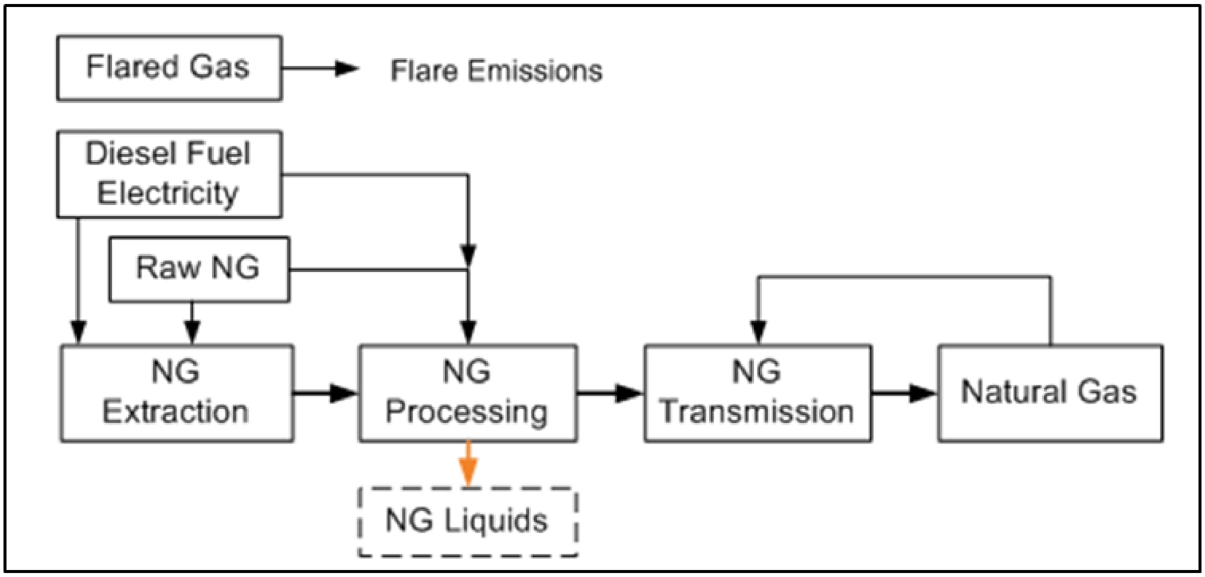


**Figure 2.2.** Natural Gas Production System Boundary Diagram

### *Power Generation and WTT*

Emissions from power generation include power plant combustion emissions for natural gas turbines and boilers as well as coal boilers. The life cycle emissions from power also includes WTT inputs for fuels and uranium for nuclear power plants. In Washington, average emissions per kWh are about half of the U.S. average, as most electricity is supplied with hydroelectric. However, the new electricity load from the Tacoma LNG project will not result in an expansion of power generation resources such as hydro and nuclear.

The system boundary for electric power in Figure 2.3 includes the WTT activities of each fuel used to produce electricity, direct combustion of these fuels at the power plant, and losses through the transmission and distribution system. This Study will examine a range of power resource mixes due to the complexity of assessing the marginal impact of power generation. Scenarios will be developed for the local utility generation mix, Washington state average mix, Northwest eGRID[15] mix, and a marginal mix that excludes hydroelectric and nuclear power that complies with Washington's 15% renewable portfolio standard by 2040. The inputs to the GREET model are the resource mix with GREET model inputs for power generation efficiency and transmission loss. Scenarios will also examine the range of LNG uses.

[15] https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

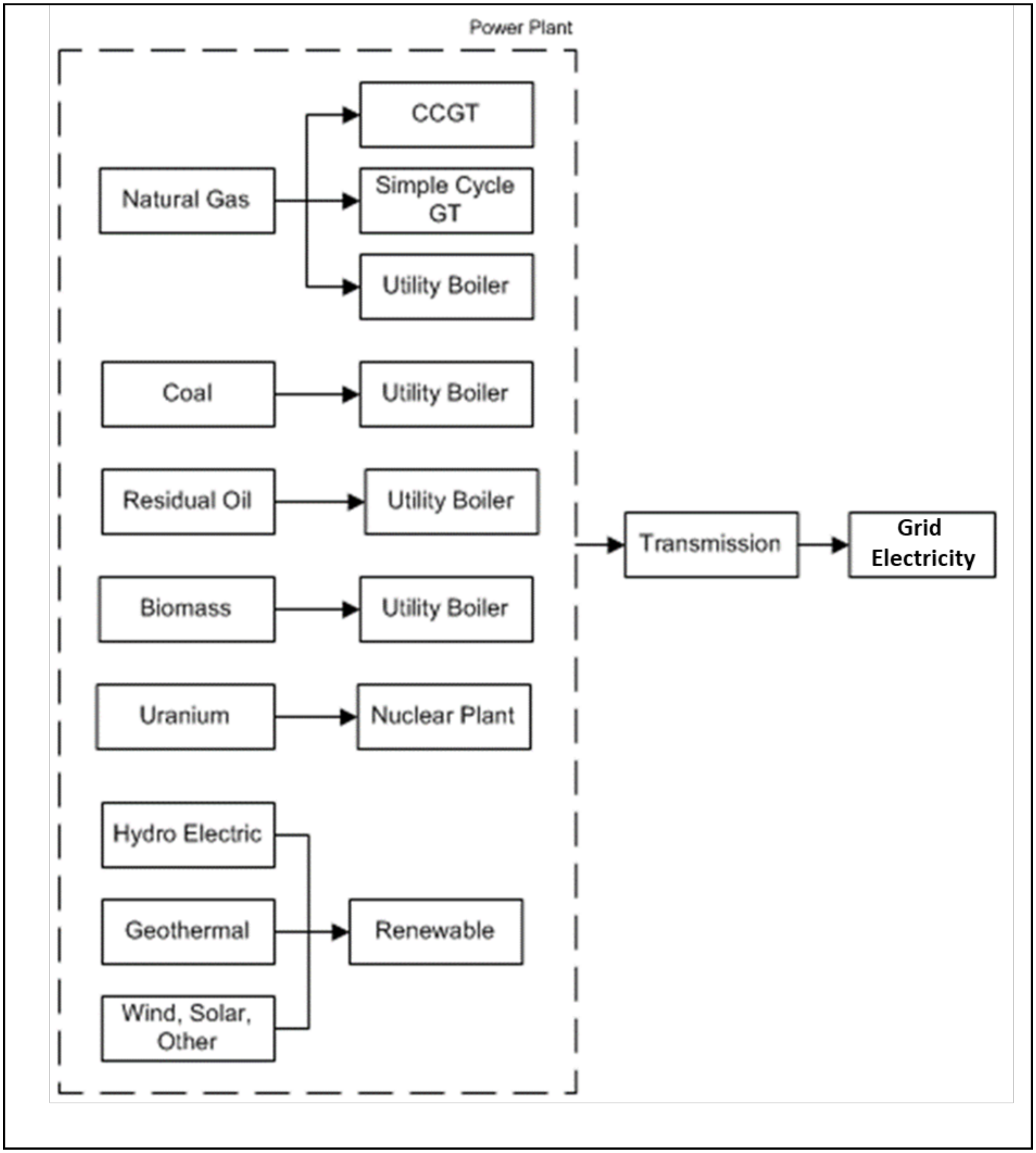


**Figure 2.3.** Electricity Production System Boundary Diagram

The GREET model calculates emissions for the fuel and power generation phase. The emission factors are represented as power delivered to a generic customer which would result in the same emissions as power delivered to Tacoma LNG for grid electricity that includes a loss factor for transmission. The system boundary in the GREET model excludes materials of construction and decommissioning for fuel production and power generation equipment. Therefore, solar, wind, and hydroelectric power are treated with the GHG intensity of 0 g $CO_2e$/kWh.

### *Direct Emissions from LNG Facility Operation*

Direct operating emissions from Tacoma LNG will include the sources shown in Figure 2.4. The natural gas contains higher weight hydrocarbons as well as small quantities of $CO_2$. The natural gas is separated into CH4 and the before mentioned components. After processing within the LNG production system process gas is burned in a boiler along with natural gas.

*Data on all aspects of facility operation have been requested.*

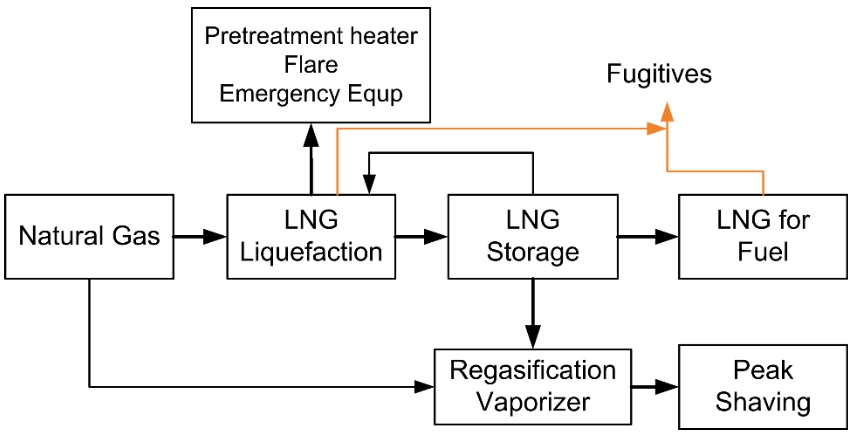


**Figure 2.4.** Direct Emissions Sources from Tacoma LNG.

In order to align the natural gas inputs with LNG production and to assure that overall $CO_2$ emissions are consistent with a mass balance, the components and carbon content of the input natural gas will be compared with the products.

Net $CO_2$ emissions for the Tacoma LNG ($C_{PSE}$) will be verified by carbon balance such that the carbon in each of the components balance. Net carbon emissions ($C_{PSE}$) are calculated such that:

$$C_{PSE} = C_{NG} - C_{LNG} \qquad (4)$$

Where:

$C_{PSE}$ = Carbon emissions from Tacoma LNG
$C_{NG}$ = Carbon in natural gas feedstock
$C_{LNG}$ = Carbon in LNG

The carbon balance will be checked for consistency with the analysis in the FEIS. For example, the carbon balance will track the carbon in the natural gas feed and LNG product. For 1 million Btu of natural gas $C_{PSE}$ will correspond to

*1 million Btu NG, LHV/(930 Btu/scf, LHV) × 20.2. g/scf × 74% carbon = 16,073 g C/mmBtu*
*– 950,000 Btu /(950 Btu/scf LNG, LHV) × 19.2 g/scf LNG × 75.2% = 15,198 g C/mmBtu × 0.95 Btu LNG/Btu NG*
= 1635 g C/mmBtu LNG

The values are representative and actual data have been requested. As shown in the example here, the carbon content of LNG decreases per mmBtu of fuel which results in net emissions. However, the lower carbon content will be reflected in the end use phase.

Natural gas also provides fuel for vaporization to re-gasify the LNG for peak shaving. Small portions of the process gas and natural gas are also combusted in the flare. Fugitive emissions occur from the LNG system and during LNG transfers for fuel use. Fugitive emissions primarily consist of methane and these GHG emissions are counted with the global warming potential (GWP) of methane.

### *Emissions from End Use of LNG (Downstream Emissions)*

End use or downstream emissions for Tacoma LNG include use of LNG as a fuel or for peak shaving operations. Emissions correspond to the combustion of fuels for:

- Combustion emissions in marine or truck engines
- Operation fugitives from on-board LNG storage tanks on trucks and ships[16]

A key parameter will be the use of LNG for the comparable amount of transport on diesel. The fuel use for each LNG application has been requested.

For each fuel application, emissions correspond to the fugitive operation emissions such as losses from TOTE ships plus combustion emissions. For fuel applications the emissions ($E_{FuelL}$) correspond to:

$$\mathbf{E}_{FuelL} = \Sigma_j(S_{Lj} \times \mathbf{EF}_{Lj} + V_O) \qquad (5)$$

Where:
$\mathbf{E}_{FuelL}$ = Emission rate from LNG use as fuel
$S_L$ = Specific Energy consumption of LNG for application j
$\mathbf{EF}_L$= Emission factor for fuel combustion
$V_O$ = Operation fugitive emission rate from LNG equipment operation[17]

For peak shaving operations, emissions ($\mathbf{G}_{PSL}$) correspond to

[16] Methane from on-board LNG storage tanks may escape during its use. Data on methane losses has been requested.
[17] This value may be zero if LNG is maintained in a closed system and all boil off is captured and used as fuel. Data and fugitive emissions from operation have been requested.

$\mathbf{G}_{PSL} = U_{NPS} \times \mathbf{EF}_{NL}$ (6)

Where:

$U_{PS}$ = LNG used for peak shaving, in Btu natural gas per gallon LNG
$\mathbf{EF}_N$ = Natural combustion emission factor, in grams of $CO_2$ per Btu natural gas

The end use emissions from natural gas and peak shaving natural gas will be calculated based on natural gas compositions and compared to the composition of natural gas derived from LNG. GHG emissions correspond to the fuel used combined with the emission factor in Section 3 for each fuel.

Pipeline gas contains some $CO_2$ which is removed by the Tacoma LNG project and emitted. These emissions are counted as part of the project direct emissions. Consequently, the end use emissions do not contain $CO_2$ and the carbon factor is slightly lower per mmBtu for LNG used for peak shaving.

### *WTT Emissions from Petroleum Fuel Production*

Crude oil is produced and transported from a variety of resources and regions in the world. Crude oil is transported to oil refineries and refined into a range of products shown in Figure 2.5. GHG emissions from petroleum production depend on the crude oil type and the extraction method as well as oil refinery configuration with about a 10% range in life cycle emissions from different crude oil types (Cai et al., 2015). The life cycle analysis of petroleum production in the GREET model takes into account the WTT emissions for crude oil production as well as the energy intensity to refine different products. The GREET inputs for petroleum product refining are based on a linear programming analysis of U.S. refineries (Elgowainy et al., 2014; Han et al., 2015). The analysis also takes into account that oil refinery units are designed to produce gasoline and diesel while residual oil is a by-product of refining. Residual oil and petroleum coke are assigned the highest refinery efficiencies while the efficiencies for gasoline and diesel are lower. Thus, emissions from the refining step are lower per mmBtu for residual oil than for diesel.

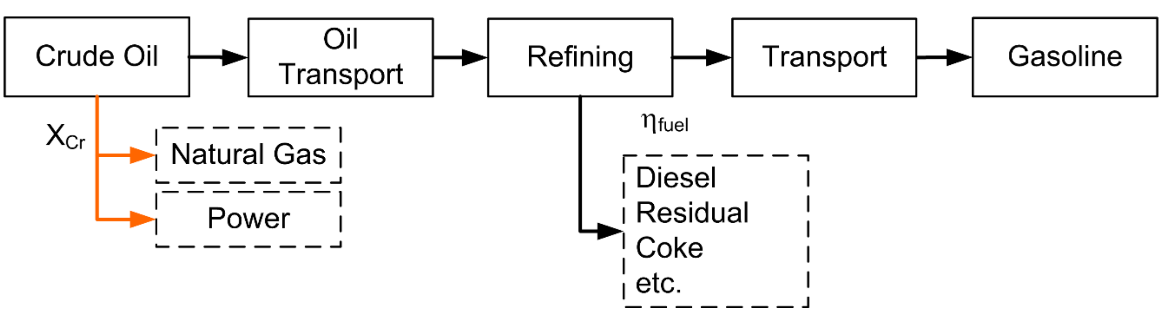

**Figure 2.5.** System Boundary Diagram for Petroleum Products.

The WTT data for refined petroleum products used for the alternative of LNG fuel will be evaluated. We will calculate petroleum refining emissions using the GREET1_2017 model with the State of Washington electricity mix. The mix of energy resources for crude oil extraction will remain as the GREET default values. The location of crude oil sources will be modified to reflect crude oil used in Washington. The effect of changing from higher sulfur to 1,000 ppm sulfur will also be examined.

### 2.2.4 Activities and Approach for Displaced Emissions (No Action Alternative)

The life cycle GHG emissions from the Tacoma LNG project are compared to the alternative of not constructing the facility. Displaced LNG is based on PSE's projections of LNG end use applications.

Alternative energy uses include marine diesel and diesel fuel in marine and truck applications as well as for peak shaving operations. GHG emissions will be calculated in the same manner as those for Tacoma LNG. The amount of diesel used for marine, trucking, or peak shaving applications will be calculated based on the LNG use rate and the appropriate efficiency for each application. For diesel fuel combustion, the product of use rate and life cycle emission rates results in total emission $\mathbf{G}_{Alt}$ which calculated by:

$$\mathbf{G}_{Alt} = U_{PS} \times S_{DSP} \times (\mathbf{EF}_D + \mathbf{E}_D) + \Sigma[U_k \times (S_{De} \times \mathbf{E}_e + S_D \times (\mathbf{EF}_D + \mathbf{E}_D))] \quad (7)$$

Where:
$U_{PS}$ = Energy use rate for LNG peak shaving
$S_{DPS}$= Specific energy of diesel used in peak shaving operations per unit for the quantity $S_{LPS}$
$\mathbf{EF}_D$ = Emission factor for diesel in marine or truck engines or diesel peak shaving
$\mathbf{E}_D$ = WTT emission rate for bunker fuel or diesel fuel
$U_k$ = Energy use rate of LNG in each application
$S_{De}$ = Specific energy of electricity used for diesel storage and transfer[18]
$\mathbf{E}_e$ = WTT emission rate for electric power
$S_D$ = Specific energy of diesel fuel and marine diesel displacing LNG for each fuel application

The term $S_D$ is a key parameter that relates the energy used in diesel operations with those from LNG fuel use. Electric power for diesel distribution so the term $S_{De}$ for alternative activities is essentially zero.

The WTT emission rates include the WTT data for diesel and marine diesel production. A small portion of these WTT emissions fall into the scope of distribution which is consistent with the activities of the Tacoma LNG project direct emissions. Emissions from alternative peak shaving are also an alternative to the Tacoma LNG project peak shaving operation.

*The inputs for alternative energy uses are being collected.*

[18] This small amount of energy provides the functional equivalence of the direct emissions from LNG production which serves also as fuel storage.

## 2.3 Scenarios for GHG Impacts

The Tacoma LNG project affects GHG through several direct and indirect effects that are examined in this analysis. The factors that affect GHG emissions are discussed in the following section.

*Scenarios that evaluate a range of parameters will be defined. The Study will examine a range of end use applications based on data that has been requested. We anticipate that the gallons of LNG for peak shaving, TOTE vessels, barge bunkering and truck applications can vary. Also, scenarios that cover the range of power generation emissions and natural gas fugitive emissions will be examined.*

## 2.4 Data Sources for Emissions

Calculations of life cycle GHG emissions are based on the energy inputs and emissions for each step in the LNG production process. The data sources for direct emissions from LNG production, and inputs for the WTT and downstream emissions in the life cycle are described below. Since many of the data sources apply to both Tacoma LNG as well as displaced emissions from the no action alternative, the data are organized by category rather than a linear path along the LNG life cycle.

### 2.4.1 Direct Combustion Emissions

Direct combustion emissions occur from a variety of sources in the life cycle. These emissions include $CO_2$, $CH_4$ and $N_2O$ which depend on the carbon content and heating value of the fuel as well as the combustion characteristics of how the fuel is burned. Table 2.3 shows the calculation of the carbon factor (g $CO_2$/mmBtu) for the primary fuels in the life cycle of LNG and alternative fuels. The carbon factor is calculated such that the carbon per Btu is multiplied by the molecular weight ratio of $CO_2$ to carbon via:

Carbon factor = wt% C/HHV (Btu/lb) × 453.59 g/lb x 44/12.01 × $10^6$

**Table 2.3.** Calculation of $CO_2$ Emission Factors from Fuel Properties, HHV basis

| Fuel | Natural Gas | LNG | Residual Oil | Diesel |
|---|---|---|---|---|
| Carbon Content (wt%) | 74.0% | 75.0% | 86.8% | 86.5% |
| Heating Value (Btu/lb), HHV | 22,902 | 23,500 | 18,148 | 19,676 |
| Heating Value (Btu/unit), HHV | 1,054 | 950 | 150,110 | 137,380 |
| Unit | scf | scf | gal | gal |
| Fully oxidized (g $CO_2$/mmBtu) | 53,690 | 53,080 | 79,478 | 73,049 |
| Source: | *Placeholder values Data requested* | Properties to be calculated from composition | GREET | GREET |

Hydrocarbon and carbon monoxide emissions are treated as fully oxidized $CO_2$ under most GHG accounting systems including IPCC AR4 (IPCC, 2007) and Argonne's GREET model (ANL, 2017). In the IPCC assessment, for example, the global warming potential (GWP) of carbon monoxide is considered to be 1.5 to 2 which is consistent with the fully oxidized treatment of CO (ratio of 44/28 = 1.57) which is the value used in the GREET model. [19] State of Washington SEPA requirements provide for the use of EPA emission factors. The emission factors and sources are consistent with this approach.

Hydrocarbon and carbon monoxide emissions are treated as fully oxidized $CO_2$ under most GHG accounting systems including IPCC AR4 (IPCC, 2007) and Argonne's GREET model (ANL, 2017). In the IPCC assessment, for example, the global warming potential (GWP) of carbon monoxide is considered to be 1.5 to 2 which is consistent with the fully oxidized treatment of CO (ratio of 44/28 = 1.57) which is the value used in the GREET model.[20] State of Washington SEPA identified emission factors and sources are consistent with this approach (Washington State Department of Ecology, 2018).

The carbon factor is the same for each fuel regardless of its end-use application. However, the methane and $N_2O$ emissions depend on combustion properties for engines, turbines, and boilers. $CO_2$ emissions for fuel combustion depend upon the carbon content, density, and heating value of fuels such that all of these properties are consistent. Table 2.4 show the carbon factor which represents $CO_2$ emissions per unit of fuel is calculated based on these properties. In this study, emission factors are identified in the units based on the original data source including the higher (HHV) or lower heating value (LHV) basis.

Emission factors for each energy source in the study are based either on SEPA emission factors, actual fuel properties, or GREET emission factors. Note that fuel combustion occurs through the upstream fuel cycle for all of the energy inputs associated with the project and displaced emissions. Therefore, calculations based on the GREET direct emission factors are more consistent than mixing and matching data from various sources.

Table 2.4 shows the fully oxidized $CO_2$ emissions as well as $CH_4$ and $N_2O$ emissions from various combusting sources in this study. The carbon factor of fully oxidized $CO_2$ ($CO_2c$) is based on the

[19] When fuel use is represented as an emission factor per MMBtu of fuel, this factor typically includes all of the carbon in the fuel. However, emission factors for individual types of equipment such as marine engines might include separate values for $CO_2$ and CO emissions. In order to be consistent with IPCC and SEPA reporting protocols, CO should be counted as fully oxidized $CO_2$. The effect of this detail is typically less than 0.5% of $CO_2$ emissions from any source. This study includes VOC and CO emissions as $CO_2c$ because these emissions are counted in the GREET LCA framework. Also, many emission inventory methods show $CO_2$ as fully oxidized carbon in fuel.

[20] When fuel use is represented as an emission factor per MMBtu of fuel, this factor typically includes all of the carbon in the fuel. However, emission factors individual types of equipment such as marine engines might include separate values for $CO_2$ and CO emissions. In order to be consistent with IPCC and SEPA reporting protocols, CO should be counted as fully oxidized $CO_2$. The effect of this detail is typically less than 0.5% of $CO_2$ emissions from any source. This study includes VOC and CO emissions as $CO_2c$ because these emissions are counted in the GREET LCA framework. Also, many emission inventory methods show $CO_2$ as fully oxidized carbon in fuel.

fuel properties. Note that the $CO_2c$ factor includes methane because the fully oxidized effect is not reflected in the GWP of methane. Emission factors for $CH_4$ and $N_2O$ depend on the type of equipment and are identified in the GREET model or will be supplemented by data that has been requested. Finally, the GWP –weighted GHG emissions in $CO_2$ equivalent ($CO_2e$) are calculated. The emission factors will be converted to other units (g/gallon, g/mmBtu, HHV as needed based on fuel specifications in GREET.

**Table 2.4.** Direct Combustion Emissions

| Fuel/ Application | Equipment Type | $CO_2c$ | $CH_4$ | $N_2O$ | $CO_2e$ |
|---|---|---|---|---|---|
| GREET Emissions (g/mmBtu), LHV [a] | | - | - | - | - |
| Diesel | Diesel Engine | 78,187 | 4.2 | 0.6 | 78,472 |
| Diesel | HD Truck | 78,187 | 4.7 | 0.2 | 78,357 |
| Gasoline, E10 | Gasoline Engine | 76,829 | 3.0 | 0.6 | 77,083 |
| Bunker Fuel | Marine Engine | 85,069 | 1.5 | 1.7 | 85,618 |
| Natural Gas | IC Engine | 58,333 | 392 | 0.1 | 68,175 |
| Natural Gas | Turbine, CC | 59,410 | 1.1 | 0.1 | 59,474 |
| Natural Gas | Boiler | 59,410 | 1.1 | 0.8 | 59,660 |
| LNG | Marine Engine | TBD | TBD | TBD | |
| LNG | Truck | TBD | TBD | TBD | |
| LNG | NG Peak Shaving | TBD | 1.1 | 0.8 | |
| LPG from Tacoma LNG | Boiler | TBD | 1.1 | 0.8 | |
| LPG, Conventional | Boiler | 68,059 | 1.1 | 4.8 | |
| Fuel Gas | Boiler | TBD | 1.1 | 4.8 | 250 |
| Coal | Boiler | 100,041 | 1.1 | 1.6 | 100,540 |

[a] Fuel properties in GREET are on the Fuel_Specs sheet with same properties at those in Table 2.3. Natural gas properties will be recalculated based on data that has been requested.

[b] SEPA permits calculations of GHG emissions based on EPA, AP-42 The emission factors are comparable to those in the GREET model. Note that $CO_2c$ factor for natural gas engines is lower than that for other end uses because of the higher $CH_4$ emissions.

### 2.4.2 Evaporative Emissions and Loss Factor

Fugitive emissions from LNG production facilities include LNG and other light hydrocarbons that escape from storage tanks and vents as well as LNG vapors that are displaced from the transfer of LNG from storage tanks to transport vessels or trucks and back to storage tanks. The Tacoma LNG will implement controls of fugitive vapors that either return these components to re-liquefy them or combust them to form $CO_2$. LNG transfers also result in fugitive emissions due to trapped volumes. These are the volume between hose and connector. Data on the trapped volumes for LNG transfers have been requested.

### 2.4.3 LNG Production Energy Inputs and Emissions

*Additional data have been requested.*

### 2.4.4 Natural Gas WTT

*Data on the source of natural gas have been requested.*

### 2.4.5 Electric Power WTT

The analysis will consider the GHG intensity of the electricity mix for:

- Local electricity mix
- Washington State average
- eGRID Region for Northwest
- Marginal mix that excludes hydroelectric, meets 15% RPS and takes into account decommissioning of coal

### 2.4.6 Construction Inputs and Materials

*Data on construction materials have been requested.*

WTT emissions will be based on the GREET2 model as well as the USLCI database.

### 2.4.7 Petroleum Fuel Upstream

The analysis will use the GREET model to determine upstream emissions for residual oil that is used for marine engines. The residual oil will meet specifications for low sulfur operation (1,000 ppm). The GREET model will also provide upstream data for diesel fuel for on-road trucks.

### 2.4.8 End Use Energy and Emissions

*Data on the end use of LNG and marine fuel in TOTE and other marine applications and diesel trucks have been requested. The volumes of LNG used for each application as well as the displacement of LNG for diesel fuels have been requested.*

For transportation applications the data will include energy use over a functional unit (miles) and comparable energy use for LNG. Emissions of $CH_4$ and $N_2O$ per mmBtu have also been requested.

For peak shaving applications, the fuel properties of LNG and fuel properties of pipeline gas will provide the basis for determining $CO_2$ emissions per mmBtu. Data on energy inputs and emission for alternative peak shaving operations have also been requested.

# 3. Life Cycle Analysis Comparison

The comparison of life cycle GHG emissions will be performed over a 40-year project lifetime. Emissions will be grouped according the life cycle steps identified in Table 3.1. Construction, Tacoma LNG, and Displaced emissions will be categorized separately and total net emissions calculated. Each category of emissions includes upstream, direct, and end use. The grouping for operational emissions for the Tacoma LNG project is shown in Figure 3.1.

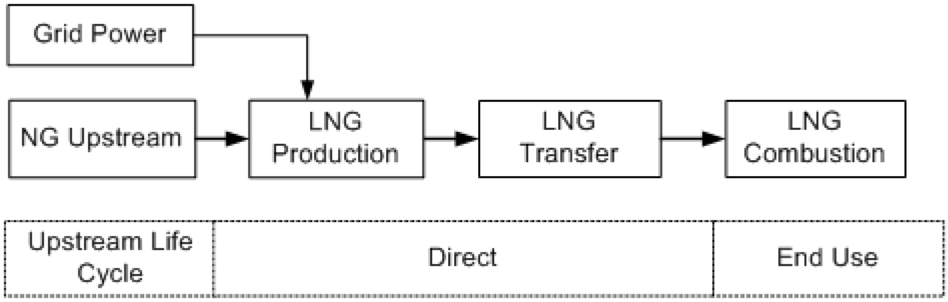


**Figure 3.1.** Grouping of Life Cycle Emissions for Tacoma LNG Operation.

**Table 3.1.** Categories for Life Cycle GHG Emissions.

| Process Step | M gal/year | TJ/y Basis | M tonne GHG/y | Subgrouping |
|---|---|---|---|---|
| Construction Emissions | | | | |
| Direct | | | | Construction |
| Upstream | | | | |
| Operational Emissions | | | | Operational |
| Upstream Natural Gas | | | | |
| Upstream Power | | | | Upstream |
| Upstream Petroleum Fuels | | | | |
| Direct LNG Production | | | | |
| Direct Peak Shaving | | | | Direct |
| End Use TOTE Marine LNG | | | | |
| End Use LNG Other Marine | | | | End Use |
| End Use LNG Truck | | | | |
| End Use LNG Peak Shaving | | | | |
| Displaced Emissions | | | | Displaced |
| Upstream Natural Gas | | | | |
| Upstream Power | | | | Upstream |
| Upstream Petroleum Fuels | | | | |
| Direct Diesel Fuel Storage/Transfer | | | | |
| Direct Peak Shaving | | | | Direct |
| End Use TOTE Marine Diesel | | | | |
| End Use Other Marine Diesel | | | | End Use |
| End Use Diesel Truck | | | | |
| End Use NG Storage Well | | | | |
| Net Emissions | | | | |

[a] GHG emissions over 40-year period

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# APPENDIX C

PSE Tacoma LNG
Project GHG Analysis Report

# PSE Tacoma LNG Project GHG Analysis Final Report

LCA.8117.194.2018
20 September 2018

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## DISCLAIMER



## ACKNOWLEDGEMENT

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# Terms and Abbreviations

| | |
|---|---|
| ALCA | Attributional Life Cycle Analysis |
| ANL | Argonne National Laboratory |
| ARB | California Air Resources Board |
| Btu | British thermal unit |
| CA | California |
| CA-GREET | The standard GREET model modified for use in CA LCFS |
| $CH_4$ | Methane |
| CI | Carbon intensity |
| CIG | Climate Impacts Group |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| $CO_2c$ | Fully oxidized $CO_2$ including CO and VOCs |
| $CO_{2e}$ | Carbon dioxide equivalent |
| DOE | U.S. Department of Energy |
| EIA | US Energy Information Agency |
| EMFAC | EPA's Emission Factors Model |
| EPA | U.S. Environmental Protection Agency |
| g $CO_2e$ | Grams of carbon dioxide equivalent |
| GBtu | Giga ($10^9$) British thermal units |
| GHG | Greenhouse Gas |
| GHGenius | LCA model based on UC Davis Life Cycle Emission Model (LEM) that was developed for Natural Resources Canada |
| GREET | The Greenhouse gas, Regulated Emissions, and Energy use in Transportation model |
| gbp | gallons per day |
| GWh | Gigawatt Hours |
| GWP | Global Warming Potential |
| HC | Hydrocarbon |
| HHV | Higher Heating Value |
| IPCC | Intergovernmental Panel on Climate Change |
| ISO | International Standards Organization |
| JRC | Joint Research Centre |
| kW | Kilowatt |
| kWh | Kilowatt-hour |
| LCA | Life Cycle Analysis or Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| LCFS | Low Carbon Fuel Standard |
| LHV | Lower Heating Value |
| mmBtu | Million British thermal units |
| MDO | Marine Diesel Oil |
| MW | Megawatt |
| $N_2O$ | Nitrous oxide |

| | |
|---|---|
| NETL | National Energy Technology Laboratory |
| NG | Natural Gas |
| NOx | Oxides of nitrogen |
| RFS2 | Revised Federal Renewable Fuels Standard |
| RPS | Renewable Portfolio Standard |
| SEIS | Supplemental Environmental Impact Statement |
| SEPA | (Washington) State Environmental Policy Act |
| UN | United Nations |
| UNFCC | United Nations Framework Convention on Climate Change |
| VOC | Volatile Organic Compound |
| WTT | Well-To-Tank |
| WTW | Well-To-Wake |

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# Executive Summary

The Tacoma LNG project will produce liquefied natural gas (LNG) that will be used as a fuel for marine and on-road transportation applications as well as for supplying natural gas to PSE customers during peak demand times (known as “peak shaving”). This study examines the greenhouse gas (GHG) emissions from the project and compares these emissions to the alternative of not completing the project, which is the conventional use of diesel and marine diesel fuels in marine and trucking applications and conventional natural gas for peak shaving.

Overall project emissions are quantified on a life cycle basis for each use of LNG with overall life cycle results weighted by the gallons of LNG consumed by each end use. For Tacoma LNG, life cycle emissions include not only the direct emissions associated with production of LNG, but also include emissions associated with recovery, refining and transport of each fuel used in production and emissions associated with end use (combustion in marine engines and heavy-duty trucks). Emissions of nitrous oxide ($N_2O$), Methane ($CH_4$) and carbon dioxide are quantified and reported on a $CO_2$ equivalent basis by applying global warming potential (GWP) factors from IPCC’s 4$^{th}$ annual assessment (AR4), which is the currently accepted international reporting standard and the method for State of Washington GHG reporting.

Life cycle GHG emissions are composed of upstream, direct, and end use emissions. Upstream emissions are the emissions associated with production and transport of fuel used at the LNG production plant: natural gas feedstock, natural gas fuel, diesel fuel, and electricity. For natural gas, upstream emissions include emissions due to natural gas recovery, processing and transport to the facility. For on-site diesel, upstream emissions are those associated with crude oil recovery, transport to the refinery, refining, and finished product transport to end use. For electricity, upstream emissions include recovery, processing and transport of each fuel type to the electricity generating plants (generally a mix of coal, nuclear, natural gas, oil, hydro and other renewables). Upstream emissions are calculated on a life cycle basis using the GREET model from Argonne National Laboratory.

Direct emissions from LNG production include all fuel combustion emissions as well as fugitive emissions at the plant. Estimates of direct energy inputs, emissions, and fugitive methane losses are based on engineering estimates and data provided by the project applicant. Emission estimates are further verified with a carbon balance such that the carbon in the natural gas feedstock is equal to the carbon in LNG produced plus emissions from LNG production. End use emissions are calculated for the amount of LNG required to displace marine diesel, on-road diesel, and peak shaving applications. The fugitive emissions of methane are taken into account in the analysis as well as the upstream life cycle emissions associated with power generation. Net GHG reductions occur over a range of scenario inputs.

To evaluate the potential change in overall emissions, the life cycle emissions from the Tacoma LNG project are compared with life cycle emissions from fuel that is displaced by the project, assuming operations at a peak capacity of 250,000 and 500,000 gallons per day (gpd) of LNG for 355 days in the year. Upstream, direct, and end use emissions would occur from the equivalent displaced marine diesel for marine engines, diesel for on-road applications, and natural gas for electric peak shaving in a power plant.

Table S.1 shows the potential effect of Tacoma LNG on GHG emissions for the case that the new liquefaction plant will be built compared to the "no project" (no action alternative) scenario. In aggregate, the Tacoma LNG project will result in 3.9% reduction in GHG emissions compared to the no action alternative for fuel uses associated with a 500,000 gpd production capacity. The net GHG reductions are 5.5% for a 250,000 gpd scenario due to a different mix of end use applications. These reductions assume that the displacement of petroleum fuels results in their reduction in use and the displaced fuels are not being produced and burned by another user.

**Table S.1.** GHG emissions from the Tacoma LNG plant compared to the "no-project" scenario at 500,000 gpd production capacity

| Life Cycle Step | Mgal/ year | GBtu/ year | GHG Emissions tonne $CO_2$e/year |
|---|---|---|---|
| **Tacoma LNG** | | | |
| Construction [a] | | | **1,581** |
| Upstream Life Cycle | | | **207,844** |
| Direct LNG Plant | | | **108,997** |
| End Use LNG | **177.50** | **13,695** | **1,068,092** |
| On-site Peak Shaving | 9.73 | 750 | 43,854 |
| Gig harbor LNG | 1.78 | 137 | 8,129 |
| On-road Trucking | 3.55 | 274 | 17,862 |
| TOTE Marine | 37.93 | 2927 | 225,993 |
| TOTE Marine Diesel Pilot Fuel [b] | 0.00 | 0 | 7,611 |
| Truck-to-Ship Bunkering | 1.78 | 137 | 10,575 |
| Truck-to-Ship Bunkering Pilot Fuel [b] | | | 356 |
| Other Marine LNG (by Bunker Barge) | 122.74 | 9470 | 729,376 |
| Other Marine Diesel Pilot Fuel [b] | | | 24,335 |
| Total | **177.50** | **13,695** | **1,386,514** |
| **NO ACTION** | | | |
| Upstream Life Cycle | | | **247,772** |
| Total End Use Diesel /Fuel Oil/LNG | **101.40** | **14,018** | **1,195,447** |
| Diesel Peak Shaving for Power | 5.89 | 750 | 58,891 |
| Gig harbor LNG | 1.78 | 137 | 8,168 |
| On-road Trucking | 1.93 | 247 | 19,316 |
| TOTE Marine Diesel | 21.48 | 3,014 | 261,325 |
| Truck-to-Ship Bunkering | 1.01 | 141 | 12,229 |
| Other Marine Diesel (by Bunker Barge) | 69.32 | 9,729 | 835,519 |
| Total | **101.40** | **14,018** | **1,443,219** |
| **Net Emissions** | | -3.93% | **-56,705** |

[a] Construction emissions over 40 years

[b] Marine diesel pilot fuel is 3% of fuel input for LNG operation.

Tacoma LNG GHG Emissions

The GHG emissions from the Tacoma LNG project were examined on full life cycle basis. These include the upstream emissions associated with natural gas and electric power production, and the direct emissions from the conversion of natural gas to LNG. The end use transportation or power generation is identical for the Tacoma LNG project and the no action alternative

Figure S-1 shows the energy inputs and estimated annual life cycle emissions from the proposed Tacoma LNG plant, compared to those from the no action alternative. The estimate of GHG emissions is consistent with steady state operation where energy inputs are closely linked to throughput. The results for both the 500,000 and 250,000 gpd production capacity scenarios are shown. The larger volume scenarios involved more LNG for marine vessels that is moved by barge to marine vessels. The peak shaving and TOTE vessel operation emissions are the same for both scenarios.

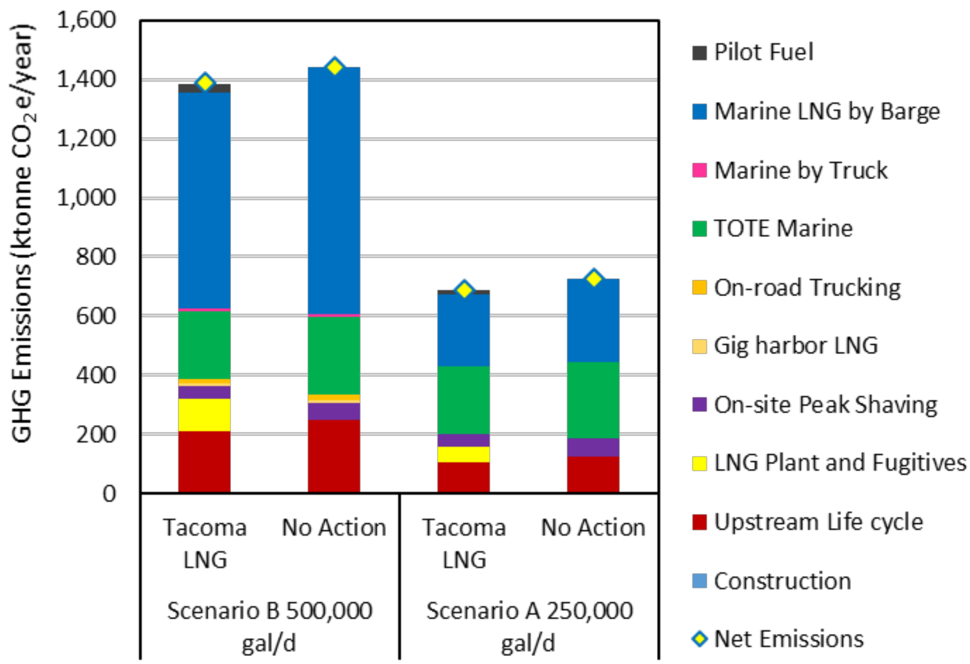


**Figure S.1.** Life cycle GHG emissions from Tacoma LNG Facility vs. No Action and displaced emissions (Alternative. Action)

The life cycle GHG emissions for Tacoma LNG are compared to GHG emissions that would be generated without the use of LNG. This analysis assumes that the LNG is used for the fuel applications identified by the applicant and that LNG displaces other fossil fuels in the no action alternative[1]. Specifically, the displaced petroleum fuels would not be used in other applications because they are available on the market. Tacoma LNG would displace Marine Diesel Oil (MDO) for marine vessel fuel and diesel fuel for peak shaving and on-road trucking as well as another source of more remote LNG.

[1] For example, LNG used for 1000 miles of marine transport would displace marine diesel that accomplishes the same 1000 miles of transport.

Figure S.2 shows the comparison of GHG emissions from Tacoma LNG with to the GHG emissions from the use of fuels being displaced by Tacoma LNG. The expected use of LNG is primarily for MDO with also some LNG displacing diesel fuel for trucking and peak shaving power generation.

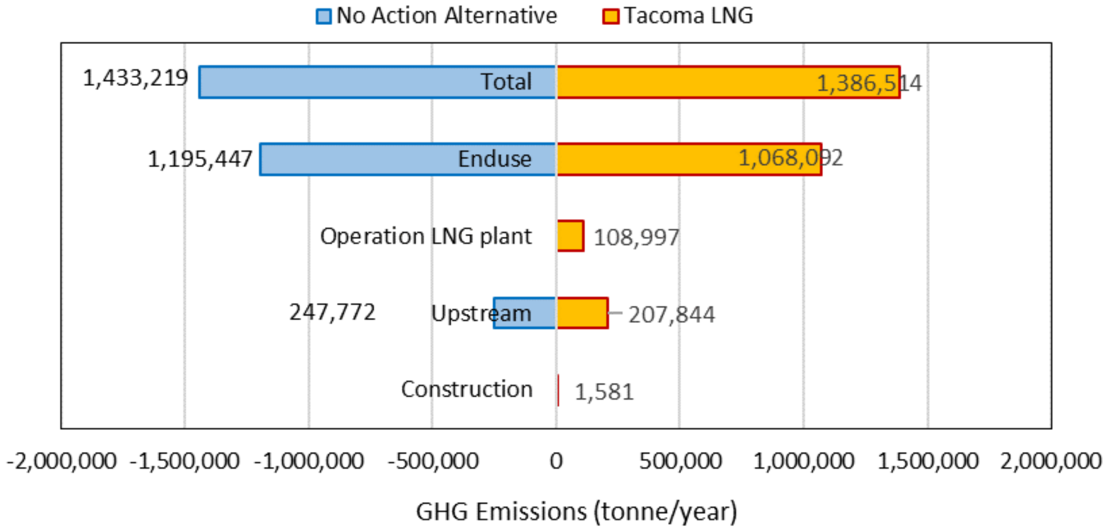


**Figure S.2.** Comparison of Life Cycle GHG Emissions, 500,000 gpd LNG capacity

<u>Key Findings</u>

This study examines the GHG emissions from Tacoma LNG on a life cycle basis. The scope of the analysis includes feedstock extraction through the delivery to an LNG liquefaction plant and its end use as marine vessel fuel and as natural gas for power peak shaving.

GHG emissions for the Tacoma LNG project are lower than those from the no action alternative due to several factors. These include:

- Lower upstream life cycle emissions from natural gas and power compared to oil production and refining
- Lower carbon content per Btu of LNG compared to diesel and MDO
- Higher $CH_4$ emissions from LNG engines compared to diesel engines
- $CH_4$ emissions from fuel transfer operations
- Flaring of non methane hydrocarbons in the LNG
- The increased capacity of LNG supply and its end use by other marine vessels in addition to the TOTE vessels offsets the increase in direct emissions from the New LNG Facility
- Avoided emission controls or sulfur removal from marine diesel applications

# 1. INTRODUCTION

## 1.1 Analysis Contents

This analysis examines the effect of Tacoma LNG on global GHG emissions. The analysis includes the following Sections.

1. Introduction
2. Methods and Data
3. Tacoma LNG Emissions
4. Displaced Emissions
5. Life Cycle Assessment

Appendices

Section 1 provides an introduction to the Tacoma LNG, GHG emissions, and LCA. The methods and data used in the analysis are described in Section 2, which includes a description of upstream fuel cycle inputs as well as the energy inputs and yields for LNG production and other data. Section 3 combines the data in Section 2 applied with inputs for Tacoma LNG to determine construction, operation, and end use emissions. Section 4 compares the energy displacement from Tacoma LNG and calculates the emissions from the no action alternative. Section 5 compares the emissions from Tacoma LNG to the no action alternative to determine net life cycle GHG emissions. The effect of different input parameters is also analyzed.

## 1.2 Proposed Project

The Tacoma LNG project will produce liquefied natural gas (LNG) that will be used as a fuel for marine and on-road transportation applications as well as for supplementing natural gas supply in the winter when demand is high (peak shaving). This study will examine the greenhouse gas (GHG) emissions from the project and compare these emissions to the alternative of not completing the project, which is the conventional use of distillate fuels in marine and trucking and applications in conjunction with pipeline natural gas use for peak shaving.

**Figure 1.1.** Tacoma LNG Facility.

The Facility will be located in the industrial Port of Tacoma with access to Puget Sound (see Figure 1-1). The general location of the site is north of East 11th Street, east of Alexander Avenue, south of Commencement Bay, and on the west shoreline of the Hylebos Waterway (see Figure 1-2). The Tacoma LNG Facility site is in an area zoned as Port Maritime Industrial. It is primarily developed for industrial maritime use and has been in industrial use for at least 75 years.


**Figure 1-2.** Existing conditions and location of proposed Tacoma LNG project facilities

The boundaries for these parcels include both in-water and upland areas, reflecting a total area of approximately 33 acres. The upland portion of the site is approximately 30 acres, and the aquatic area is approximately 3 acres.

Overall project emissions will be quantified on a life cycle basis for each use of LNG with overall life cycle results weighted by the gallons of LNG consumed by each end use. For Tacoma LNG, life cycle emissions include not only the direct emissions associated with production of LNG, but also include emissions associated with recovery, refining and transport of each fuel used in production and emissions associated with end use (combustion in marine engines and heavy duty trucks and peak shaving). Life cycle GHG emissions are composed of upstream life cycle, direct, and end use emissions. Upstream life cycle [2]or well to tank (WTT) emissions are the emissions associated with production and transport of fuel used at the LNG production plant: natural gas feedstock, natural gas fuel, diesel fuel, and electricity. For natural gas, upstream life cycle includes emissions due to natural gas recovery, processing and transport to the facility. For on-site diesel, upstream life cycle emissions are those associated with crude oil recovery, transport to the refinery, refining, and finished product transported to end use Tacoma LNG. For electricity, upstream life cycle emissions include recovery, processing and transport of each fuel type to the electricity generating plants and the operation of the plants (generally a mix of coal, nuclear, natural gas, oil, hydro and other renewables). Upstream life cycle emissions are calculated on a life cycle basis using the GREET model from Argonne National Laboratory.

[2] Upstream life cycle emissions are referred to as well to tank emissions the GREET modeling framework. The end use of fuels are referred to as tank to wheel or well to wake emissions.

Direct emissions from LNG production include all fuel combustion emissions as well as fugitive emissions at the plant. Estimates of direct emissions will be based on inputs provided by the project applicant and verified with a carbon balance such that the carbon in the natural gas feedstock is equal to the carbon in LNG produced plus emissions from LNG production.

End use emissions are calculated for the amount of LNG required to displace marine diesel, on-road diesel, electric power peak shaving, and other LNG use applications.

Finally, the emissions from the Tacoma LNG project emissions are compared with life cycle emissions from the no action alternative which consists of fuel that is displaced by the project (diesel for marine engines, diesel for on-road applications, and fuel for peak shaving).
The analysis is based on a 1:1 displacement of the end use for the no action alternative. No market induced displacement effects are calculated because these effects are small[3].

Emissions of nitrous oxide ($N_2O$), methane ($CH_4$) and carbon dioxide ($CO_2$) are quantified and reported on a $CO_2$ equivalent basis by applying global warming potential (GWP) factors from IPCC AR4, which is the currently accepted international reporting standard and the method for State of Washington GHG reporting.

## 1.3 No Action Alternative

Absent the Tacoma LNG project, petroleum fuels will continue to be used to produce marine diesel oil and on-road diesel. The applicant estimates that peak shaving with diesel fuel will occur for up to 10 years absent the Tacoma LNG project. Tacoma LNG would provide natural gas for gas turbine power generation at a peaker plant or for residential or commercial heating. In the no action alternative, there would be insufficient gas to run the turbines in addition to the heating demand and the peaker plant would need to be run on diesel fuel. Another use of LNG from Tacoma LNG is to supply the Gig Harbor LNG facility. Tacoma LNG displaces LNG trucked in from Canada and the primary difference is in transporting the LNG. The next application is using LNG to displace bunker fuel in TOTE marine vessels which involves using a small amount of pilot diesel fuel with LNG. In the no action alternative, the vessels would continue to be fueled with bunker fuel. Another marine application involves trucking LNG for bunkering. Since the delivery route for the displaced diesel is unknown, this application is comparable to other marine fuel use, except for transfer losses to fuel delivery truck. In the no action alternative the ships would continue to use petroleum-based fuel, delivered by truck or ship. Finally most of the LNG will be used in other unspecified marine applications which are

[3] Displacing MDO will have a small effect on MDO consumption. The classical consequential LCA approach is to assume that more MDO is available on the market and that the price of MDO drops in response to increased supply. The drop in price results in an increase in consumption elsewhere due to price induced demand. The effect the Tacoma LNG project on Washington MDO prices will be extremely small since it represents a very small fraction of the total fuel market. Ultimately, this assumption implies that crude oil to make MDO is not produced and that no additional demand for marine diesel fuel or other oil refinery products is induced elsewhere in the world.

essentially similar to the TOTE marine application. In the no action alternative bunker fuel or other marine fuels would continue to be used in these applications.

## 1.4 Effect of Tacoma LNG Project

The Tacoma LNG project will affect several energy use applications including marine diesel, on-road trucking, and natural gas peak shaving. Currently, marine diesel and on-road diesel fuel are produced in Washington oil refineries. Natural Gas from underground storage caverns or diesel fuel are used for peak shaving. Puget Sound Energy (PSE) forecasts that additional natural gas storage will be required to meet future wintertime peak demand; (PSE, 2018); stored LNG can be re-gasified and introduced to the pipeline to meet peak demand. The Tacoma LNG project will displace a significant portion of the fuels currently used for marine diesel and on-road diesel applications and increase natural gas for peak shaving capacity.

## 1.5 Greenhouse Gases and Climate Change

### 1.5.1 The Greenhouse Effect

The greenhouse effect is a natural process that results in warmer temperatures on the surface of the earth than that which would occur without it. The effect is due to concentrations of certain gases in the atmosphere that increase trapped heat as infrared radiation from the sun instead of reradiated back to outer space. The greenhouse effect is essential to the survival of most life on earth, by keeping some of the sun's warmth from reflecting back into space and sustaining temperatures that make the Earth livable. Man-made or anthropogenic GHG emissions are responsible for the majority of the increase in $CO_2$ and other GHGs in the atmosphere (IPCC, 2007; Myhre et al., 2013). The effect on global temperatures, climate, and weather is therefore a source of significant concern.

### 1.5.2 Greenhouse Gases

The gases emitted globally that contribute to the greenhouse effect are known as greenhouse gases (or GHGs). Primary GHGs include water vapor, carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), and other trace gases. Natural sources of GHGs include biological and geological sources such as plant and animal respiration, forest fires and volcanoes. However, industrial sources of GHGs are of concern because they also generate GHGs, adding to the natural concentrations. The GHGs of primary importance emitted by industrial sources are $CO_2$, $CH_4$, and $N_2O$. Because $CO_2$ is the most abundant of these gases, GHGs are usually quantified in terms of $CO_2$ equivalent ($CO_2e$), based on the relative longevity of the gas in the atmosphere and its related global warming potential (GWP).

#### *Global Warming Potential*

The analysis determines the GHG emissions from fuel combustion and fugitive emissions including $CO_2$, $CH_4$, and $N_2O$. These emissions also include fugitive LNG from facility operations and product transfer.

Greenhouse gases (GHGs) warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space; they act like a blanket insulating the Earth. Different GHGs can have different effects on the Earth's warming. Two key ways in which these gases differ from each other are their ability to absorb energy (their "radiative efficiency"), and how long they stay in the atmosphere (also known as their "lifetime")(US EPA, 2018).

The Global Warming Potential (GWP) allows for the weighted summation of greenhouse gases. Specifically, it is a measure of how much energy the emissions of 1 tonne of a gas will absorb over a given period of time, relative to the emissions of 1 tonne of carbon dioxide ($CO_2$). The larger the GWP, the more that a given gas warms the Earth compared to $CO_2$ over that time period. The 100 year time horizon for GWPs are the basis for weighting GHG emissions.

The GWP was introduced in the IPCC First Assessment Report, where it was also used to illustrate the difficulties in comparing components with differing physical properties using a single metric. The 100-year GWP (GWP100) was adopted by the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol and is now used widely as the default metric. Global Warming Potential (GWP) values have been updated in successive IPCC reports; the AR5 GWP100 values are different from those adopted for the Kyoto Protocol's First Commitment Period. The following table shows how the global warming potential of $CH_4$ has been increased by 17% and that of $N_2O$ has decreased by 11% from the 4$^{th}$ to the 5$^{th}$ Assessment Report (IPCC, 2007; Myhre et al., 2013).

**Table 1.1.** Global Warming Potential of GHG Pollutants

| IPCC Assessment | AR5 | AR4 |
|---|---|---|
| Time Horizon | 100 | 100 |
| $CO_2$ | 1 | 1 |
| $CH_4$ | 30 | 25 |
| $N_2O$ | 265 | 298 |

GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases. Factors that affect GWP are discussed in Appendix A.4.

The 100-year GWP is consistent with the time horizons for the Tacoma LNG project. The project will have a duration of about 40 years and the consequences of the emissions will remain in the atmosphere for the lifetime of the long-lived $CO_2$ emissions. The 100-year GWP is also consistent with the policy targets of the Paris Climate Agreement (United Nations/Framework Convention on Climate Change, 2015) which sets targets with the objective to “reduce aggregate greenhouse gas emission levels in 2025 and 2030” such that temperature increases of 2˚C or greater are avoided.

GHG emissions are weighted based on the 100-year GWP from the United Nations Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007), which is consistent with the State Environmental Policy Act (SEPA) guidelines and Washington GHG inventory protocols as well as other GHG policy initiatives (WA department of Commerce, 2018). The 100-year GWP is also consistent with the long-term goals of the Paris agreement. The effect of the GHG species is discussed in Appendix A.4.

### 1.5.3 Analysis Scope

The goal of the study is to provide the technical analysis in support of the Supplemental Environmental Impact Statement (SEIS) being prepared for the Puget Sound Clean Air Agency (PSCAA) under the Washington State Environmental Policy Act (SEPA). The PSCAA determined that although the Final Environmental Impact Statement prepared for the Project addressed GHG, it did not fully account for all GHG emissions, appeared to have incomplete data, and relied on SEPA guidance from the Washington Department of Ecology (WDOE), which has since been withdrawn.

The scope of this analysis is limited to addressing the life-cycle analysis of natural gas used to produce LNG including the extraction and transport of natural gas, construction of the facility and end use of the LNG as a fuel and regasification for peak shaving (proposed action). The scope also includes comparing the GHG emissions from the project to the life-cycle of the extraction and transportation of crude oil, production of marine diesel fuel, and use as a fuel (no-action). For use as a marine fuel the scope for estimating GHG emissions is one complete LNG fueling of a TOTE roll-on/roll-off vessel in transit from the Port of Tacoma to Alaska. The analysis includes the life cycle upstream emissions, fuel delivery, and end use. Construction emissions are included over the project life.

## 1.6 Life Cycle Assessment Background

The following provides background on life cycle analysis (LCA) for fuel applications. Since the effect of GHG emissions occurs over a long duration, the life cycle and total global emissions are considered the relevant metric.

LCA is a technique used to model the environmental impacts associated with a product, from "cradle to grave," or through its useful life. The product assessed can be anything manmade, from breakfast cereals to sneakers to drop in renewable jet fuel. LCA models assess environmental impacts upon a range of categories, including energy consumption, GHG emissions, criteria air pollution, eutrophication, acidification, water use, land use, and others. This is done by taking a full inventory of all the inputs and outputs involved in a product's life cycle. Environmental impacts may be generated whenever a material flow enters or exits the product system and affects the environment.

Most LCA models used for transportation fuels are spreadsheet-based and use a life cycle inventory (LCI) database to calculate the environmental impacts associated with the material flows and inputs to a fuel value chain. Additionally, LCA has been used to support fuel regulatory and/or legislative initiatives for renewable fuel targets, such as targets for GHG emission reductions. The phases of an LCA are outlined below and in Figure 1.4.

a) The goal and scope definition phase: during this phase the study objective is defined, the system boundaries are determined, and modeling approaches are decided upon.

b) The inventory analysis phase: during this phase, inventory data regarding the life cycle inputs and outputs is collected and analyzed.

c) The impact assessment phase: during this phase, life cycle inventory data and impacts results are scrutinized for further accuracy and insight. This often involves sensitivity analysis and can lead to additional data collection and inventory modeling.

d) The interpretation phase: during this phase, results are interpreted, summarized, and discussed. (ISO, 2006)

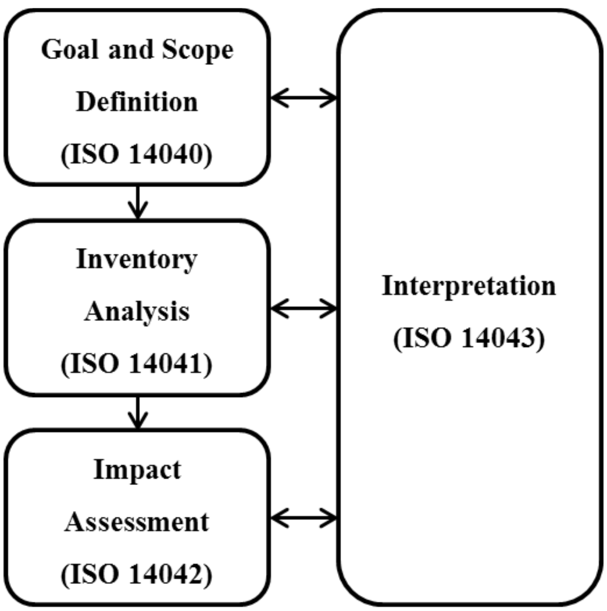


**Figure 1.3.** Process Framework for Life Cycle Assessment

Life cycle emissions are generally considered to cover the full life cycle from resource extraction to end use or the cradle to grave. Life cycle assessments are generally limited to construction and operation. However, the scope can also extend to facility decommissioning and indirect land use conversion (ILUC) effects. A preliminary calculation shows that life cycle decommissioning emissions will be less than 1 percent of the total emissions and therefore lower than the cutoff criteria defined for this analysis. Moreover, ILUC captures emissions associated with diverting crops from one use to another; because this project does not include land cover change from crops or significant vegetation, there are no ILUC emissions. An LCA includes the upstream life cycle emissions for inputs to a process. In most cases, these upstream life cycle emissions occur in the production of upstream inputs. For example, producing fuel used for electric power, an upstream component of LNG production, requires upstream WTT energy inputs.

Because finished fuels are used in recovery of feedstocks (e.g. diesel fuel is used to recover crude oil to produce diesel), determining life cycle emissions for all inputs requires an iterative analysis. Several LCA models perform these calculations for fuels and materials as shown in Table 1.2. All of the models include life cycle data for LNG production. Fuel LCA models provide upstream life cycle emissions for all of the energy inputs considered in this analysis, which consists of natural gas, electric power, diesel fuel, and marine fuel. The GREET and GHGenius models have the most regionally specific detail for the U.S. and Canada. These models also contain an upstream life cycle or WTT analysis for generic natural gas to LNG and are publicly available.

**Table 1.2.** Life Cycle Models and Databases

| Primary Author | Year | Organization | Location of Use | Scope of Products | Model/ Database | Citation |
|---|---|---|---|---|---|---|
| Wang | 2017<br>2013 | ANL | USA | Fuel Vehicles | GREET1<br>GREET2 | (ANL, 2017) |
| O'Conner | 2016 | (S&T)[2] | Canada | Fuels | GHGenius | ((S&T)2, 2013) |
| Delucchi | 1998 | UC Davis | USA | Fuels | LEM | (Delucchi, 2003) |
| JRC | 2011 | JRC | Europe | Fuels | JRC/ LBST Database | (JEC - Joint Research Centre-EUCAR-CONCAWE collaboration, 2014) |
| Neeft | 2012 | Intelligent Energy Europe | Europe | Fuels | BioGrace | (JRC, 2012) |
| ThinkStep | 2016 | ThinkStep | Global | All Materials | GaBi TS | (Thinkstep, 2017) |
| Wernet | 2013 | Swiss Centre for Life Cycle Inventories. | Global | All Materials | EcoInvent | (Weidema et al., 2013) |
| NREL | 2005 | NREL | USA | All Materials | USLCI Database | (NREL, 2012) |
| Skone | 2014 | NETL | USA | Fuels | Studies of NG and Coal | (Skone, 2012) |

Several LCA models and databases also include LCI data on materials of construction for LNG facilities and marine vessels. The GaBi TS, EcoInvent, and USLCI databases contain life cycle analysis results for materials such as steel and concrete, which are used in facility construction. The GREET2 model also calculates life cycle emissions for materials of construction used in vehicles. The GREET and GHGenius models provide the basis for the analysis because these models are publically available and include details for natural gas production, power generation, and petroleum production and refining that are readily modified. Generally, all of the LCA models described here produce the same life cycle GHG results with the same input assumptions.

The GREET and GHGenius models are publicly available and provide complete transparency to calculations. These models provide the basis for the upstream life cycle data in this analysis.

## 2. METHODS AND DATA

This analysis examines the GHG emissions from the Puget Sound Energy Liquefied Natural Gas (Tacoma LNG) facility on a life cycle basis. The life cycle emissions from the Tacoma LNG (including end use) are compared to displaced emissions (e.g., use of diesel fuel) on a life cycle basis. This section describes the system boundary for the analysis, approach for calculating life cycle emissions, scenarios considered in the analysis, and data sources. The discussion of the approach describes a summary of the activity in each step of the life cycle and calculation methods.

For Tacoma LNG, the life cycle analysis will calculate the energy inputs and emissions with each step of the Tacoma LNG process. Each energy input will include a direct and WTT fuel cycle component. The end use of emissions will then be calculated for the volume of fuel used in each LNG application. The life cycle emissions for the alterative use of LNG (No action alternative) are calculated. These emissions will include the direct emissions and upstream fuel cycle or WTT emission. The net difference between the Tacoma LNG project and alternative energy use are reported on an annual basis.

Emissions to be reviewed: for the LNG Project:

- Upstream:
  - Power generation for electricity used at the facility
  - Manufacturing of the materials used to construct the facility
  - Production, processing and transport of the natural gas used as a feedstock
  - Leaks of natural gas from the equipment used to transport, handle and process the natural gas
  - Upstream production, processing and transport of diesel fuel for emergency equipment
- Direct:
  - Combustion of natural gas and natural gas liquids at the facility in the revaporizer and flare
  - Leaks of natural gas and LNG from the equipment at the facility
  - Loading (bunkering) of LNG into TOTE vessels
  - Loading of LNG into trucks and barges
  - Truck transport of LNG
  - Vaporization of LNG for peak shaving
- End Use:
  - Use of LNG in Totem Ocean Trailer Express, Inc. (TOTE) Marine vessels
  - Use of LNG that is delivered by barge to other (non-TOTE[4]) marine vessels
  - Use of LNG that is delivered by truck to other marine vessels
  - Use of LNG in on-road trucks
  - Use of LNG for regasification and peak shaving for power production
  - Use of LNG trucked to Gig Harbor to displace LNG from Canada

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[4] LNG would be transferred by bunkering barges.

- Use of natural gas liquids that are trucked off site as a substitute for propane

For the no-action alternative (existing use of traditional fuels in marine vessels and trucks and use of diesel fuel for peak shaving of electric power) the emissions to be reviewed include:

- Upstream Life Cycle (WTT):
  - Production of crude oil for Washington and out of state oil refineries
  - Production, processing and transport of diesel and marine fuel
  - Production, processing and transport of LNG for Gig Harbor
  - Power generation for electricity used to load and transfer diesel and marine fuel
- Direct:
  - Direct emissions for the functional equivalent of fuel storage are included in the upstream step
- End Use:
  - Use of marine diesel fuel in TOTE Marine vessels
  - Use of marine diesel fuel for other (non-TOTE) marine vessels
  - Use of diesel in on-road trucks
  - Use of diesel to power fuel flexible turbines when natural gas customers are curtailed[5]
  - Trucking of LNG to Gig Harbor

The assumptions used to calculate GHG emissions for the Tacoma LNG project and the no action alternative activities include the following:

- Upstream Life cycle (WTT):
  - GREET model for power generation for electricity used at the facility
  - GHGenius and GREET data for the upstream production of natural gas.
  - CA ARB OPGEE model analysis of crude oil production
  - GREET model analysis of residual oil/bunker fuel, diesel, and gasoline
  - GREET2 model for manufacturing of metals used to construct the facility
- Direct and end use:
  - Fugitive emissions from MDO and Diesel fuel storage are negligible.
  - GREET emission factors for combustion of petroleum fuels
  - Emission data from the applicant
  - Combustion emission factors for LNG and natural gas based on fuel properties from PSE
  - Loading LNG into barges, trucks and TOTE vessels
  - Transporting LNG by truck
  - Energy consumption data for LNG and alternative equipment
  - Leakage rate from the applicant and literature sources

[5] Peak shaving for power production is expected to occur for 10 years. Afterwards the Tacoma LNG project will presumably sell LNG for additional marine fuel applications. This application with no peak shaving was not analyzed because it represents only 5% of annual LNG usage for a 500,000 gpd scenario.

## 2.1 System Boundary

Life cycle emissions include WTT (upstream), direct and end use emissions.

Life cycle GHG emissions are quantified for production of LNG and four different end uses:

a) In Totem Ocean Trailer Express, Inc. (TOTE) marine engines for cargo hauling between Tacoma and Anchorage;
b) Transfer to LNG bunkering barges which will fuel other marine engines;
c) Transfer to tanker trucks which will fuel heavy duty vehicles
d) Re-vaporize the LNG to the pipeline for power peak shaving
e) Truck LNG to Gig Harbor to displace a Canadian source of LNG.

WTT or Upstream emissions include natural gas feedstock extraction, processing and transmission as well as emissions associated with production of imported grid power. No Action WTT emissions include crude oil recovery, refining, transport and combustion in a marine engine.

Direct emissions from LNG production include fuel combustion (emergency generator, process heater and flaring) and fugitive emissions.

For the TOTE end use, the life cycle emissions include other end use emissions include also transfer to end use as either fuel or peak shaving and corresponding combustion emissions.

GHG emissions associated with construction activities and materials of construction are also included in the analysis for Tacoma LNG.

### *Definition of Functional Unit*

The functional unit provides the reference to which all other data in a life cycle assessment are normalized and is use as a reference unit. To define the analyzed system, it is necessary to start with a quantified description of the performance requirements that the product system fulfils. This quantified description is called the "functional unit" of the product system.

The functional unit for this analysis is the LNG produced and used in operation in one year of continuous operation. The life cycle emissions from the Tacoma LNG and displaced emissions are analyzed over this functional unit. The emissions and displaced emissions are also reported per tonne of LNG produced over a 40-year facility life. Current natural gas liquefaction plants are planned with a 30-year technical life time. An analysis about the possibility of extending the life of LNG assets, carried by DNG GL, showed that many existing plants have been running for more than 40 years. Based on this information we defined a lifetime of 40 years for the Tacoma LNG project (Tronskar, 2016).

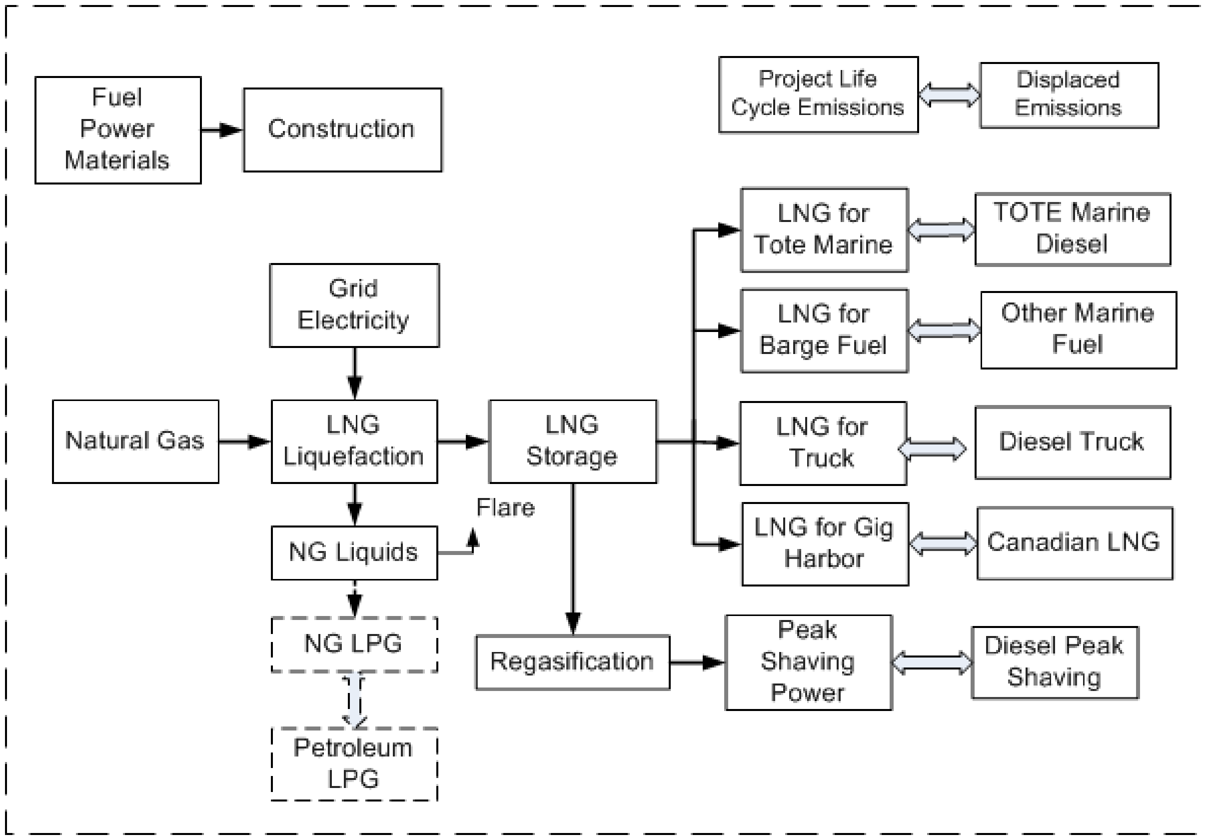


**Figure 2.1.** System Boundary Diagram for Tacoma LNG Life Cycle Analysis and No Action Alternative. WTT emissions are defined in Figure 2.2 and Figure 2.3. Double arrows represent effect of alternative activity. Use of LPG is not planned but treated as an option.

### *Functional Unit*

The functional unit for the analysis is the annual LNG produced in one year of continuous operation. The life cycle emissions from the Tacoma LNG and displaced emissions are analyzed over this functional unit. The emissions are also reported per 1000 gallons of LNG produced.

### *Operational Basis*

The analysis is based on the continuous operation of the facility to allow for a comparison with alternative sources of energy. GHG emissions are calculated on the expected operational basis (for example 500,000 gpd of LNG production will be produced for 355 days per year). The life cycle GHG emissions from the Tacoma LNG project are compared with diesel production where the life cycle emissions data are also on a continuous operation basis. Similarly, LNG used for peak shaving are is compared with conventional natural gas storage.

The analysis of GHG emissions for the Tacoma LNG includes emissions associated with feedstock production and transportation, the production of power, the direct emissions from the Tacoma LNG and the und use as peak shaving, truck, or marine diesel fuel.

The analysis is performed on a lifecycle basis. Upstream emissions include natural gas feedstock extraction, processing and transmission as well as imported grid power. Direct emissions from the Tacoma LNG include combustion emissions from construction activities, boilers, power generation, and fugitive emissions[6] associated with construction materials, fuel production and marine diesel are also counted. The same scope of emissions is applied to the displaced fuel.

The system boundary for Tacoma LNG fuel is shown in Figure 2.1.The displacement of fuel or other displacement effects is determined through an economic analysis.

The analysis determines the GHG emissions from fuel combustion and fugitive emissions including $CO_2$, $CH_4$, and $N_2O$. Other GHG emission sources include unburned and fugitive methane and nitrous oxide ($N_2O$) from fuel combustion. Combustion sources include boilers, fired heaters, power generation equipment and engines for transport. Feedstock is also converted to $CO_2$ in the fuel production process and these process emissions are also counted. As discussed in Section 1.5.2, $CO_2$ emissions correspond to fully oxidized fuel. These emissions also include fugitive fuel from storage tanks and product transfers as well as carbon monoxide and VOC emissions from fuel combustion. Other GHG emissions such as fluorocarbons are not a significant source of emissions from Tacoma LNG.

***Cut Off Criteria***

This LCA tracks GHG emissions based on life cycle models. Emissions that are less than 1% of the life cycle GHG emissions from the Tacoma LNG plus upstream and downstream are under the threshold of significance and not examined as emission categories (for example plant decommissioning). The 1% criterion reflects the variability in GHG estimate from life cycle analysis studies.

## 2.2 Activities and Approach to GHG Analysis

The GHG analysis encompasses the emissions associated with construction and operation of the Tacoma LNG Project construction, compared to the no action alternative in which TOTE, other marine vessel, trucking, and peak shaving operations would continue to operate using MDO and Diesel Fuel. The life cycle steps and map to the description of the activities for each step, emission factors, energy inputs, upstream emissions and life cycle results are shown in Table 2.1.

The activities in the life cycle and approach to GHG calculations is first discussed followed by a description of data and inputs for each step
The GHG analysis encompasses the emissions associated with Tacoma LNG construction and operation and the alternative to not construct the project, which would be the life cycle effect of not producing LNG and using conventional sources of diesel fuel for marine and transportation applications. The alternative case for the option would also include conventional

[6] Upstream life cycle emissions correspond to scope 2 and scope 3 emissions (Greenhouse Gas Protocol, 2013; World Resources Institute, 2004)

natural gas storage for peak shaving. The life cycle analysis of Tacoma LNG follows the steps outlined in Table 2.1. For each step, the emissions include direct plus upstream (WTT) emissions and end use emissions. The table shows the life cycle steps, a and the section of this report that contains the description of the activities for each step, emission factors, energy inputs, upstream WTT emissions, life cycle results.

**Table 2.1.** Life Cycle Steps

| Steps in Tacoma LNG LCA | Description |
|---|---|
| Construction | Construction equipment, materials of construction |
| Operational Emissions | |
| Tacoma LNG Upstream | Natural gas, electric power, diesel fuel production [a,b] |
| Tacoma LNG Direct | Boiler, plant operation |
| Tacoma LNG End Use | LNG fueled marine and truck operation<br>LNG vaporization for peak shaving and gas use |
| Displaced Emissions | |
| Alternative Upstream | Crude oil production<br>Natural gas production Marine diesel and diesel fuel refining, Electric Power |
| Alternative Direct Emission [7] | Diesel filling operations<br>Other Natural Gas peak shaving |
| Alternative End Use | Marine diesel and diesel fueled marine and truck operation<br>Stored NG gas use |

[a] GREET and GHGenius models include similar emission factors for direct combustion as described in Appendix C
[b] Small amounts of diesel for emergency equipment are used by the Tacoma LNG project which result in both direct and WTT emissions

The activities in the life cycle and approach to GHG calculations is first discussed followed by a description of data and inputs for each step.

### 2.2.1 Life Cycle Analysis

Life cycle emissions generally consist of direct and upstream life cycle emissions. Depending on the application, the direct emissions are referred to as end use, tank to wheel, or tank to wake phase. The direct emissions are also part of the life cycle of fuels such that the total upstream life cycle emissions for a process consist of the sum of direct and upstream life cycle emissions

[7] The Tacoma LNG project would displace current marine diesel operations, which are the no action or alternative case.

for all of the inputs to a process. Argonne National Laboratory's GREET (Argonne National Laboratory, 2009) model has been extensively used for quantification of life cycle emissions associated with fuels and other products. This analysis uses the GREET framework to calculate upstream life cycle emissions from cradle to gate (ANL, 2017). Cradle to gate emissions are also referred to as well to tank or upstream life cycle. The term upstream life cycle is used in this Study. Fuel life cycle emissions are referred to as cradle to grave or well to wheels (or wake). The end use for no action alternative is the same as that for Tacoma LNG fuel.

### *Upstream Life Cycle Data*

The upstream life cycle for an individual fuel such as natural gas includes direct and upstream life cycle emissions ($\mathbf{E}_u$). Upstream life cycle emissions include a variety of energy inputs and emissions including natural gas, petroleum fuels, and electric power. Emissions ($\mathbf{E}_i$) for each fuel used in the the lifecycle are calculated from the specific energy ($S_k$), direct emission factor ($\mathbf{EF}_k$), and upstream emissions for the step such that:

$$\mathbf{E}_i = \sum \left[ S_k \times (\mathbf{EF}_k + \mathbf{E}_{uk}) \right] \qquad (1)$$

Where:
$\mathbf{E}_i$ = Life Cycle Emissions for Fuel i in life cycle
$\mathbf{EF}_k$ = Direct Emission Factor for fuel k, for each type of equipment and fuel[8] )
$S_k$ = Specific Energy for each fuel k
$\mathbf{E}_{uk}$ = Upstream emissions for fuel k

This approach applies to upstream life cycle emissions as well as end use emissions and is used to generate the results in the GREET model.

Typically, GHG calculations are based on a specific energy basis[9]. For example, the term $S_i$ for natural gas use is represented in mmBtu/tonne of fuel in this Study. The emission factor (**EF**) depends upon the carbon content of fuel as well as $CH_4$ and $N_2O$ emissions for the type of equipment. For electric power and construction materials, the term EF is zero because they don't emit any GHGs once they used. Upstream emissions are calculated using the same principles as all other upstream emissions in this analysis, for example upstream emissions from production of diesel fuel. The terms **EF** and **E** represent a data array that includes $CO_2$, $CH_4$ and $N_2O$ emissions.

Upstream emissions ($\mathbf{E}_u$) depend on the energy inputs and emissions for each fuel or material and are calculated in the same manner as shown in Equation 1.

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[8] Upstream emissions for fuel i can include the use of fuel i, which requires handling the use of a fuel within its own fuel pathway.

[9] GREET inputs are typically in Btu/mmBtu. However, the calculations are the same for a functional unit of one tonne of fuel with the appropriate unit conversions. The nomenclature here assumes appropriate unit conversions.

### *Application of Upstream Data to GHG Analysis*

GHG emissions in this Study are calculated using the GREET and GHGenius model with inputs described in Section 2.4. A detailed discussion of the calculations and upstream life cycle approach is described in Appendix A.

In the case of Tacoma LNG, the upstream life cycle emissions are calculated based on the details presented in this analysis. For the no action alternative, the upstream emissions are based on the specific energy for fuel use.

### *Construction Emissions*

Construction activities consist of development of the Tacoma LNG site, construction of the fuel plant, storage tanks at the site. Construction activities include operation of earth moving equipment, cranes, trucks, pile drivers, compressors, pumps, and other equipment. Employee commute traffic and material transport also generates GHG emissions[10] and are included.

### *Upstream Natural Gas Production, Separation and Transport Emissions*

Natural gas produced in British Columbia will be the feedstock for the Tacoma LNG. The Energy Information Agency (EIA, 2018a) published the net flows of natural gas among U.S. states. Over 99% of the gas entering Washington comes from Canada.

A range of GHG emission estimates correspond to natural gas production based on the energy inputs for production as well as fugitive methane releases. The analysis examines the range of GHG estimates in the GREET model and scientific literature. Calculations are based on the GREET inputs for extraction, processing and transport with a sensitivity analysis based on a range in fugitive methane emissions.

GHG emissions from natural gas production are associated with well operation, separation of light hydrocarbons, transport, and fugitive emissions. The energy inputs for production are expressed as extraction efficiency in the GREET model. The GREET estimates for energy inputs for natural gas extraction, processing, and transmission will provide the primary estimate of upstream life cycle energy inputs for natural gas. The GREET model also includes estimates of fugitive $CO_2$ from gas processing as well as flared natural gas. The study calculations are based on the GREET inputs for extraction, processing and transport with a sensitivity analysis bases on a range in fugitive methane emissions.

Natural gas is transported by pipeline at pressure of about 800 psi. Natural gas fuel compressor engines compress and move gas along the pipeline network. The GREET model calculates energy inputs for transport based on a transport distance in Btu/ton-mi. The GREET model also calculates distribution fugitive emissions. Since the natural gas for the Tacoma LNG project is supplied directly by a transmission pipeline, the fugitive emissions associated with transmission

[10] It is unclear if employee transportation creates a new source of GHG emissions since the employees would be driving to work with or without construction of the Tacoma LNG. These emissions are calculated nonetheless.

lines will be attributed to Tacoma LNG emissions, but the local delivery or distribution portion will be estimated as zero.

Natural gas is primarily composed of methane ($CH_4$), with small amounts of light hydrocarbons ($C_2$ to $C_4$) and inert gases ($N_2$ and $CO_2$). The composition of the gas affects its carbon factor discussed in Appendix C. Releases of $CO_2$ from the amine separation system will occur at the Tacoma LNG facility, which lowers the amount of carbon species available to be condensed into LNG, making the carbon factor for LNG lower than that of pipeline natural gas. The bulk of the light hydrocarbons are separated to avoid condensation during pipeline transportation.

The total upstream life cycle emissions are calculated in the GREET model. Figure 2.2 shows the system boundary diagram for natural gas in the GREET model. The model calculates upstream life cycle emissions from natural gas pathways including LNG as well as fuel for applications such as power plants and oil refineries. The pathway for natural gas consists of extraction, processing, and transmission. The key inputs are energy inputs and fugitive emissions for each step. Energy inputs are represented as Btu of fuel used to process each million Btu of natural gas in each step. These include the GREET model default assumptions on extraction efficiency, processing efficiency, mix of process fuels, and flared gas per mmBtu of produced gas. This Study will focus on the range of fugitive methane emissions from these activities. Other data from natural gas production will also be examined.

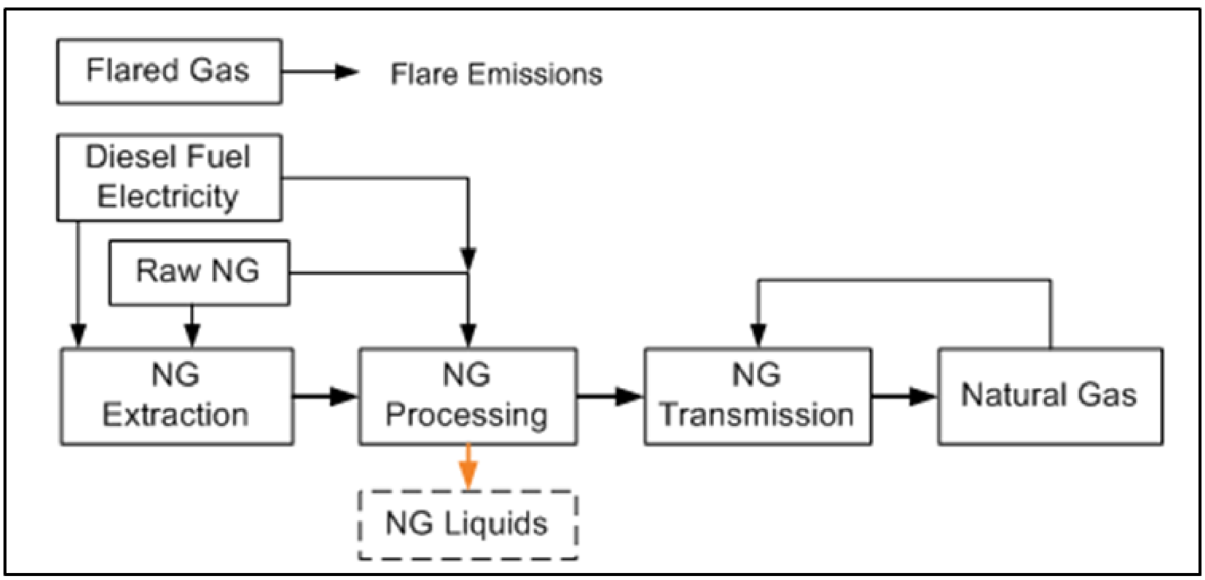


**Figure 2.2.** Natural Gas Production System Boundary Diagram

### *Power Generation and WTT Upstream Life Cycle Emissions*

Emissions from power generation include power plant combustion emissions from natural gas turbines and boilers as well as coal boilers. The life cycle emissions from power also include WTT upstream life cycle inputs for fuels and uranium for nuclear power plants. In Washington, average emissions per kWh are about half of the U.S. average, as most electricity is supplied with hydroelectric. However, the new electricity load from the Tacoma LNG project will not result in an expansion of power generation resources. Therefore generation resources such as hydroelectric, nuclear, and coal will not produce additional power to provide energy for the project.

The system boundary for electric power in Figure 2.3 includes the upstream life cycle activities of each fuel used to produce electricity, direct combustion of these fuels at the power plant, and losses through the transmission and distribution system. This analysis examines a range of power resource mixes due to the complexity of assessing the marginal impact of power generation. The effect of power generation mix were examined for the local Tacoma Power utility generation mix, Washington state average mix, Northwest eGRID[11] mix, and a marginal mix that excludes hydroelectric and nuclear power that complies with Washington's 15% renewable portfolio standard by 2040. The inputs to the GREET model are the resource mix with GREET model inputs for power generation efficiency and transmission loss, which are described in Appendix B.2.

[11] https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

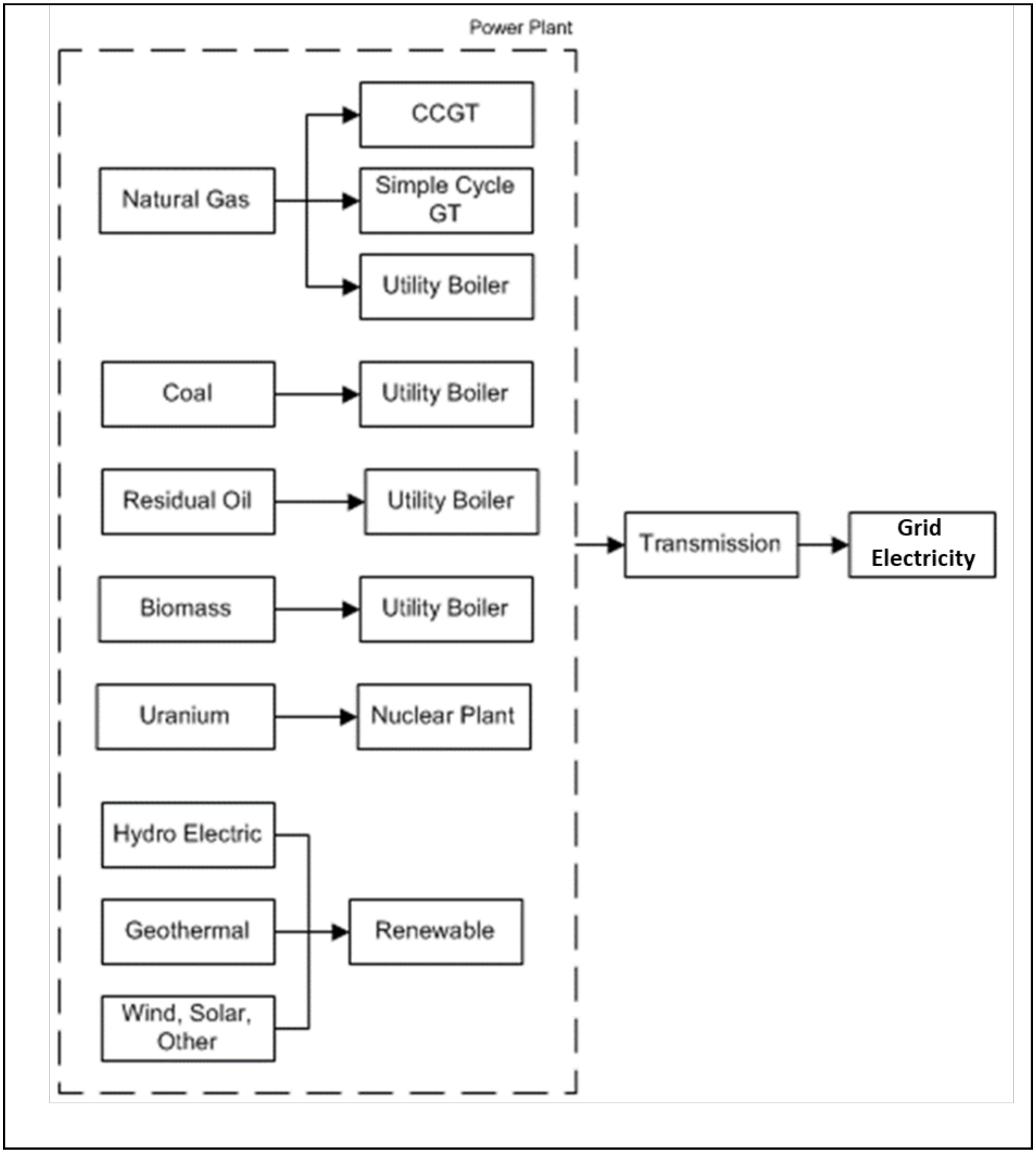


**Figure 2.3.** Electricity Production System Boundary Diagram

The GREET model calculates upstream emissions for the fuel and power generation phase. The emission factors are represented as power delivered to a generic customer which are representative of the emissions for power delivered to Tacoma LNG for grid electricity that includes a loss factor for transmission. The system boundary in the GREET model excludes materials of construction and decommissioning for fuel production and power generation equipment. Therefore, solar, wind, and hydroelectric power are treated with the GHG intensity of 0 g $CO_2e$/kWh.

### *Direct Emissions from LNG Facility Operation*

Direct operating emissions from Tacoma LNG will include the sources shown in Figure 2.4. The natural gas contains higher weight hydrocarbons (non-methane hydrocarbons) as well as small quantities of $CO_2$. The natural gas is separated into $CH_4$ and the before mentioned components. After processing within the LNG production system non-methane hydrocarbons are burned in a flare.

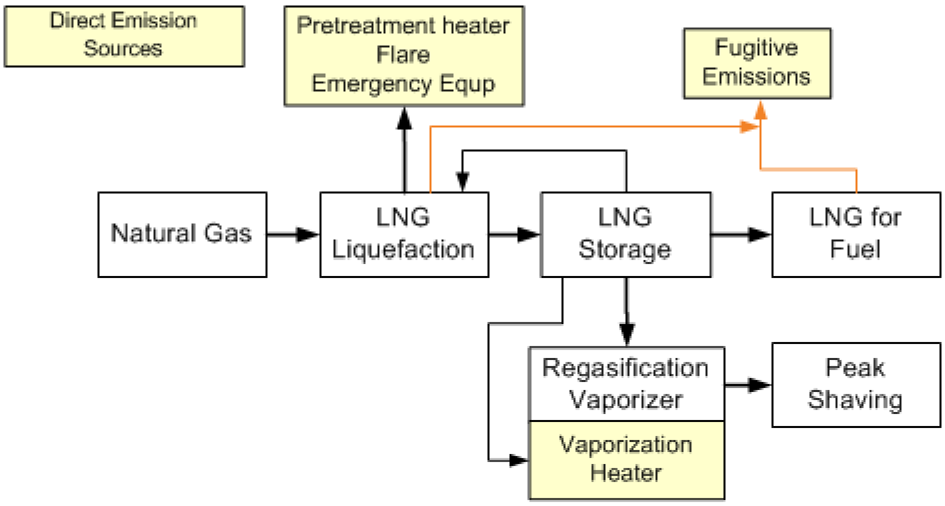


**Figure 2.4.** Direct Emissions Sources from Tacoma LNG.

In order to align the natural gas inputs with LNG production and to assure that overall $CO_2$ emissions are consistent with a mass balance, the components and carbon content of the input natural gas are compared with the products.

Net $CO_2$ emissions for the Tacoma LNG ($C_{PSE}$) are verified by carbon balance such that the carbon in each of the components balance. Net carbon emissions ($C_{PSE}$) are calculated such that:

$$C_{PSE} = C_{NG} - C_{LNG} \quad (2)$$

Where:

$C_{PSE}$ = Carbon emissions from Tacoma LNG
$C_{NG}$ = Carbon in natural gas feedstock
$C_{LNG}$ = Carbon in LNG

The carbon balance provides the best estimate of vent $CO_2$ and flared light hydrocarbons based on the gas composition. The carbon balance tracks the carbon in the natural gas feed and LNG product. For 1 million Btu of natural gas $C_{PSE}$ corresponds to the mass balance in Appendix D.

As shown in the example here, the carbon content of LNG decreases per mmBtu of fuel which results in net emissions. However, the lower carbon content will be reflected in the end use phase.

Natural gas also provides fuel for vaporization to re-gasify the LNG for peak shaving. Small portions of the process gas and natural gas are also combusted in the flare. Fugitive emissions occur from the LNG system and during LNG transfers for fuel use. Fugitive emissions primarily consist of methane and these GHG emissions are counted with the global warming potential (GWP) of methane.

### *End Use Applications*

The following end use applications would continue to operate in the no action alternative and LNG is not built.

Peak Shaving for Power Generation

PSE operates peak shaving gas turbines that provide electricity for the grid when demand is too high for base load electrical power. These gas turbine engines operate on natural gas but are also fuel flexible; so they can operate on diesel fuel when natural gas is not available. Under the no action alternative, PSE would operate the peak shaving units on diesel fuel until additional natural gas pipeline capacity is installed. For this analysis, the construction of new natural gas pipeline capacity was not analyzed because the GHG emissions would be relatively small compared to the emissions from the natural gas combustion.

The peak shaving is assumed to be only for power generation and not to be a substitute for natural gas storage for other applications. This peak shaving activity may be limited to 10 years and other uses for the LNG will presumably be found if peak shaving is not required. In the no action alternative, the quantity of diesel fuel corresponds to the same kWh of electric power that would be generated from the turbines operating on natural gas.

Gig Harbor LNG Supply

LNG trucked to Gig Harbor displaces LNG from Canada. The upstream emissions from LNG from Canada are assumed to be the same as those for Tacoma LNG.

On-Road Trucking

Without LNG fuel, on-road trucks would continue to operate on diesel fuel. LNG is one of the alternative fuel options for heavy-duty trucks. Other fuel such as biodiesel and renewable diesel will also be used in heavy-duty applications. However, the supply of these fuels is expected to be used in states with a low carbon fuel standard and not exceed 20% of the on-road diesel market. Therefore, any displacement of fuel would primarily be the diesel component as the use of biodiesel and renewable diesel is governed by fuel policies such as the renewable fuel standard. In the NAA case the quantity of diesel fuel corresponds to the same miles traveled on LNG.

Marine Propulsion

Without LNG fuel, marine engines would continue to operate on marine diesel or bunker fuel. Bunker fuel is essentially residual oil produced from oil refineries. Marine propulsion engines are compression ignition engines. Marine fuel is injected into the cylinder in a manner similar to a diesel engine. The efficiency of the engine would be similar to that of marine diesel. In the NAA case, the quantity of marine fuel that is displaced corresponds to the same distance traveled on LNG. The effect of removing sulfur from marine diesel and applying emission controls is examined in a sensitivity analysis.

LPG

The sale of light hydrocarbons for LPG or other fuel production is not planned. Propane and other light hydrocarbons will be flared. The use of non-methane hydrocarbons as a source of process heat and for LPG sales is examined in a sensitivity analysis.

### 2.2.2 Displaced Emissions (No Action Alternative)

The life cycle GHG emissions from Tacoma LNG are compared to the alternative of not completing the Tacoma LNG project. Table 2.2 shows the activities in the no action alternative (NAA) that would be displaced by Tacoma LNG. These include peak shaving with diesel fired gas turbines, on road heavy-duty diesel trucks, and bunker fuel for marine engines. The analysis assumes a 1:1 displacement of the end use of the fuels produced by the Tacoma LNG project.

**Table 2.2.** Activities and End Use Applications Displaced by Tacoma LNG

| Displaced Activity | Fuel | Equipment Type |
|---|---|---|
| Diesel Dual Fuel Peak Shaving | Diesel | Dual Fuel Gas Turbine |
| Gig harbor LNG Supply | LNG | Various LNG and LNG transport |
| On-road Trucking | Diesel | Diesel Truck |
| TOTE Marine | Bunker Fuel | Marine Engine |
| Truck-to-Ship Bunkering | Bunker Fuel | Marine Engine |
| Other Marine by Bunker Barge | Bunker Fuel | Marine Engine |
| LPG production | LPG | No activity planned |

The life cycle GHG emissions from the Tacoma LNG project are compared to the alternative of not constructing the facility. Displaced fuel is based on PSE’s projections of LNG end use applications.

The no action alternative energy uses include marine diesel and diesel fuel in marine and truck applications as well as for peak shaving operations. GHG emissions are calculated in the same manner as those for Tacoma LNG. The amount of diesel used for marine, trucking, or peak shaving applications are calculated based on the equivalent LNG use rate and the appropriate efficiency for each application. For diesel fuel combustion, the product of use rate and life cycle emission rates results in total emission $\mathbf{G}_{Alt}$ which calculated by:

$$\mathbf{G}_{Alt} = U_{PS} \times S_{DSP} \times (\mathbf{EF}_D + \mathbf{E}_D) + \Sigma[U_k \times (S_{De} \times \mathbf{E}_e + S_D \times (\mathbf{EF}_D + \mathbf{E}_D))] \quad (3)$$

Where:
$U_{PS}$ = Energy use rate for LNG peak shaving
$S_{DPS}$= Specific energy of diesel used in peak shaving operations (Btu/kWh)
$\mathbf{EF}_D$ = Emission factor for diesel in marine or truck engines or diesel peak shaving
$\mathbf{E}_D$ = WTT Upstream emission rate for bunker fuel or diesel fuel
$U_k$ = Energy use rate of LNG in each application
$S_{De}$ = Specific energy of electricity used for diesel storage and transfer[12]
$\mathbf{E}_e$ = WTT Upstream emission rate for electric power
$S_D$ = Specific energy of diesel fuel and marine diesel displacing LNG for each fuel application

The term $S_D$ is a key parameter that relates the energy used in diesel operations with those from LNG fuel use. Electric power is used for diesel distribution so the term $S_{De}$ for no action alternative activities is essentially zero.

The WTT upstream emission rates include the WTT upstream data for diesel and marine diesel production. A small portion of these WTT upstream emissions fall into the scope of distribution which is consistent with the activities of the Tacoma LNG project direct emissions

### *Upstream Life Cycle Emissions associated with the production of Petroleum Products*

Crude oil is produced and transported from a variety of resources and regions in the world. In some cases, crude oil production results in the production of associated gas and the cogeneration of electric power. Crude oil is transported to oil refineries and refined into a range of products shown in Figure 2.5. The export of electric power from cogeneration with oil production and the co-production of natural gas are treated by energy allocation within the GREET model data analysis. The allocation factor $X_{Cr}$ is dealt with as an external model input. The allocation between refined products is treated with a refining efficiency ($\eta$fuel)

GHG emissions from petroleum production depend on the crude oil type and the extraction method as well as oil refinery configuration with about a 10% range in life cycle emissions from different crude oil types (Gordon, Brandt, Bergerson, & Koomey, 2015; Keesom, Blieszner, & Unnasch, 2012). The life cycle analysis of petroleum production in the GREET model takes into account the upstream emissions for crude oil production as well as the energy intensity to refine different products. The GREET inputs for petroleum product refining are based on a linear programming analysis of U.S. refineries (Elgowainy et al., 2014). The analysis of refining emissions is oriented toward the production of gasoline and diesel fuel as show in Figure 2.5. Diesel fuel and residual oil are co-products to gasoline based on an overall allocation of emissions in the oil refinery.

[12] This small amount of energy provides the functional equivalence of the direct emissions from LNG production which serves also as fuel storage.

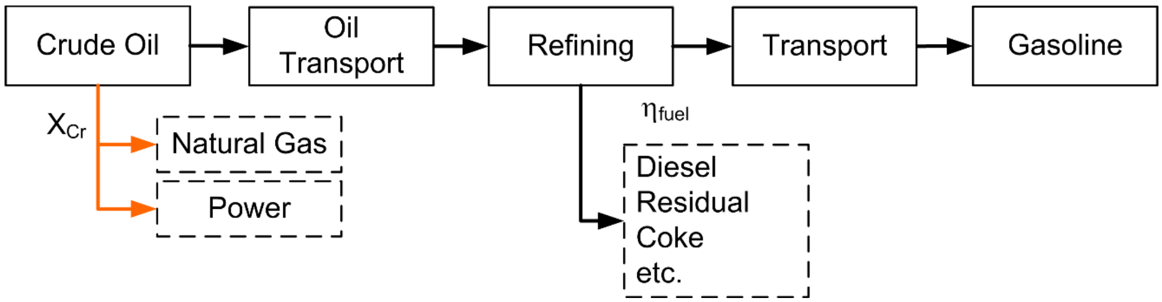


**Figure 2.5.** System Boundary Diagram for Petroleum Products.

The upstream data for refined petroleum products used for fuel transport are shown in Section 2.4.5.

### *Crude Oil Refining*

Five oil refineries operate in Washington State[13] with a combined refining capacity of over 230 million barrels per year. Although the state is a net exporter of refined product, gasoline and diesel are imported from Montana and Utah into eastern Washington. The most recent available pipeline transfer data[14] indicate that 6% of diesel consumed in Washington is refined in Montana and transported to Washington via the Yellowstone pipeline and 10% is refined in Utah and transported via the Tesoro pipeline. The balance (84% of diesel) is assumed to be refined in Washington State. The analysis assumes that all of the marine diesel consumed is refined in-state.

Petroleum refineries convert crude oil primarily into transportation fuels. The first step in refining is fractionation of the petroleum crude oil feed into major components: naphtha, distillate, gas oil, and residual oil. Subsequent steps convert these streams into lighter components or treat them to remove sulfur and nitrogen, improving octane or cetane, or make other changes to optimize refinery output. Crude oil refining is described in more detail in Appendix B.

Crude oil is processed from various locations around the world using various and production methods and transported to oil refineries by tanker ship, pipeline, or rail car. The energy intensity of oil refining depends upon its sulfur content and density (represented by API gravity). The energy inputs and emissions are described in Appendix B.

## 2.3 Key Parameters and Scenarios for GHG Impacts

The Tacoma LNG impacts GHG emissions through several direct and indirect effects. The factors that affect GHG emissions are discussed in the following section. Scenarios that evaluate a range of these factors are described below in Table 2.4. Scenarios that represent the best range of estimates of emissions are identified as Baseline, Lower, and Upper in this analysis.

[13] British Petroleum Cherry Point, Shell Oil Anacortes, Tesoro Anacortes, Phillips 66 Ferndale, and US Oil Tacoma.

[14] 2013 data provided by Hedia Adelman, Washington State Department of Ecology

### 2.3.1 Key Parameters Affecting Life Cycle GHG Emissions

Table 2.3 shows the key parameters that affect GHG emissions, variability in these parameters, and effect on net GHG emissions.

**Table 2.3.** Key Parameters Affecting Life Cycle GHG Emissions.

| Parameter | Effect on GHG Emissions |
|---|---|
| a. Tacoma LNG Energy Inputs | Total natural gas input per gallon of LNG affects direct emissions from Tacoma LNG. Upstream natural gas and imported electric power emissions are proportional to the use rates. Other emissions from $CO_2$ venting and light hydrocarbon flaring are based on mass balance. Non methane hydrocarbons from the liquefaction process are flared. |
| b. Loss factors | Fugitive emissions of fuel from storage and distribution requires the production of additional fuel to yield 1 gallon of LNG to the end user. The overall product loss is shown in Appendix A.3. |
| c. Natural Gas Upstream | Leak rates from extraction, processing, and transmission represent about half of the upstream emissions from natural gas, the other half are from operational energy use. Research into the assumptions used to estimate these emissions are on-going, and estimates vary depending on data sources. |
| d. Electric Power Generation | Electric power emissions depend on the generation mix. Several methods for assessing the generation mix were examined based on precedent with other government GHG analyses as well as constraints on the regional electricity grid. |
| e. End use fuel efficiency | The relative efficiency of LNG fueled equipment compared with the equipment used in the no action alternative determines the amount of petroleum fuel that is displaced. A range of fuel efficiency factors are assumed. A mix of end use applications is examined. |
| f. Market displacement | Displacing diesel and MDO will have an effect of petroleum fuel markets. In principal, providing additional supply will reduce the price and induce a small increase in demand. This effect is very small since the amount of petroleum fuel displaced is a small fraction of the global supply. |

The range of GHG emissions associated with the Tacoma LNG were examined via the scenarios shown in Table 2.4.

**Table 2.4.** Parameters for Sensitivity Analysis

| Parameter \ Scenario | Baseline | Lower | Upper |
|---|---|---|---|
| a. Tacoma LNG | PSE data for LNG facility operation | Use waste gas for pretreatment and LPG sales | PSE data for LNG facility operation |
| b. Loss Factor | PSE estimates for fugitive emissions from LNG transfers | | |
| c. Natural Gas Upstream | BC Gas from GHGenius | British Columbia Gas inventory sensitivity analysis | U.S. GREET |
| d. Electricity Mix | Washington State | Tacoma Power | eGRID NWPP Region sensitivity analysis |
| e. Energy economy ratio | 1.0 for marine<br>0.90 for trucking<br>1.0 for power | 1.015 for marine<br>0.90 for trucking<br>1.0 for power | 1.0 for marine<br>0.90 for trucking<br>1.0 for power |
| f. Economic effects | Assume 1:1 displacement of end use for each application. Price induced effects are assumed to be minor. | | |

## 2.4 Assumptions and Data Sources

Calculations of life cycle GHG emissions are based on the energy inputs and emissions factors and assumptions for each step in the fuel production process. The assumptions used to develop direct emissions from fuel production, and inputs to GREET modeling tools for the upstream and downstream emissions in the life cycle are described below. Since many of the data sources apply to both Tacoma LNG as well as displaced emissions, the data are organized by category rather than a linear path along the fuel life cycle.

### 2.4.1 Natural Gas Upstream

Natural gas provides a feedstock for the Tacoma LNG Facility. It is also an input to power generation and crude oil refining. The production of natural gas includes extraction at a gas well, processing to separate natural gas liquids, and transport to the Tacoma LNG Facility or other users of natural gas. The Tacoma LNG Facility will have a capacity to produce an average of 500,000 gpd of LNG.

The gas supply for Tacoma LNG Facility would come exclusively from British Columbia. No natural gas would be obtained from other regions for the Tacoma LNG Facility. British Columbia has adopted comprehensive drilling and production regulations that reduce methane emissions.

**Table 2.5.** Composition of natural gas used in Tacoma LNG Facility project

| NG Composition [a] | Mole Fraction |
|---|---|
| Methane | 0.913137 |
| Ethane | 0.060699 |
| Propane | 0.015437 |
| i-Butane | 0.002239 |
| n-Butane | 0.002415 |
| i-Pentane | 0.000476 |
| n-Pentane | 0.000341 |
| Hexanes, plus | 0.000299 |
| Nitrogen | 0.002717 |
| Carbon Dioxide | 0.002240 |
| Water | 0.000000 |
| Hydrogen Sulfide | 0.000000 |

*Source:* PSE

[a] Major species use to determine mass balance are shown here.
Trace levels of other components may also be present.

Historically, natural gas in the U.S. has been produced from conventional gas wells, but in recent years, there has been substantial growth in production from horizontal wells, which require additional hydraulic fracturing (EIA, 2018b; National Energy Technology Laboratory, 2014). Figure 2.6 shows the growth of natural gas production in the U.S. Conventional gas production has declined while shale gas and other tight gas resources that are recovered through hydraulic fracturing have grown significantly and are expected to result in a doubling of natural gas production by 2040. These natural gas resources are not representative of the production methods used in British Columbia as flaring is prohibited here. Nonetheless, natural gas production is projected to grow significantly and any additional demand from the Tacoma LNG project will represent a small impact on the total natural gas market.

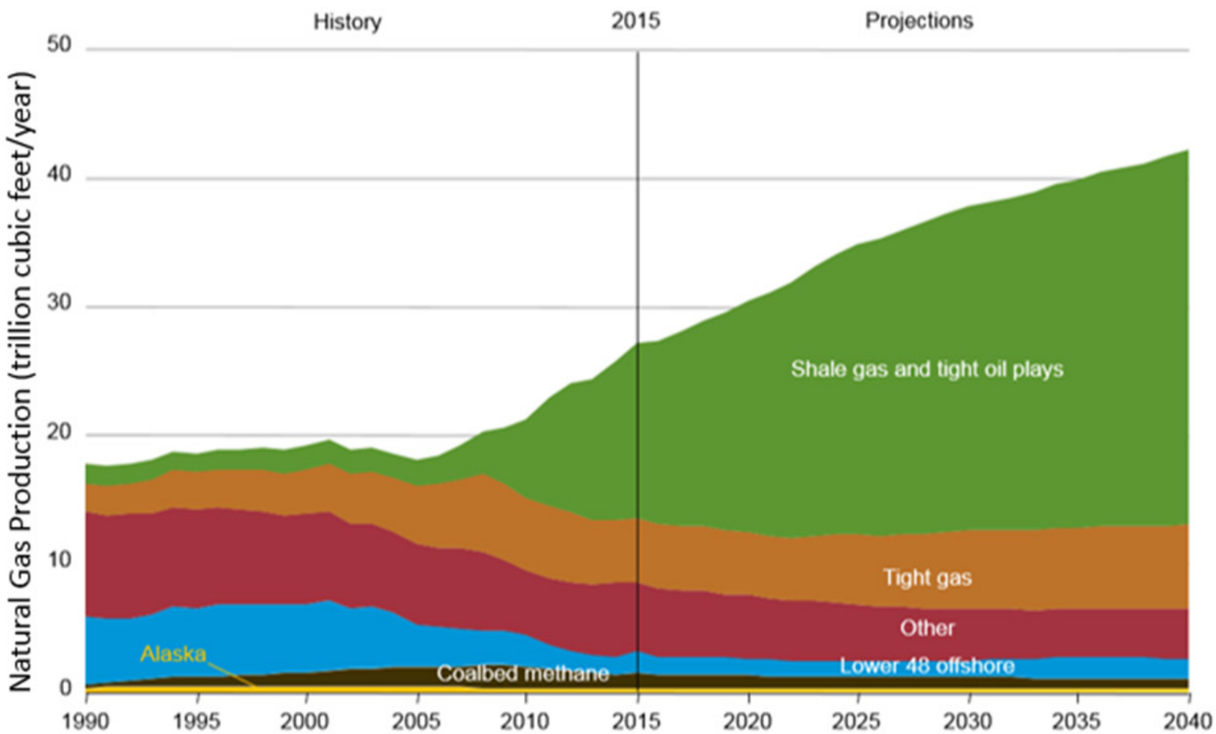


**Figure 2.6.** U.S. Dry Natural Gas Production by Source. Shale gas is expected to grow as a source of natural gas in the U.S.
*Source:* (U.S. Energy Information Administration, 2015) Figure MT-46 U.S. Dry natural gas production source in reference case

### *Natural Gas Production*

Natural gas is transported by pipeline that typically operates at pressures between 200 and 800 psi[15]. Natural gas fueled compressor engines compress and move gas along the pipeline network. Natural gas sold for residential and commercial use also requires distribution through a local network. Energy inputs for natural gas production provide the basis for estimating combustion emissions for the upstream component of natural gas in the GREET and GHGenius model.

## 2.4.2 LNG Plant Operation

Natural gas would enter the Tacoma LNG from a pipeline. The gas is first filtered and pressured before entering clean up systems.

### *Pretreatment*

The gas entering the Tacoma LNG Facility is composed primarily of methane, but will also contain ethane, propane, butane, and small quantities of pentanes and hexanes as well as nitrogen, $CO_2$, sulfur compounds ($H_2S$ and odorants) and low levels of trace contaminants.

[15] http://naturalgas.org/naturalgas/transport/

An Amine Pretreatment System will be designed to treat up to 26 million standard cubic feet per day (MMscfd) of inlet gas with a 2 percent $CO_2$ concentration, which is higher than the composition of pipeline gas. $CO_2$ emissions correspond to the difference between the $CO_2$ in the gas and $CO_2$ in the LNG. A natural gas fired Water Propylene Glycol (WPG) heater will provide the energy source. The "rich" aqueous amine solution would then be heated in a regenerator to remove the $CO_2$ and $H_2S$, resulting in a "lean" amine solution that would be reused in the process. The exhaust from the amine regenerator would be routed to the enclosed ground flare which would oxidize $H_2S$.

### *Hydrocarbon Removal*

Prior to liquefaction of the natural gas, hydrocarbons that may freeze at the cryogenic temperatures encountered downstream would be removed by partial refrigeration. The composition of the hydrocarbons corresponds to the difference between the hydrocarbons in the natural gas feed and the LNG product. There are no plans to capture the hydrocarbons as fuel for pretreatment or sale as liquefied propane gas (LPG). The proposed project would burn the hydrocarbons in a flare. These hydrocarbons could also be used on-site or transported to appropriate markets. $C_3$ and $C_4$ hydrocarbons are a feedstock for LPG or as chemical feedstocks.

### *Liquefaction*

After the hydrocarbon removal process, the natural gas would be mixed with compressed boil-off gas (BOG) and condensed to a liquid by cooling the gas to approximately negative 260 degrees Fahrenheit (°F). Compressor seal leakage would be captured and sent to the enclosed ground flare. Liquefaction is expected to typically occur during 355 days out of the years. Up to 10 days per year, the Tacoma LNG Facility is expected to operate in a holding mode while LNG is vaporized. Liquefaction will not occur at the same time as vaporization.

**Table 2.6.** Operational Hours of LNG plant processes

| Overall Operational Hours | hours/year | days/year |
|---|---|---|
| LNG Liquefaction Plant | 8,520 | 355 |
| LNG Pretreatment | 8,520 | 355 |
| LNG Flaring | 8,760 | 365 |
| LNG Vaporizer | 240 | 10.0 |
| Emergency Diesel Generator | 500 | 20.8 |

### *LNG Storage*

The facility will include an 8 million gallon LNG storage tank. LNG is stored at 3 psi above ambient pressure and will have a temperature of negative 260°F. The tank is insulated to minimize heat leakage. As heat enters the tank, LNG warms and some of the liquid boils off into the vapor space. The phase change cools the remaining liquid and the boil off gas (BOG) is collected in BOG recovery system to maintain a low pressure in the tank (less than 3 psi gauge).

### 2.4.3 Electric Power Generation

Tacoma LNG will consume 1.35 kWh/gallon of LNG of grid power to meet its electricity requirements based on information provided by the applicant.

GHG emissions are calculated with the GREET(ANL, 2015) model upstream emission factors using the resource mixes described in this section[16]. This section presents several generation resource mixes in order to assess the effect of electric power generation.

The electric power generation mix affects the GHG emissions associated with purchased power. Power will be delivered through Tacoma Power. Due to the changing nature of the regional power grid several scenarios for power generation are examined in this analysis. These include:

- Washington State average mix
- Tacoma Power average mix
- eGRID NWPP mix
- Marginal Washington mix

### 2.4.4 LNG Product Delivery

LNG would be pumped out from the Tacoma LNG facility's storage tank for either (a) vaporization and reintroduction into the local distribution system, or (b) transfer to the Gig harbor LNG facility, use as marine vessel fuel or on-road truck fuel. LNG would be removed from the storage tank by way of submerged motor in-tank pumps. The submerged motor LNG pumps would be contained within the enclosed LNG tank and therefore are not a source of fugitive emissions.

***LNG Vaporization***

The LNG vaporization system would produce natural gas for customers connected to PSE's existing distribution system during peak demand periods. PSE indicates that the peak shaving will occur to meet natural gas demand for power generation. LNG vaporization will consume 0.045 kWh/gallon of LNG of grid power to meet its electricity needs.

***Marine Vessel Fuel Bunkering and Delivery***

The LNG would be conveyed via cryogenic pipeline to the TOTE Marine Vessel LNG Fueling System. Marine vessels would be bunkered with LNG for fuel using a dedicated marine bunkering arm equipped with a vapor return line. Swivel joints that would be swept with nitrogen to prevent ingress of moisture that could freeze and impede arm movement. When connected to the receiving vessel, the LNG bunkering arm and connected piping would be purged with nitrogen, which would be routed to the enclosed ground flare. Once purged, LNG would be bunkered onto the receiving vessel at a maximum design rate of 2,640 gallons per minute. Once bunkering is complete, the liquid in the bunkering arm and in the adjacent piping

[16] The 2016 EIS examines an imported power with a direct GHG emission factor from eGRID2012 these values include power plant emissions only and is therefore not a life cycle GHG estimate.

would be drained back to the LNG storage tank. After draining, the arm and connected piping would be purged with nitrogen again. The nitrogen purge would be routed to the enclosed ground flare and the arm and piping depressurized prior to disconnection.

LNG may also be supplied to bunker vessels for subsequent transfer to ships. In this process, the bunker vessel would load LNG via the Marine Vessel LNG Fueling System. The bunker vessel would then transit to the LNG-fueled marine vessel, anchor alongside the vessel, and conduct a ship-to-ship transfer of the LNG.

Table 2.7 summarizes the methane loss rates estimates by PSE combined with a review on LNG transfer operations in Appendix A.2. Note that a small portion of LNG production may be transferred to on-road LNG tanker trucks and then bunkered directly into vessels from the LNG tanker trucks. Emissions from this process are assumed to be similar to a Ship-to-Ship transfer where no vapor recovery system is employed.

**Table 2.7.** Methane Loss Rates from LNG Transfer Operations[17]

**Bunker Barge Loading**

| Vapor Displaced | Recovery Rate | Loss per Bunkering Event | Volume per Bunkering Event (gallons) | Loss per Bunkering Event (gallons) | $CH_4$ Emissions (g/mmBtu) |
|---|---|---|---|---|---|
| 0.22% | 95% | 0.011% | 380,994 | 41.9 | 2.4 |

**Bunker Vessel Storage**

| Boil off rate (%/day) | Recovery Rate | Loss per Bunkering Event | Volume per Bunkering Event (gallons) | Loss per Bunkering Event (gallons) | $CH_4$ Emissions (g/mmBtu) |
|---|---|---|---|---|---|
| 0.15% | 95% | 0.0300% | 380,952 | 114 | 6.4 |

**Truck/Ship-to-Ship Transfer**

| Vapor Displaced | Recovery Rate | Loss per Bunkering Event | Volume per Bunkering Event (gallons) | Loss per Bunkering Event (gallons) | $CH_4$ Emissions (g/mmBtu) |
|---|---|---|---|---|---|
| 0.22% | 0.00% | 0.22% | 380,838 | 838 | 47.0 |

[17] (Corbett, Thomson, & Winebrake, 2015)

#### *Truck Loading*

Two loading bays at the Tacoma LNG Facility will have the capacity to load LNG to 10,000-gallon capacity tanker trucks. Each truck bay would have a liquid supply and vapor return hose. After truck loading, the liquid hose would be drained to a common, closed truck station sump connected to the Tacoma LNG Facility vapor handling system where it would be allowed to boil off and be re-liquefied or sent to the pipeline. Nitrogen would be used to purge the hoses and facilitate liquid draining and would then be routed to the enclosed ground flare.

#### *Enclosed Ground Flare*

A flare will burn the light hydrocarbons that are removed from the natural gas. These hydrocarbons correspond to the difference in the natural gas and product LNG.

#### *Fugitives from Equipment Leaks*

Fugitive methane emissions can occur from leaks in valves, pump seals, flanges, connectors, and compressor seals. Estimates of component leaks are shown in Appendix A.3

#### *Emergency Generator*

A 1,500 kW ultra-low sulfur diesel-fired emergency generator will be used for back-up power to maintain critical systems in the event of power loss. Under normal operating conditions this generator would only be used once per month for up to 2 hours for readiness testing. Emissions have been conservatively estimated based on 500 hours per year of operation, but this greatly overstates anticipated levels of operation.

### 2.4.5 LNG Consumption

LNG produced by the Tacoma LNG Facility will be used in one of the following ways: peak shaving, supply the Gig Harbor LNG facility, on-road trucking fuel and marine vessel fuel.

The following end use mix is assumed as input, based on an annual operation of 355 days of the Tacoma liquefaction facility:

**Table 2-8.** LNG end use mix of Tacoma LNG facility, 500,000 gpd production

| LNG Production | End use share | Gallons/ day (gpd) | lb/day | Mgal/ year | tonne/ year |
|---|---|---|---|---|---|
| **Total** | **100.00%** | **500,000** | **1,814,384** | **177.50** | **292,165** |
| On-site Peak Shaving | 5.48% | 27,397 | 99,418 | 9.73 | 16,009 |
| Gig Harbor Peak Shaving | 1.00% | 5,000 | 18,144 | 1.78 | 2,922 |
| On-road Trucking | 2.00% | 10,000 | 36,288 | 3.55 | 5,843 |
| TOTE Marine | 21.37% | 106,849 | 387,732 | 37.93 | 62,435 |
| Truck-to-Ship Bunkering | 1.00% | 5,000 | 18,144 | 1.78 | 2,922 |
| Other Marine (by Bunker Barge) | 69.15% | 345,753 | 1,254,659 | 122.74 | 202,034 |

***On-site Peak Shaving***

The Tacoma LNG Facility would provide LNG for peak shaving natural gas to the pipeline system. The applicant indicates that its obligations to customers would results in the operation of diesel fired power generation during periods of natural gas shortages. Therefore, natural gas used for peak shaving would enable natural gas fired power generation.

In the absence of the Tacoma LNG Facility, during peak periods PSE would have to use gas to supply gas residential customers and thus would be required to operate "peaker" dual-fuel combustion electric generating units utilizing fuel oil rather than using natural gas.

PSE owns nine natural gas-fired plants, all in Washington State. One of these plants is Frederickson 1 Generating Station, located southeast of Tacoma, near Frederickson, Pierce County and has a capacity of 249 MW. Reviewing the data sheets of all PSE natural gas power plants, it seems that is the only one, which can boost its output by supplemental duct-firing generation using fuel oil to 275 MW. This plant is used as dual-fuel "peaker"in this analysis. [18]

***Gig Harbor LNG***

Tacoma LNG will also be trucked to the Gig Harbor LNG facility. Gig harbor currently receives LNG by truck from Fortis BC in Delta, British Columbia. The transport distance from Fortis is 175 miles compared with 17 miles from Tacoma LNG. Trucking LNG from Tacoma will result in a shorter transport distance. The gas will be transported a slightly longer distance from BC but the additional transport distance was assumed to be covered in the upstream life cycle of natural gas delivered from British Columbia.

This analysis assumes that the Fortis BC liquefaction facility has similar GHG emissions rates as the proposed facility. The primary differentiators between Tacoma LNG no action alternative is the tanker truck transport distance of the LNG assuming that the Fortis facility also flares the light hydrocarbon components.

***On-Road Trucking***

A small portion of the annual LNG production at the facility may be supplied for use in on-road heavy-duty trucks. Based on GREET 2017 default assumptions, the natural gas combination tractor has a 10% efficiency penalty relative to the diesel tractor. This input is represented as and energy economy ratio of 0.9 such that the diesel tractor consumes 90% of the Btus as the LNG tractor.

[18] PSE, "Frederickson Generating Stations Ensuring reliable electric service" (15. July 2018). Retrieved from https://pse.com/aboutpse/PseNewsroom/MediaKit/067_Frederickson.pdf

### *TOTE Marine Vessel Fuel*

One of the primary purposes of the Tacoma LNG Facility would be to supply the TOTE Marine Vessel LNG Fueling System. PSE analyzed the load factors for marine vessel operation which affect the methane emissions from these engines. The analysis relies primarily on emissions factors and methodologies employed in the Puget Sound Maritime Air Emissions Inventory (Emissions Inventory), developed by the Puget Sound Maritime Air Forum. [19]

The marine engines are dual-fuel LNG engines rely on a small amount of fuel oil injected to act as a "pilot" to initiate combustion in the engine cylinder. This pilot fuel is typically injected at rates of approximately 1 to 5% of the total fuel rate, with the balance of the fuel being LNG. The pilot fuel contributes to the emissions of the vessel and these contributions are reflected in the emissions factors reported in the studies referenced above. Three percent pilot fuel was assumed in this analysis. The relative energy efficiency for marine diesels operation was assumed to be 1:1 on a lower heating value basis.

Table 2.9 summarizes the assumed route details for the TOTE vessel. These route details are based on direct travel from the Port of Tacoma to the Port of Anchorage. The EER for marine diesel relative to LNG and fuel use determines the GHG emissions.

**Table 2.9**. Route Assumptions for TOTE Vessel Emissions Modeling

| Ship Type | Origin | Distance at Sea | Transit Speed | Transit Time | Maneu -vering Time | Time at Berth (Origin) | Time at Berth (Destination) | Transit | Maneu -vering | Hoteling |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (nm) | (knots) | (hours) | (hours) | (hours) | (hours) | (within 200 nm) | | |
| RoRo | Anchorag | 1450 | 22 | 65.9 | 2 | 10 | 10 | 14% | 50% | 50% |

### *Truck-to-Ship Bunkering*

The Tacoma LNG Facility would also be able to load tanker trucks for delivering LNG directly to marine vessels for use as marine vessel fuel. It was assumed that these vessels would receive fuel by truck in the no action alternative.

### *Other Marine Vessel Fuel*

The Tacoma LNG will also provide fuel for other marine vessel fueling. The fuel will be transferred to bunkering barges and then loaded onto the marine vessels.

### *Truck Loading*

The Tacoma LNG Facility would have the capacity to load LNG to 10,000-gallon capacity tanker trucks. The loading bays would be designed to fill a tanker truck at a rate of 300 gallons per minute. LNG in the transfer hoses would be trained and the hoses would be purged with nitrogen and the trapped vapors would then be routed to the enclosed ground flare.

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[19] Puget Sound Maritime Emissions Inventory, 2016. Available at: https://pugetsoundmaritimeairforum.org/2016-puget-sound-maritime-air-emissions-inventory/

### 2.4.6 Construction Inputs and Materials

#### *Construction Direct Equipment Emissions*

Construction equipment emissions correspond to the fuel use combined with emission factors for diesel and gasoline during the construction time of about three and a half years. Another portion of construction emissions consists of vehicle trips (workers and heavy-duty trucks).

For construction equipment, the analysis consists of listing the equipment type, count, number of months used, horsepower, load factor, utilization factor and emission factors (grams per horsepower per hour [g/hp-hr]). The emission factors are from the United States Environmental Protection Agency NONROAD model and are specific to Washington State. For GHGs, the fuel consumption is also provided. The assumed average time of operation during the construction is 48 hours per week; 4.28 weeks per month, resulting in 205.4 hours per month.

The other portion of construction emissions consists of vehicle trips (workers and heavy-duty trucks). For these calculations, the winter and summer vehicle miles travelled (VMT) by workers and trucks were quantified for 2015–2018 and combined with emission factors from MOVES (g/minute). The IPCC 4th assessment report (AR4) GWPs were used to calculate $CO_2e$. Workers were assumed to drive exclusively passenger cars.

**Table 2.10.** Estimated trip to and from construction site

| | | |
|---|---|---|
| Cars VMT round trip | 40 | mi/day |
| Truck VMT round trip | 100 | mi/day |

| Summary VMTs | | Car VMT/ month | Truck VMT/ month |
|---|---|---|---|
| 1.Year | Winter | 0 | 38 |
| | Summer | 0 | 1,225 |
| 2.Year | Winter | 309,120 | 9,999 |
| | Summer | 309,120 | 5,789 |
| 3.Year | Winter | 302,400 | 6,356 |
| | Summer | 614,880 | 4,160 |
| 4.Year | Winter | 0 | 457 |
| | Summer | 0 | 306 |
| **Total** | | **1,535,520** | **28,330** |

#### *Construction Materials*

Materials of construction for the Tacoma LNG Facility include steel and other metals, asphalt, and concrete. PSE estimated the weight of materials based on the facility design as shown in Table 2.11. Concrete was divided between the aggregate and Portland cement components.

**Table 2.11.** Weight of Construction Materials

| Input | Metric Tonnes |
|---|---|
| Steel | 4,745 |
| Rebar | 1,666 |
| Stainless Steel | 290.0 |
| Copper | 26 |
| Asphalt | 7,570 |
| Aggregate | 80,110 |
| Cement | 1,716 |

*Source:* Response Tacoma LNG Supplementary SEIS Questions, July 07, 2018.

The total power consumption during construction is 10.51 GWh based on information supplied by PSE[20].

### 2.4.7 Petroleum Upstream Emissions

Natural gas, residual oil used for bunker fuel, and diesel fuel provide energy inputs to the life cycle of fuel from Tacoma LNG or alternative sources of fuel. GREET estimates the emissions from crude oil to a variety of refined products based on the complexity of the oil refineries in different regions of the U.S. Among other parameters the GHG emissions from a refinery are directly related to the density of crude oils measured in API gravity. Crude oils that are light (higher degrees of API gravity or lower density) tend to require less intensive processing which results in lower GHG emissions. Data affecting Washington-specific inputs for crude oil sources are shown in Appendix B.3.

[20] Source: Response Tacoma LNG Supplementary SEIS Questions, July 7, 2018, page 5.

# 3. Tacoma LNG Project Emissions

Tacoma LNG Project emissions are grouped according to construction, operational, and downstream emissions. Direct emissions include fuel combustion and fugitive emissions. Upstream emissions include the upstream WTT emissions for natural gas feedstock, electric power, diesel and other fuels as well as those associated with materials of construction. Downstream emissions include end use emissions from use of LNG as marine vessel fuel, on-road diesel, or natural gas peak shaving for power generation. A small amount of LNG will also replace an LNG source from Canada.

## 3.1 Construction Emissions

Construction emissions include the combustion of fuel used to operate construction equipment. Upstream emissions consist of electric power for construction as well as the upstream WTT emissions for diesel fuel. Construction emissions are estimated to be the same for the scenarios examined in this analysis because the capacity of key pieces of equipment such as the LNG storage tank as well as peak shaving heaters would not change with the different volume scenarios.

GHG emissions were calculated for the following:

- Construction equipment fuel use
- Construction equipment power
- Material delivery
- Material manufacturing for Tacoma LNG facility

### 3.1.1 Direct Construction Emissions

Direct emissions from construction correspond to the fuel combusted from cranes, dozers, compressors, and other construction equipment. Table 3.1 shows the direct emissions from construction. These correspond to the fuel use from Appendix A.1 combined with combustion emission factors for diesel fuel from Appendix C. Construction emissions occur over 3.5 years and the average annual construction emissions are calculated over a 40 year project life.

**Table 3.1.** Direct Emissions from Energy Inputs for Construction for Years 1 through 4

| **Equipment (Direct)** | **$CO_2$** (tonne/ year) | **$CH_4$** (tonne/ year) | **$N_2O$** (tonne/ year) | **$CO_2e$** (tonne/ year) |
|---|---|---|---|---|
| 1. Year - Construction Equipment | 1,703 | 0.018 | 0.012 | 1,707 |
| 1. Year - Road Vehicles/Commuting | 3 | 0.000 | 0.000 | 3 |
| 1. Year - Fugitive Dust | | | | 0 |
| 1. Year - Total Emissions | 1,706 | 0.018 | 0.012 | 1,710 |
| | | | | |
| 2. Year - Construction Equipment | 3,417 | 0.049 | 0.030 | 3,427 |
| 2. Year - Road Vehicles/Commuting | 227 | 0.002 | 0.001 | 227 |
| 2. Year - Fugitive Dust | | | | 0 |
| 2. Year - Total Emissions | 3,643 | 0.051 | 0.030 | 3,654 |
| | | | | |
| 3. Year - Construction Equipment | 62 | 0.023 | 0.014 | 67 |
| 3. Year - Road Vehicles/Commuting | 307 | 0.003 | 0.001 | 308 |
| 3. Year - Fugitive Dust | | | | 0 |
| 3. Year - Total Emissions | 369 | 0.026 | 0.015 | 374 |
| | | | | |
| 4. Year - Construction Equipment | 1,545 | 0.028 | 0.017 | 1,550 |
| 4. Year - Road Vehicles/Commuting | 2 | 0.000 | 0.000 | 2 |
| 4. Year - Fugitive Dust | | | | 0 |
| 4. Year - Total Emissions | 1,546 | 0.028 | 0.017 | 1,552 |
| **Project Total:** | **7,265** | **0.123** | **0.074** | **7,289** |

### 3.1.2 Upstream Construction

Upstream emissions for construction activity include the production of diesel and gasoline for construction equipment, as well as the generation of power. Upstream emissions also includes the manufacturing of materials.

Upstream emissions for construction energy inputs correspond to the total energy inputs multiplied by the upstream emission factor from GREET. The Washington State electricity mix is applied to power during the construction phase as this a conservative approach (i.e., it is the mix with the highest GHG emissions) identified by State Energy Office at the Washington Department of Commerce 2017 guidelines[21]. Upstream construction emissions associated with energy inputs from Appendix A.1 are also shown in Table 3.2.

[21] A range of power generation options is examined for LNG operation in the sensitivity analysis in Section 5.

**Table 3.2.** Upstream construction emissions

| Equipment (Upstream) | $CO_2$ (tonne/ year) | $CH_4$ (tonne/ year) | $N_2O$ (tonne/ year) | $CO_2e$ (tonne/ year) |
|---|---|---|---|---|
| 1. Year - Construction Equipment | 104 | 0.1 | 0.00 | 107 |
| 1. Year - Road Vehicles/Commuting | 1 | 0.0 | 0.00 | 1 |
| 1. Year - Fugitive Dust | | | | 0 |
| 1. Year - Total Emissions | 105 | 0.1 | 0.00 | 108 |
| 2. Year - Construction Equipment | 221 | 0.2 | 0.00 | 228 |
| 2. Year - Road Vehicles/Commuting | 72 | 0.0 | 0.00 | 72 |
| 2. Year - Fugitive Dust | | | | 0 |
| 2. Year - Total Emissions | 293 | 0.2 | 0.00 | 299 |
| 3. Year - Construction Equipment | 189 | 0.2 | 0.00 | 195 |
| 3. Year - Road Vehicles/Commuting | 97 | 0.0 | 0.00 | 97 |
| 3. Year - Fugitive Dust | | | | 0 |
| 3. Year - Total Emissions | 286 | 0.2 | 0.00 | 292 |
| 4. Year - Construction Equipment | 110 | 0.1 | 0.00 | 113 |
| 4. Year - Road Vehicles/Commuting | 0 | 0.0 | 0.00 | 0 |
| 4. Year - Fugitive Dust | | | | 0 |
| 4. Year - Total Emissions | 111 | 0.1 | 0.00 | 114 |
| **Project TOTAL:** | **795** | **0.6** | **0.00** | **812** |

### *Upstream Construction Materials*

Table 3.3 shows the upstream emissions from manufacturing construction materials based on fuel use rates and upstream life cycle emission rates. The GREET2 model estimated the emissions associated with the manufacture of materials for automotive manufacturing. These upstream results are consistent with the energy inputs and emissions for the GREET1 model and provide the basis for materials such as steel, copper, and stainless steel. The remaining upstream emissions are derived from the USLCI database and the GREET1 model. The heaviest materials of construction include concrete and asphalt. These materials; however, require relatively low upstream emissions in their manufacture as emissions from aggregate are relatively low compared with other materials. GHG emission associated with metals manufacturing includes energy for mining, smelting, and processing to materials of construction.

**Table 3.3.** Upstream Emissions for Construction Materials

| Pollutant | $CO_2$ | $CH_4$ | $N_2O$ | $CO_2e$ | Source |
|---|---|---|---|---|---|
| Life Cycle Emission Factor (g/kg) | | | | | |
| Structural Steel | 2,687 | 4.3 | 0.0 | 2,802 | GREET2_2017 |
| Rebar | 2,020 | 3.5 | 0.0 | 2,115 | GREET2_2017 |
| Stainless Steel | 5,204 | 11.3 | 0.1 | 5,512 | GREET2_2017 |
| Copper | 3,083 | 6.31 | 0.1 | 3,257 | GREET2_2017 |
| Asphalt [a] | 639 | 0.42 | 0.0 | 651 | GREET1_2017 |
| Aggregate | 300 | 0.20 | 0.0 | 305 | GREET1_2017 |
| Cement | 2,900 | 0.70 | 0.0 | 2,918 | GREET1_2017 |
| Emissions (tonne) | | | | | |
| Structural Steel | 12,748 | 20.6 | 0.10 | 13,293 | |
| Rebar | 3,366 | 5.9 | 0.04 | 3,524 | |
| Stainless Steel | 1,509 | 3.3 | 0.03 | 1,598 | |
| Copper | 80.2 | 0.2 | 0.00 | 84.7 | |
| Asphalt | 4,841 | 3.2 | 0.02 | 4,927 | |
| Aggregate | 24,033 | 16.0 | 0.00 | 24,434 | |
| Cement | 4,976 | 1.2 | 0.00 | 5,007 | |
| **Total** | **51,553** | **50.3** | **0.19** | **52,869** | |

[a] Asphalt assumed to be a mixture of residual oil and aggregate. Cement based on CaO. Aggregate based on surface extracted minerals.

### *Upstream Construction Power*

Upstream emissions for power are based on the amount of power used for construction combined with the upstream life cycle emission rates for power generation. The Washington average mix is used as a conservative assumption.

**Table 3.4.** Upstream Emissions for Electric Power

| Power Consumption LNG Construction | Baseline | GHG Emissions (tonnes) | | | |
|---|---|---|---|---|---|
| Power Total during construction (kWh) | 10,512,000 | $CO_2$ | $CH_4$ | $N_2O$ | $CO_2e$ |
| **Mix** | **WAUP** | **2,146.6** | **4.1** | **0.0** | **2,261.6** |

## 3.2 Operational Emissions

Operational emissions from Tacoma LNG include the emissions from fuel combustion, vented $CO_2$ from natural gas, fugitive $CH_4$ and the upstream emissions associated with these inputs. Direct project emissions include the on-site emissions from fuel combustion and evaporative emissions. Downstream emissions correspond to LNG bunkering and marine vessel loading facilities and end use fuel combustion.

Table 3.5 shows the operational emissions from the Tacoma LNG facility. The energy inputs are based on the gas composition and natural gas to LNG yield provided by PSE combined with the natural gas firing rate for pretreatment. Pretreatment emissions include the combustion of natural gas to operate the separation system as well as $CO_2$ in the natural gas. The emission rates for natural gas and waste gas are based on the gas compositions and mass balance shown in Appendix A.2. Natural gas is fired to operate the pretreatment system. Waste gas, which consists of light hydrocarbons are separated as part of the liquefaction process. The emission factors for natural gas and waste gas are based on the compositions in the mass balance. The waste gas is represented as waste gas and the LPG fraction in order to examine the effect of flaring and to illustrate the effect of the carbon balance on overall GHG emissions. The natural gas usage is higher than that of the default GREET usage parameters and the non-methane hydrocarbons grouped as LPG represent most of the difference.

**Table 3.5.** Operational Emissions from Tacoma LNG Facility

| **Direct Combustion Emission Factor** | | **Emissions (g/mmBtu), LHV** | | | |
|---|---|---|---|---|---|
| **Process** | **Equipment** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$CO_2e$** |
| LNG Pretreatment | Boiler, NG | 59,330 | 1.06 | 0.35 | 59,461 |
| Waste gas flaring | Flare | 68,662 | 1.06 | 1.07 | 59,660 |
| LPG flaring | Flare | 68,773 | 1.07 | 1.07 | 69,118 |
| Emergency Generator | Diesel Genset | 78,187 | 4.22 | 0.60 | 78,472 |
| | | **Emissions (tonne/year)** | | | |
| **Process** | **Equipment** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$CO_2e$** |
| LNG Pretreatment | Boiler, NG | 10,716 | 0.19 | 0.06 | 10,740 |
| Pretreatment $CO_2$ | Vent/flare | 1,683 | | | 1,683 |
| Waste LPG flaring | Flare | 57,219 | 1 | 1 | 57,506 |
| Waste gas flaring | Flare | 23,573 | 0 | 0 | 23,691 |
| Emergency Generator | Diesel Genset | 0 | 7.56 | 0.00 | 189 |
| Fugitives | Equip. Leaks | 521 | 0.03 | 0.00 | 523 |
| **Sub - Total** | | **93,712** | **9.03** | **1.32** | **94,333** |
| Vaporizer | Boiler | 940 | 0 | 0 | 942 |
| Vaporizer | Pump - power | 0.7 | 0.0 | 0.0 | 0.8 |
| Fugitives | | | | | |
| Ship/Barge Loading | Equip. Leaks | 0.0 | 7.5 | 0.0 | 187.8 |
| Bunker Vessel Storage | Equip. Leaks | 0.0 | 528.5 | 0.0 | 13,212.5 |
| Truck to Ship | Equip. Leaks | 1.0 | 12.9 | 1.0 | 322.1 |
| **Total** | | **94,654** | **558** | **2** | **108,998** |

The flow rate of natural gas is based on the hourly firing rate provided by PSE. The flow rate of the light hydrocarbon is based on the difference in the gas streams such that:

NG input = Fired NG + Pretreatment $CO_2$ + Flared Waste Gas + Fugitive $CH_4$ + LNG

The emission factors for natural gas and the light hydrocarbon components are based on the gas compositions and carbon content calculated in Appendix A.2. Since determining the exact feed gas composition and flared gas compositions is challenging, the overall CO2 emissions tie to a carbon balance in Appendix A.2. The distribution of carbon between the gas streams depends on many design parameters but the total CO2 emissions depend only on the net carbon balance shown above.

### 3.2.1 Operational Upstream Emissions

Upstream emissions from Tacoma LNG operation include the emissions for natural gas production and transmission, as well as power generation. The use of petroleum fuels for LNG transport also results in upstream emissions.

#### *Natural Gas Production*

Natural gas is the feedstock for the Tacoma LNG Facility as well as a key energy input for power generation and crude oil refining. Table 3.6 identifies the data sources for upstream natural gas emissions calculations. The assumptions for the feedstock for Tacoma LNG are varied to reflect the range in estimates of methane leakage rates, giving a baseline, a lower and an upper estimate.

The upstream GHG emissions for British Columbia gas are based on the GHGenius model (S&T 2013). The other assumptions on upstream emissions provide a range for sensitivity analysis. The upper bound, is based on the GREET North American Natural Gas model for U.S. natural gas. The upstream data sources are described in Appendix A.

**Table 3.6.** Upstream Data Sources for Natural Gas

| Scenario | Baseline |
|---|---|
| Baseline | GHGenius |
| Lower | BC Inventory Estimate |
| Upper | GREET NA NG |

Table 3.7 shows the upstream emissions for natural gas. The GHGenius result for BC gas is shown here as this estimate is a regionally specific estimate for the feedstock for the Tacoma LNG facility. The input assumptions and results for the other upstream estimates are in Appendix B.1.

**Table 3.7.** Upstream Natural Gas Emission Rates

| Natural Gas upstream | Emissions (g/mmBtu), LHV | | | |
|---|---|---|---|---|
| **Processing Step** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$CO_2e$** |
| Natural Gas Extraction | 2,356 | 8.9 | 0.021 | 2,584 |
| Extraction Fugitive | 0 | 135.7 | 0.000 | 3,394 |
| Natural Gas Processing | 1,845 | 4.4 | 0.014 | 1,959 |
| Processing Fugitive | 778 | 6.8 | 0.000 | 948 |
| Transmission & Storage | 377 | 13.7 | 0.295 | 807 |
| Transmission Fugitive | 0.0 | 19.2 | 0.000 | 480 |
| **Total Natural Gas** | **5,355** | **189** | **0.3** | **10,172** |

*Source:* GHGenius for BC

### *Other Upstream Emissions*

Upstream emissions are associated with diesel and gasoline fuel used for construction and LNG transport. Diesel and marine fuel are also used for the no action alternative. The upstream life cycle emission rate for petroleum fuel are shown in Table 3.8. The crude oil resource mix is based on the analysis in Appendix B.3.

**Table 3.8.** Upstream GHG Emission Rates for Petroleum Fuels

| | Emissions (g/mmBtu), LHV | | | |
|---|---|---|---|---|
| **Processing Step** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$CO_2e$** |
| WA. Bunker Fuel | | | | |
| Crude Oil Production[a] | 12,627 | 0 | 0 | 12,627 |
| Extraction Fugitive | 0 | 0 | 0 | 0 |
| Crude Oil Refining | 4,049 | 10 | 0.07 | 4,333 |
| Processing Fugitive | 0 | 0 | 0 | 0 |
| Transport | 419 | 1 | 0.01 | 439 |
| Transport Fugitive | 0 | 0 | 0 | 0 |
| Total U.S. Bunker Fuel | 17,095 | 11. | 0.08 | 17,399 |
| WA. Diesel Fuel | | | | |
| Crude Oil Production[a] | 13,155 | 0 | 0 | 13,155 |
| Extraction Fugitive | 0 | 0 | 0 | 0 |
| Crude Oil Refining | 7,386 | 20 | 0.1 | 7,939 |
| Processing Fugitive | 0 | 0 | 0 | 0 |
| Transport | 376 | 1 | 0 | 395 |
| Transport Fugitive | 0 | 0 | 0 | 0 |
| Total WA. Diesel Fuel | 20,918 | 21 | 0.1 | 21,488 |
| WA Gasoline Fuel | | | | |
| Crude Oil Production[a] | 11,533 | 0 | 0 | 11,533 |
| Extraction Fugitive | 0 | 0 | 0 | |
| Crude Oil Refining | 13,232 | 0 | 0 | 13,232 |
| Processing Fugitive | 0 | 0 | 0 | |
| Transport | 491 | 0 | 0 | 491 |
| Transport Fugitive | 0 | 0 | 0 | |
| Ethanol blending | -1,006 | 0 | 0 | -1,006 |
| Total WA. Gasoline Fuel | 24,251 | 0 | 0 | 24,251 |

*Source:* GREET1_2017 with Washington specific inputs, WA average electricity mix.

[a] Crude oil production emissions determined from CA ARB reporting of OPGEE model results which are reported on a $CO_2e$ basis including $CH_4$ and $N_2O$

Energy use rates are combined with the upstream emission factors to calculate the upstream emissions associated with petroleum fuels for Tacoma LNG. The upstream components of the calculations of emissions are summarized in shown in Table 3.9. The emissions are expressed per 1000 gallons of LNG with the use rate also indicated in the table.

**Table 3.9.** Upstream GHG Emission Rates for Tacoma LNG project

| Pollutant | $CO_2$ | $CH_4$ | $N_2O$ | $CO_2e$ | Use Rate | |
|---|---|---|---|---|---|---|
| Emissions (kg/1000 gal), LHV | | | | | | |
| Upstream Natural Gas | 458.3 | 16.2 | 0.0 | 870.4 | 85,407 | Btu/gal |
| Upstream Power LNG production | 275.3 | 0.5 | 0.0 | 290.0 | 1.35 | kWh/gal |
| Upstream Diesel Emergency | 0.79 | 0.00 | 0.00 | 0.8 | 37.6 | Btu/gal |
| Upstream Power LNG Vaporizer | 9.2 | 0.0 | 0.0 | 9.7 | 0.045 | kWh/gal |
| **Total Upstream** | **743.5** | **16.7** | **0.0** | **1170.9** | | |

### 3.2.2 Direct Operational Emissions

Direct emissions from Tacoma LNG correspond primarily to the combustion of natural gas for pretreatment and the vented $CO_2$ from the LNG production process. Natural gas for process boilers, flares and emergency equipment also contribute to direct GHG emissions. The natural gas use rate affects the upstream natural gas emissions previously discussed.

### 3.2.3 Carbon Balance

Emissions from Tacoma LNG are calculated assuming continuous operation in order to provide a basis of comparison for the no action alternative. Energy inputs and emissions from continuous operation are based on the process design and correspond to a mass and energy balance between the natural gas feed, LNG produced, and emissions. Table 3.10 shows the mass and energy inputs for data based on 500,000 gpd of production.

**Table 3.10.** Mass Balance of LNG plant processes

| Energy Input/Output | NG Feed | LNG Output | Ratio NG/LNG | Btu NG / gal LNG |
|---|---|---|---|---|
| NG Feed (lb/day) | 2,025,990 | 1,814,026 | 1.117 | |
| LHV (mmBtu/day) | 42,695 | 38,570 | 1.107 | 85,577 |
| LHV, Btu/lb | 21,074 | 21,262 | | |

*Source:* PSE and mass balance in Appendix A.2

GHG emissions from the LNG production process consist of fired natural gas, light hydrocarbons, $CO_2$, and fugitive $CH_4$. A carbon balance provides the basis for the net emissions followed by a summary of the total Tacoma LNG facility emissions in Appendix A. The mass flow of feedstocks, products, and emissions are represented by the carbon balance shown in Figure 3.1. Natural gas is combusted in a boiler. In addition, light hydrocarbons from the LNG plant are burned in a flare. The mass balance shown here represents the maximum emissions since the waste gas is burned in a flare. The composition and mass balance of the waste gas are calculated based on the gas composition and natural gas to LNG yield provided by PSE. The carbon balance shows the mass, energy content and carbon in the natural gas to the facility. Thus, the carbon in the fuel gas is determined by difference and is also consistent with the process design reported by PSE.

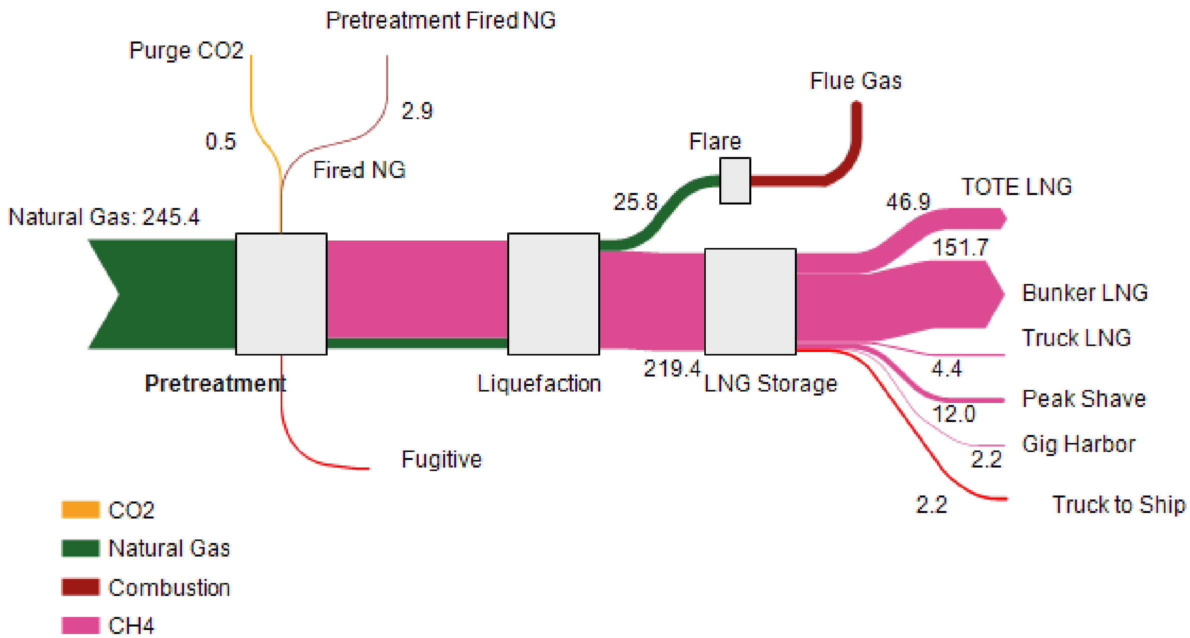



**Figure 3.1.** Carbon Balance for Tacoma LNG Plant k tonne C/year)
*Source:* Appendix A.2

Figure 3.1 also shows the distribution of LNG among end use applications. The most significant uses are as marine fuel for TOTE vessels or other marine applications. Note that the peak shaving use may only occur for 10 years but the amount of LNG used is a small fraction of the overall use and presumably the LNG would be used for applications similar to the ones analyzed here. Table 3.11 summarizes the mass flow for the LNG production system. No LPG is produced and the incoming natural gas and products are based on information provided by PSE. Note that the carbon in is equal to the carbon exiting the LNG production system.

**Table 3.11.** Carbon Mass Balance of LNG plant processes

| | Input/Ouput | | $CO_2$ | Methane | C content |
|---|---|---|---|---|---|
| | lb/day | tonne/yr | tonne/yr | tonne/yr | tonne/yr |
| Input NG | | | | | |
| Natural gas | 2,025,990 | 326,239 | | | **245,411** |
| **Total NG Input** | 2,025,990 | 326,239 | | | **245,411** |
| Products | - | | | | |
| LPG sold | 0 | 0 | | | **0** |
| LNG | 1,814,026 | 291,636 | | | **219,013** |
| **Total Products** | 1,814,026 | 291,636 | | | **219,013** |
| Emissions | - | | | | |
| Pretreatment | | | 10,716 | | **2,923** |
| $CO_2$ Separated (non-combustion) | | | 1,683 | | **459** |
| Flaring (combustion) | | | 55,535 | | **15,619** |
| Flaring from LPG (combustion) | | | 23,573 | | **7,135** |
| Fugitives $CH_4$ | | | | 7.56 | **6** |
| Vaporizing for peak shaving | | | 940 | | **257** |
| **Total Emissions** | | | 92,448 | 8 | **26,398** |
| **Total Product + Emissions** | | | 92,448 | 8 | **245,411** |
| **Total NG Input - Product + Emissions** | | | Mass Balance Closes | | **0** |

The carbon balance Figure 3.1 provides the basis for determining $CO_2$ emissions and validates the net waste gas that is flared. The energy inputs to the boiler, flare, and diesel equipment provides the basis for determining $CH_4$ and $N_2O$ emissions based on emission factors per mmBtu of combusted fuel in Appendix C.

### 3.2.4 Peak Shaving Vaporizer

Emissions from the vaporizer for peak shaving are presented under section 3.2.2 Direct Operational Emissions of Tacoma LNG. Emissions associated with the vaporizer are shown below.

**Table 3.12.** End use emissions from On-site Peak Shaving

| | | Emissions (tonne/year) | | | |
|---|---|---|---|---|---|
| **Process** | **Equipment** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$CO_2e$** |
| Vaporizer | Small Industrial NG Boiler | 940 | 0 | 0 | 942 |
| Vaporizer | Pump - power | 0.7 | 0.0 | 0.0 | 0.8 |

## 3.3 Downstream Tacoma LNG End Use Emissions

LNG from the Tacoma facility will primarily deliver the LNG to marine vessels as marine fuel at the Tacoma port. LNG will also be vaporized and injected into the pipeline for peak shaving for power production.

The following end use mix is assumed as input, based on an annual operation of 355 days of Tacoma LNG.

**Table 3.13.** LNG end use mix of Tacoma LNG facility – 500,000 gpd Production

| LNG End use | Mgal/yr | GBtu/yr, LHV |
|---|---|---|
| Peak Shaving | 9.73 | 750 |
| Gig Harbor Delivery | 1.78 | 137 |
| On-road Trucking | 3.55 | 274 |
| TOTE Marine | 37.93 | 2,927 |
| Truck-to-Ship Bunkering | 1.78 | 137 |
| Other Marine (by Bunker Barge) | 122.74 | 9,470 |
| Total LNG | 177.5 | 13,695 |

**Table 3.14.** Tacoma LNG End use emissions –500,000 gpd Production

| | | Emissions (tonne/year) | | | |
|---|---|---|---|---|---|
| **LNG Project** | **Equipment Type** | **$CO_2c$** | **$CH_4$** | **$N_2O$** | **$CO_2e$** |
| Vaporizer/Peak Shaving | | | | | |
| LNG | NG Turbine | 43,755 | 1 | 0 | 43,854 |
| Gig Harbor Delivery | | | | | |
| LNG | Truck Engine | 4 | 0 | 0 | 4 |
| LNG End Use | NG Boiler | 8,125 | 0 | 0 | 8,125 |
| On-road Trucking | | | | | |
| LNG | Truck Engine | 15,738 | 85 | 0 | 17,862 |
| TOTE Marine | | | | | |
| LNG | Marine Engine | 171,718 | 2,029 | 12 | 225,993 |
| Pilot fuel | Marine Engine | 7,508 | 0 | 0 | 7,611 |
| Truck-to-Ship Bunkering | | | | | |
| LNG | Marine Engine | 8,036 | 95 | 1 | 10,575 |
| Pilot fuel | Marine Engine | 351 | 0 | 0 | 356 |
| Diesel Truck | Truck Engine | Assumed same for no action alternative | | | |
| Other Marine (by Bunker Barge) | | | | | |
| LNG | Marine Engine | 554,208 | 6,548 | 39 | 729,376 |
| Pilot fuel | Marine Engine | 24,232 | 0 | 0 | 24,335 |
| **Total End Use** | | **833,676** | **8,757** | **52** | **1,068,092** |

### 3.3.1 Gig Harbor LNG

LNG shipped to Gig Harbor will displace LNG from Fortis, British Columbia. The primary effect will be a difference in transport distance. The life cycle analysis of the Fortis facility was assumed to be the same as that for Tacoma LNG.

**Table 3.15.** Inputs and Calculation for End use Emissions from Gig Harbor Transport

| General inputs | | |
|---|---|---|
| Total LNG delivery to Gig Harbor per year | 1,775,000 | Gal |
| Truck capacity | 10,000 | Gal |
| Number of trips | 177.5 | |

| Calculation of annual Diesel Truck Consumption | LNG Project | |
|---|---|---|
| Distance to Gig Harbor | 17 | miles/trip |
| Annual miles for delivery | 3,018 | miles/year |
| Diesel consumption per mile | 17,738 | Btu/mile |
| **Total Diesel Consumption** | **53.52** | **mmBtu/year** |

**Table 3.16.** End use emissions from Gig Harbor LNG delivery

| | **Diesel Consumption** | Emissions (tonnes/year) | | | |
|---|---|---|---|---|---|
| **Processing Step** | **mmBtu/year** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$CO_{2e}$** |
| LNG Project | 53.5 | 4.18 | 0.00023 | 0.00003 | 4.2 |

### 3.3.2 On-road Trucking

Energy inputs and emission for trucking are shown below. $CO_2$ emissions include all of the carbon in the fuel including CO and VOC emissions.

**Table 3-17.** LNG consumption from On-road Trucking

| | | **Consumption** | |
|---|---|---|---|
| | **Equipment** | **Mgal/year** | **GBtu/year** |
| LNG | Tractor engine | 3.55 | 274 |

**Table 3.18.** End use emissions from LNG On-Road Trucking, LNG (Proposed Action) and Diesel (No Action)

| | **Consumption** | **Emissions (t/year)** | | | |
|---|---|---|---|---|---|
| **Processing Step** | **mmBtu/year** | **$CO_2c$** | **$CH_4$** | **$N_2O$** | **$CO_{2e}$** |
| LNG Project - LNG Tractor | 273,902 | 15,738 | 84.85 | 0.01 | 17,862 |
| Diesel tractor | 246,512 | 19,274 | 1.17 | 0.04 | 19,316 |

### 3.3.3 Marine Vessel LNG consumption

GHG Emissions from LNG consumption in TOTE and other marine vessels are also listed in Table 3.14. These emissions have been estimated as described modeling in Section 2.4.5, and more detail on emissions rates for TOTE and other marine vessels are calculated from fuel use and the emission factors is provided in Appendix C.

# 4. DISPLACED EMISSIONS

The use of LNG as marine vessel and truck fuel as well as natural gas peak shaving primarily replaces the use of petroleum-based fuels:

1. Marine diesel assumed to be bunker fuel or residual oil
2. On-road diesel fuel
3. Diesel in dual-fuel power generation units and as on-road transportation fuel.

Fuel use for LNG and the alternative use is calculated based on the energy consumed and the Energy Economy Ratios (EER) values in Table 4.1. EER of Marine vessels.

For ships operating outside designated Emission Control Areas (ECA) IMO has set a limit for sulfur in fuel oil used on board ships of 0.50% m/m (mass by mass) from 1 January 2020. The current global limit for sulfur content of ships' fuel oil is 3.50% m/m (mass by mass). Sulphur Emission Control Areas (SECAs), or Emission Control Areas (ECAs), are sea areas in which stricter controls were established to minimize airborne emissions from ships as defined by Annex VI[1] of the 1997 MARPOL Protocol. Current limits for sulfur content in these areas is 1000 ppm wt.

Several options are available to comply with the new limits, including marine gas oil (MGO). These include LNG, heavy fuel oil operation with scrubbers, or the production of low sulfur fuel oil. Since marine gas oil is more expensive than heavy fuel oil, scrubbers have received attention over the last years and the number of scrubbers installed onboard of ships has increased.

Scrubbers reduce the emission of sulfur to the atmosphere by more than 90%. Also PM emissions, in terms of mass not number, are reduced significantly, by 60-90%. The emission of NOx is reduced by 10% or less. Due to the additional power needed to drive pumps and caustic soda consumption, the estimated additional GHG emissions range between 1.5 and 3.5%, including caustic soda consumption for the latter figure. It should be noted, however, that also the use additional MGO in the SECA causes an increase of GHG refinery emissions by roughly 6.5%.

The use of scrubbers increases the fuel consumption by 3 % in case of seawater scrubber and by 1% in case of freshwater scrubber (Boer & Hoen, 2015; Yang et al., 2017). Based on the above mentioned state of the art in reducing the sulfur content in bunker fuel an energy efficiency ratio of 1.015 for marine vessels using bunker fuel compared to ships using LNG as fuel was examined in the sensitivity analysis in Section 5. The Baseline scenario assumes an EER of 1.0 for marine fuel displacement.

### *EER of On-Road Trucking*

The EER for on-road trucking for LNG displacing diesel is 0.9, which is based on the value analyzed by the California Air Resources Board for the Low Carbon Fuel Standard. The EER corresponds to spark-ignited LNG engines displacing more efficient diesel engines. For spark-ignited LNG engines displacing spark-ignited gasoline engines or for diesel pilot injected LNG engines displacing diesel engines, the EER would be 1.0 but the prior comparison is more common for commercial trucking applications.

**Table 4.1.** Fuel consumption and applied Energy Economy Ratios (EERs) for 500,000 gpd Production

| | | Consumption | | | |
|---|---|---|---|---|---|
| **LNG End Use** | **Equipment Type** | **Mgal/yr** | **GBtu, LHV/yr** | **EER** | **Btu/gal** |
| Power Peak Shaving | | - | | | |
| LNG | Dual Fuel Turbine | 9.73 | 750 | 1 | 77,156 |
| Displaced Diesel | Dual Fuel Turbine | 5.89 | 750 | | 127,464 |
| Gig Harbor LNG | | - | | | |
| LNG | NG Boiler | 1.78 | 137 | 1 | 77,156 |
| LNG | NG Boiler | 1.78 | 137 | | 77,156 |
| On-road Trucking | | - | | | |
| LNG | Truck Engine | 3.55 | 274 | 0.9 | 77,156 |
| Diesel | Truck Engine | 1.93 | 247 | | 127,464 |
| TOTE Marine | | - | | | |
| LNG | Marine Engine | 37.93 | 2,927 | 1 | 77,156 |
| Pilot diesel Fuel for LNG | Marine Engine | 0.63 | 88 | 1 | 140,353 |
| Displaced MDO Fuel | Marine Engine | 21.48 | 3,014 | | 140,353 |
| Truck-to-Ship Bunkering | | | | | |
| LNG | Marine Engine | 1.78 | 137 | 1 | 77,156 |
| Pilot Fuel for LNG | Marine Engine | 0.03 | 4 | | 140,353 |
| Displaced MDO Fuel | Marine Engine | 1.01 | 141 | | 140,353 |
| Other Marine (by Bunker Barge) | | | | | |
| LNG | Marine Engine | 122.74 | 9,445 | 1 | 77,156 |
| Pilot Fuel for LNG | Marine Engine | 2.02 | 283 | 1 | 140,353 |
| Displaced MDO Fuel | Marine Engine | 69.50 | 9,729 | | 140,353 |
| Total LNG | | 177.5 | 13,670 | | |

EER: Energy Economy Ratio

In the case of not building Tacoma LNG total displaced end use emissions and corresponding upstream emissions would be as follows:

**Table 4.2.** Displaced upstream and end use emission for Tacoma LNG project for 500,000 gpd LNG Production.

| | | Emissions (tonne/year) | | | |
|---|---|---|---|---|---|
| **NO LNG Project** | **Equipment Type** | **$CO_2c$** | **$CH_4$** | **$N_2O$** | **$CO_2e$** |
| Peak Shaving | | | | | |
| Diesel - Upstream | | 15,697 | 15.8 | 0.1 | 16,125 |
| Diesel - Power pumping | | 2 | 0.0 | 0.0 | 2 |
| Diesel - End use | Dual Fuel Boiler | 58,682 | 0.1 | 0.7 | 58,891 |
| Gig harbor Delivery | | | | | |
| LNG | Truck Engine | 43 | 0.0 | 0.0 | 43 |
| LNG End Use | NG Boiler | 8,125 | 0 | 0.0 | 8,125 |
| On-road Trucking | | | | | |
| Diesel | Truck Engine | 19,274 | 1.2 | 0.0 | 19,316 |
| TOTE Marine | | | | | |
| MDO - Upstream | | 51,531 | 33.7 | 0.2 | 52,448 |
| MDO fuel | Marine Engine | 257,783 | 3.9 | 11.6 | 261,325 |
| Truck-to-Ship Bunkering | | | | | |
| MDO Fuel | Marine Engine | 12,063 | 0.2 | 0.5 | 12,229 |
| Other Marine (by Bunker Barge) | | | | | |
| MDO - Upstream | | 166,313 | 108.8 | 0.8 | 169,272 |
| MDO fuel | Marine Engine | 831,977 | 3.9 | 11.6 | 835,519 |
| **Total Upstream and End Use Emissions** | | **1,405,792** | **152** | **25** | **1,425,170** |

# 5. Life Cycle Assessment

Net greenhouse gas emissions were evaluated for the two volumetric scenarios considered in this analysis. Scenario A corresponds to 250,000 gpd of LNG production and Scenario B corresponds to 500,000 gpd of production. Scenarios A and B both include the same amount of TOTE marine vessels and peak shaving. Additional fuel applications are included in Scenario B. The operational and displaced emissions are further broken out by upstream direct and downstream emissions.

### *Scenario B*

Scenario B includes the use of more LNG for marine applications where the LNG is transferred by bunkering barge. This LNG transfer results in potential fugitive emissions. This scenario results in the greatest GHG emissions from the project but since the LNG produced to displace petroleum fuels is also greater than that of Scenario A.

Table 5.1 shows the life cycle GHG emissions for Tacoma LNG for Scenario B which is consistent with the technical life expectancy for the Tacoma LNG facility. Emissions are grouped according to construction, operational, and end use emissions. Note that energy outputs from the facility displace another source of energy for the no action alternative, which is shown in Table 5.2.

**Table 5.1.** Life Cycle GHG Emissions for Tacoma LNG over 1 year – 500,000 gpd Production (Scenario B)

| Life Cycle Step | Mgal/ year | GBtu/ year | GHG Emissions tonne/year |
|---|---|---|---|
| **NEW LNG PLANT** | | | |
| Construction Emissions | | | |
| **Total Construction** | | | **1,581** |
| Direct (Equipment) | | | 182 |
| Upstream Life Cycle (Equipment) | | | 20 |
| Upstream Life Cycle (Power) | | | 57 |
| Upstream Life Cycle (Material) | | | 1,322 |
| Operational Emissions | | | |
| **Upstream Life cycle** | | | **207,844** |
| Natural Gas | | | 154,504 |
| Power LNG production | | | 51,477 |
| Diesel Emergency | | | 143 |
| Power LNG Vaporizer -Peak Shaving | | | 1,718 |
| Gig harbor Diesel truck fuel | | | 1.2 |
| **Direct LNG Plant** | | | **108,997** |
| LNG Production | | | 94,333 |
| Vaporizer - Peak Shaving | | | 942 |
| Bunkering and Transfer $CH_4$ | | | 13,722 |
| **End Use LNG** | **177.50** | **13,695** | **1,068,092** |
| On-site Peak Shaving | 9.73 | 750 | 43,854 |
| Gig Harbor LNG | 1.78 | 137 | 8,129.5 |
| On-road Trucking | 3.55 | 274 | 17,862 |
| TOTE Marine | 37.93 | 2,927 | 225,993 |
| TOTE Marine Diesel Pilot fuel | | | 7,611 |
| Truck-to-Ship Bunkering | 1.78 | 137 | 10,575 |
| Truck-to-Ship Bunkering Pilot Fuel | | | 356 |
| Other Marine LNG (by Bunker Barge) | 122.74 | 9,470 | 729,376 |
| Other Marine Diesel Pilot Fuel | | | 24,335 |
| **Total Emissions (Tacoma LNG)** | | | **1,386,514** |

Fuel from the Tacoma LNG facility will be used in applications that either require low emissions or where natural gas is unavailable. The LNG will displace petroleum diesel, marine diesel, or other sources of LNG. The analysis is based on a 1:1 displacement, which assumes that the petroleum fuels are not used elsewhere and that the emissions reductions propagate throughout the life cycle of petroleum and effectively crude oil remains unused.

**Table 5.2.** Displaced emissions over 1 year – 500,000 gpd Production (Scenario B)

| Life Cycle Step | Mgal/ year | GBtu/ year | GHG Emissions tonne/year |
|---|---|---|---|
| Upstream Displaced Emissions | | | |
| **Total Upstream** | | | **247,772** |
| No Peak Shaving - Diesel Dual Fuel | | 750 | 16,127 |
| Upstream Gig Harbor Peak Shaving | | 137 | 2,174 |
| Upstream On-road trucking | | 247 | 5,297 |
| Upstream TOTE Marine Diesel | | 3014 | 52,448 |
| Upstream Truck-to-Ship Bunkering | | 141 | 2,454 |
| Upstream Other Marine Diesel (by Bunker Barge) | | 9754 | 9729 |
| End Use Emissions | | | |
| **Total End Use Diesel /Fuel Oil/LNG** | **101** | **14,018** | **1,195,447** |
| Diesel Peak Shaving for Power | 5.89 | 750 | 58,891 |
| Gig Harbor LNG | 1.78 | 137 | 8,168 |
| On-road trucking | 1.93 | 247 | 19,316 |
| TOTE Marine Diesel | 21.48 | 3,014 | 261,325 |
| Truck-to-Ship Bunkering | 1.01 | 141 | 12,229 |
| Other Marine Diesel (by Bunker Barge) | 69.32 | 9,729 | 835,519 |
| **Total Emission (No Action)** | | | **1,443,219** |
| **Net Emission reduction** | | | **-56,705** |
| in percentage | | | -3.93% |

The displacement of LNG for each end use application is shown in Figure 5.1. The annual emissions are also shown for the major end use applications and aggregate upstream life cycle emissions[22]. The analysis shows the scenario with peak shaving for electric power generation. This end use application is expected to continue for 10 years and the LNG would presumably be used for other applications that displace petroleum fuels. For each end use application, GHG emissions of LNG plus pilot fuel are lower than those of the displaced petroleum product. This trend persists for all of the end use applications although the displacement of GHG emissions from LNG to petroleum varies with carbon content of the displaced fuel as well as the methane emissions that occur during combustion.

[22] The construction emissions, emergency equipment diesel plus upstream life cycle of power, fuels, and materials are aggregated together as "Construct Diesel Materials". LNG facility emissions include fuel combustion for pretreatment, flare, and peak shaving heater, and fugitive emissions from equipment. LNG fugitives for fuel loading include transfer to TOTE vessels, bunker barge, trucks as well as boil off loss during barge operation.

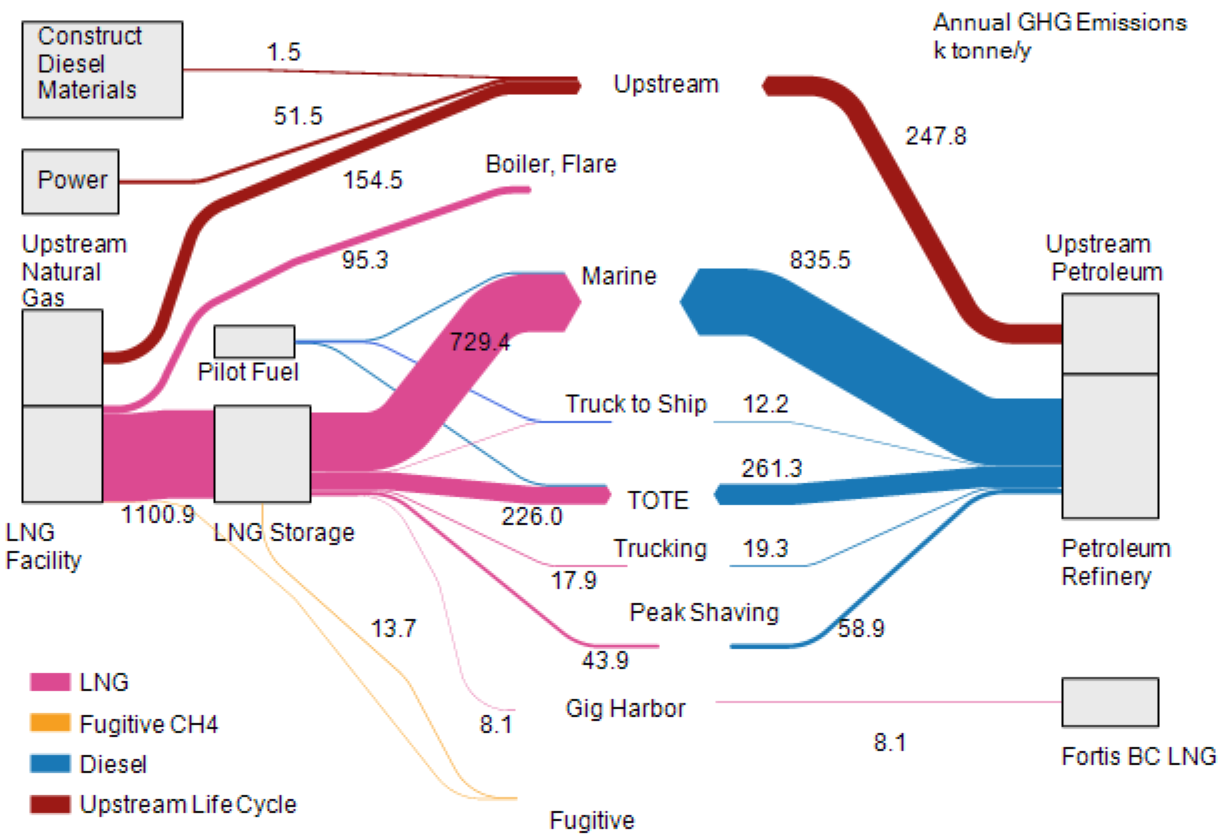



**Figure 5.1.** Direct and upstream life cycle GHG emissions from LNG and displaced fuel applications for Scenario B.

Net GHG emissions for each category are also shown in Figure 5.2. Note that the emissions from the LNG facility plus upstream emissions are higher than those for the no action alternative. However, the carbon content of LNG results in lower end use emissions; so, the net life cycle GHG emissions are reduced under most situations.

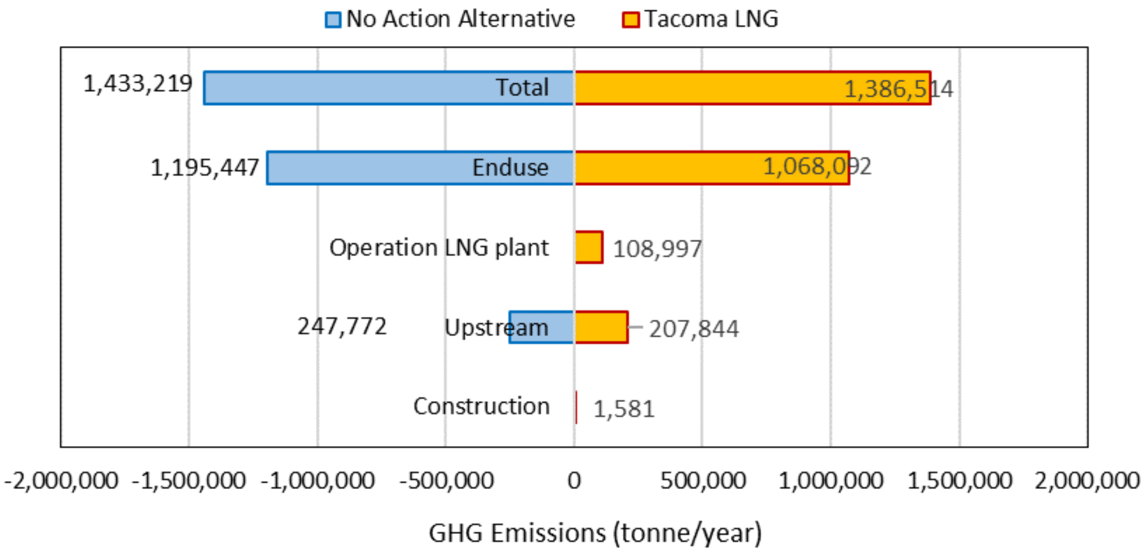



**Figure 5.2.** GHG emissions from the Tacoma LNG plant compared to the no action alternative for Scenario B.

### *Scenario A*

Scenario A includes the use of proportionately less LNG for marine applications where the LNG is transferred by bunkering barge. Scenario A is based on a smaller fuel volume than Scenario B; so the role of peak shaving to displace diesel peak shaving has a greater effect on net GHG emissions.

Table 5.3 shows the life cycle GHG emissions for Tacoma LNG for Scenario A which is consistent with the technical life expectancy for the Tacoma LNG facility. Emissions are grouped according to construction, operational, and end use emissions. Emissions from the no action alternative are shown in Table 5.4.

**Table 5.3.** Life Cycle GHG Emissions for Tacoma LNG over 1 year – 250,000 gpd Production (Scenario A)

| Life Cycle Step | Mgal/ year | GBtu/ year | GHG Emissions tonne/year |
|---|---|---|---|
| **NEW LNG PLANT** | | | |
| Construction Emissions | | | |
| **Total Construction** | | | **1,581** |
| Direct (Equipment) | | | 182 |
| Upstream Life Cycle (Equipment) | | | 20 |
| Upstream Life Cycle (Power) | | | 57 |
| Upstream Life Cycle (Material) | | | 1,322 |
| Operational Emissions | | | |
| **Upstream Life cycle** | | | **103,949** |
| Natural Gas | | | 77,208 |
| Power LNG production | | | 25,739 |
| Diesel Emergency | | | 143 |
| Power LNG Vaporizer -Peak Shaving | | | 859 |
| Gig harbor Diesel truck fuel | | | 0.0 |
| **Direct LNG Plant** | | | **52,251** |
| LNG Production | | | 46,714 |
| Vaporizer - Peak Shaving | | | 942 |
| Marine vessel bunkering $CH_4$ | | | 4,595 |
| **End Use LNG** | **88.75** | **6,848** | **529,859** |
| On-site Peak Shaving | 9.73 | 750 | 43,854 |
| Gig Harbor LNG | 0.00 | 0 | 0.0 |
| On-road Trucking | 0.00 | 0 | 0 |
| TOTE Marine | 37.93 | 2,927 | 225,993 |
| TOTE Marine Diesel Pilot fuel | | | 7,611 |
| Truck-to-Ship Bunkering | 0.00 | 0 | 0 |
| Truck-to-Ship Bunkering Pilot Fuel | | | 0 |
| Other Marine LNG (by Bunker Barge) | 41.09 | 3,171 | 244,185 |
| Other Marine Diesel Pilot Fuel | | | 8,216 |
| **Total Emissions (Tacoma LNG)** | | | **687,639** |

**Table 5.4.** Displaced emissions over 1 year – 250,000 gpd Production (Scenario A)

| Life Cycle Step | Mgal/ year | GBtu/ year | GHG Emissions tonne/year |
|---|---|---|---|
| Upstream Displaced Emissions | | | |
| **Total Upstream** | | | **125,245** |
| No Peak Shaving - Diesel Dual Fuel | | 750 | 16,127 |
| Upstream Gig Harbor Peak Shaving | | 0 | 0 |
| Upstream On-road trucking | | 0 | 0 |
| Upstream TOTE Marine Diesel | | 3014 | 52,448 |
| Upstream Truck-to-Ship Bunkering | | 0 | 0 |
| Upstream Other Marine Diesel (by Bunker Barge) | | 3257 | 56,670 |
| End Use Emissions | | | |
| **Total End Use Diesel /Fuel Oil/LNG** | **50.6** | **7,022** | **602,291** |
| Diesel Peak Shaving for Power | 5.89 | 750 | 58,891 |
| Gig Harbor LNG | 0.00 | 0 | 0 |
| On-road trucking | 0.00 | 0 | 0 |
| TOTE Marine Diesel | 21.48 | 3,014 | 261,325 |
| Truck-to-Ship Bunkering | 0.00 | 0 | 0 |
| Other Marine Diesel (by Bunker Barge) | 23.21 | 3,257 | 282,076 |
| **Total Emission (No Action)** | | | **727,536** |
| **Net Emission reduction** | | | **-39,897** |
| in percentage | | | -5.48% |

The displacement of LNG for each end use application is shown in Figure 5.3. The annual emissions are also shown for the major end use applications and aggregate upstream life cycle emissions. The analysis shows the scenario with peak shaving for electric power generation. This end use application is expected to continue for 10 years and the LNG would presumably be used for other applications that displace petroleum fuels. For each end use application, GHG emissions of LNG plus pilot fuel are lower than those of the displaced petroleum product. This trend persists for all of the end use applications although the displacement of GHG emissions from LNG to petroleum varies with carbon content of the displaced fuel as well as the methane emissions that occur during combustion.

Net GHG emissions for each category are also shown in Figure 5.4. Note that the emissions from the LNG facility plus upstream emissions are higher than those for the no action alternative. However, the carbon content of LNG results in lower end use emissions; so, the net life cycle GHG emissions are reduced under most situations.

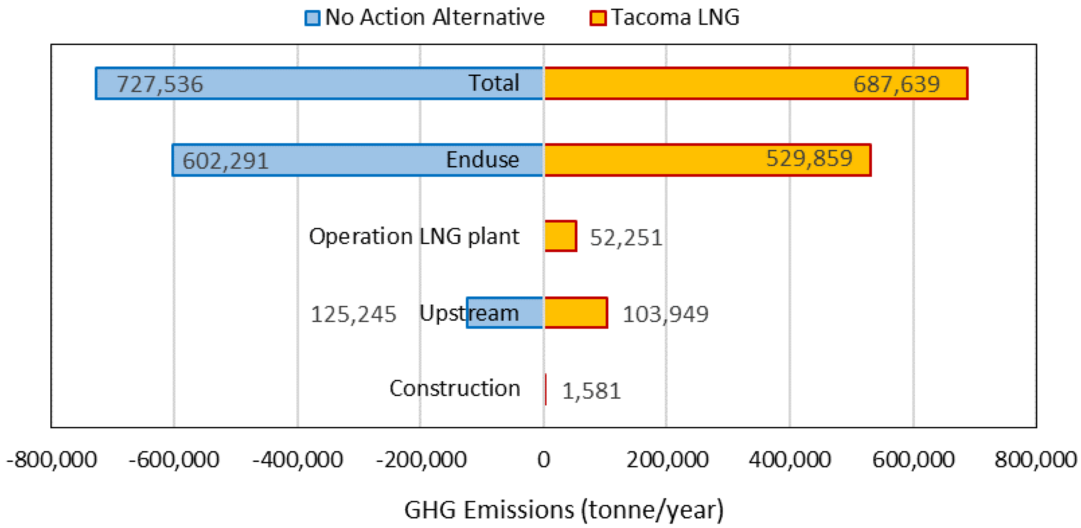



**Figure 5.3.** GHG emissions from the Tacoma LNG plant compared to the no action alternative for Scenario A.

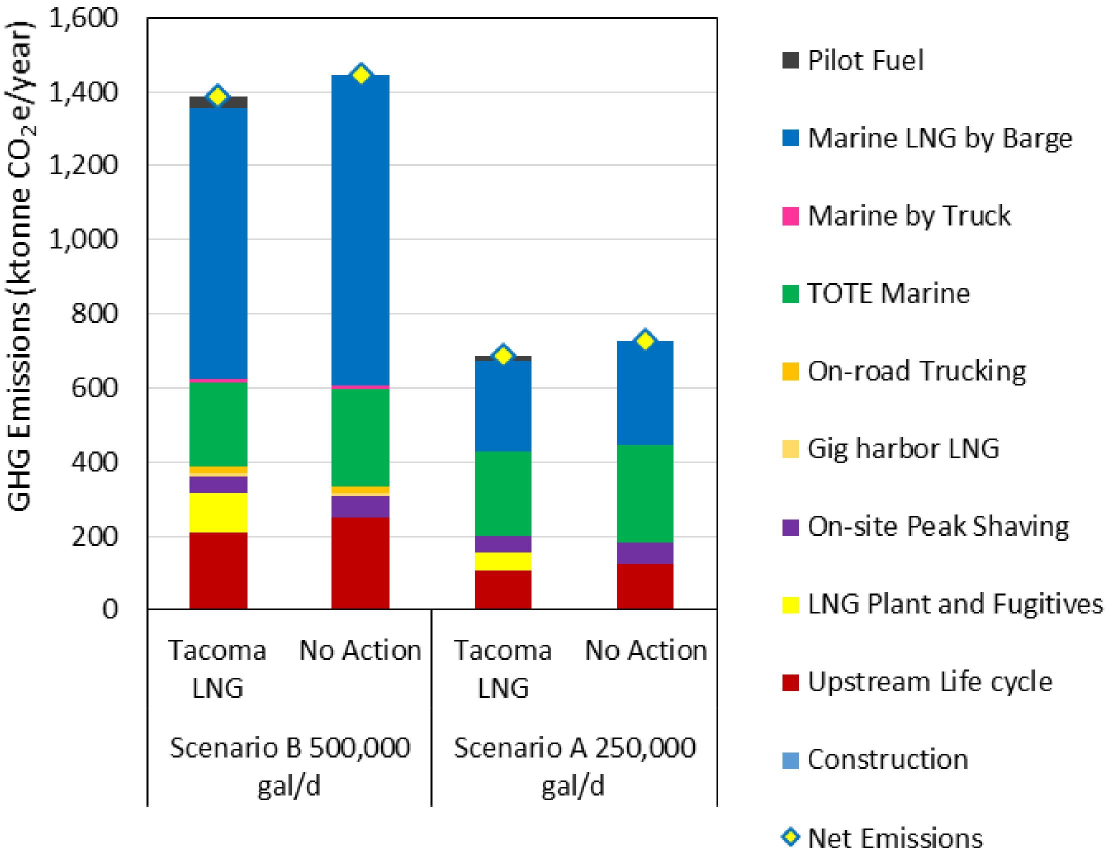



**Figure 5.4.** Range of GHG emissions for different fuel volume scenarios.

### *Sensitivity Analysis*

Many factors affect the net life cycle GHG emissions as shown in Figure 5.5. The Baseline Scenario with 500,000 gal/day of LNG produciton is represented as a green line with the effect of different inputs illustrated. The effect of key inputs is also indicated to illustrate the effect on net GHG emissions.

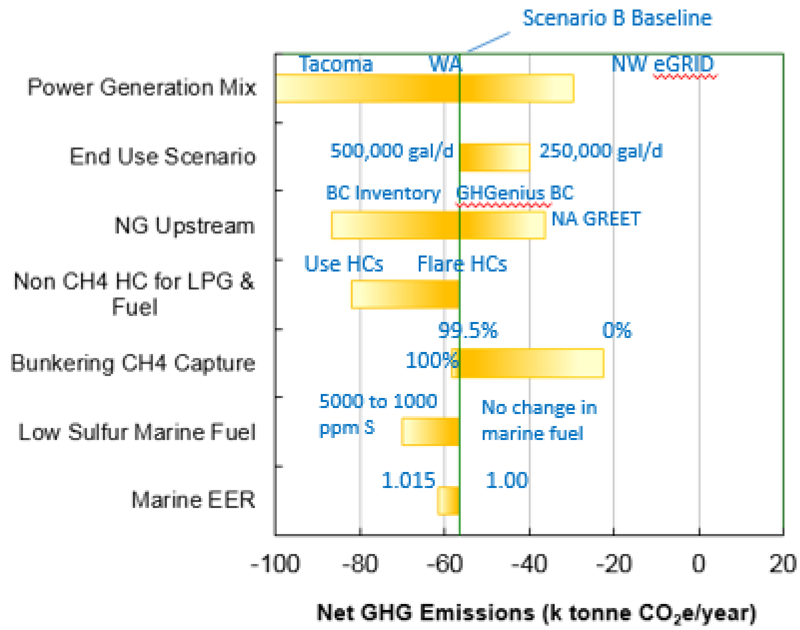



**Figure 5.5.** Sensitivity of net GHG emissions to key assumptions.

Key parameters that affect upstream emission include the power generation mix and the estimates of life cycle GHG emission for natural gas production and distribution. The effect of the eGRID Northwest region illustrates the effect of power generation mix on the upstream emission. However, this resource mix represents a very large geographical area and includes significant coal power generation. Since coal power is declining, such emissions are unlikely to be related to the Tacoma LNG project.

The volumetric scenario with 250,000 gpd production capacity results in lower net GHG reductions than the 500,000 gpd production capacity scenario even though the percentage GHG emission reductions are higher for Scenario A. Upstream emission estimates for natural gas also affect overall GHG emissions. The baseline estimate is based on the BC specific analysis from GHGenius. Emissions associated with specific components of the BC inventory result in a lower estimate and the U.S. emissions estimated by GREET result in a higher estimate; though these extraction practices in BC are represented in GHGenius. The analysis was based on flaring non methane hydrocarbons, although these could be used for process fuel or LPG. The use of waste gas is a significant potential GHG savings. The effect of marine fuel parameters is also shown including the effect of capturing CH4 from bunkering barges and the relative efficiency of LNG compared to marine fuel with emission controls or sulfur removal.

# A. APPENDIX A CALCULATION APPROACH

The following paragraphs summarize the generalized approach utilized to quantify construction emissions and emissions associated with operation of the plant. A description of evaporative emission estimation methods is also provided.

## A.1. Construction Emissions

Construction activities consist of development of the Tacoma LNG site, construction of equipment, and storage tanks. Construction activities would include operation of earth moving equipment, cranes, trucks, pile drivers, compressors, pumps, and other equipment. Employee commute traffic for construction workers would also generate GHG emissions[23].

Construction emissions consist of diesel burned in construction equipment, imported power. Construction emissions also include emissions from power used and other sources of emissions generated in the production of the construction materials. Life cycle construction emissions were calculated based on the following:

$$\mathbf{G}_C = \Sigma(U_{DC} \times (\mathbf{EF}_D + \mathbf{E}_D)) + T + U_{eC} \times \mathbf{E}_e + \Sigma(U_m \times \mathbf{E}_m) \qquad (4)$$ [24]

Where:
$\mathbf{G}_C$ = Tacoma LNG Construction GHG emissions in total tonnes
$\Sigma$ refers to summation of inputs for each specific energy input or material input
$U_{DC}$ = Use rate for diesel fuel use for each type of equipment
$\mathbf{EF}_D$ = Emission factor for diesel equipment
$\mathbf{E}_D$ = WTT emission rate from diesel fuel
T = Construction employee commute emissions
$U_{eC}$ = Use rate for electric power used during constructions
$\mathbf{E}_e$ = WTT emission rate for imported electric power
$U_m$ = Use rate for materials used in construction
$\mathbf{E}_m$ = WTT emission rate for materials of construction

Emissions from diesel equipment will be summed over the totally fuel use for each type of construction equipment. Similarly, emissions from construction materials are summed over all the materials used for the Tacoma LNG. Inputs, emission factors, and WTT emission data are described in Section 2.4 and the construction emission results will be examined. WTT emission rates for fuels will be obtained from the GREET1_2017 model. Upstream life cycle emission

[23] It is unclear if employee transportation creates a new source of GHG emissions since the employees would be driving to work with or without construction of the PSEL. These emissions are calculated nonetheless.
[24] The nomenclature assumes appropriate unit conversions such as grams to tonnes or Btu to mmBtu. For example, gallons of diesel fuel use × Btu/gal diesel × (diesel equipment emission factor in g/mmBtu + upstream diesel emission factor from GREET in g/mmBtu) for each pollutant $CO_2$, $CH_4$, and $N_2O$. Similarly, for construction materials tons of steel × g/ton of steel.

rates for materials or construction will be obtained from the GREET2 model as well as the USLCI database (NREL, 2012) and other sources.

**Table A.1.** Equipment list with technical specifications used during construction

| Equipment List | No. | Horsepower | Utilization | Load Factor |
|---|---|---|---|---|
| **Upland Construction (demo, soil, utilities)** | | | | |
| Cat 345 Backhoe 4 cy | 1 | 165 | 75% | 21% |
| 100 Ton Crawler Crane | 1 | 250 | 85% | 43% |
| 200 Ton Crawler Crane | 1 | 300 | 85% | 43% |
| 22 Ton Hydrocrane | 1 | 85 | 85% | 43% |
| 30 Ton Hydrocrane | 1 | 100 | 85% | 43% |
| Air Compressor | 2 | 55 | 100% | 43% |
| Cat Compactor | 2 | 65 | 85% | 59% |
| Cat D6 Dozer | 2 | 65 | 85% | 59% |
| Crew Truck, 3/4 ton | 2 | 250 | 85% | 59% |
| Dump Trucks 15 cy | 2 | 285 | 75% | 59% |
| Flatbed Truck (Matl. Handling) | 1 | 200 | 85% | 59% |
| Forklift, 8,000 lbs | 1 | 85 | 50% | 59% |
| Fuel Truck | 2 | 200 | 85% | 59% |
| Loader, Cat 966, 4 cy | 2 | 100 | 85% | 21% |
| Manlifts | 1 | 50 | 85% | 21% |
| *In-water Construction* | | | | |
| Forklift, 8,000 lbs | 2 | 65 | 75% | 59% |
| Air Compressor | 4 | 55 | 100% | 43% |
| Crane, 60 ton | 3 | 290 | 85% | 43% |
| Crew Truck, 3/4 ton | 3 | 250 | 25% | 59% |
| Diesel Pile Driver Hammer | 3 | 85 | 85% | 59% |
| Flatbed Truck (Matl. Handling) | 3 | 200 | 85% | 59% |
| Fuel Truck | 2 | 200 | 25% | 59% |
| Loader, Cat 966, 4 cy | 2 | 100 | 75% | 21% |
| Personnel Work Boat | 1 | 30 | 75% | 45% |
| Tug/Work Barge w/crane | 1 | 250 | 85% | 45% |
| *LNG Facility Construction* | | | | |
| Cat 345 Backhoe 4 cy | 1 | 165 | 85% | 21% |
| 100 Ton Crawler Crane | 2 | 250 | 85% | 43% |
| 200 Ton Crawler Crane | 3 | 300 | 85% | 43% |
| 22 Ton Hydrocrane | 4 | 85 | 85% | 43% |
| 30 Ton Hydrocrane | 3 | 100 | 85% | 43% |
| Air Compressor | 4 | 55 | 85% | 43% |
| Cat Compactor | 3 | 65 | 85% | 59% |
| Cat D6 Dozer | 3 | 65 | 85% | 59% |
| Concrete Pump | 3 | 150 | 85% | 43% |
| Crane, 60 ton | 1 | 290 | 50% | 43% |
| Crew Truck, 3/4 ton | 6 | 250 | 85% | 59% |
| Dump Trucks 15 cy | 1 | 285 | 75% | 59% |
| Flatbed Truck (Matl. Handling) | 3 | 200 | 85% | 59% |
| Forklift, 8,000 lbs | 3 | 85 | 50% | 59% |
| Fuel Truck | 3 | 200 | 85% | 59% |
| Loader, Cat 966, 4 cy | 3 | 100 | 85% | 21% |
| Manlifts | 6 | 50 | 85% | 21% |

**Table A.2.** Equipment list with emission factors

| Equipment List | Fuel Use Rate (gal/hr) | CO Emission Factor (g/hp-hr) | VOC Emission Factor (g/hp-hr) | $CO_2$ Emission Factor (g/hp-hr) | $CO_2c$ Emission Factor (g/hp-hr) |
|---|---|---|---|---|---|
| **Upland Construction (demo, soil, utilities)** | | | | | |
| Cat 345 Backhoe 4 cy | 0.52 | 2.330 | 0.606 | 625 | 631 |
| 100 Ton Crawler Crane | 0.17 | 0.429 | 0.175 | 530 | 531 |
| 200 Ton Crawler Crane | 0.17 | 0.429 | 0.175 | 530 | 531 |
| 22 Ton Hydrocrane | 0.42 | 1.542 | 0.230 | 590 | 593 |
| 30 Ton Hydrocrane | 0.42 | 1.542 | 0.230 | 590 | 593 |
| Air Compressor | 1.02 | 0.908 | 0.207 | 590 | 592 |
| Cat Compactor | 0.73 | 2.408 | 0.280 | 595 | 600 |
| Cat D6 Dozer | 0.49 | 1.769 | 0.192 | 596 | 599 |
| Crew Truck, 3/4 ton | 0.07 | 0.203 | 0.137 | 536 | 537 |
| Dump Trucks 15 cy | 0.07 | 0.203 | 0.137 | 536 | 537 |
| Flatbed Truck (Matl. Handling) | 0.11 | 0.322 | 0.141 | 536 | 537 |
| Forklift, 8,000 lbs | 0.65 | 2.265 | 0.257 | 595 | 599 |
| Fuel Truck | 0.11 | 0.322 | 0.141 | 536 | 537 |
| Loader, Cat 966, 4 cy | 0.65 | 5.288 | 0.839 | 693 | 704 |
| Manlifts | 3.66 | 5.873 | 1.516 | 691 | 705 |
| *In-water Construction* | | | | | |
| Forklift, 8,000 lbs | 0.65 | 2.265 | 0.257 | 595 | 599 |
| Air Compressor | 1.02 | 0.908 | 0.207 | 590 | 592 |
| Crane, 60 ton | 0.17 | 0.429 | 0.175 | 530 | 531 |
| Crew Truck, 3/4 ton | 0.07 | 0.203 | 0.137 | 536 | 537 |
| Diesel Pile Driver Hammer | 0.73 | 2.408 | 0.280 | 595 | 600 |
| Flatbed Truck (Matl. Handling) | 0.11 | 0.322 | 0.141 | 536 | 537 |
| Fuel Truck | 0.11 | 0.322 | 0.141 | 536 | 537 |
| Loader, Cat 966, 4 cy | 0.65 | 5.288 | 0.839 | 693 | 704 |
| Personnel Work Boat | 3.90 | 3.728 | 0.224 | 515 | 521 |
| Tug/Work Barge w/crane | 15.90 | 3.728 | 0.224 | 515 | 521 |
| *LNG Facility Construction (including Storage Tank)* | | | | | |
| Cat 345 Backhoe 4 cy | 0.52 | 2.330 | 0.606 | 625 | 631 |
| 100 Ton Crawler Crane | 0.17 | 0.429 | 0.175 | 530 | 531 |
| 200 Ton Crawler Crane | 0.17 | 0.429 | 0.175 | 530 | 531 |
| 22 Ton Hydrocrane | 0.42 | 1.542 | 0.230 | 590 | 593 |
| 30 Ton Hydrocrane | 0.42 | 1.542 | 0.230 | 590 | 593 |
| Air Compressor | 1.02 | 0.908 | 0.207 | 590 | 592 |
| Cat Compactor | 0.73 | 2.408 | 0.280 | 595 | 600 |
| Cat D6 Dozer | 0.49 | 1.769 | 0.192 | 596 | 599 |
| Concrete Pump | 1.06 | 2.355 | 0.473 | 589 | 594 |
| Crane, 60 ton | 0.17 | 0.429 | 0.175 | 530 | 531 |
| Crew Truck, 3/4 ton | 0.07 | 0.203 | 0.137 | 536 | 537 |
| Dump Trucks 15 cy | 0.07 | 0.203 | 0.137 | 536 | 537 |
| Flatbed Truck (Matl. Handling) | 0.11 | 0.322 | 0.141 | 536 | 537 |
| Forklift, 8,000 lbs | 0.65 | 2.265 | 0.257 | 595 | 599 |
| Fuel Truck | 0.11 | 0.322 | 0.141 | 536 | 537 |
| Loader, Cat 966, 4 cy | 0.65 | 5.288 | 0.839 | 693 | 704 |
| Manlifts | 3.66 | 5.873 | 1.516 | 691 | 705 |

## **Table A.3.** Construction Emissions during 1. year

| Construction Emission during 1. Year | | | | | | | | | | | | | | | | | | Upstream Emission Diesel production | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equipment List | No. | Equipment Use Duration (months) | Horsepower | Utilization | Load Factor | Fuel Use Rate (gal/hr) | CO Emission Factor (g/hp-hr) | VOC Emission Factor (g/hp-hr) | $CO_2$ Emission Factor (g/hp-hr) | $CO_2c$ Emission Factor (g/hp-hr) | $CH_4$ Emission Factor (g/gal) | $N_2O$ Emission Factor (g/gal) | CO2c (tonne/ year) | CH4 (tonne/ year) | N2O (tonne/ year) | CO2e use (tonne/ year) | Fuel consumption (mmBtu/year) | Upstream CO2 (tonne/ year) | Upstream CH4 (tonne/ year) | Upstream N2O (tonne/ year) | Upstream CO2e (tonne/ year) | Total CO2e (tonne/ year) |
| **Upland Construction (demo, soil, utilities)** | | | | | | | | | | | | | | | | | | | | | | |
| Cat 345 Backhoe 4 cy | 1 | 6 | 165 | 75% | 21% | 0.52 | 2.600 | 0.664 | 624 | 630 | 0.740 | 0.450 | 20 | 0.0004 | 0.0002 | 20.3 | 82 | 1.7156 | 0.0017 | 0.00001 | 1.7624 | 22.0 |
| 100 Ton Crawler Crane | 1 | 6 | 250 | 85% | 43% | 0.17 | 0.491 | 0.188 | 530 | 531 | 0.740 | 0.450 | 60 | 0.0001 | 0.0001 | 59.9 | 28 | 0.5763 | 0.0006 | 0.00000 | 0.5920 | 60.5 |
| 200 Ton Crawler Crane | 1 | 6 | 300 | 85% | 43% | 0.17 | 0.491 | 0.188 | 530 | 531 | 0.740 | 0.450 | 72 | 0.0001 | 0.0001 | 71.8 | 28 | 0.5763 | 0.0006 | 0.00000 | 0.5920 | 72.4 |
| 22 Ton Hydrocrane | 1 | 6 | 85 | 85% | 43% | 0.42 | 1.733 | 0.255 | 590 | 594 | 0.740 | 0.450 | 23 | 0.0003 | 0.0002 | 22.8 | 67 | 1.3976 | 0.0014 | 0.00001 | 1.4358 | 24.2 |
| 30 Ton Hydrocrane | 1 | 6 | 100 | 85% | 43% | 0.42 | 1.733 | 0.255 | 590 | 594 | 0.740 | 0.450 | 27 | 0.0003 | 0.0002 | 26.8 | 67 | 1.3976 | 0.0014 | 0.00001 | 1.4358 | 28.2 |
| Air Compressor | 2 | 6 | 55 | 100% | 43% | 1.02 | 1.090 | 0.227 | 590 | 592 | 0.740 | 0.450 | 35 | 0.0019 | 0.0011 | 34.9 | 323 | 6.7564 | 0.0068 | 0.00005 | 6.9407 | 41.9 |
| Cat Compactor | 2 | 6 | 65 | 85% | 59% | 0.73 | 2.600 | 0.664 | 595 | 601 | 0.740 | 0.450 | 48 | 0.0011 | 0.0007 | 48.5 | 232 | 4.8487 | 0.0049 | 0.00003 | 4.9810 | 53.5 |
| Cat D6 Dozer | 2 | 6 | 65 | 85% | 59% | 0.49 | 2.663 | 0.309 | 595 | 600 | 0.740 | 0.450 | 48 | 0.0008 | 0.0005 | 48.4 | 155 | 3.2391 | 0.0033 | 0.00002 | 3.3275 | 51.7 |
| Crew Truck, 3/4 ton | 2 | 6 | 250 | 85% | 59% | 0.07 | 2.090 | 0.216 | 536 | 540 | 0.740 | 0.450 | 167 | 0.0001 | 0.0001 | 166.9 | 23 | 0.4902 | 0.0005 | 0.00000 | 0.5035 | 167.4 |
| Dump Trucks 15 cy | 2 | 6 | 285 | 75% | 59% | 0.07 | 0.274 | 0.141 | 536 | 537 | 0.740 | 0.450 | 167 | 0.0001 | 0.0001 | 166.9 | 23 | 0.4902 | 0.0005 | 0.00000 | 0.5035 | 167.4 |
| Flatbed Truck (Matl. Handling) | 1 | 6 | 200 | 85% | 59% | 0.11 | 0.519 | 0.150 | 536 | 537 | 0.740 | 0.450 | 66 | 0.0001 | 0.0001 | 66.4 | 18 | 0.3709 | 0.0004 | 0.00000 | 0.3811 | 66.8 |
| Forklift, 8,000 lbs | 1 | 6 | 85 | 50% | 59% | 0.65 | 2.535 | 0.284 | 595 | 600 | 0.740 | 0.450 | 19 | 0.0003 | 0.0002 | 18.6 | 103 | 2.1627 | 0.0022 | 0.00001 | 2.2217 | 20.8 |
| Fuel Truck | 2 | 6 | 200 | 85% | 59% | 0.11 | 0.519 | 0.150 | 536 | 537 | 0.740 | 0.450 | 133 | 0.0002 | 0.0001 | 132.9 | 35 | 0.7419 | 0.0007 | 0.00001 | 0.7621 | 133.7 |
| Loader, Cat 966, 4 cy | 2 | 6 | 100 | 85% | 21% | 0.65 | 5.700 | 0.924 | 693 | 705 | 0.740 | 0.450 | 31 | 0.0010 | 0.0006 | 31.2 | 205 | 4.2790 | 0.0043 | 0.00003 | 4.3958 | 35.6 |
| Manlifts | 1 | 6 | 50 | 85% | 21% | 3.66 | 6.316 | 1.643 | 691 | 706 | 0.740 | 0.450 | 8 | 0.0028 | 0.0017 | 8.4 | 580 | 12.1250 | 0.0122 | 0.00008 | 12.4559 | 20.8 |
| In-water Construction | | | | | | | | | | | | | | | | | | | | | | |
| Forklift, 8,000 lbs | 2 | 6 | 65 | 75% | 59% | 0.65 | 2.535 | 0.294 | 595 | 600 | 0.740 | 0.450 | 43 | 0.0009 | 0.0005 | 42.7 | 207 | 4.3254 | 0.0044 | 0.00003 | 4.4434 | 47.2 |
| Air Compressor | 4 | 6 | 55 | 100% | 43% | 1.02 | 1.090 | 0.181 | 590 | 592 | 0.740 | 0.450 | 69 | 0.0037 | 0.0023 | 69.8 | 646 | 13.5127 | 0.0136 | 0.00009 | 13.8814 | 83.7 |
| Crane, 60 ton | 3 | 6 | 290 | 85% | 43% | 0.17 | 0.491 | 0.098 | 530 | 531 | 0.740 | 0.450 | 208 | 0.0004 | 0.0002 | 208.2 | 83 | 1.7288 | 0.0017 | 0.00001 | 1.7760 | 210.0 |
| Crew Truck, 3/4 ton | 3 | 6 | 250 | 25% | 59% | 0.07 | 2.090 | 0.219 | 536 | 540 | 0.740 | 0.450 | 74 | 0.0001 | 0.0000 | 73.6 | 35 | 0.7353 | 0.0007 | 0.00001 | 0.7553 | 74.4 |
| Diesel Pile Driver Hammer | 3 | 6 | 85 | 85% | 59% | 0.73 | 2.663 | 0.327 | 595 | 600 | 0.740 | 0.450 | 95 | 0.0017 | 0.0010 | 95.0 | 348 | 7.2730 | 0.0073 | 0.00005 | 7.4715 | 102.4 |
| Flatbed Truck (Matl. Handling) | 3 | 6 | 200 | 85% | 59% | 0.11 | 0.519 | 0.121 | 536 | 537 | 0.740 | 0.450 | 199 | 0.0003 | 0.0002 | 199.3 | 53 | 1.1128 | 0.0011 | 0.00001 | 1.1432 | 200.4 |
| Fuel Truck | 2 | 6 | 200 | 25% | 59% | 0.11 | 0.519 | 0.121 | 536 | 537 | 0.740 | 0.450 | 39 | 0.0001 | 0.0000 | 39.1 | 35 | 0.7419 | 0.0007 | 0.00001 | 0.7621 | 39.8 |
| Loader, Cat 966, 4 cy | 2 | 6 | 100 | 75% | 21% | 0.65 | 5.700 | 0.832 | 693 | 705 | 0.740 | 0.450 | 27 | 0.0009 | 0.0005 | 27.5 | 205 | 4.2790 | 0.0043 | 0.00003 | 4.3958 | 31.9 |
| Personnel Work Boat | 1 | 4.99 | 30 | 75% | 45% | 3.90 | 3.728 | 0.298 | 515 | 521 | 0.020 | 0.090 | 5 | 0.0001 | 0.0003 | 5.5 | 513 | 10.7362 | 0.0108 | 0.00007 | 11.0291 | 16.5 |
| Tug/Work Barge w/crane | 1 | 1.04 | 500 | 85% | 45% | 31.80 | 3.728 | 0.224 | 515 | 521 | 0.020 | 0.090 | 21 | 0.0001 | 0.0005 | 21.5 | 876 | 18.3325 | 0.0185 | 0.00013 | 18.8328 | 40.4 |
| | | | | | | | | | | | | Annual To | 1,703 | 0.0178 | 0.0115 | 1707.1 | 4969 | 103.9 | 0.1 | 0.0 | 106.8 | 1,813.9 |

## **Table A.4.** Construction Emissions during 2. year

| Construction Emission during 2. Year | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equipment List | No. | Equipment Use Duration (months) | Horsepower | Utilization | Load Factor | Fuel Use Rate (gal/hr) | CO Emission Factor (g/hp-hr) | VOC Emission Factor (g/hp-hr) | $CO_2$ Emission Factor (g/hp-hr) | $CO_2c$ Emission Factor (g/hp-hr) | $CH_4$ Emission Factor (g/gal) | $N_2O$ Emission Factor (g/gal) | $CO_2c$ (tonne/ year) | CH4 (tonne/ year) | N2O (tonne/ year) | CO2e use (tonne/ year) | Fuel consumption (mmBtu/year) | Upstream CO2 (tonne/ year) | Upstream CH4 (tonne/ year) | Upstream N2O (tonne/ year) | Upstream CO2e (tonne/ year) | Total CO2e (tonne/ year) |
| **Upland Construction (demo, soil, utilities)** | | | | | | | | | | | | | | | | | | | | | | |
| Cat 345 Backhoe 4 cy | 1 | 6 | 165 | 75% | 21% | 0.52 | 2.330 | 0.606 | 625 | 631 | 0.740 | 0.450 | 20.2 | 0.0004 | 0.0002 | 20.3 | 82 | 1.7222 | 0.0017 | 0.00001 | 1.7692 | 22.0 |
| 100 Ton Crawler Crane | 1 | 6 | 250 | 85% | 43% | 0.17 | 0.429 | 0.175 | 530 | 531 | 0.740 | 0.450 | 59.8 | 0.0001 | 0.0001 | 59.9 | 27 | 0.5630 | 0.0006 | 0.00000 | 0.5784 | 60.4 |
| 200 Ton Crawler Crane | 1 | 6 | 300 | 85% | 43% | 0.17 | 0.429 | 0.175 | 530 | 531 | 0.740 | 0.450 | 71.8 | 0.0001 | 0.0001 | 71.8 | 27 | 0.5630 | 0.0006 | 0.00000 | 0.5784 | 72.4 |
| 22 Ton Hydrocrane | 1 | 6 | 85 | 85% | 43% | 0.42 | 1.542 | 0.230 | 590 | 593 | 0.740 | 0.450 | 22.7 | 0.0003 | 0.0002 | 22.8 | 66 | 1.3910 | 0.0014 | 0.00001 | 1.4290 | 24.2 |
| 30 Ton Hydrocrane | 1 | 6 | 100 | 85% | 43% | 0.42 | 1.542 | 0.230 | 590 | 593 | 0.740 | 0.450 | 26.7 | 0.0003 | 0.0002 | 26.8 | 66 | 1.3910 | 0.0014 | 0.00001 | 1.4290 | 28.2 |
| Air Compressor | 2 | 6 | 55 | 100% | 43% | 1.02 | 0.908 | 0.207 | 590 | 592 | 0.740 | 0.450 | 34.5 | 0.0019 | 0.0011 | 34.9 | 323 | 6.7564 | 0.0068 | 0.00005 | 6.9407 | 41.8 |
| Cat Compactor | 2 | 6 | 65 | 85% | 59% | 0.73 | 2.408 | 0.280 | 595 | 600 | 0.740 | 0.450 | 48.2 | 0.0011 | 0.0007 | 48.4 | 231 | 4.8354 | 0.0049 | 0.00003 | 4.9674 | 53.4 |
| Cat D6 Dozer | 2 | 6 | 65 | 85% | 59% | 0.49 | 1.769 | 0.192 | 596 | 599 | 0.740 | 0.450 | 48.2 | 0.0008 | 0.0005 | 48.3 | 155 | 3.2457 | 0.0033 | 0.00002 | 3.3343 | 51.7 |
| Crew Truck, 3/4 ton | 2 | 6 | 250 | 85% | 59% | 0.07 | 0.203 | 0.137 | 536 | 537 | 0.740 | 0.450 | 165.9 | 0.0001 | 0.0001 | 165.9 | 22 | 0.4637 | 0.0005 | 0.00000 | 0.4763 | 166.4 |
| Dump Trucks 15 cy | 2 | 6 | 285 | 75% | 59% | 0.07 | 0.203 | 0.137 | 536 | 537 | 0.740 | 0.450 | 166.9 | 0.0001 | 0.0001 | 166.9 | 22 | 0.4637 | 0.0005 | 0.00000 | 0.4763 | 167.4 |
| Flatbed Truck (Matl. Handling) | 1 | 6 | 200 | 85% | 59% | 0.11 | 0.322 | 0.141 | 536 | 537 | 0.740 | 0.450 | 66.4 | 0.0001 | 0.0001 | 66.4 | 17 | 0.3643 | 0.0004 | 0.00000 | 0.3743 | 66.8 |
| Forklift, 8,000 lbs | 1 | 6 | 85 | 50% | 59% | 0.65 | 2.265 | 0.257 | 595 | 599 | 0.740 | 0.450 | 18.5 | 0.0003 | 0.0002 | 18.6 | 103 | 2.1528 | 0.0022 | 0.00001 | 2.2115 | 20.8 |
| Fuel Truck | 2 | 6 | 200 | 85% | 59% | 0.11 | 0.322 | 0.141 | 536 | 537 | 0.740 | 0.450 | 132.8 | 0.0002 | 0.0001 | 132.8 | 35 | 0.7286 | 0.0007 | 0.00001 | 0.7485 | 133.6 |
| Loader, Cat 966, 4 cy | 2 | 6 | 100 | 85% | 21% | 0.65 | 5.288 | 0.839 | 693 | 704 | 0.740 | 0.450 | 31.0 | 0.0010 | 0.0006 | 31.2 | 206 | 4.3055 | 0.0043 | 0.00003 | 4.4230 | 35.6 |
| Manlifts | 1 | 6 | 50 | 85% | 21% | 3.66 | 5.873 | 1.516 | 691 | 705 | 0.740 | 0.450 | 7.8 | 0.0028 | 0.0017 | 8.3 | 579 | 12.1217 | 0.0122 | 0.00008 | 12.4525 | 20.8 |
| *In-water Construction* | | | | | | | | | | | | | | | | | | | | | | |
| Forklift, 8,000 lbs | 2 | 1 | 65 | 75% | 59% | 0.65 | 2.265 | 0.257 | 595 | 599 | 0.740 | 0.450 | 7.1 | 0.0001 | 0.0001 | 7.1 | 34 | 0.7176 | 0.0007 | 0.00000 | 0.7372 | 7.9 |
| Air Compressor | 4 | 1 | 55 | 100% | 43% | 1.02 | 0.908 | 0.207 | 590 | 592 | 0.740 | 0.450 | 11.5 | 0.0006 | 0.0004 | 11.6 | 108 | 2.2521 | 0.0023 | 0.00002 | 2.3136 | 13.9 |
| Crane, 60 ton | 3 | 1 | 290 | 85% | 43% | 0.17 | 0.429 | 0.175 | 530 | 531 | 0.740 | 0.450 | 34.7 | 0.0001 | 0.0000 | 34.7 | 13 | 0.2815 | 0.0003 | 0.00000 | 0.2892 | 35.0 |
| Crew Truck, 3/4 ton | 3 | 1 | 250 | 25% | 59% | 0.07 | 0.203 | 0.137 | 536 | 537 | 0.740 | 0.450 | 12.2 | 0.0000 | 0.0000 | 12.2 | 6 | 0.1159 | 0.0001 | 0.00000 | 0.1191 | 12.3 |
| Diesel Pile Driver Hammer | 3 | 1 | 85 | 85% | 59% | 0.73 | 2.408 | 0.280 | 595 | 600 | 0.740 | 0.450 | 15.8 | 0.0003 | 0.0002 | 15.8 | 58 | 1.2089 | 0.0012 | 0.00001 | 1.2418 | 17.1 |
| Flatbed Truck (Matl. Handling) | 3 | 1 | 200 | 85% | 59% | 0.11 | 0.322 | 0.141 | 536 | 537 | 0.740 | 0.450 | 33.2 | 0.0000 | 0.0000 | 33.2 | 9 | 0.1822 | 0.0002 | 0.00000 | 0.1871 | 33.4 |
| Fuel Truck | 2 | 1 | 200 | 25% | 59% | 0.11 | 0.322 | 0.141 | 536 | 537 | 0.740 | 0.450 | 6.5 | 0.0000 | 0.0000 | 6.5 | 6 | 0.1214 | 0.0001 | 0.00000 | 0.1248 | 6.6 |
| Loader, Cat 966, 4 cy | 2 | 1 | 100 | 75% | 21% | 0.65 | 5.288 | 0.839 | 693 | 704 | 0.740 | 0.450 | 4.6 | 0.0001 | 0.0001 | 4.6 | 34 | 0.7176 | 0.0007 | 0.00000 | 0.7372 | 5.3 |
| Personnel Work Boat | 1 | 1 | 30 | 75% | 45% | 3.90 | 3.728 | 0.224 | 515 | 521 | 0.020 | 0.090 | 1.1 | 0.0000 | 0.0001 | 1.1 | 103 | 2.1528 | 0.0022 | 0.00001 | 2.2115 | 3.3 |
| Tug/Work Barge w/crane | 1 | 1 | 250 | 85% | 45% | 15.90 | 3.728 | 0.224 | 515 | 521 | 0.020 | 0.090 | 10.2 | 0.0001 | 0.0002 | 10.3 | 420 | 8.7767 | 0.0089 | 0.00006 | 9.0161 | 19.3 |
| *LNG Facility Construction (including Storage Tank)* | | | | | | | | | | | | | | | | | | | | | | |
| Cat 345 Backhoe 4 cy | 1 | 7 | 165 | 85% | 21% | 0.52 | 2.330 | 0.606 | 625 | 631 | 0.740 | 0.450 | 26.7 | 0.0005 | 0.0003 | 26.8 | 96 | 2.0092 | 0.0020 | 0.00001 | 2.0641 | 28.9 |
| 100 Ton Crawler Crane | 2 | 7 | 250 | 85% | 43% | 0.17 | 0.429 | 0.175 | 530 | 531 | 0.740 | 0.450 | 139.6 | 0.0003 | 0.0002 | 139.7 | 63 | 1.3137 | 0.0013 | 0.00001 | 1.3496 | 141.0 |
| 200 Ton Crawler Crane | 3 | 7 | 300 | 85% | 43% | 0.17 | 0.429 | 0.175 | 530 | 531 | 0.740 | 0.450 | 251.3 | 0.0005 | 0.0003 | 251.4 | 94 | 1.9706 | 0.0020 | 0.00001 | 2.0244 | 253.4 |
| 22 Ton Hydrocrane | 4 | 7 | 85 | 85% | 43% | 0.42 | 1.542 | 0.230 | 590 | 593 | 0.740 | 0.450 | 106.0 | 0.0015 | 0.0009 | 106.3 | 310 | 6.4914 | 0.0066 | 0.00004 | 6.6685 | 113.0 |
| 30 Ton Hydrocrane | 3 | 7 | 100 | 85% | 43% | 0.42 | 1.542 | 0.230 | 590 | 593 | 0.740 | 0.450 | 93.5 | 0.0011 | 0.0007 | 93.8 | 233 | 4.8686 | 0.0049 | 0.00003 | 5.0014 | 98.8 |
| Air Compressor | 4 | 7 | 55 | 85% | 43% | 1.02 | 0.908 | 0.207 | 590 | 592 | 0.740 | 0.450 | 68.5 | 0.0037 | 0.0022 | 69.2 | 754 | 15.7649 | 0.0159 | 0.00011 | 16.1950 | 85.4 |
| Cat Compactor | 3 | 7 | 65 | 85% | 59% | 0.73 | 2.408 | 0.280 | 595 | 600 | 0.740 | 0.450 | 84.3 | 0.0020 | 0.0012 | 84.7 | 405 | 8.4620 | 0.0085 | 0.00006 | 8.6929 | 93.4 |
| Cat D6 Dozer | 3 | 7 | 65 | 85% | 59% | 0.49 | 1.769 | 0.192 | 596 | 599 | 0.740 | 0.450 | 84.3 | 0.0013 | 0.0008 | 84.6 | 272 | 5.6800 | 0.0057 | 0.00004 | 5.8350 | 90.4 |
| Concrete Pump | 3 | 7 | 150 | 85% | 43% | 1.06 | 2.355 | 0.473 | 589 | 594 | 0.74 | 0.450 | 140.5 | 0.0029 | 0.0017 | 141.1 | 587 | 12.2873 | 0.0124 | 0.00008 | 12.6226 | 153.8 |
| Crane, 60 ton | 1 | 7 | 290 | 50% | 43% | 0.17 | 0.429 | 0.175 | 530 | 531 | 0.740 | 0.450 | 47.6 | 0.0001 | 0.0001 | 47.7 | 31 | 0.6569 | 0.0007 | 0.00000 | 0.6748 | 48.3 |
| Crew Truck, 3/4 ton | 6 | 7 | 250 | 85% | 59% | 0.07 | 0.203 | 0.137 | 536 | 537 | 0.740 | 0.450 | 580.6 | 0.0004 | 0.0002 | 580.7 | 78 | 1.6229 | 0.0016 | 0.00001 | 1.6671 | 582.4 |
| Dump Trucks 15 cy | 1 | 7 | 285 | 75% | 59% | 0.07 | 0.203 | 0.137 | 536 | 537 | 0.740 | 0.450 | 97.3 | 0.0001 | 0.0000 | 97.4 | 13 | 0.2705 | 0.0003 | 0.00000 | 0.2779 | 97.6 |
| Flatbed Truck (Matl. Handling) | 3 | 7 | 200 | 85% | 59% | 0.11 | 0.322 | 0.141 | 536 | 537 | 0.740 | 0.450 | 232.3 | 0.0003 | 0.0002 | 232.4 | 61 | 1.2751 | 0.0013 | 0.00001 | 1.3099 | 233.7 |
| Forklift, 8,000 lbs | 3 | 7 | 85 | 50% | 59% | 0.65 | 2.265 | 0.257 | 595 | 599 | 0.740 | 0.450 | 64.8 | 0.0010 | 0.0006 | 65.1 | 360 | 7.5347 | 0.0076 | 0.00005 | 7.7403 | 72.8 |
| Fuel Truck | 3 | 7 | 200 | 85% | 59% | 0.11 | 0.322 | 0.141 | 536 | 537 | 0.740 | 0.450 | 232.3 | 0.0003 | 0.0002 | 232.4 | 61 | 1.2751 | 0.0013 | 0.00001 | 1.3099 | 233.7 |
| Loader, Cat 966, 4 cy | 3 | 7 | 100 | 85% | 21% | 0.65 | 5.288 | 0.839 | 693 | 704 | 0.740 | 0.450 | 54.2 | 0.0018 | 0.0011 | 54.6 | 360 | 7.5347 | 0.0076 | 0.00005 | 7.7403 | 62.3 |
| Manlifts | 6 | 7 | 50 | 85% | 21% | 3.66 | 5.873 | 1.516 | 691 | 705 | 0.740 | 0.450 | 54.3 | 0.0199 | 0.0121 | 58.4 | 4,056 | 84.8520 | 0.0856 | 0.00058 | 87.1673 | 145.6 |
| | | | | | | | | | | | | Annual To | 3,417 | 0.0486 | 0.0298 | 3427 | 10587.4376 | 221.4642 | 0.2235 | 0.0015 | 227.5070 | 3,654 |

## **Table A.5.** Construction Emissions during 3. year

**Construction Emission during 3. Year**

| Equipment List | No. | Equipment Use Duration (months) | Horsepower | Utilization | Load Factor | Fuel Use Rate (gal/hr) | CO Emission Factor (g/hp-hr) | VOC Emission Factor (g/hp-hr) | CO2 Emission Factor (g/hp-hr) | CO2c Emission Factor (g/hp-hr) | $CH_4$ Emission Factor (g/gal) | $N_2O$ Emission Factor (g/gal) | CO2c (tonne/ year) | CH4 (tonne/ year) | N2O (tonne/ year) | CO2e use (tonne/ year) | Fuel consumption (mmBtu/year) | Upstream CO2 (tonne/ year) | Upstream CH4 (tonne/ year) | Upstream N2O (tonne/ year) | Upstream CO2e (tonne/ year) | Total CO2e (tonne/ year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LNG Facility Construction (no Storage Tank Construction)** | | | | | | | | | | | | | | | | | | | | | | |
| 100 Ton Crawler Crane | 2 | 12 | 250 | 85% | 43% | 0.17 | 0.371 | 0.166 | 531 | 532 | 0.740 | 0.450 | 240 | 0.0005 | 0.0003 | 239.8 | 110 | 2.3051 | 0.0023 | 0.00002 | 2.3680 | 242.2 |
| 200 Ton Crawler Crane | 2 | 12 | 300 | 85% | 43% | 0.17 | 0.371 | 0.166 | 531 | 532 | 0.740 | 0.450 | 288 | 0.0005 | 0.0003 | 287.8 | 110 | 2.3051 | 0.0023 | 0.00002 | 2.3680 | 290.2 |
| 22 Ton Hydrocrane | 3 | 12 | 85 | 85% | 43% | 0.42 | 1.359 | 0.208 | 590 | 593 | 0.740 | 0.450 | 136 | 0.0020 | 0.0012 | 136.6 | 401 | 8.3858 | 0.0085 | 0.00006 | 8.6147 | 145.2 |
| 30 Ton Hydrocrane | 2 | 12 | 100 | 85% | 43% | 0.42 | 1.359 | 0.208 | 590 | 593 | 0.740 | 0.450 | 107 | 0.0013 | 0.0008 | 107.1 | 267 | 5.5906 | 0.0056 | 0.00004 | 5.7431 | 112.8 |
| Air Compressor | 3 | 12 | 55 | 85% | 43% | 1.02 | 0.734 | 0.189 | 590 | 592 | 0.740 | 0.450 | 88 | 0.0047 | 0.0029 | 89.0 | 969 | 20.2691 | 0.0205 | 0.00014 | 20.8222 | 109.8 |
| Cat Compactor | 2 | 12 | 65 | 85% | 59% | 0.73 | 2.163 | 0.254 | 595 | 599 | 0.740 | 0.450 | 96 | 0.0023 | 0.0014 | 96.8 | 464 | 9.6974 | 0.0098 | 0.00007 | 9.9620 | 106.7 |
| Cat D6 Dozer | 2 | 12 | 65 | 85% | 59% | 0.49 | 1.503 | 0.177 | 596 | 599 | 0.740 | 0.450 | 96 | 0.0015 | 0.0009 | 96.6 | 310 | 6.4782 | 0.0065 | 0.00004 | 6.6549 | 103.2 |
| Concrete Pump | 2 | 12 | 150 | 85% | 43% | 1.06 | 2.214 | 0.445 | 589 | 594 | 0.740 | 0.450 | 161 | 0.0033 | 0.0020 | 161.2 | 670 | 14.0161 | 0.0141 | 0.00010 | 14.3986 | 175.6 |
| Crane, 60 ton | 1 | 12 | 290 | 50% | 43% | 0.17 | 0.371 | 0.166 | 531 | 532 | 0.740 | 0.450 | 82 | 0.0002 | 0.0001 | 81.8 | 55 | 1.1526 | 0.0012 | 0.00001 | 1.1840 | 83.0 |
| Crew Truck, 3/4 ton | 4 | 12 | 250 | 85% | 59% | 0.07 | 0.163 | 0.135 | 536 | 537 | 0.740 | 0.450 | 664 | 0.0005 | 0.0003 | 663.6 | 94 | 1.9607 | 0.0020 | 0.00001 | 2.0142 | 665.6 |
| Flatbed Truck (Matl. Handling) | 2 | 12 | 200 | 85% | 59% | 0.11 | 0.239 | 0.137 | 536 | 537 | 0.740 | 0.450 | 265 | 0.0003 | 0.0002 | 265.5 | 71 | 1.4838 | 0.0015 | 0.00001 | 1.5242 | 267.1 |
| Forklift, 8,000 lbs | 2 | 12 | 85 | 25% | 59% | 0.65 | 2.007 | 0.233 | 595 | 599 | 0.740 | 0.450 | 37 | 0.0006 | 0.0004 | 37.1 | 414 | 8.6508 | 0.0087 | 0.00006 | 8.8868 | 46.0 |
| Fuel Truck | 2 | 12 | 200 | 85% | 59% | 0.11 | 0.239 | 0.137 | 536 | 537 | 0.740 | 0.450 | 265 | 0.0003 | 0.0002 | 265.5 | 71 | 1.4838 | 0.0015 | 0.00001 | 1.5242 | 267.1 |
| Loader, Cat 966, 4 cy | 2 | 12 | 100 | 85% | 21% | 0.65 | 4.895 | 0.759 | 694 | 704 | 0.740 | 0.450 | 62 | 0.0020 | 0.0012 | 62.4 | 409 | 8.5581 | 0.0086 | 0.00006 | 8.7916 | 71.2 |
| Manlifts | 4 | 12 | 50 | 85% | 21% | 3.66 | 5.441 | 1.393 | 692 | 705 | 0.740 | 0.450 | 62 | 0.0227 | 0.0138 | 66.7 | 4,637 | 97.0002 | 0.0979 | 0.00067 | 99.6470 | 166.4 |
| | | | | | | | | | | | | Annual To | 2,649 | 0.0428 | 0.0260 | 2,658 | 9,052 | 189 | 0 | 0 | 195 | 2,852 |

## **Table A.6.** Construction Emissions during 4. year

**Construction Emission during 4. Year**

| Equipment List | No. | Equipment Use Duration (months) | Horsepower | Utilization | Load Factor | Fuel Use Rate (gal/hr) | CO Emission Factor (g/hp-hr) | VOC Emission Factor (g/hp-hr) | CO2 Emission Factor (g/hp-hr) | CO2c Emission Factor (g/hp-hr) | $CH_4$ Emission Factor (g/gal) | $N_2O$ Emission Factor (g/gal) | CO2c (tonne/ year) | CH4 (tonne/ year) | N2O (tonne/ year) | CO2e use (tonne/ year) | Fuel consumption (mmBtu/year) | Upstream CO2 (tonne/ year) | Upstream CH4 (tonne/ year) | Upstream N2O (tonne/ year) | Upstream CO2e (tonne/ year) | Total CO2e (tonne/ year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LNG Facility Construction (no Storage Tank Construction)** | | | | | | | | | | | | | | | | | | | | | | |
| 100 Ton Crawler Crane | 2 | 7 | 250 | 85% | 43% | 0.17 | 0.317 | 0.159 | 531 | 532 | 0.740 | 0.450 | 140 | 0.0004 | 0.0002 | 139.9 | 64 | 1.3446 | 0.0014 | 0.00001 | 1.3813 | 141.3 |
| 200 Ton Crawler Crane | 2 | 7 | 300 | 85% | 43% | 0.17 | 0.317 | 0.159 | 531 | 532 | 0.740 | 0.450 | 168 | 0.0004 | 0.0002 | 167.8 | 64 | 1.3446 | 0.0014 | 0.00001 | 1.3813 | 169.2 |
| 22 Ton Hydrocrane | 3 | 7 | 85 | 85% | 43% | 0.42 | 1.183 | 0.188 | 590 | 592 | 0.740 | 0.450 | 79 | 0.0013 | 0.0008 | 79.7 | 234 | 4.8917 | 0.0049 | 0.00003 | 5.0252 | 84.7 |
| 30 Ton Hydrocrane | 2 | 7 | 100 | 85% | 43% | 0.42 | 1.183 | 0.188 | 590 | 592 | 0.740 | 0.450 | 62 | 0.0008 | 0.0005 | 62.5 | 156 | 3.2612 | 0.0033 | 0.00002 | 3.3501 | 65.8 |
| Air Compressor | 3 | 7 | 55 | 85% | 43% | 1.02 | 0.572 | 0.172 | 590 | 591 | 0.740 | 0.450 | 51 | 0.0031 | 0.0019 | 51.9 | 565 | 11.8236 | 0.0119 | 0.00008 | 12.1463 | 64.1 |
| Cat Compactor | 2 | 7 | 65 | 85% | 59% | 0.73 | 1.930 | 0.232 | 595 | 599 | 0.740 | 0.450 | 56 | 0.0015 | 0.0009 | 56.4 | 270 | 5.6568 | 0.0057 | 0.00004 | 5.8112 | 62.3 |
| Cat D6 Dozer | 2 | 7 | 65 | 85% | 59% | 0.49 | 1.257 | 0.164 | 596 | 598 | 0.740 | 0.450 | 56 | 0.0010 | 0.0006 | 56.3 | 181 | 3.7789 | 0.0038 | 0.00003 | 3.8820 | 60.2 |
| Concrete Pump | 2 | 7 | 150 | 85% | 43% | 1.06 | 2.078 | 0.417 | 589 | 594 | 0.740 | 0.450 | 94 | 0.0021 | 0.0013 | 94.0 | 391 | 8.1761 | 0.0083 | 0.00006 | 8.3992 | 102.4 |
| Crane, 60 ton | 1 | 7 | 290 | 50% | 43% | 0.17 | 0.317 | 0.159 | 531 | 532 | 0.740 | 0.450 | 48 | 0.0001 | 0.0001 | 47.7 | 32 | 0.6723 | 0.0007 | 0.00000 | 0.6907 | 48.4 |
| Crew Truck, 3/4 ton | 4 | 7 | 250 | 85% | 59% | 0.07 | 0.139 | 0.133 | 536 | 537 | 0.740 | 0.450 | 387 | 0.0003 | 0.0002 | 387.1 | 55 | 1.1437 | 0.0012 | 0.00001 | 1.1749 | 388.3 |
| Flatbed Truck (Matl. Handling) | 2 | 7 | 200 | 85% | 59% | 0.11 | 0.192 | 0.134 | 536 | 537 | 0.740 | 0.450 | 155 | 0.0002 | 0.0001 | 154.9 | 41 | 0.8655 | 0.0009 | 0.00001 | 0.8891 | 155.8 |
| Forklift, 8,000 lbs | 2 | 7 | 85 | 25% | 59% | 0.65 | 1.762 | 0.211 | 595 | 598 | 0.740 | 0.450 | 22 | 0.0004 | 0.0002 | 21.7 | 241 | 5.0463 | 0.0051 | 0.00003 | 5.1840 | 26.8 |
| Fuel Truck | 2 | 7 | 200 | 85% | 59% | 0.11 | 0.192 | 0.134 | 536 | 537 | 0.740 | 0.450 | 155 | 0.0002 | 0.0001 | 154.9 | 41 | 0.8655 | 0.0009 | 0.00001 | 0.8891 | 155.8 |
| Loader, Cat 966, 4 cy | 2 | 7 | 100 | 85% | 21% | 0.65 | 4.557 | 0.694 | 694 | 703 | 0.740 | 0.450 | 36 | 0.0013 | 0.0008 | 36.4 | 239 | 4.9922 | 0.0050 | 0.00003 | 5.1284 | 41.5 |
| Manlifts | 4 | 7 | 50 | 85% | 21% | 3.66 | 5.021 | 1.273 | 692 | 704 | 0.740 | 0.450 | 36 | 0.0150 | 0.0089 | 39.2 | 2,705 | 56.5835 | 0.0571 | 0.00039 | 58.1274 | 97.3 |
| | | | | | | | | | | | | Annual To | 1,545 | 0.0280 | 0.0168 | 1,550 | 5,280 | 110 | 0 | 0 | 113 | 1,664 |

Notes:
- Assume 48 hours per week; 4.28 weeks per month 205 hrs/month
- Emission factors for CO, VOC, and CO2 are average NONROAD emission rates for the State of Washington.
- Emission factors for CH4 and N2O are from the Climate Registry 2014 Default Emission Factors, Table 13.7.
- Tugboat, Workboat, and Personnel Boat Emissions factors from U.S. Environmental Protection Agency Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories Final Report April 2009, Table 3-8: Harbor Craft Emission Factors (g/kWh)

**Table A.7.** Road Vehicle Terminal Construction Criteria Pollutant Emissions for 1. and 2. Year of Construction

**Road Vehicle Terminal Construction Criteria Pollutant Emissions**

PSE LNG

Construction Vehicle Emissions - Winter 1. Year

| Vehicle Class | Area From Which Workers Commute | VMT | $CO_2$ (g/VMT) | $CH_4$ (g/VMT) | $N_2O$ (g/VMT) | CO (g/VMT) | VOCs (g/VMT) | $CO_2c$ (g/VMT) | $CO_2$ (tonne/ year) | $CH_4$ (tonne/ year) | $N_2O$ (tonne/ year) | $CO_2e$ (tonne/ year) | Fuel consumption (mmBtu/ year) | Upstream $CO_2$ (tonne/ year) | Upstream $CH_4$ (tonne/ year) | Upstream $N_2O$ (tonne/ year) | Upstream $CO_2e$ (tonne/ year) | Total $CO_2e$ (tonne/ year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Construction Workers Car | Seattle-Tacoma | 0 | 311.0 | 0.0 | 0.0 | 2.83 | 0.0 | 316 | 0.0 | 0.000 | 0.000 | 0.00 | 0.000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Heavy Duty Delivery Trucks | | 38 | 1942.0 | 0.0 | 0.0 | 3.11 | 0.5 | 1,949 | 0.074 | 0.000 | 0.000 | 0.07 | 0.949 | 0.02300 | 0.00000 | 0.00000 | 0.02300 | 0.09710 |
| | | | | | | | | Total | 0.074 | 0.000 | 0.000 | 0.074 | 0.949 | 0.023 | 0.000 | 0.000 | 0.023 | 0.097 |

Construction Vehicle Emissions - Summer 1. Year

| Vehicle Class | Area From Which Workers Commute | VMT | $CO_2$ (g/VMT) | $CH_4$ (g/VMT) | $N_2O$ (g/VMT) | CO (g/VMT) | VOCs (g/VMT) | $CO_2c$ (g/VMT) | $CO_2$ (tonne/ year) | $CH_4$ (tonne/ year) | $N_2O$ (tonne/ year) | $CO_2e$ (tonne/ year) | Fuel consumption (mmBtu/ year) | Upstream $CO_2$ (tonne/ year) | Upstream $CH_4$ (tonne/ year) | Upstream $N_2O$ (tonne/ year) | Upstream $CO_2e$ (tonne/ year) | Total $CO_2e$ (tonne/ year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Construction Workers Car | Seattle-Tacoma | 0 | 325.2 | 0.0 | 0.0 | 1.83 | 0.0 | 328 | 0.0 | 0.000 | 0.000 | 0.00 | 0.000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Heavy Duty Delivery Trucks | | 1,225 | 2017.0 | 0.0 | 0.0 | 3.11 | 0.5 | 2,024 | 2.5 | 0.000 | 0.000 | 2.48 | 31.756 | 0.77011 | 0.00000 | 0.00000 | 0.77011 | 3.25051 |
| | | | | | | | | Total | 2.5 | 0.000 | 0.000 | 2.48 | 31.756 | 0.770 | 0.000 | 0.000 | 0.770 | 3.251 |
| | | | | | | | | **Annual Total** | **2.6** | **0.0** | **0.0** | **2.6** | **32.7** | **0.8** | **0.0** | **0.0** | **0.8** | **3.3** |

Construction Vehicle Emissions - Winter 2. Year

| Vehicle Class | Area From Which Workers Commute | VMT | $CO_2$ (g/VMT) | $CH_4$ (g/VMT) | $N_2O$ (g/VMT) | CO (g/VMT) | VOCs (g/VMT) | $CO_2c$ (g/VMT) | $CO_2$ (tonne/ year) | $CH_4$ (tonne/ year) | $N_2O$ (tonne/ year) | $CO_2e$ (tonne/ year) | Fuel consumption (mmBtu/ year) | Upstream $CO_2$ (tonne/ year) | Upstream $CH_4$ (tonne/ year) | Upstream $N_2O$ (tonne/ year) | Upstream $CO_2e$ (tonne/ year) | Total $CO_2e$ (tonne/ year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Construction Workers | Seattle-Tacoma | 309,120 | 306.0 | 0.0 | 0.0 | 2.68 | 0.0 | 310 | 95.9 | 0.001 | 0.000 | 96.03 | 1250.964 | 30.33651 | 0.00000 | 0.00000 | 30.33651 | 126.37105 |
| Heavy Duty Delivery Trucks | | 9,999 | 1942.0 | 0.0 | 0.0 | 2.86 | 0.5 | 1,948 | 19.5 | 0.000 | 0.000 | 19.49 | 249.548 | 6.05165 | 0.00000 | 0.00000 | 6.05165 | 25.54304 |
| | | | | | | | | Total | 115.4 | 0.001 | 0.000 | 115.53 | 1500.512 | 36.388 | 0.000 | 0.000 | 36.388 | 151.914 |

Construction Vehicle Emissions - Summer 2. Year

| Vehicle Class | Area From Which Workers Commute | VMT | $CO_2$ (g/VMT) | $CH_4$ (g/VMT) | $N_2O$ (g/VMT) | CO (g/VMT) | VOCs (g/VMT) | $CO_2c$ (g/VMT) | $CO_2$ (tonne/ year) | $CH_4$ (tonne/ year) | $N_2O$ (tonne/ year) | $CO_2e$ (tonne/ year) | Fuel consumption (mmBtu/ year) | Upstream $CO_2$ (tonne/ year) | Upstream $CH_4$ (tonne/ year) | Upstream $N_2O$ (tonne/ year) | Upstream $CO_2e$ (tonne/ year) | Total $CO_2e$ (tonne/ year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Construction Workers Car | Seattle-Tacoma | 309,120 | 319.3 | 0.0 | 0.0 | 1.70 | 0.0 | 322 | 99.6 | 0.001 | 0.000 | 99.68 | 1298.405 | 31.48698 | 0.00000 | 0.00000 | 31.48698 | 131.16349 |
| Heavy Duty Delivery Trucks | | 5,789 | 2018.0 | 0.0 | 0.0 | 2.86 | 0.5 | 2,024 | 11.7 | 0.000 | 0.000 | 11.72 | 150.110 | 3.64025 | 0.00000 | 0.00000 | 3.64025 | 15.36491 |
| | | | | | | | | Total | 111.3 | 0.001 | 0.000 | 111.40 | 1448.515 | 35.127 | 0.000 | 0.000 | 35.127 | 146.528 |
| | | | | | | | | **Annual Total** | **226.7** | **0.0** | **0.0** | **226.9** | **2949.0** | **71.5** | **0.0** | **0.0** | **71.5** | **298.4** |

**Table A.8.** Road Vehicle Terminal Construction Criteria Pollutant Emissions for 3. and 4. Year of Construction

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Construction Vehicle Emissions - Winter 3. Year | | | | | | | | | | | | | | | | | | |
| Vehicle Class | Area From Which Workers Commute | VMT | $CO_2$ (g/VMT) | $CH_4$ (g/VMT) | $N_2O$ (g/VMT) | CO (g/VMT) | VOCs (g/VMT) | $CO_2c$ (g/VMT) | $CO_2$ (tonne/ year) | $CH_4$ (tonne/ year) | $N_2O$ (tonne/ year) | $CO_2e$ (tonne/ year) | Fuel consumption (mmBtu/ year) | Upstream $CO_2$ (tonne/ year) | Upstream $CH_4$ (tonne/ year) | Upstream $N_2O$ (tonne/ year) | Upstream $CO_2e$ (tonne/ year) | Total $CO_2e$ (tonne/ year) |
| Construction Workers Car | Seattle-Tacoma | 302,400 | 300.0 | 0.0 | 0.0 | 2.56 | 0.0 | 304 | 92.0 | 0.001 | 0.000 | 92.07 | 1199.349 | 29.08482 | 0.00000 | 0.00000 | 29.08482 | 121.15696 |
| Heavy Duty Delivery Trucks | | 6,356 | 1942.0 | 0.0 | 0.0 | 2.62 | 0.4 | 1,947 | 12.4 | 0.000 | 0.000 | 12.39 | 158.591 | 3.84592 | 0.00000 | 0.00000 | 3.84592 | 16.23300 |
| | | | | | | | | Total | 104.3 | 0.001 | 0.000 | 104.46 | 1357.940 | 32.931 | 0.000 | 0.000 | 32.931 | 137.390 |
| Construction Vehicle Emissions - Summer 3. Year | | | | | | | | | | | | | | | | | | |
| Vehicle Class | Area From Which Workers Commute | VMT | $CO_2$ (g/VMT) | $CH_4$ (g/VMT) | $N_2O$ (g/VMT) | CO (g/VMT) | VOCs (g/VMT) | $CO_2c$ (g/VMT) | $CO_2$ (tonne/ year) | $CH_4$ (tonne/ year) | $N_2O$ (tonne/ year) | $CO_2e$ (tonne/ year) | Fuel consumption (mmBtu/ year) | Upstream $CO_2$ (tonne/ year) | Upstream $CH_4$ (tonne/ year) | Upstream $N_2O$ (tonne/ year) | Upstream $CO_2e$ (tonne/ year) | Total $CO_2e$ (tonne/ year) |
| Construction Workers Car | Seattle-Tacoma | 614,880 | 313.8 | 0.0 | 0.0 | 1.59 | 0.0 | 316 | 194.5 | 0.002 | 0.001 | 194.76 | 2536.972 | 61.52286 | 0.00000 | 0.00000 | 61.52286 | 256.28219 |
| Heavy Duty Delivery Trucks | | 4,160 | 2018.0 | 0.0 | 0.0 | 2.62 | 0.4 | 2,023 | 8.4 | 0.000 | 0.000 | 8.42 | 107.846 | 2.61531 | 0.00000 | 0.00000 | 2.61531 | 11.03881 |
| | | | | | | | | Total | 202.9 | 0.002 | 0.001 | 203.18 | 2644.818 | 64.138 | 0.000 | 0.000 | 64.138 | 267.321 |
| | | | | | | | | **Annual Total** | **307.3** | **0.0** | **0.0** | **307.6** | **4002.8** | **97.1** | **0.0** | **0.0** | **97.1** | **404.7** |
| Construction Vehicle Emissions - Winter 4. Year | | | | | | | | | | | | | | | | | | |
| Vehicle Class | Area From Which Workers Commute | VMT | $CO_2$ (g/VMT) | $CH_4$ (g/VMT) | $N_2O$ (g/VMT) | CO (g/VMT) | VOCs (g/VMT) | $CO_2c$ (g/VMT) | $CO_2$ (tonne/ year) | $CH_4$ (tonne/ year) | $N_2O$ (tonne/ year) | $CO_2e$ (tonne/ year) | Fuel consumption (mmBtu/ year) | Upstream $CO_2$ (tonne/ year) | Upstream $CH_4$ (tonne/ year) | Upstream $N_2O$ (tonne/ year) | Upstream $CO_2e$ (tonne/ year) | Total $CO_2e$ (tonne/ year) |
| Construction Workers Car | Seattle-Tacoma | 0 | 295.0 | 0.0 | 0.0 | 2.46 | 0.0 | 299 | 0.0 | 0.000 | 0.000 | 0.00 | 0.000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Heavy Duty Delivery Trucks | | 457 | 1942.0 | 0.0 | 0.0 | 2.38 | 0.4 | 1,947 | 0.9 | 0.000 | 0.000 | 0.89 | 11.400 | 0.27646 | 0.00000 | 0.00000 | 0.27646 | 1.16689 |
| | | | | | | | | Total | 0.9 | 0.000 | 0.000 | 0.89 | 11.400 | 0.276 | 0.000 | 0.000 | 0.276 | 1.167 |
| Construction Vehicle Emissions - Summer 4. Year | | | | | | | | | | | | | | | | | | |
| Vehicle Class | Area From Which Workers Commute | VMT | $CO_2$ (g/VMT) | $CH_4$ (g/VMT) | $N_2O$ (g/VMT) | CO (g/VMT) | VOCs (g/VMT) | $CO_2c$ (g/VMT) | $CO_2$ (tonne/ year) | $CH_4$ (tonne/ year) | $N_2O$ (tonne/ year) | $CO_2e$ (tonne/ year) | Fuel consumption (mmBtu/ year) | Upstream $CO_2$ (tonne/ year) | Upstream $CH_4$ (tonne/ year) | Upstream $N_2O$ (tonne/ year) | Upstream $CO_2e$ (tonne/ year) | Total $CO_2e$ (tonne/ year) |
| Construction Workers Car | Seattle-Tacoma | 0 | 308.5 | 0.0 | 0.0 | 1.51 | 0.0 | 311 | 0.0 | 0.000 | 0.000 | 0.00 | 0.000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Heavy Duty Delivery Trucks | | 306 | 2019.0 | 0.0 | 0.0 | 2.38 | 0.4 | 2,024 | 0.6 | 0.000 | 0.000 | 0.62 | 7.935 | 0.19243 | 0.00000 | 0.00000 | 0.19243 | 0.81221 |
| | | | | | | | | Total | 0.6 | 0.000 | 0.000 | 0.62 | 7.935 | 0.192 | 0.000 | 0.000 | 0.192 | 0.812 |
| | | | | | | | | **Annual Total** | **1.5** | **0.0** | **0.0** | **1.5** | **19.3** | **0.5** | **0.0** | **0.0** | **0.5** | **2.0** |

Notes:
EFs from EPA MOVES model.
Construction Worker vehicles assumed to be ID 21 - Passenger Car. Heavy-Duty Delivery trucks assumed to be 61 - Combination Short-haul truck.
Assume 48 hours per week; 4.28 weeks per month

**Table A.9.** Monthly car and truck trips during construction

| Month/Year | Season | # of work days/ month | # of Cars/day | # of cars/ month | Car VMT/ month | # of Trucks/ month | Truck VMT/ month | Total On-Site VMT/ month (Car and Truck) |
|---|---|---|---|---|---|---|---|---|
| Jan-1. Year | Winter 1. Year | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Feb-1. Year | | 24 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Mar-1. Year | | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Apr-1. Year | Summer 1. Year | 25.7 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| May-1. Year | | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Jun-1. Year | | 25.7 | 0 | 0 | 0 | 85.00 | 331 | 331 |
| Jul-1. Year | | 26.6 | 0 | 0 | 0 | 85.00 | 320 | 320 |
| Aug-1. Year | | 26.6 | 0 | 0 | 0 | 75.00 | 282 | 282 |
| Sep-1. Year | | 25.7 | 0 | 0 | 0 | 75.00 | 292 | 292 |
| Oct-1. Year | Winter 1. Year | 26.6 | 0 | 0 | 0 | 5.00 | 19 | 19 |
| Nov-1. Year | | 25.7 | 0 | 0 | 0 | 5.00 | 19 | 19 |
| Dec-1. Year | | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Jan-2. Year | Winter 2. Year | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Feb-2. Year | | 24.9 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Mar-2. Year | | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Apr-2. Year | Summer 2. Year | 25.7 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| May-2. Year | | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Jun-2. Year | | 25.7 | 0 | 0 | 0 | 174.00 | 677 | 677 |
| Jul-2. Year | | 26.6 | 98 | 2,604 | 104,160 | 244.00 | 918 | 105,078 |
| Aug-2. Year | | 26.6 | 98 | 2,604 | 104,160 | 294.00 | 1,106 | 105,266 |
| Sep-2. Year | | 25.7 | 98 | 2,520 | 100,800 | 794.00 | 3,088 | 103,888 |
| Oct-2. Year | Winter 2. Year | 26.6 | 98 | 2,604 | 104,160 | 844.00 | 3,176 | 107,336 |
| Nov-2. Year | | 25.7 | 98 | 2,520 | 100,800 | 894.00 | 3,477 | 104,277 |
| Dec-2. Year | | 26.6 | 98 | 2,604 | 104,160 | 889.00 | 3,346 | 107,506 |
| Jan-3. Year | Winter 3. Year | 26.6 | 98 | 2,604 | 104,160 | 888.00 | 3,342 | 107,502 |
| Feb-3. Year | | 24 | 98 | 2,352 | 94,080 | 329.00 | 1,371 | 95,451 |
| Mar-3. Year | | 26.6 | 98 | 2,604 | 104,160 | 279.00 | 1,050 | 105,210 |
| Apr-3. Year | Summer 3. Year | 25.7 | 98 | 2,520 | 100,800 | 279.00 | 1,085 | 101,885 |
| May-3. Year | | 26.6 | 98 | 2,604 | 104,160 | 252.00 | 948 | 105,108 |
| Jun-3. Year | | 25.7 | 98 | 2,520 | 100,800 | 189.00 | 735 | 101,535 |
| Jul-3. Year | | 26.6 | 98 | 2,604 | 104,160 | 139.00 | 523 | 104,683 |
| Aug-3. Year | | 26.6 | 98 | 2,604 | 104,160 | 139.00 | 523 | 104,683 |
| Sep-3. Year | | 25.7 | 98 | 2,520 | 100,800 | 89.00 | 346 | 101,146 |
| Oct-3. Year | Winter 3. Year | 26.6 | 0 | 0 | 0 | 78.00 | 294 | 294 |
| Nov-3. Year | | 25.7 | 0 | 0 | 0 | 39.00 | 152 | 152 |
| Dec-3. Year | | 26.6 | 0 | 0 | 0 | 39.00 | 147 | 147 |
| Jan-4. Year | Winter 4. Year | 26.6 | 0 | 0 | 0 | 39.00 | 147 | 147 |
| Feb-4. Year | | 24 | 0 | 0 | 0 | 39.00 | 163 | 163 |
| Mar-4. Year | | 26.6 | 0 | 0 | 0 | 39.00 | 147 | 147 |
| Apr-4. Year | Summer 4. Year | 25.7 | 0 | 0 | 0 | 41.00 | 159 | 159 |
| May-4. Year | | 26.6 | 0 | 0 | 0 | 39.00 | 147 | 147 |
| Jun-4. Year | | 25.7 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Jul-4. Year | | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Aug-4. Year | | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Sep-4. Year | | 25.7 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Oct-4. Year | Winter 4. Year | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Nov-4. Year | | 25.7 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Dec-4. Year | | 26.6 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| Total | | | | | 1,535,520 | | 28,330 | |
| Note: Commute round-trip distance was assumed | | | | | | | | |

## A.2. Operational Emissions

Operational emissions consist of direct emissions from on-site combustion and fugitive

Emissions during plant operation include WTT emission rates from natural gas production and transport and power generation, as well as emissions from direct facility operation including fuel combustion on site, and emissions from end use fuel transfer for transfer operations[25] and fuel combustion. The emissions are grouped according to upstream, direct project, and end use. All of these emissions have WTT components such that the product of LNG use rate $U_{TLNG}$ and total emission rate per gallon of LNG, $\mathbf{E}_{TLNG}$ correspond to the total GHG emissions $\mathbf{G}_{LNG}$ via the following:

$$\mathbf{G}_{LNG} = U_{TLNG} \times \mathbf{E}_{TLNG} = U_{TLNG} \times [S_{NG} \times \mathbf{E}_N + S_e \times \mathbf{E}_e + V_{TLNG} + \Sigma(S_i \times \mathbf{EF}_i)] + \Sigma[U_k \times (\mathbf{EF}_L + V_O)] + U_{PS} \times (S_{NPS} \times \mathbf{EF}_{PS}) + \Sigma[U_t \times (\mathbf{EF}_D + \mathbf{E}_D)] \quad (5)$$

Where:

$U_{TLNG}$ = Total LNG use rate for Tacoma LNG = LNG produced
$\mathbf{E}_{TLNG}$ =Average WTT emission rate for Tacoma LNG
$S_{NG}$ = Specific energy of natural gas feedstock (Btu/mmBtu LNG) for Tacoma LNG
$\mathbf{E}_N$ = WTT natural gas emission rate
$S_e$ = Specific Energy of electric power consumed per unit of LNG (kWh/gal)
$\mathbf{E}_e$ = WTT emission rate for electric power
$V_{TLNG}$ = Tacoma LNG fugitive emission rate (g/gal)
$S_i$ = Specific energy for Tacoma LNG combustion emissions and process emissions for LNG production
$\mathbf{EF}_i$ = Emission factor for combustion equipment for each fuel type (natural gas, light hydrocarbons, etc.)
$U_k$ = Use rate of LNG for marine vessel and diesel truck combustion
$\mathbf{EF}_L$ = Emission factor for LNG Marine vessel and diesel truck combustion as well as natural gas for stationary power
$V_O$ = Fugitive emission rate from LNG operations in marine and truck operations
$U_{PS}$ = Use rate of LNG for peak shaving
$S_{NPS}$ =Specific energy of fuel uses for vaporization in peak shaving
$\mathbf{EF}_{PS}$ = Emission factor for fuel fired in peak shaving vaporizer (LNG or light hydrocarbons)
$U_t$ = Diesel use rate for LNG transport to peak shaving and bunkering
$\mathbf{EF}_D$ = Emission factor for diesel trucks
$\mathbf{E}_D$ = WTT emission rate for diesel

[25] The fuel transfer emissions will be tracked for each type of fuel transfer activity including filling TOTE ships, barges, and trucks. The fuel transfer hardware for trucks will be different than that for ships.

Example Calculation of emissions for 20 million gallons of LNG

$U_{TLNG}$ × [$\mathbf{S}_N$ × $\mathbf{E}_N$ + $\mathbf{S}_e$ × $\mathbf{E}_e$ + $V_{TLNG}$]: 20 million gallons ×[(1,060,000 Btu NG/mmBtu LNG × 11,000 g $CO_2$/mmBtu NG WTT)+ (1.35 kWh/gal LNG × 200 g $CO_2$/kWh power) + 10 g $CH_4$/gal LNG] ×76,000 Btu/gal LNG +

$U_{TLNG}$ × Σ($S_i$ × $\mathbf{EF}_i$): +20 million gal × (200 Btu NG liquids fired/gal LNG × 65,000 g $CO_2$/mmBtu NGL) + (800 Btu NG fired/gal LNG× 56,000 g $CO_2$/mmBtu NG) × 76,000 Btu/gal LNG +

$U_k$ × ($\mathbf{E}_{FL}$ + $V_O$): + 15 million gallons LNG for TOTE engines × 76,000 Btu/gal × (55,000 g $CO_2$/mmBtu LNG + 0.1 g $CH_4$/gal boil off loss/gal LNG)

$\mathbf{E}_{NL}$ + 5 million gallons LNG for peak shaving × 76,000 Btu/gal × 55,000 g $CO_2$/mmBtu NG from LNG

Note: All values are illustrative.

$S_{NG}$ is a representative value for all of the natural gas to the Tacoma LNG during normal operation. The term $E_{TLNG}$ represents emissions from both the combustion of natural gas as well as combustion of process gas from the separation unit. Each emission factor is based on the equipment type and design of the LNG production system. The term $S_L$ includes LNG used in all applications with unique value for each application. The LNG provided for peak shaving (one of the $S_L$ terms) will have a slightly different composition than conventional natural gas from underground storage wells.

### *Direct Emissions from LNG Facility Operation*

*1 million Btu NG, LHV/(930 Btu/scf, LHV) × 20.2. g/scf × 74% carbon = 16,073 g C/mmBtu*
*– 950,000 Btu /(950 Btu/scf LNG, LHV) × 19.2 g/scf LNG × 75.2% = 15,198 g C/mmBtu × 0.95 Btu LNG/Btu NG*
= 1635 g C/mmBtu LNG

The values are representative and actual data have been requested. As shown in the example here, the carbon content of LNG decreases per mmBtu of fuel which results in net emissions. However, the lower carbon content will be reflected in the end use phase.

Natural gas also provides fuel for vaporization to re-gasify the LNG for peak shaving. Small portions of the process gas and natural gas are also combusted in the flare. Fugitive emissions occur from the LNG system and during LNG transfers for fuel use. Fugitive emissions primarily consist of methane and these GHG emissions are counted with the global warming potential (GWP) of methane.

*Energy Efficiency of the Tacoma LNG facility*

| Input | Unit | Tacoma | CA_GREET |
|---|---|---|---|
| NG | lb/lb LNG | 1.117 | 1.109 |
| Electricity | kWh/1000 gal LNG | 1,348.00 | 43.89 |

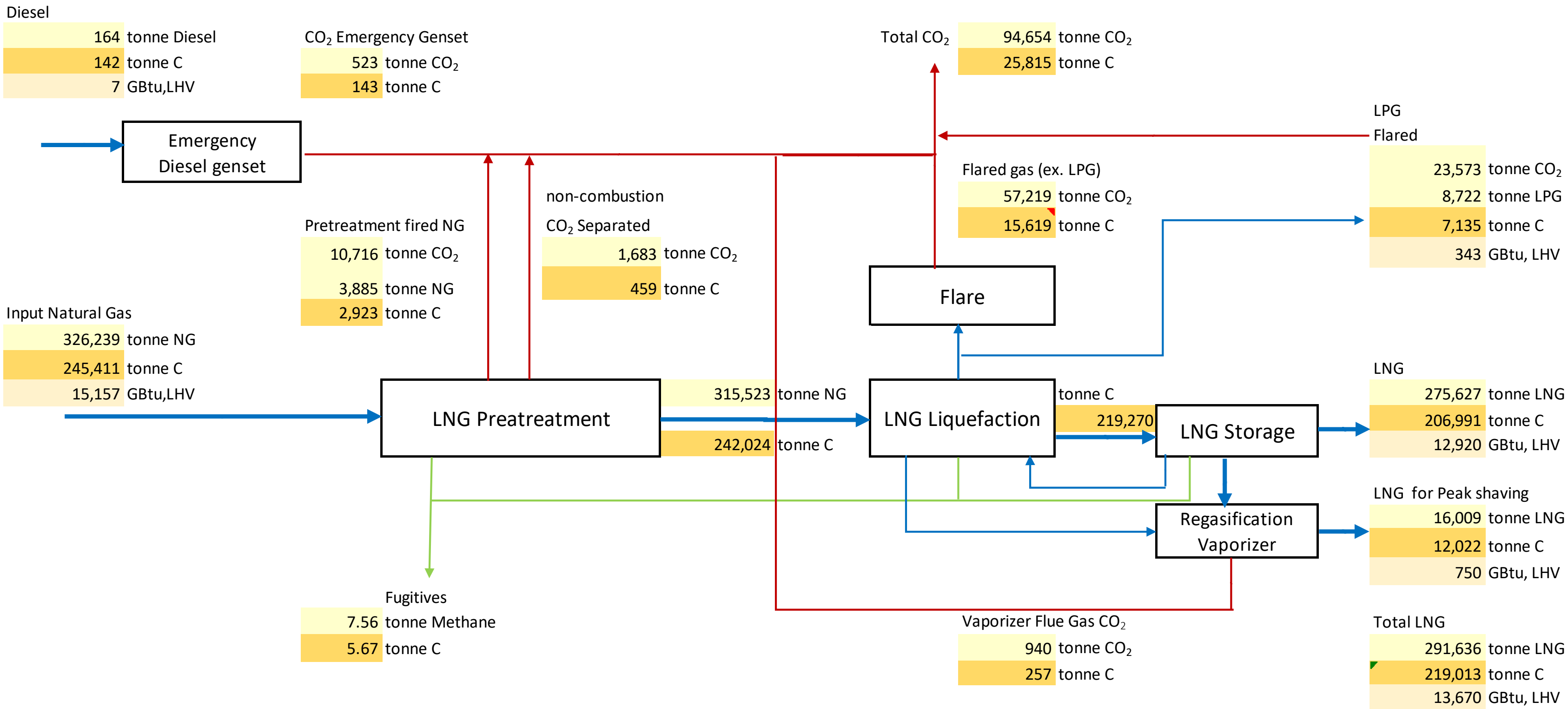
The above table compares the aggregate natural gas inputs and power input for LNG production with the CA_GREET default value (ARB, 2014). These values are based on Argonne National Laboratory's GREET model and typically represent a state-of-the-art-fuel production system. The overall energy efficiency for Tacoma LNG is 86.3 % compared to 91 % in GREET. The lower efficiency is due to high power consumption, flaring the waste gas as well as potentially conservative assumptions provided by PSE. The power consumption of Tacoma LNG is considerably higher than the CA_GREET default value. The use of waste gas to substitute some of the electricity use can increase the energy efficiency.

### *Carbon Balance of Natural Gas Input to LNG*

| Component | NG - fired NG | Pretreatment Vent | To LNG | Waste Gas | LPG | Tacoma LNG |
|---|---|---|---|---|---|---|
| | mol% | mol% | mol% | mol% | mol% | mol% |
| CH4 | 91.31% | 0.00% | 5.12% | 5.01% | 5.36% | 94.36% |
| C2H6 | 6.07% | 0.00% | 55.73% | 79.83% | 2.86% | 4.32% |
| | | | | | | 0.00% |
| C3H8 | 1.54% | 0.00% | 21.83% | 1.59% | 66.26% | 0.83% |
| i-C4H10 | 0.22% | 0.00% | 3.72% | 0.27% | 11.28% | 0.10% |
| n-C4H10 | 0.24% | 0.00% | 4.55% | 0.33% | 13.79% | 0.09% |
| i-C5H12 | 0.05% | 0.00% | 1.08% | 1.41% | 0.34% | 0.01% |
| n-C5H12 | 0.03% | 0.00% | 0.81% | 1.18% | 0.00% | 0.01% |
| C6+ | 0.03% | 0.00% | 0.84% | 1.23% | 0.00% | 0.00% |
| N2 | 0.27% | 54.81% | 0.04% | 0.05% | 0.00% | 0.28% |
| CO | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| H2 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| H2S | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| O2 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| He | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| CO2 | 0.22% | 45.19% | 6.29% | 9.11% | 0.10% | 0.01% |
| **Total** | **100.00%** | **100.00%** | **100.00%** | **100.00%** | **100.00%** | **100.00%** |
| C factor (lb CO2/mmBtu)HHV | 118.11 | 0.00 | 136.68 | 136.87 | 136.42 | 116.87 |
| C factor (lb CO2/scf) | 0.1287 | 0.0000 | 0.2741 | 0.2339 | 0.3625 | 0.1236 |
| LHV (MJ/kg) | 49.0 | 0.0 | 43.3 | 41.5 | 46.2 | 49.5 |
| (g CO2/mmBtu), LHV | 59333.7 | 0.0 | 68663.1 | 68755.6 | 68532.5 | 58709.2 |
| average molar weight | 17.7 | 35.2 | 36.9 | 32.8 | 45.8 | 17.0 |
| mol "C" per mol gas | 1.11 | 0.45 | 2.36 | 2.01 | 3.12 | 1.06 |
| carbon weight % | 75.22% | 15.40% | 76.88% | 73.74% | 81.81% | 75.10% |
| Carbon factor, gCO2/MJ | 56.2 | 0.0 | 65.1 | 65.2 | 65.0 | 55.6 |
| g CO2/mmBtu, LHV | 59,333 | 0 | 68,662 | 68,755 | 68,531 | 58,708 |
| Btu/scf (LHV) | 983.9 | 0.0 | 1811.0 | 1542.8 | 2399.4 | 954.7 |
| Btu/scf (HHV) | 1089.7 | 0.0 | 2005.6 | 1708.6 | 2657.4 | 1057.3 |
| MJ/m3 | 36.7 | 0.0 | 67.5 | 57.5 | 89.4 | 35.6 |
| SG | 0.610 | 1.216 | 1.272 | 1.132 | 1.581 | 0.587 |
| Density (g/ft3) | 21.2 | 42.2 | 44.1 | 39.3 | 54.9 | 20.4 |
| Density (g/m3) | 747.9 | 1490.2 | 1558.8 | 1386.3 | 1937.1 | 719.3 |

| Component | NG - fired NG | Pretreatment Vent | To LNG | Waste Gas | LPG | Tacoma LNG |
|---|---|---|---|---|---|---|
| | mol/d | mol/d | mol/d | mol/d | mol/d | mol/d |
| $CH_4$ | 94.536 | 0.000 | 0.181 | 0.121 | 0.059 | 94.356 |
| $C_2H_6$ | 6.284 | 0.000 | 1.967 | 1.935 | 0.032 | 4.317 |
| $C_3H_8$ | 1.598 | 0.000 | 0.771 | 0.039 | 0.732 | 0.828 |
| i-$C_4H_{10}$ | 0.232 | 0.000 | 0.131 | 0.007 | 0.125 | 0.101 |
| n-$C_4H_{10}$ | 0.250 | 0.000 | 0.160 | 0.008 | 0.152 | 0.090 |
| i-$C_5H_{12}$ | 0.049 | 0.000 | 0.038 | 0.034 | 0.004 | 0.011 |
| n-$C_5H_{12}$ | 0.035 | 0.000 | 0.029 | 0.029 | 0.000 | 0.007 |
| $C_6$+ | 0.031 | 0.000 | 0.030 | 0.030 | 0.000 | 0.001 |
| $N_2$ | 0.281 | 0.281 | 0.001 | 0.001 | 0.000 | 0.280 |
| CO | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| $H_2$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| $H_2S$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| $O_2$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| He | | | | | | |
| $CO_2$ | 0.232 | 0.232 | 0.222 | 0.221 | 0.001 | 0.010 |
| Total | 103.5 | 0.5 | 3.5 | 2.4 | 1.1 | 100.0 |
| | | | | | | |
| **Mass** | **NG Feed** | **CO2** | **Flare** | **Waste Gas** | **LPG** | **LNG** |
| | t/d | t/d | t/d | | | t/d |
| $CH_4$ | 1516.5 | 0.0 | 2.9 | 1.9 | 1.0 | 1513.6 |
| $C_2H_6$ | 188.9 | 0.0 | 59.1 | 58.2 | 1.0 | 129.8 |
| | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| $C_3H_8$ | 70.5 | 0.0 | 34.0 | 1.7 | 32.3 | 36.5 |
| i-$C_4H_{10}$ | 13.5 | 0.0 | 7.6 | 0.4 | 7.2 | 5.8 |
| n-$C_4H_{10}$ | 14.5 | 0.0 | 9.3 | 0.5 | 8.9 | 5.2 |
| i-$C_5H_{12}$ | 3.6 | 0.0 | 2.7 | 2.5 | 0.3 | 0.8 |
| n-$C_5H_{12}$ | 2.5 | 0.0 | 2.1 | 2.1 | 0.0 | 0.5 |
| $C_6$+ | 2.6 | 0.0 | 2.5 | 2.5 | 0.0 | 0.1 |
| $N_2$ | 7.9 | 7.9 | 0.0 | 0.0 | 0.0 | 7.8 |
| CO | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $H_2$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $H_2S$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $O_2$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| He | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $CO_2$ | 10.2 | 10.2 | 9.8 | 9.7 | 0.1 | 0.4 |
| Total | 1830.7 | 18.1 | 130.1 | 79.5 | 50.6 | 1700.7 |
| Mass ratio: LNG | 1.0765 | 0.0106 | 0.0765 | 0.0467 | 0.0298 | 1 |

## Annual throughput




The carbon balance accounts for the hydocarbons and $CO_2$ in the natural gas such that the carbon entering the LNG system is equal to the carbon in the combustion gas, fugitive emissions and LNG. Carbon in the Flared gas ex. LPG is determined by difference. Inputs to the analysis include overall NG to LNG mass balance, and fired pretreament NG. Waste gas to flare is based on elemental composition and mass flows.

### *Displaced Emissions (No Action Alternative)*

The life cycle GHG emissions from the Tacoma LNG project are compared to the alternative of not constructing the facility. Displaced LNG is based on PSE's projections of LNG end use applications.

Alternative energy uses include marine diesel and diesel fuel in marine and truck applications as well as for peak shaving operations. GHG emissions will be calculated in the same manner as those for Tacoma LNG. The amount of diesel used for marine, trucking, or peak shaving applications will be calculated based on the LNG use rate and the appropriate efficiency for each application. For diesel fuel combustion, the product of use rate and life cycle emission rates results in total emission $\mathbf{G}_{Alt}$ which calculated by:

$$\mathbf{G}_{Alt} = U_{PS} \times S_{DSP} \times (\mathbf{EF}_D + \mathbf{E}_D) + \Sigma[U_k \times (S_{De} \times \mathbf{E}_e + S_D \times (\mathbf{EF}_D + \mathbf{E}_D))] \quad (6)$$

Where:

$U_{PS}$ = Energy use rate for LNG peak shaving

$S_{DPS}$= Specific energy of diesel used in peak shaving operations per unit for the quantity $S_{LPS}$

$\mathbf{EF}_D$ = Emission factor for diesel in marine or truck engines or diesel peak shaving

$\mathbf{E}_D$ = WTT emission rate for bunker fuel or diesel fuel

$U_k$ = Energy use rate of LNG in each application

$S_{De}$ = Specific energy of electricity used for diesel storage and transfer[26]

$\mathbf{E}_e$ = WTT emission rate for electric power

$S_D$ = Specific energy of diesel fuel and marine diesel displacing LNG for each fuel application[27]

The term $S_D$ is a key parameter that relates the energy used in diesel operations with those from LNG fuel use. Electric power for diesel distribution so the term $S_{De}$ for alternative activities is essentially zero.

The WTT emission rates include the WTT data for diesel and marine diesel production. A small portion of these WTT emissions fall into the scope of distribution which is consistent with the activities of the Tacoma LNG project direct emissions. Emissions from alternative peak shaving are also an alternative to the Tacoma LNG project peak shaving operation.

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[26] This small amount of energy provides the functional equivalence of the direct emissions from LNG production which serves also as fuel storage.

[27] The specific energy of displaced diesel or marine fuel is based on the EER for each application.

| Scenario B | | Emissions (tonne/year) | | | |
|---|---|---|---|---|---|
| GHG Emissions | Equipment Type | $CO_2c$ | $CH_4$ | $N_2O$ | $CO_2e$ |
| Power Peak Shaving | | | | | |
| LNG | Duct Firing | 43,755 | 1 | 0.26 | 43,854 |
| Diesel | Duct Firing | 58,682 | 0 | 0.69 | 58,891 |
| Gig Harbor Delivery | | | | | |
| LNG Tacoma | Truck Engine | 4 | 0 | 0.00 | 4.2 |
| LNG | Truck Engine | 43 | 0 | 0.00 | 43 |
| LNG Tacoma End Use | NG Boiler | 8,125 | 0 | 0 | 8,143 |
| LNG End Use | NG Boiler | 8,125 | 0 | 0 | 8,143 |
| On-road Trucking | | | | | |
| LNG | Truck Engine | 15,738 | 85 | 0.01 | 17,862 |
| Diesel | Truck Engine | 19,274 | 1 | 0.04 | 19,316 |
| TOTE Marine | | | | | |
| LNG | Marine Engine | 171,718 | 2,029 | 12 | 225,993 |
| Pilot fuel | Marine Engine | 7,508 | 0 | 0.34 | 7,611 |
| MDO Fuel | Marine Engine | 257,783 | 4 | 11.55 | 261,325 |
| Truck-to-Ship Bunkering | | | | | |
| LNG incl. Pilot fuel | Marine Engine | 8,036 | 95 | 0.56 | 10,575 |
| Pilot fuel | Marine Engine | 351 | 0 | 0.02 | 356 |
| Diesel Truck | Truck Engine | 0 | 0 | 0.00 | 0 |
| MDO Fuel | Marine Engine | 12,063 | 0 | 0.54 | 12,229 |
| Other Marine (by Bunker Barge) | | | | | |
| LNG | Marine Engine | 554,208 | 6,548 | 39 | 729,376 |
| Pilot fuel | Marine Engine | 24,232 | 0 | 0.34 | 24,335 |
| MDO Fuel | Marine Engine | 831,977 | 4 | 11.55 | 835,519 |

Assume barge delivers
MDO for displaced emissions

## A.3. Evaporative Emissions and Loss Factor

Fugitive emissions from LNG production facilities include LNG and other light hydrocarbons that escape from storage tanks and vents as well as LNG vapors that are displaced from the transfer of LNG from storage tanks to transport vessels or trucks and back to storage tanks. The Tacoma LNG will implement controls of fugitive vapors that either return these components to re-liquefy them or combust them to form $CO_2$. LNG transfers also result in fugitive emissions due to trapped volumes. These are the volume between hose and connector. Table A.10 and Table A.11 shows fugitive emissions from LNG operation and transfer activities.

### *Boil off gas during holding period on LNG bunker barges*

Pressurized offshore bunker systems have been designed and their concept follows the idea of minimizing maintenance on key units such as rotating equipment. LNG is transferred to the customer by increasing the pressure in the IMO C-Type tank. Pressure build-up units (PBU) ensure the necessary pressure level. Boil-off gas is generated during loading of the C-Type tanks or during the holding time. Typically, the boil-off gas is consumed by the ship engine. Boil-off gas compressors pressurize BOG to transfer it for use in engines or to route it to a flare. Due to the fact that LNG bunker barges have higher standstill times, boil-off gas is also used to increase the pressure inside the C-type tanks. If the pressure increases above the design level, boil-off gas is transferred to a thermal oxidation unit. No methane from the boil-off gas is released to the environment (Gastech, 2018; MAN Diesel and Turbo, 2016).

Other LNG bunker vessels on the market are equipped with a re-liquefaction unit, which cools down the boil-off gas and re-liquefies about 70% of the boil-off gas to LNG (Wärtsilä Oil & Gas Systems AS, 2014). Based on the above state of the art in treating boil-off gas on LNG bunker barges a recovery rate of 95% for the boil-off gas during the holding period on LNG bunker barges was assume for this analysis

**Table A.10.** Inventory of Fugitive Equipment Leak Components

| Component | Acid | BOG | Ethylene | Fuel Gas | HC Liquid | Liquefied NG | Mixed Refrigerant | NG | Untreated NG |
|---|---|---|---|---|---|---|---|---|---|
| Valves | 39 | 9 | 12 | 36 | 33 | 244 | 112 | 185 | 30 |
| Pressure Relief Valves | 3 | -- | 1 | 3 | 1 | 19 | 8 | 9 | 2 |
| Flanges/ Connectors | -- | 7 | 2 | 15 | 6 | 114 | 28 | 77 | 15 |
| Pump Seals | -- | -- | -- | | 1 | -- | -- | -- | -- |
| Compressor Seals | -- | 2 | -- | -- | -- | -- | 1 | 1 | -- |
| Swivel Joints | | | | | | 4 | | | |

HC = hydrocarbon NG = natural gas

**Table A.11.** Fugitive Emissions from LNG Transfer Operations

| **Activity: Bunker Barge Loading** | | | | | | Emissions (g/mmBtu) | |
|---|---|---|---|---|---|---|---|
| Vapor Displaced | | Recovery Rate | Loss per Bunkering Event | Volume per Bunkering Event (gallons) | Volume Lost per Bunkering Event (gallons) | $CH_4$ | $CO_2e$ |
| 0.22% | | 95.00% | 0.011% | 380,994 | 42.1 | 2.4 | 59 |
| **Bunker Vessel Storage** | | | | | | | |
| Boil off rate (%/day) | Duration (days) | Recovery Rate | Loss per Bunkering Event | Volume per Bunkering Event (gallons) | Volume Lost per Bunkering Event (gallons) | $CH_4$ | $CO_2e$ |
| 0.15% | 4 | 95.00% | 0.0300% | 380,952 | 2,299 | 129.4 | 3,235 |
| **Truck/Ship-to-Ship Transfer** | | | | | | | |
| Vapor Displaced | | Recovery Rate | Loss per Bunkering Event | Volume per Bunkering Event (gallons) | Volume Lost per Bunkering Event (gallons) | $CH_4$ | $CO_2e$ |
| 0.22% | | 0.00% | 0.22% | 380,838 | 838 | 47.2 | 1,179 |

*Source:* PSE

**Table A.12.** Fugitive Emission Rates for Fuel Transfers

| LNG Bunkering and Vessel loading Emissions | $CH_4$ (g/mmBtu delivered) | $CO_{2e}$ (g/mmBtu delivered) | Fraction of Gas Delivered by this Process |
|---|---|---|---|
| Ship/Barge Loading | 2.4 | 58.82 | 98% |
| Bunker Vessel Storage | 6.4 | 160 | 73% |
| Truck/Ship-to-Ship Transfer | 47.0 | 1,176 | 75% |
| Total | 55.8 | 1,060 | |
| GREET | | | |
| **Loss Factor** | 0.1988% | Gas lost through the system | |
| | | | |
| Net Delivered LNG | 380,000 | gallons per typical bunkering event | |

*Source:* BID

## A.4. Greenhouse Gases and Global Warming Potential

The gases emitted globally that contribute to the greenhouse effect are known as greenhouse gases (or GHGs). Natural sources of GHGs include biological and geological sources such as forest fires, volcanoes and living creates. However, industrial sources of GHGs are the primary concern. The GHGs of primary importance are $CO_2$, methane, and nitrous oxide because they represent. Because $CO_2$ is the most abundant of these gases, GHGs are usually quantified in terms of $CO_2$ equivalent ($CO_2$e), based on the relative longevity in the atmosphere and the related global warming potential (GWP)

The greenhouse effect is due to concentrations of gases in the atmosphere that trap heat as infrared radiation is reradiated back to outer space. The phenomena of natural and human-caused effects on the atmosphere that cause changes in long-term meteorological patterns due to global warming and other factors is generally referred to as climate change. Due to the importance of the greenhouse effect and related atmospheric warming to climate change, the gases emitted globally that affect such warming are called GHGs. The GHGs of primary importance are $CO_2$, methane, and nitrous oxide. Because $CO_2$ is the most abundant of these gases, GHGs are usually quantified in terms of $CO_2$ equivalent ($CO_2$e), based on the relative longevity in the atmosphere and the related "global warming

The atmospheric lifetime of a species measures the time required to restore equilibrium following a sudden increase or decrease in its concentration in the atmosphere. Individual atoms or molecules may be lost or deposited to sinks such as the soil, the oceans and other waters, or vegetation and other biological systems, reducing the excess to background concentrations. The average time taken to achieve this is the mean lifetime.

Carbon dioxide has a variable atmospheric lifetime of about 30 to 95 years. This figure accounts for $CO_2$ molecules being removed from the atmosphere by mixing into the ocean, photosynthesis, and other processes. However, this excludes the balancing fluxes of $CO_2$ into the atmosphere from the geological reservoirs, which have slower characteristic rates. Although more than half of the $CO_2$ emitted is removed from the atmosphere within a century, some fraction (about 20%) of emitted $CO_2$ remains in the atmosphere for many thousands of years. Similar issues apply to other greenhouse gases, many of which have longer mean lifetimes than $CO_2$. e.g., $N_2O$ has a mean atmospheric lifetime of 121 years (Myhre et al., 2013).

Figure A.1 shows the components of radiative forcing in the atmosphere. The largest contributor to warming is $CO_2$, which depends on its radiation absorbing characteristics as well as the concentration in the atmosphere. The next most prominent heat trapping gas is methane. Its heat trapping effect is about half that of $CO_2$ and the lifetime of methane in the atmosphere is much shorter. Each of the greenhouse gases also result in secondary effects. For example, methane dissociates to form $CO_2$. It also has a role in ozone formation in the atmosphere.

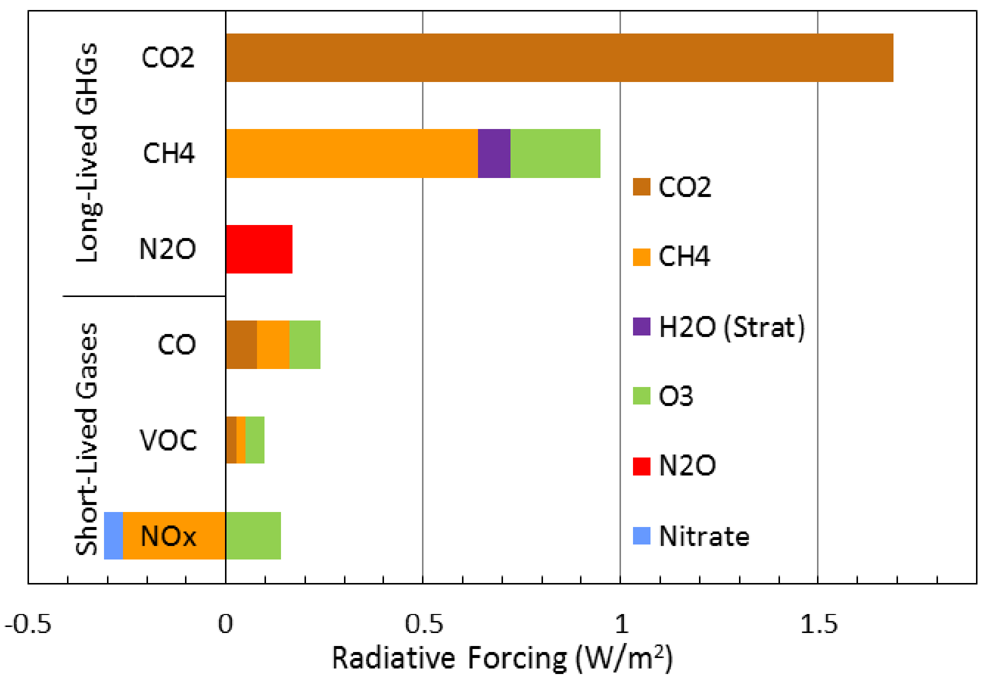


**Figure A.1.** Components of Radiative Forcing for Principal Emissions.
*Source:* (Myhre et al., 2013)

The absolute global warming potential (AGWP) of greenhouse gases is shown in Figure A.2. This figure shows the heat trapping effect of different gases over time. The yellow and blue curves show how the AGWPs changes with increasing time horizon. Because of the integrative nature the AGWP for $CH_4$ (yellow curve) reaches its primary effect after two decades as $CH_4$ is removed from the atmosphere. The AGWP for $CO_2$ continues to increase for centuries.

Thus, the ratio which is the GWP (black curve) drops with increasing time horizon as the relative importance of $CO_2$ is reflected with its longer atmospheric lifetime.

The time horizon affects the relative GWP of $CO_2$, $CH_4$, and $N_2O$ emissions. As indicated in Figure A.2, most of the cumulative effect of CH4 takes place after 20 years. Subsequently, the $AGWP_{CH4}$ curve levels off while the cumulative effect of $CO_2$ continues on for several hundred years. Therefore, the 100 year GWP provides a representation of GHG emissions that take into account more of the warming effect of the pollutants.

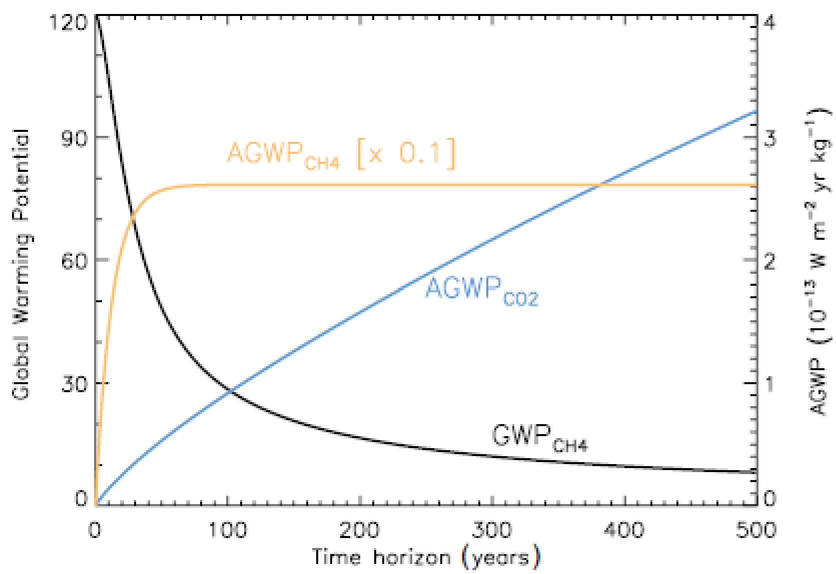


**Figure A.2.** Development of AGWP-$CO_2$, AGWP-$CH_4$ and GWP-$CH_4$ with time horizon.
*Source:* (Myhre et al., 2013)

# B. Appendix B Upstream Life Cycle Emissions

For each direct emission event, upstream life cycle emissions correspond to the overall life cycle emissions. The upstream life cycle contribution are the emissions associated with producing and transporting the fuel to the point of use. This section describes the quantification of upstream life cycle emissions for natural gas, electricity and petroleum fuels.

## B.1. Natural Gas

The upstream life cycle emission events for natural gas include extraction, processing, transport and distribution. Table B.1 shows the energy inputs for natural gas production and processing as well as the mix of shale gas and conventional gas as GREET inputs. The recovery efficiency and processing efficiency[28] are converted to Btu/mmBtu of natural gas in the GREET model as indicated in the table. As can be seen, the process fuels used for recovery and processing are mainly natural gas with small amounts of diesel, gasoline, residual oil, and electricity. The upstream life cycle emissions resulting from process fuel use is also accounted for recursively in the model. This includes the upstream emissions associated with electricity production, petroleum recovery and refining, as well as natural gas recovery and processing emissions (the upstream emissions of the upstream emissions). The GREET analysis includes flared natural gas as well as fugitive methane and $CO_2$ which are discussed in more detail below.

**Table B.1.** GREET 1_2017 Default Inputs for Conventional Gas Production.

| | NG Recovery | | NG Processing | |
|---|---|---|---|---|
| **Energy Inputs** | **Fuel Shares** | **Btu/mmBtu** | **Fuel Shares** | **Btu/mmBtu** |
| Total | | 25,641 | | 26,694 |
| Residual oil | 1% | 256 | | |
| Diesel fuel | 11% | 2,821 | 1% | 267 |
| Gasoline | 1% | 256 | | |
| Natural gas fuel | 86% | 22,051 | 96% | 25,626 |
| Natural gas flared | -- | 9,940 | | |
| Electricity | 1% | 256 | 3% | 801 |
| Fugitive Emissions (g/mmBtu), LHV | | | | |
| $CH_4$ | | 135.4 | | 6.8 |
| $CO_2$ | | | | 776 |

[a] Efficiency combined with fuel shares determines energy input per mmBtu of natural gas such that 1,000,000 × (1/efficiency-1) × fuel shares = energy input for each fuel.

[28] The GREET model efficiency inputs which are represented as efficiencies and fuel shares are derived from statistics on energy use.

Note that the GREET default values in Table B.1 reflect the allocation of emissions between natural gas and natural gas liquids[29].

Although Table B.1 provides the GREET default assumptions for conventional NG recovery, the calculation to convert process efficiency to fuel consumption is the same for shale gas recovery. Table B.2 provides the GREET assumptions regarding the relative shares of conventional and shale gas production as well as their corresponding recovery and processing efficiencies. Note that the energy inputs (and therefore emissions) for conventional gas and shale gas production are very similar. The GREET projection for growth in shale gas is less than that shown in Figure 2.6. The energy inputs for conventional and shale gas are essentially the same as the GREET defaults utilized in this study.

**Table B.2.** GREET1_2017 Inputs for North American NG Recovery and Processing

| Year | NG Supply from Shale | Recovery Efficiency[a] | | Processing Efficiency | |
|---|---|---|---|---|---|
| | | Conventional | Shale | Conventional | Shale |
| 2016 | 51.5% | 97.5% | 97.6% | 97.4% | 97.4% |
| 2020 | 53.6% | 97.5% | 97.6% | 97.4% | 97.4% |
| 2040 | 55.2% | 97.5% | 97.6% | 97.4% | 97.4% |

[a] Efficiency in combination with fuel shares input determined energy input per mmBtu of natural gas.

The GREET model also calculates energy inputs and emissions from compressors used for natural gas transport. The GREET values provide the basis for natural gas transmission.

In response to increased natural gas production and recognizing the significant uncertainty associated with fugitive methane emissions this subject has received intense investigation in recent years. The Environmental Defense Fund (EDF) recently commissioned a suite of studies to try to better quantify natural gas industry methane emissions. The EDF sponsored reports include one for gas field emissions (Allen et al., 2013), and another for gathering and processing emissions (Marchese et al., 2015), a report by (Zimmerle et al., 2015) on methane emissions in transmission, and another (Lamb et al., 2015) on distribution emissions. To compare the emission estimates, ANL divided the emission estimates in these reports by EIA estimated total withdrawals to arrive at an emission rate normalized to gas throughput. The EPA cites these studies as references for methane fugitive emissions in the most recent (2016) national emission inventory.

[29] The original GREET documentation shows the relationship between energy inputs for the natural gas industry and the allocation of the inputs to natural gas and natural gas liquids on an energy basis. Subsequent updates to GREET presumably followed this approach. Studies on leaks from natural gas systems generally do not allocate emissions to natural gas liquids. From EIA in 2015 Dry Natural Gas production 27,065 bcf (EIA, 2018b). 289.5 bcf vented and flared Natural Gas liquids as NG 1817 bcf with allocation factor of 93.7% to natural gas..

The previously mentioned ANL papers on quantifying fugitive methane emissions provide comparisons between the EPA GHGI values divided by throughput, the GREET model values and the aggregated values from the EDF studies. Table B.3 summarizes these estimates. The EPA estimate for gas field emissions more than doubled between 2015 and 2016; the GREET value followed suit and is slightly lower for the 2017 version of the model (based on 2015 year data), but slightly higher than the EDF study composite[30]
The current GREET estimate for processing emissions has decreased sharply based on EPA's 2017 estimates of reduced emissions from reciprocating engines and centrifugal compressors. Transmission and distribution emissions in GREET1_2017 are similar to those from the EDF studies. For this analysis, the GHGenius inputs and GREET inputs span the range of GHG emissions

Alternatively, British Columbia quantifies its methane leakage as 4.65 billion cubic meters from all oil and gas operations (Province of British Columbia, 2018). Dividing by the total natural gas production in the province (1,801 billion cubic feet) yields a methane leak rate of 0.26%.

[30] Which is the EPA gas field value plus Marchese's gathering emissions.

**Table B.3.** Summary of Recent Upstream Natural Gas Leakage Estimates (% of gas delivered)

| Activity | Type | Gas Field | Processing | Transmission | Distribution | Total |
|---|---|---|---|---|---|---|
| GREET1_2015 | Shale | 0.34% | 0.13% | 0.41% | 0.43% | 1.30% |
| | Conv | 0.30% | | | | 1.26% |
| GREET1_2016 | Shale | 0.77% | 0.13% | 0.36% | 0.14% | 1.38% |
| | Conv | 0.70% | | | | 1.32% |
| GREET1_2017* | Shale | 0.67% | 0.03% | 0.22% | 0.08% | 1.00% |
| | Conv | 0.66% | | | | 0.99% |
| EPA GHGI 2013 data [a] | U.S. | 0.31% | 0.15% | 0.36% | 0.22% | 1.04% |
| EPA GHGI 2014 data [a] | U.S. | 0.68% | 0.15% | 0.20% | 0.07% | 1.11% |
| Allen, 2013 [b] | | 0.38% | n/a | n/a | n/a | |
| EDF Studies 2015 [c] | | 0.58% | 0.09% | 0.25% | 0.07% | 0.99% |
| (Tong, Jaramillo, & Azevedo, 2015) [d] | | 0.49% | 0.04% | 0.46% | 0.31% | 1.30% |
| GHGenius 2016, BC | BC | 0.18% | 0.003% | 0.014% | 0.13% | 0.32% |
| BC 2017 | BC | 0.26% | 0.1% | 0.03% | 0.01% | 0.4% |
| G7 study (Brandt et al., 2017) | BC | 0.18% | n/a | n/a | n/a | n/a |
| (Alvarez et al., 2018) | U.S. | 1.8% | 0.13% | 0.32% | 0.08% | 2.3% |

* The extraction and transmission fugitives are 143.6 and 44.7 g $CH_4$/mmBtu respectively. GREET model identifies the distribution but does not utilize it since industrial and commercial NG users are upstream of the local distribution.

[a] Reported in EPA 2015, @ Reported in EPA 2016

[b] Taken from ANL "Updates to $CH_4$ Emissions with Natural Gas Pathways in GREET1_2015" Table 5 – ANL divided reported methane emission values by EIA gross withdrawals.

[c] The Gas Field value utilizes EPA's value for gas field emissions (0.31%) and Marchese's value for gathering (0.27%). The processing value is a combination of EPA's value for routine maintenance and (Marchese et al., 2015)'s processing value. Transmission is from (Zimmerle et al., 2015).; Distribution is from (Lamb et al., 2015)

[d] Gas field estimate also includes road construction, well drilling, and fracking emissions

Fugitive methane emissions from the natural gas delivery chain are material to the project's Life Cycle GHG emissions. The methane leak (i.e. fugitive emissions) assumptions in the GREET model reflect the most recent emissions published by the EPA in the national emission inventory as quantified by ANL (Burnham, 2016, 2017; Burnham, Han, Elgowainy, & Wang, 2015). Recent studies e.g., (Heath, Warner, Steinberg, & Brandt, 2015; Lamb et al., 2015; Peischl et al., 2016; Zimmerle et al., 2015) have reported a range in methane emissions from natural gas that compare to the U.S.GHG inventory (GHGI).

It is worth noting that fugitive gas emissions are significantly different from jurisdiction to jurisdiction due to both geophysical considerations and regulatory regimes. As Ravinder and Brandt noted that measurements in the Bakken Shale in North Dakota have demonstrated emission rates over 10% while recent data from the Marcellus shale show emission rates lower than 1% (Ravikumar & Brandt, 2018).

Estimate of upstream GHG emissions from natural gas in British Columbia and Canada are lower than United States averages. The GHGenius model estimates BC GHG emissions of 0.32% of production vs estimates of US emissions from 1.0% to 1.5%, or higher .Similarly average US emissions measured in $CO_2e$/MJ are about 12 (ICF International, 2017) vs Natural Resources Canada estimates of Canadian emissions of 7 to 8 (ICF Consulting CANADA, 2012).

An analysis from Stanford University for the British Columbia G7 project estimate methane losses from Canadian projects that correspond to 0.18% of the produced gas (Brandt et al., 2017). These emissions are due to better management practices and potentially Canadian requirements on emission controls. Brandt et al measured emissions from Canadian company Seven Generations Energy, at .18% (Wellhead only) which corresponds to the GHGenius result. Finally, newer wells have distinctly lower emissions than older wells, and pads and “super pads” (the drilling of multiple wells from a single site which is now common practice) have distinctly lower emissions (This is common practice in BC).

## B.2. Power Generation

One key input for life cycle GHG quantification is the resource mix used to generate electricity that is purchased by the plant. 239 GWh of electricity will be purchased each year[31] for scenario B. Several different resource mixes that could be used for the electricity purchased by the Tacoma LNG facility are discussed below. A key question is whether to use an average mix or the resources that come online to service the new demand (marginal mix).

### *Average Mix*

The Tacoma LNG facility will consume electricity from the regional power market for the Bonneville Power Administration (BPA) and Tacoma Power. Regional power consists of dozens of federal hydroelectric plants, the Columbia Nuclear Generating Station (publicly owned), various wind facilities as well as natural gas and coal-fired plants.

Washington State publishes the Electric Utility Fuel Mix Disclosure Report (State Energy Office at the Washington Department Of Commerce, 2017) each year, summarizing the statewide and utility level (e.g. Tacoma Power) retail power sales by fuel type. In addition to state and local resource mixes, the U.S. EPA manages the eGRID database which catalogs electricity generation data for a number of electricity generating regions. The Tacoma LNG facility is located within the Northwest Power Pool (NWPP) region shown in Figure B.1.

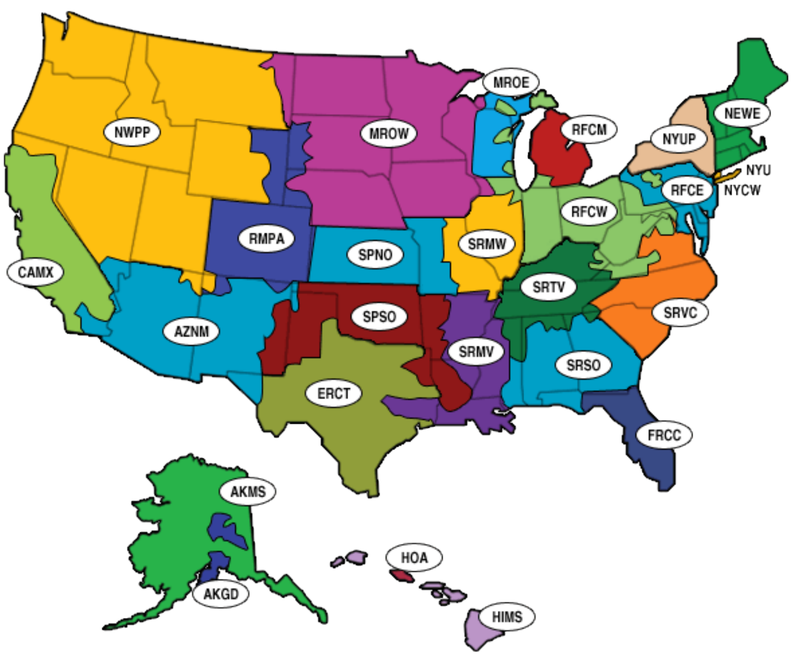


**Figure B.1.** Map of eGRID Subregions

Resource mix data for Tacoma Power and Washington State in 2016 are summarized in Table B.4. Also shown are the 2014 and 2016 eGRID data for the NWPP region. The Tacoma Power

[31] 1.348kWh/gallon LNG x 500,000 gpd

mix results in very low GHG emissions per kWh since it predominately consists of hydro and nuclear power. The Washington state average mix for 2016 has more fossil generation and less hydro than the Tacoma Power mix. The NWPP mix is higher carbon due to its larger share of coal generation. Note that between 2014 and 2016 coal generation in the NWPP decreased significantly while hydro, renewables and natural gas generation all increased.

**Table B.4.** Applicable Electric Power Generation Resource Mixes

| Resource | 2016 Washington Average | 2014 NWPP eGRID[32] | 2016 NWPP eGRID[33] | Tacoma Power |
|---|---|---|---|---|
| Residual oil | 0.1% | 0.2% | 0.2% | 0% |
| Natural gas | 11.5% | 11.9% | 15.3% | 1% |
| Coal | 14.1% | 36.2% | 22.5% | 2% |
| Nuclear | 4.9% | 2.8% | 3.4% | 6% |
| Biomass, LFG | 1.1% | 1.1% | 1.3% | 0% |
| Hydroelectric | 64.0% | 40.0% | 47.2% | 84% |
| Geothermal, Wind, Solar | 4.2% | 8.0% | 9.7% | 7% |
| Others | 0.1% | 0.0% | 0.4% | 0% |

### *Marginal Mix*

One question that might be raised regarding electricity emission estimates is whether an average grid mix or a marginal grid mix should be utilized. Specifically, which new resources will come online to meet the new load. Given the load growth anticipated for the Tacoma LNG facility is 20% of the recent decrease between 2014 and 2016, one approach is to simply assume the growth is met by conservation.

The second trend that must be considered is the decline in the coal fleet. Table B.5 provides the coal fired units within the NW Power and Conservation Council's territory (Idaho, Montana, Washington, Oregon). As shown in the table, the two remaining coal plants in Washington State will both retire by 2025 and 61% of the region's coal generating capacity will have retired by 2025. Note that even though Washington's two coal plants will have retired by 2025, utilities will still import coal generated electricity from other states as needed.

[32] eGRID2014v2 Generation Resource Mix eGRID2014v2 Generation Resource Mix (US EPA, 2014)

[33] eGRID2016 https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid eGrid 2016 (US EPA, 2016)

**Table B.5.** Regional Coal Plant Retirement Dates

| Coal Fired Boiler | State | MW | Retirement |
|---|---|---|---|
| Colstrip Energy LP | MT | 46 | |
| Colstrip Unit 1 | MT | 360 | 2022 |
| Colstrip Unit 2 | MT | 360 | 2022 |
| Colstrip Unit 3 | MT | 780 | |
| Colstrip Unit 4 | MT | 780 | |
| Lewis & Clark | MT | 50 | |
| Hardin Gen Project | MT | 116 | |
| Boardman | OR | 642 | 2021 |
| Centralia 1 | WA | 730 | 2020 |
| Centralia 2 | WA | 730 | 2025 |
| | Total Coal | 4594 | |
| | Total Retiring | 2822 | |

The third trend to consider is the Washington State Energy Independence Act of 2006 which establishes a renewable portfolio standard of 15% new renewables (hydro plants existing before 1999 do not count) by 2020 and each year after.

Given the uncertainty and complexity of calculating a marginal grid electricity mix, use of an average grid mix can be more appealing. Moreover, there is considerable precedence for using an average resource grid mix. For example, CalEEMod, the model utilized in California to quantify project emissions for CEQA purposes (California's version of the Washington State Environmental Policy Act) stipulates that to quantify GHG emissions for electricity consumption, the emission factors for the local utility should be used. The Washington State Agency GHG Calculator tool[34] utilizes electricity emission factors from the State Fuel Mix Disclosure Report. Finally, the California Air Resources Board chose an average mix for quantification of electric vehicle carbon intensity values for use in their Low Carbon Fuel Standard.

The assorted resource mixes considered in this Study are summarized in Table B.6. The corresponding GHG emissions from the GREET model with these mixes is provided in Table B.7. The Washington state average is approximately 60 g $CO_2$e/MJ (215 g $CO_2$e/kWh), the current NWPP eGRID value is 90 g $CO_2$e/MJ and the estimated marginal mix is 69 g $CO_2$e/MJ.

[34] The tool may be downloaded at https://ecology.wa.gov/Regulations-Permits/Reporting-requirements/Climate-change-emissions-reporting/State-agency-reports-tools

**Table B.6.** Resource Mixes Evaluated

| Fuel | 2016 WA State Average | 2016 NWPP eGRID | Tacoma Power | WA State Marginal |
|---|---|---|---|---|
| Residual oil | 0.1% | 0.2% | 0% | 0.0% |
| Natural gas | 11.5% | 15.3% | 1% | 44% |
| Coal | 14.1% | 22.5% | 2% | 2% |
| Nuclear | 4.9% | 3.4% | 6% | 0.0% |
| Biomass | 0.9% | 1.3% | 0% | 1% |
| Other (Renewable) | 68.5% | 57.3% | 91% | 52% |

**Table B.7.** GREET Estimated GHG Emissions for Each Electricity Resource Mix

| | g/MMBtu | | | | gCO2e/MJ |
|---|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | $CO_2c$ | GHG* |
| 2016 WA State Avg | 59,684 | 112 | 1 | 59,751 | 59.6 |
| 2016 Tacoma Power | 13,413 | 31 | 1 | 13,537 | 13.9 |
| 2014 NWPP eGRID | 127,042 | 213 | 2 | 127,141 | 126.2 |
| 2016 NWPP eGRID | 90,466 | 166 | 2 | 95,118 | 90.2 |
| Marginal 2040 | 67,990 | 192 | 1 | 75,351 | 69.3 |

* AR4 100-yr GWP factors

## B.3. Petroleum Upstream Life Cycle

Upstream life cycle GHG emissions for petroleum fuels including diesel, bunker fuel, and gasoline, were calculated based on the regional resource mix for Washington. Inputs for the life cycle of petroleum fuels include:

- Location of crude oil resources
- Transportation distance and mode
- API gravity of crude oil

These inputs were applied to the GREET analysis of crude oil refining. GHG emissions were based on the more detailed regionally specific OPGEE analysis published by the California Air Resources Board (California ARB, 2018; El-Houjeiri, Masnadi, Vafi, Duffy, & Brandt, 2018).

### B.3.1. Petroleum Fuels Consumed in Washington

Five refineries operate in Washington State[35] with a combined refining capacity of over 230 million barrels per0 year. Although the state is a net exporter of refined product, gasoline and diesel are imported from Montana and Utah into eastern Washington. The most recent available pipeline transfer data[36] indicate that 6% of diesel consumed in Washington is refined in Montana and transported to Washington via the Yellowstone pipeline and 10% is refined in Utah and transported via the Tesoro pipeline. The balance (84% of diesel) is assumed to be refined in Washington State. We assume that all residual oil/marine diesel consumed is refined in-state. The following sections describe quantification of CI values for petroleum products refined in Washington, Utah and Montana and also provide composite CI values for residual oil, gasoline and diesel consumed in Washington State.

#### *Sources of Crude Oil Refined in Washington, Utah and Montana*

Washington State receives crude oil by vessel, pipeline, and rail. DOE's Energy Information Administration (EIA) provides quantity of oil as well as corresponding API and sulfur content for all crude oil imported from foreign countries to each state. The Washington state foreign imports are indicated in Table B.8. Most of the foreign crude oil comes from Canada. Canadian crude oil can be derived from oil sands and upgraded before introducing it to the pipeline or it can by conventional crude oil. Data are no longer published specifying the share of crude exported to each PADD that is oil sands derived vs conventional. Instead, the Canada National Energy Board simply distinguishes between light and heavy where heavy is defined as upgraded bitumen (Natural Resources Canada, 2015). For PADD 5 (where Washington state is located), the NEB data indicate that 58% of the crude is light and 42% is heavy (assumed to be oil sands derived).

[35] British Petroleum Cherry Point, Shell Oil Anacortes, Tesoro Anacortes, Phillips 66 Ferndale, and US Oil Tacoma.

[36] 2013 data provided by Hedia Adelman, Washington State Department of Ecology

**Table B.8.** Foreign crude imports to Washington State, 2017 per EIA

| 2017 Foreign Imports | | | | |
|---|---|---|---|---|
| **Country** | **1000 bbl** | **Share** | **Avg API** | **Avg S** |
| Brazil | 5,855 | 7% | 28.9 | 1.3 |
| Brunei | 245 | 0% | 40.9 | 0.2 |
| Canada | 66,780 | 84% | 32.7 | 1.4 |
| Ecuador | 690 | 1% | 20.7 | 1.9 |
| Mexico | 451 | 1% | 20.0 | 4.3 |
| Russia | 2,480 | 3% | 43.2 | 0.3 |
| Saudi Arabia | 1,297 | 2% | 39.5 | 1.1 |
| Trinidad & Tobago | 1,367 | 2% | 39.9 | 0.3 |

EIA Company Level Imports sorted for Washington state refineries
https://www.eia.gov/petroleum/imports/companylevel

In addition to foreign imports, Washington receives crude oil from the Alaska North Slope (via pipeline to Valdez and vessel to the west coast ports) and from North Dakota on rail cars. The Department of Ecology tracks and publishes quarterly reports (Washington State Department of Ecology, 2017) on all crude oil receipts (foreign and U.S.), distinguishing between rail car, pipeline and vessel transport modes. These data help determine the quantity of Alaska and North Dakota crude oil received and also helps determine the split between different transport modes for Canadian crude oil.

The railcar deliveries are posted weekly and provide source and route taken. The routes through Washington are provided in Figure B.2. For crude shipments from Alberta, additional mileage is added to reflect travel from Calgary to Edmonton and then to British Columbia. Shipments from Saskatchewan are assumed to travel from Saskatoon to Edmonton and then British Columbia. North Dakota crude oil is assumed to travel 1500 miles before entering eastern Washington near Spokane. Table B.9 summarizes the crude oil receipts by rail and associated total transport miles. As indicated, the total shipments by rail from Canada in 2017 was 4,691 thousand bbl. The quarterly reports also state that an additional 60,728 thousand bbl came by pipeline. The EIA data provided below is for all crude from Canada, so the amount by tanker is determined by difference to be 1,361 thousand bbl.

**Figure B.2.** Crude oil rail routes to Washington refineries
*Source:* (Washington State Department of Ecology, 2017)

**Table B.9.** Washington State Crude oil receipts by rail, 2017

| Source | API | 1000 bbl | Rail Miles |
|---|---|---|---|
| North Dakota | 31-50 | 49,585 | 2,183 |
| North Dakota | 10-22 | 130 | 2,080 |
| Alberta | 31-50 | 536 | 1,124 |
| Alberta | 22-31 | 956 | 1,175 |
| Alberta | 10-22 | 2,601 | 1,344 |
| Saskatchewan | 31-50 | 534 | 1,156 |
| Saskatchewan | 10-22 | 65 | 1,145 |
| Total by Rail | | 54,407 | |

Finally, the quarterly reports state that the total amount received by vessel is 98,024 thousand bbl. The foreign imports in Table B.9 total to 12,385 bbl (excluding Canada). If we add the portion from Canada determined to come by vessel, we find that the total foreign crude arriving by vessel is 13,746 thousand bbl. The difference between the total from the quarterly reports and the foreign crude arriving by vessel is 84,278 thousand bbl and is assumed to be Alaska North Slope crude. Table B.10 summarizes the sources of crude oil and their mode of transport. Also shown is total crude supplied and total refinery capacity. Comparing to crude slates in the 2013 timeframe, the main difference is a large increase in crude sourced from North Dakota at the expense of crude from Alaska.

**Table B.10.** Summary of 2017 crude oil influx to Washington State.

| Origin | Quantity | | API | S | Transport |
|---|---|---|---|---|---|
| | 1000 bbl | % | degree | % | Mode |
| Brazil | 5,855 | 3% | 29 | 1.3 | Vessel |
| Brunei | 245 | 0% | 41 | 0.2 | Vessel |
| Canada | 66,780 | 31% | 33 | 1.4 | Mixed |
| Ecuador | 690 | 0% | 21 | 1.9 | Vessel |
| Mexico | 451 | 0.2% | 20 | 4.3 | Vessel |
| Russia | 2,480 | 1.2% | 43 | 0.3 | Vessel |
| Saudi Arabia | 1,297 | 0.6% | 39 | 1.1 | Vessel |
| Trinidad & Tobago | 1,367 | 1% | 40 | 0.3 | Vessel |
| North Dakota | 49,715 | 23% | 40 | | Rail |
| Alaska NS | 84,278 | 40% | 40 | | Mixed |
| Total Crude | 213,159 | | | | |
| Total Capacity | 231,301 | | | | |

According to the Montana Department of Natural Resources (Department of Natural Resources and Conservation of the State of Montana, 2016), the crude oil refined in Montana is largely from Canada. As can be seen in Table B.11, most of the crude refined in Montana is from Canada. The Canadian Energy Board states that 89% of crude sent to PADD 4 was heavy (oil sands).

**Table B.11.** Sources of crude oil for Montana refineries, 2016

| Source | Share |
|---|---|
| MT | 2% |
| WY | 7% |
| Canada | 91% |

The most recent published tabulation of Utah sources (Utah Department of Natural Resources, 2016) of crude oil is from 2015 and is provided in Table B.12. A small portion of crude is supplied from Canada; because Utah is in the same PADD as Montana, the mix of Canada heavy and light is assumed to be the same.

**Table B.12.** Sources of crude oil for Utah refineries, 2015

| Source | Share |
|---|---|
| Utah | 43% |
| Colorado | 13% |
| Wyoming | 36% |
| Canada | 8% |

### *Crude Oil CI Estimate (Recovery & Transport)*

The California Air Resources Board (ARB) utilizes the Oil Production Greenhouse Gas Emission Estimator (OPGEE) model, developed by researchers at Stanford University to quantify the carbon intensity of the crude oil recovery and transport portion of petroleum fuel pathways. Each year the CI is quantified for all of the oil fields that supply California refineries. For this analysis we utilize the 2016 CI values developed for California using OPGEE (California Air Resources Board, 2017); the underlying assumption is that the emission difference between transport to California and transport to Washington is very minor. In many cases, the OPGEE results provide data from a number of oil fields in a given country. For example, CI values four different oil fields in Brazil are provided along with barrels of oil transferred. For this analysis, a volume weighted average of the four Brazil oil field CI values is assumed to represent crude oil CI from Brazil.

The sources of crude oil for Washington refineries and corresponding CI values are provided in Table B.13, indicating that the average value for Washington refineries is 12 g/MJ[37]. Composite crude CI values for Montana (17 g/MJ) and Utah (14 g/MJ) are provided in Table B.14 and Table B.15. These values are combined with refining and finished fuel transport CI estimates from the GREET model based on crude type and electricity mix at the refinery.

**Table B.13.** Sources of crude for Washington State Refineries

| Source | Share | OPGEE CI ($gCO_2e/MJ$) |
|---|---|---|
| Brazil | 2.8% | 11.1 |
| Canada Conventional | 18.3% | 8.3 |
| Canada Oil Sands Derived | 13.3% | 17.7 |
| Ecuador | 0.3% | 10.3 |
| Mexico | 0.2% | 10.2 |
| Russia | 1.2% | 13.5 |
| Saudi Arabia | 0.6% | 9.1 |
| North Dakota Bakken | 23.5% | 10.2 |
| Alaska North Slope | 39.8% | 12.9 |
| | **Weighted Average** | **12.0** |

[37] a very small amount of crude also came from Brunei and Trinidad & Tobago, because OPGEE did not provide CI values for oil fields in these countries they were omitted from the average.

**Table B.14.** Sources of Crude Oil for Montana Refineries

| Source | Share | OPGEE CI ($gCO_2e/MJ$) |
|---|---|---|
| Montana (Bakken) | 2% | 12.9 |
| Wyoming | 7% | 24.11 |
| Canada Conventional | 10% | 8.3 |
| Canada Oil Sands Derived | 81% | 17.7 |
| | **Weighted Average** | **17.1** |

**Table B.15.** Sources of crude for Utah Refineries

| Source | Share | OPGEE CI ($gCO_2e/MJ$) |
|---|---|---|
| Utah | 43% | 5.99 |
| Colorado | 13% | 8.03 |
| Wyoming | 36% | 24.1 |
| Canada Conventional | 0.90% | 8.3 |
| Canada Oil Sands Derived | 7.10% | 17.7 |
| | **Weighted Average** | **13.6** |

### *Refining & Transport CI Estimates from GREET*

The CI from refining and finished fuel (gasoline, diesel and residual oil) were calculated with the GREET model for each refining location (Washington, Montana, and Utah). The GREET model adjusts refining energy inputs based on correlations between crude location and both sulfur content at API degree. We have also customized the model to use state average electricity grid mixes at each of the refining locations. The electricity grid mixes are shown in Table B.16.

**Table B.16.** Electricity grid mixes for each refining location

| | Residual Oil | Natural Gas | Coal | Nuclear | Biomass | Non-Emitting |
|---|---|---|---|---|---|---|
| Washington | 0.1% | 11.5% | 14.1% | 4.9% | 0.9% | 68.5% |
| Montana | 1.7% | 2.1% | 55.3% | 0.0% | 0.0% | 40.9% |
| Utah | 0.7% | 15.3% | 80.6% | 0.0% | 0.4% | 3.0% |

The well-to-tank (WTT) CI values for gasoline blendstock, low sulfur diesel and residual oil refined in Washington, Montana and Utah are shown in Table B.17. These values do not include the tank-to-wheel (TTW) contribution from burning the fuel. Montana products have the highest CI values because they have a high content of Canada oil sands crude oil. The Montana refining emissions are highest because of the high Canadian crude slate. Again, we assume 82% of gasoline blendstock is refined in Washington with 11% from Montana and 6% from Utah. For distillate, 84% is refined in Washington with 6% from Montana and 10% from Utah. Residual oil consumed in Washington is assumed to be refined in state.

**Table B.17.** WTT Carbon Intensity Values

| Fuel | Refined in | | | Consumed in Washington |
|---|---|---|---|---|
| | Washington | Montana | Utah | |
| Gasoline Blendstock | 22.8 | 31.6 | 25.3 | 23.9 |
| Low Sulfur Diesel | 19.7 | 26.8 | 22.1 | 20.4 |
| Residual Oil | 16.5 | 22.7 | 18.5 | 16.5 |

# C. Appendix C Direct Combustion Emissions

Direct combustion emissions occur from a variety of sources in the life cycle. These emissions include $CO_2$, $CH_4$ and $N_2O$ which depend on the carbon content and heating value of the fuel as well as the combustion characteristics of how the fuel is burned. Table C.1 shows the calculation of the carbon factor (g $CO_2$/mmBtu) for the primary fuels in the life cycle of LNG and alternative fuels. The carbon factor is calculated such that the carbon per Btu is multiplied by the molecular weight ratio of $CO_2$ to carbon via:

Carbon factor = wt% C/HHV (Btu/lb) × 453.59 g/lb x 44/12.01 × $10^6$

**Table C.1.** Calculation of $CO_2$ Emission Factors from Fuel Properties, HHV basis

| Fuel | Natural Gas | LNG | Residual Oil | Diesel |
|---|---|---|---|---|
| Carbon Content (wt%) | 75% | 74.0% | 86.8% | 86.5% |
| Heating Value (Btu/lb), HHV | 22,902 | 23,500 | 18,148 | 19,676 |
| Heating Value (Btu/unit), HHV | 1,054 | 950 | 150,110 | 137,380 |
| Unit | scf | scf | gal | gal |
| Fully oxidized (g $CO_2$/mmBtu) | 53,690 | 53,080 | 79,478 | 73,049 |
| Source: | *Placeholder values Data requested* | Properties to be calculated from composition | GREET | GREET |

Hydrocarbon and carbon monoxide emissions are treated as fully oxidized $CO_2$ under most GHG accounting systems including IPCC AR4 (IPCC, 2007) and Argonne's GREET model (ANL, 2017). In the IPCC assessment, for example, the global warming potential (GWP) of carbon monoxide is considered to be 1.5 to 2 which is consistent with the fully oxidized treatment of CO (ratio of 44/28 = 1.57) which is the value used in the GREET model. [38] State of Washington SEPA requirements provide for the use of EPA emission factors. The emission factors and sources are consistent with this approach.

Hydrocarbon and carbon monoxide emissions are treated as fully oxidized $CO_2$ under most GHG accounting systems including IPCC AR4 (IPCC, 2007) and Argonne's GREET model (ANL, 2017). In the IPCC assessment, for example, the global warming potential (GWP) of carbon monoxide is considered to be 1.5 to 2 which is consistent with the fully oxidized treatment of CO (ratio of

[38] When fuel use is represented as an emission factor per MMBtu of fuel, this factor typically includes all of the carbon in the fuel. However, emission factors for individual types of equipment such as marine engines might include separate values for $CO_2$ and CO emissions. In order to be consistent with IPCC and SEPA reporting protocols, CO should be counted as fully oxidized $CO_2$. The effect of this detail is typically less than 0.5% of $CO_2$ emissions from any source. This study includes VOC and CO emissions as $CO_2$c because these emissions are counted in the GREET LCA framework. Also, many emission inventory methods show $CO_2$ as fully oxidized carbon in fuel.

44/28 = 1.57) which is the value used in the GREET model.[39] State of Washington SEPA identified emission factors and sources are consistent with this approach (Washington State Department of Ecology, 2018).

The carbon factor is the same for each fuel regardless of its end-use application. However, the methane and $N_2O$ emissions depend on combustion properties for engines, turbines, and boilers. $CO_2$ emissions for fuel combustion depend upon the carbon content, density, and heating value of fuels such that all of these properties are consistent. Table C.2 show the carbon factor which represents $CO_2$ emissions per unit of fuel is calculated based on these properties. In this study, emission factors are identified in the units based on the original data source including the higher (HHV) or lower heating value (LHV) basis.

Emission factors for each energy source in the study are based either on SEPA emission factors, actual fuel properties, or GREET emission factors. Note that fuel combustion occurs through the upstream fuel cycle for all of the energy inputs associated with the project and displaced emissions. Therefore, calculations based on the GREET direct emission factors are more consistent than mixing and matching data from various sources.

Table C.2 shows the fully oxidized $CO_2$ emissions as well as $CH_4$ and $N_2O$ emissions from various combusting sources in this study. The carbon factor of fully oxidized $CO_2$ ($CO_2c$) is based on the fuel properties. Note that the $CO_2c$ factor includes methane because the fully oxidized effect is not reflected in the GWP of methane. Emission factors for $CH_4$ and $N_2O$ depend on the type of equipment and are identified in the GREET model or will be supplemented by data that has been requested. Finally, the GWP –weighted GHG emissions in $CO_2$ equivalent ($CO_2e$) are calculated. The emission factors will be converted to other units (g/gallon, g/mmBtu, HHV as needed based on fuel specifications in GREET.

[39] When fuel use is represented as an emission factor per MMBtu of fuel, this factor typically includes all of the carbon in the fuel. However, emission factors individual types of equipment such as marine engines might include separate values for $CO_2$ and CO emissions. In order to be consistent with IPCC and SEPA reporting protocols, CO should be counted as fully oxidized $CO_2$. The effect of this detail is typically less than 0.5% of $CO_2$ emissions from any source. This study includes VOC and CO emissions as $CO_2c$ because these emissions are counted in the GREET LCA framework. Also, many emission inventory methods show $CO_2$ as fully oxidized carbon in fuel.

**Table C.2.** Direct Combustion Emissions

| Fuel/ Application | Equipment Type | $CO_2c$ | $CH_4$ | $N_2O$ | $CO_2e$ |
|---|---|---|---|---|---|
| Direct Emissions (g/mmBtu), LHV | | | | | |
| Diesel | Diesel Engine | 78,187 | 4.2 | 0.6 | 78,472 |
| Diesel | HD Truck | 78,186 | 4.7 | 0.2 | 78,357 |
| Diesel | Industrial Boiler | 78,198 | 0.2 | 0.9 | 78,477 |
| Gasoline, E10 | Gasoline Engine | 76,829 | 3.0 | 0.6 | 77,083 |
| Bunker Fuel | Marine Engine | 85,517 | 1.3 | 3.8 | 86,691 |
| Natural Gas | IC Engine | 58,333 | 392 | 0.1 | 68,175 |
| Natural Gas | Turbine, CC | 59,410 | 1.1 | 0.1 | 59,474 |
| Natural Gas | Small Boiler | 59,330 | 1.1 | 0.4 | 59,461 |
| Natural Gas | Large Boiler | 59,410 | 1.1 | 0.8 | 59,660 |
| LNG | Marine Engine | 58,090 | 686.3 | 4.0 | 76,450 |
| LNG | Truck | 57,459 | 309.8 | 0.0 | 65,213 |
| LNG | NG Peak Shaving | 58,308 | 1.1 | 0.4 | 58,439 |
| LPG from Tacoma LNG | Boiler | 68,058 | 1.1 | 1.1 | 68,403 |
| LPG, conventional | Boiler | 68,729 | 1.1 | 1.1 | 69,074 |
| Waste Flare LPG | Flare | 68,729 | 1.1 | 1.1 | 69,074 |
| Waste Flare gas | Flare | 67,144 | 1.1 | 0.8 | 59,660 |
| Coal | Boiler | 100,041 | 1.1 | 1.6 | 100,540 |

[a] Fuel properties in GREET are on the Fuel_Specs sheet with same properties at those in Table C.1. Natural gas properties will be recalculated based on data that has been requested.

[b] SEPA permits calculations of GHG emissions based on EPA, AP-42 The emission factors are comparable to those in the GREET model. Note that $CO_2c$ factor for natural gas engines is lower than that for other end uses because of the higher $CH_4$ emissions.

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