APPENDIX 5.3-1
Greenhouse Gas Methodology

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REPORT

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Golder Associates

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1.0 PURPOSE

This Appendix documents the methods, data and assumptions that were used to estimate greenhouse (GHG) emissions for the Project. The GHGs emitted from the Project include Carbon dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O). These three GHGs can be combined as "*equivalent* CO_2" (CO_2e) by considering the individual global warming potentials.

The calculated GHG emissions reported herein are based on conservative estimates and may overestimate the actual emissions. GHG reporting requirements should be assessed based on actual annual emission totals and not those reported in this document.

2.0 GHG EMISSION ESTIMATE FRAMEWORK

The emissions estimation methods for GHGs follow generally accepted practices for assessing GHGs for Environmental Assessments and, where applicable, international standards, and federal, and provincial (British Columbia; B.C.) regulatory reporting guidance documents. Table 1presents the relevant reference material that forms the basis of GHG emission estimates for the project.

Table 1: Applicable Guidelines for Estimation of Greenhouse Gas Emissions

Guideline	Program	Source	Date
The Greenhouse Gas Protocol/A Corporate Accounting and Reporting Standard	Multiple Programs (e.g., Global Reporting Initiative (GRI), ISO14001	World Business Council for Sustainable Development/World Resources Institute (WBCSD and WRI 2004)	April 2004
Final Essential Requirements of Mandatory Reporting	Western Climate Initiative (WCI)	Western Climate Initiative (WCI 2011)	December 2011 (December 2013 Addendum)
Technical Guidance on Reporting Greenhouse Gas Emissions	Greenhouse Gas Reporting Program	Environment Canada 2013	November 2013
British Columbia Reporting *Regulation* – Guidance Document	B.C. Reg. 272/2009	MOE (MOE 2009)	August 2011

2.1 The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard World Business Council for Sustainable Development/World Resource Institute (2004)

The World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) have developed the GHG Protocol Corporate Standard (GHG Protocol), which provides guidance for preparing

corporate GHG inventories, as well as sector-specific and general calculation tools that can be used for estimating GHG emissions. The GHG protocol has been adopted by the Global Reporting Initiative (GRI), which provides guidance on sustainability reporting for industry.

Following the GHG Protocol, emissions are classified as either direct or indirect. Direct emissions are those generated from sources that are owned by the company. Indirect emissions are those that result from activities of the operating company, but occur at sources owned by another company, such as electrical power consumption. For the purposes of accounting and reporting, these are typically classified as Scope 1, Scope 2 or Scope 3, and are defined as follows:

Scope 1 – Direction GHG emissions:

> Carbon emissions occurring from sources that are owned or controlled by the company (e.g. emissions from combustion in owned or controlled boilers, furnaces and vehicles, process and fugitive emissions).

Scope 2 – Electricity indirect GHG emissions:

> Carbon emissions from the generation of purchased electricity, heat or steam consumed by the company.

Scope 3 – Other indirect GHG emissions:

> Carbon emissions which are a consequence of a company's activities, but occur from sources not financially or operationally controlled by the company (e.g. emissions from waste, the extraction and production of purchased materials; and employee travel to and from work) (ISO, 2006).

The GHG Protocol requires reporting of Scope 1 (direct emissions from site) and Scope 2 (emissions from on-site energy consumption) emissions only. Scope 1 and Scope 2 emissions are typically the focus of most corporate inventories, although many organizations choose to account for other activities such as employee travel and downstream emissions from waste. These sources are classified as Scope 3 (indirect) emissions, and are reported as an option.

Given the nature of LNG operations, Scope 1 emissions will be the most significant. Accordingly, Scope 1 will be the primary focus of the GHG inventory. In addition indirect emissions including, electricity consumption (Scope 2) has been considered. The following figure illustrates examples of sources of GHGs.

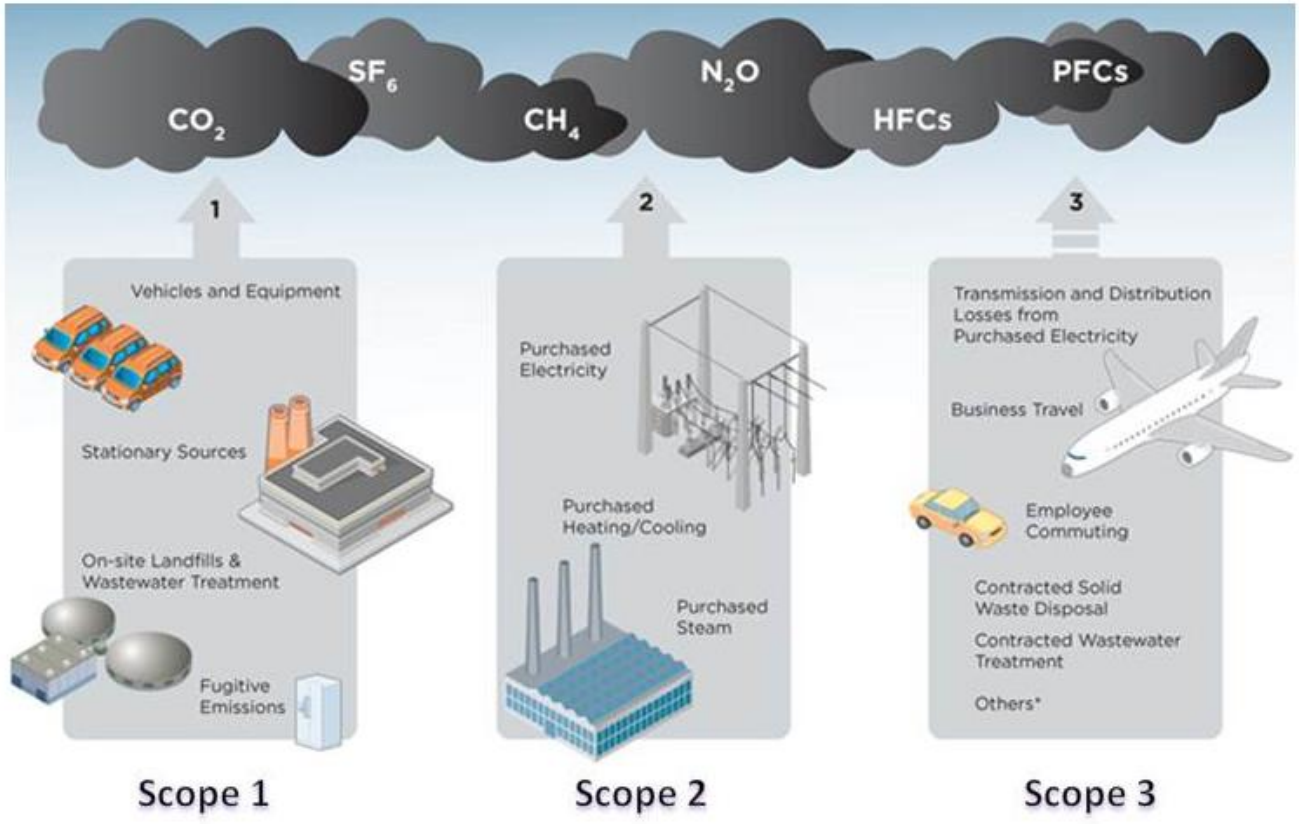


Image adapted from U.S. EPA, http://www.epa.gov/oaintrnt/ghg/index.htm

Figure 1: Greenhouse Gas Emissions (U.S. EPA 2012)

2.2 Final Essential Requirements of Mandatory Reporting, Western Climate Initiative (2011)

Western Climate Initiative's Final Essential Requirements of Mandatory Reporting (WCI) provides guidance for reporting and verification of GHG emissions by certain facilities that directly emit GHG's. Calculation methodologies are specified for emission sources required to be included in the emissions calculations, including

stationary and mobile sources. Details regarding reporting requirements and schedule are outlined. British Columbia (BC) is a signatory to the WCI, therefore the requirements under this program were taken into consideration.

The reporting threshold for the WCI is 10 kilotonnes of CO2e.

2.3 Technical Guidance on Reporting Greenhouse Gas Emissions, Environment Canada (2012)

The Technical Guidance on Reporting Greenhouse Gas Emissions (2012) (the Greenhouse Gas Reporting Program [GHGRP] Guideline), provides direction in determining if facilities are required to submit a GHG report to Environment Canada, an overview of the reporting process, as well as technical information related to GHG emissions estimations. Technical information includes GHG emission sources subject to reporting and information on emission estimation methodologies.

The GHGRP Guideline references GHG estimation methodologies from the United Nations Framework Convention on Climate Change (UNFCCC) and developed by the Intergovernmental Panel on Climate Change (IPCC). The GHGRP guideline states that "no specific estimation methods are prescribed" and that facilities should choose estimation methods that are most appropriate for their particular industry but are consistent with the guidelines adopted by the UNFCCC for preparing GHG inventories.

Table 2 of the GHGRP references specific Intergovernmental Panel on Climate Change document sections pertaining to each GHG emission source category.

The reporting threshold for the GHGRP is 50 kilotonnes of CO2e.

2.4 British Columbia Reporting Regulation Guidance Document, B.C. Ministry of Environment (2011)

British Columbia Regulation (B.C. Reg.) 272/2009 governs the documentation and reporting of GHG emissions in B.C. The Reporting Regulation Guidance Document was developed to provide clarity of the requirements of the Reporting Regulation, which was ordered under the authority of the Greenhouse Gas Reduction Act. The regulation specifies criteria for determining which facilities are required to report to the Ministry of Environment (MOE), what to include in the report and when to report. Emission sources are outlined and appropriate calculation methodologies are specified, referencing the Western Climate Initiative's Final Essential Requirements of Mandatory Reporting.

The reporting threshold for BC Reg. 272/2009 is 10 kilotonnes of CO2e.

The BC Ministry of Environment (BCMOE) has created a document (BCMOE 2012) outlining the current best practices for quantifying and reporting greenhouse gas emissions. The document divides GHG sources into four groups: stationary sources, indirect emissions (supplies – paper), mobile sources and travel for business (Provincial Government only). The stationary and mobile sources are further divided up into direct emissions (i.e. fuel combustion) and indirect emissions (i.e. electricity consumption). The document specifies where to find emission factors and provides a sample GHG calculation.

3.0 INVENTORY BOUNDARY

The definition of the inventory boundary, which frames the GHG emission sources that are included in the GHG emissions inventory for the project, is based on the GRI's GHG Protocol. Table 2 outlines the GHG inventory boundaries of the programs and presents the source categories included in this report.

Table 2: Source Categories Included in the GRI, GHGRP, B.C. Reg. 272/2009 and Assessed in the Environmental Assessment (EA)

Source Category	GRI	GHGRP	B.C. Reg. 272/2009	Assessed in EA
On-site stationary fuel combustion sources (Scope 1)	Y	Y	Y	Y
On-site mobile fuel combustion sources (Scope 1)	Y	Y	Y	Y
On-site fugitive process release sources (Scope 1)	Y	Y	Y	Y
On-site fugitive landfill release sources (Scope 1)	Y	Y	Y	Y
Electricity purchases (Scope 2)	Y	N	N	Y
Off-site mobile fuel combustion (Scope 3)	N	N	N	Y
Other indirect emissions (Scope 3)	Y	N	N	Y

4.0 IDENTIFICATION OF GREENHOUSE GAS SOURCES

The project has three distinct phases which have differing annual GHG emissions. The phases and GHG emissions are presented in Table 3.

Table 3: GHG Emission Sources and Phases for the Project

Phase	Source Type	Emission Sources
Construction	Mobile Combustion	Marine fleet combustion emissions; and Construction fleet combustion emissions.
	Land clearing	The site is located at a brownfield site and does not require land clearing
Operational	Stationary Combustion	Amine Incinerator, flaring, heaters, HVAC and EPG combustion emissions from various waste and fuel gas; and Flaring during tank inspection and EPG combustion emission.
	Fugitive Releases	Fugitive natural gas emissions from the LNP Plant; Fugitive landfill gas emissions; and Fugitive natural gas emissions from floating storage vessels.
	Purchased Electricity	Electricity is purchased to power the LNG plant and compressors.
	Mobile Combustion	Marine fleet combustion emissions.
Closure/Post-closure	Not assessed quantitatively.	

The only potential emissions for the closure and post-closure phase would be from mobile equipment. The closure plan will be developed for the environmental assessment; however, the number of vehicles needed for closure is unknown. The construction vehicle fleet would be considerably larger than the fleet needed for closure. Therefore, as a bounding assumption, the direct emissions from the closure and post-closure phase can be assumed to be at most equal to the emissions generated during the construction phase.

The sources above are summarized by their source category below in Table 4 and include the carbon containing materials from each source.

Table 4: Greenhouse gas sources by Source Category

Source	Source Category	Carbon Containing Materials
Stationary Combustion	On-site stationary fuel combustion sources (Scope 1)	Diesel, waste process fuel (flaring and amine incinerator) and natural gas
Mobile Combustion	On-site mobile fuel combustion sources (Scope 1)	Marine Gas Oil
Fugitive Releases	On-site fugitive process release sources (Scope 1)	Natural gas
Fugitive Releases	On-site fugitive landfill release sources (Scope 1)	Landfill gas
Purchased Electricity	Electricity Purchases (Scope 2)	Net GHG intensity of electrical grid

***Note**: minor maintenance vehicles during operational phase of the facility have been considered negligible and have not been included in the assessment.*

5.0 GREENHOUSE GAS EMISSION ESTIMATION METHODOLOGY

The following sections describe the methodologies used for calculating GHG emissions for the project.

5.1 Global Warming Potentials

The emissions of GHG's are expressed as kilotonnes of CO_2e, calculated by multiplying the annual emissions of each GHG by its 100-year global warming potential (GWP). The GWP of each gas represents the gas's ability to trap heat in the atmosphere in comparison to CO_2. The GWP's that are used to calculate the Project's GHG's are accepted values of 1, 25 and 298 for CO_2, CH_4 and N_2O, respectively, provided in the IPCC's Fourth Assessment Report (referred to as AR4; Solomon et al., 2007). These values are currently consistent with federal and provincial reporting regulations.

5.2 Calculation Methodology

The basic equation for estimating the GHG emissions from the project is presented below.

Equation 0: Basic Equation for GHG Estimation

$$ER = (ER_{CO2} \times GWP_{CO2} + ER_{CH4} \times GWP_{CH4} + ER_{N2O} \times GWP_{N2O}) \times OF$$

Where:

- *ER = the emission rate (kg CO_2e / year)*
- *ER_{CO2} = the annual emission rate (g CO_2/s)*
- *ER_{CH4} = the annual emission rate (g CH_4/s)*
- *ER_{N2O} = the annual emission rate (g N_2O/s)*
- *GWP_{CO2} = global warming potential of CO_2*
- *GWP_{CH4} = global warming potential of CH_4*
- *GWP_{N2O} = global warming potential of N_2O*
- *OF is the annual operational factor*

Many of the direct sources of GHG emissions from the Project do not emit continuously over an entire year. Therefore, the emissions have been estimated using the above general approach, assuming that emergency conditions have been dealt with in Section 11.0 Accidents and Malfunctions of the environmental assessment The typical annual operational factor was provided by the proponent.

5.3 Stationary Equipment Emissions

The approach presented by the GHG Protocol for calculating CO_2, CH_4 and N_2O emissions from stationary sources is based on fuel consumption and fuel-specific emission factors on a volume basis (e.g., kg CO_2/L). The emission factor used can be a facility-specific, locally available or default value.

For this project, facility-specific emission rates were provided by the proponent for CO_2, CH_4 and $N_2O$and were based on stoichiometric combustion chemistry that took into account Project and source specific fuels with known compositions. The methodology presented below is expected to provide a representative estimate of the Project emissions.

Equation 1: Stationary Combustion Emissions

$$ER_i = (ER_{CO2,i} \times GWP_{CO2}) + (ER_{CH4,i} \times GWP_{CH4}) + (ER_{N2O,i} \times GWP_{N2O}) \times UC \times CF_i$$

Where:

- *ER_i is the emission rate (kt CO_2e / year) of the stationary source*
- *$ER_{CO2,i}$ is the daily emission rate (g CO_2/s) of the stationary source*
- *$ER_{CH4,i}$ is the daily emission rate (g CH_4/s) of the stationary source*
- *$ER_{N2O,i}$ is the daily emission rate (g N_2O/s) of the stationary source*
- *GWP_{CO2} = global warming potential of CO_2*
- *GWP_{CH4} = global warming potential of CH_4*
- *GWP_{N2O} = global warming potential of N_2O*
- *UC =unit conversion to ktCO_2e/year.*
- *CF_i is the conversion to the annual operation of the amine incinerator*

5.4 Mobile Equipment Emissions

The approach presented by the GHG Protocol for calculating CO_2, CH_4 and N_2O emissions from mobile sources is based on fuel consumption and fuel-specific emission factors on a volume basis (e.g., kg CO_2/L). The emission factor used can be a facility-specific, locally available or default value. Details of the approach for construction equipment and marine fleet are summarized in the following sections.

5.4.1 Construction Equipment

The following equation was used to estimate the mobile emissions from the construction phase only. Fuel usage was estimated based on methods outlined in the U.S. EPA Exhaust and Crankcase Emissions Factors for Nonroad Engine Modeling — Compression-Ignition, NR-009d, July 2010 (US EPA, 2010).

Equation 2: Construction Fleet Emissions

$$ER = (EF_{CO2} \times GWP_{CO2} + EF_{CH4} \times GWP_{CH4} + EF_{N2O} \times GWP_{N2O}) \times F_y$$

Where:

- *ER is the emission rate (kg CO_2e / year)*
- *EF_{CO2} is the CO_2 emission factor provided in EC NIR Part 2 Table A8-11 (kg CO_2 / L)*
- *EF_{CH4} is the CH_4 emission factor provided in EC NIR Part 2 Table A8-11 (kg CH_4 / L)*
- *EF_{N2O} is the N_2O emission factor provided in EC NIR Part 2 Table A8-11 (kg N_2O / L)*
- *Fy* is the fuel use (L / year)

5.4.2 Marine Fleet

For the marine fleet, the following equation was used to estimate the daily emission rates of CO_2, CH_4 and N_2O.

Equation 3: Marine Fleet Emissions

$$ER = P \times EF \times LF \times T \times UC$$

Where:

- *ER = the emission rate (g/duration of travel)*
- *P = the engine power at maximum continuous rating (kW)*
- *EF = the emission factor (g/kWh)*
- *LF = the load factor (%)*
- *T = the duration of travel per day (hour/day)*
- *UC = the unit conversion factor to equate to daily g/s*

The following presents the relevant data inputs for the marine vessels that was obtained from Woodfibre.

Table 5: Marine Vessels Specifications and Operating Characteristics

Vessels	Frequency	Maximum Power (kW)	Average Speed [km/h]	Maximum Speed [km/h]
Three Tugboats (accompanying LNG Tanker)	3.5 times/month	7,456 per vessel	15.6	28.7
LNG tanker	3.5 times/month	2,000 Auxiliary Engine (while Loading)	22.2	38.9
Passenger Ferry	3 times per day	4400	24.4	34.1
Water Taxi	10 trip per week	400	37.0	55.6
Fuel Barge	1 trip per week during construction	N/A – Pulled by Tug	N/A	N/A
Fuel Barge Tug	1 trip per week during construction	2088	12.8	16.5
Crew boat	3 trips per day during construction	1194	42.6	50

The following presents the various emissions factors used to estimate the GHG emissions from the marine fleet. Please note that the emission factors varied depending on the type of operation (i.e., maneuvering, underway). The emission factors were obtained from the 2005 - 2006 BC Ocean-Going Vessel Emissions Inventory (The Chamber of Shipping 2007).

Table 6: Marine Fleet Emission Factors

Description	Emission Factor [g/kW-h]		
	CO2	CH4	N2O
Slow Vessel - Underway Mode	588.000	0.074	0.017
Slow Vessel - Maneuvering Mode	1764.00	0.22	0.05
Medium Vessel - Underway Mode	645.00	0.08	0.02
Medium Vessel - Maneuvering Mode	1935.00	0.24	0.06
Fast Vessel - Underway Mode	677.00	0.08	0.02
Fast Vessel - Maneuvering Mode	1935.00	0.24	0.05
Auxiliary Engine	690.00	0.09	0.02

The above daily emission rates can be used in conjunction with Equation 1 presented in Section 5.2 to estimate the annual GHG estimates from the marine fleet.

5.5 Process Fugitive Emissions

The approach presented by the GRI for calculating CH_4 emissions from fugitive releases at the LNG facility are typically based on emission factors. The source of fugitive GHG emissions form the project is from the LNG facility operations (e.g., valve and seal leaks). Fugitive process related emissions from the LNG facility have been calculated using the IPCC Good Practice Guidance and Uncertainty Management in Natural Greenhouse Gas Inventories (IPCC, 2006).

Equation 4: Fugitive Emissions from LNG Plant

$$ER = Q_T \times EF \times CH_4\% \times GWP_{CH4} \times UC$$

Where:

- *ER is the emission rate (kt CO_2e / year)*
- *EF is the percent of LNG released per processed LNG*
- *Q_T is the plants annual LNG production (kt of LNG/year)*
- *CH_4% is the average CH_4 content of the LNG (%,m/m)*
- *UC = the unit conversion factor to equate to kt CO_2e/year*

5.6 Landfill Fugitive Emissions

The Facility has two historic closed landfills. Neither landfill is equipped with a landfill gas collection system, therefore fugitive emissions are released through the capped area. Emission rates for the two landfills were calculated using the US EPA LandGEM model (US EPA 2005). LandGEM is a Landfill Gas Emissions Model which was developed by the US EPA to estimate air pollutants and other gases from municipal solid waste gases. Inputs to the model include annual waste tonnages from the year of opening to closure which were estimated based on the total volume of the landfill, a waste density of 625kg/m³ and the number of operating years. BCMOE defaults for the methane generation rate constant and methane generation potential were also used. A summary of the input data used for each landfill is included in Table 7.

Table 7: LandGEM Model Inputs

Landfill	Area [m²]	Depth [m]	Year opened	Year Closed	Methane Generation Rate Constant [1/yr]	Methane Generation Potential [m³/tonne]	NMOC as hexane (ppmv)
Pre 1992	16000	10	1975	1991	0.02	230	8000
Post 1992	29000	10	1991	2007	0.02	230	8000

The landfill gas emissions produced by each landfill were indicated to be on the decrease; therefore, emission rates for 2014, the current year, were used for conservatism, as 2014 is the highest anticipated year of landfill gas generation.

The equation used to estimate the annual GHG estimates from the landfill is presented below.

Equation 5: Fugitive Landfill Emissions

$$ER = (ER_{CO2} \times GWP_{CO2} + ER_{CH4} \times GWP_{CH4}) \times UC$$

Where:

- *ER is the emission rate (kt CO_2e / year)*
- *$ER_{CO2,i}$ is the annual emission of CO_2 from the landfills (tonne/year) from LandGEM*
- *$ER_{CH4,i}$ is the annual emission of CO_2 from the landfills (tonne/year) from LandGEM*

5.7 Electricity Consumption

GHG emissions due to electricity consumption are calculated based on the anticipated annual electricity consumption of the project. British Columbia specific emission factors, provided by Environment Canada in the National Inventory Report (Environment Canada 2014), specify the emission factor for CO_2, CH_4 or N_2O per kilowatt-hour used.

Equation 6: Total purchased electricity emissions

$$ER = (EF_{CO2} \times GWP_{CO2} + EF_{CH4} \times GWP_{CH4} + EF_{N2O} \times GWP_{N2O}) \times \frac{1tonne}{10^6 g} \times E_y$$

Where:

- *ER* is the emission rate (t CO_2e / year)
- *EF_{CO2}* is the carbon dioxide emission factor (g CO_2 / kWh)
- *EF_{CH4}* is the methane emission factor (g CH_4 / kWh)
- *EF_{N2O}* is the nitrous oxide emission factor (g N_2O / kWh)
- *E_y* is the annual electricity consumption (kWh / year)

5.8 Other Indirect Sources

There are other indirect sources that could be associated with the project and in accordance with the provincial and federal reporting programs that are not included in the inventory boundary and are not included in this assessment. These other indirect sources are considered to be negligible sources of GHG emissions in comparison to the direct emissions from the project and have not been quantitatively assessed.

5.9 Methodology Summary

Table 8 presents a summary of the various methodologies used to estimate the GHG from the project.

Table 8: Methodology Summary

Scenario	Source	Source Category	Scope	Methodology
Construction	Marine Vessels	Mobile Combustion	Scope 1/Scope 3	2005 – 2006 BC Ocean-Going Vessel Emissions Inventory (Chamber of Shipping 2007)
	Construction Equipment	Mobile Combustion	Scope 1	National Inventory Report 1990 - 2012: Greenhouse Gas Sources and Sinks in Canada (Environment Canada 2014).
Operational	Amine Unit Incinerator	Stationary Combustion	Scope 1	Combustion Chemistry using Stoichiometric Mass Balances
	Process Flares (WWGF, LPCF, CDGF and LPWF)	Stationary Combustion	Scope 1	Combustion Chemistry using Stoichiometric Mass Balances
	Hot Oil Heater	Stationary Combustion	Scope 1	Combustion Chemistry using Stoichiometric Mass Balances
	HVAC Units	Stationary Combustion	Scope 1	Combustion Chemistry using Stoichiometric Mass Balances
	Fugitive Natural Gas from Operations	Process Fugitives	Scope 1	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Chapter 4 (IPCC 2006)
	Landfill	Landfill Fugitives	Scope 1	LandGEM - landfill gas prediction model
	Marine Vessels	Mobile Combustion	Scope 1/Scope 3	2005 - 2006 BC Ocean-Going Vessel Emissions Inventory (The Chamber of Shipping 2007)
	Plant Electrical Demand	Purchased Electricity	Scope 2	National Inventory Report 1990 - 2012: Greenhouse Gas Sources and Sinks in Canada (Environment Canada 2014).
	Floating Storage and Offloading Unit	Process Fugitives	Scope 1	Combustion Chemistry using Stoichiometric Mass Balances

6.0 DATA REQUIREMENTS

6.1 Parameters Used to Calculate Greenhouse Gas Emission Estimates

Data requirements to calculate GHG emissions at the Project fall into two categories, these being:

- **Project-Specific Input Parameters –** Project-specific consumption data for processes resulting in GHG emissions; and
- **Default Parameters –** Emission factor data or physical data obtained from GHG emission estimation guidelines or reference material.

Table 11 presents the data required for calculating GHG emissions at the facility, broken down into the above categories.

Table 9: Summary of data required for estimating GHG emissions

Data	Variable	Equation	Value	Unit	Source of data
Project-Specific Input Parameters					
Stationary Combustion - Amine Incinerator	ER_{CO2}	Equation 1	897.12	g/s	Woodfibre LNG Limited
	ER_{CH4}		0.05		
	ER_{N2O}		—		
	CF		0.95	—	
Stationary Combustion - Flare WWGF	ER_{CO2}	Equation 1	24.72	g/s	Woodfibre LNG Limited
	ER_{Ch4}		0.01		
	ER_{N2O}		—		
	CF		0.95	—	
Stationary Combustion - Flare LPCF	ER_{CO2}	Equation 1	24.72	g/s	Woodfibre LNG Limited
	ER_{Ch4}		0.01		
	ER_{N2O}		—		
	CF		0.95	—	
Stationary Combustion - Flare CDGF	ER_{CO2}	Equation 1	24.72	g/s	Woodfibre LNG Limited
	ER_{Ch4}		0.01		
	ER_{N2O}		—		
	CF		0.95	—	
Stationary Combustion - Flare LPWF	ER_{CO2}	Equation 1	24.72	g/s	Woodfibre LNG Limited
	ER_{Ch4}		0.01		
	ER_{N2O}		—		
	CF		0.95	—	
Stationary Combustion - Hot Oil Heater	ER_{CO2}	Equation 1	1254.00	g/s	Woodfibre LNG Limited
	ER_{Ch4}		0.02		
	ER_{N2O}		—		
	CF		0.95	—	

Data	Variable	Equation	Value	Unit	Source of data
Stationary Combustion - HVACs	ER_{CO2}	Equation 1	692.22	g/s	Woodfibre LNG Limited
	ER_{Ch4}		0.19		
	ER_{N2O}		—		
	CF		0.47	—	
Stationary Combustion - Flare WWGF (Depressuring Feed Gas)	ER_{CO2}	Equation 1	193380.00	g/s	Woodfibre LNG Limited
	ER_{Ch4}		1208.00		
	ER_{N2O}		—		
	CF		1.14E-04	—	
Stationary Combustion - Flare LPCF (Shut down Tank RG)	ER_{CO2}	Equation 1	49410.00	g/s	Woodfibre LNG Limited
	ER_{Ch4}		174.00		
	ER_{N2O}		—		
	CF		3.20E-03	—	
Stationary Combustion - Flare CDGF (Major Maintenance of MR Compressor Unit)	ER_{CO2}	Equation 1	580278.00	g/s	Woodfibre LNG Limited
	ER_{Ch4}		850.00		
	ER_{N2O}		—		
	CF		1.14E-04	—	
Stationary Combustion - EPG1	ER_{CO2}	Equation 1	167.50	g/s	Woodfibre LNG Limited
	ER_{Ch4}		0.02		
	ER_{N2O}		—		
	CF		6.85E-04	—	
Stationary Combustion - EPG2	ER_{CO2}	Equation 1	492.50	g/s	Woodfibre LNG Limited
	ER_{Ch4}		0.00		
	ER_{N2O}		—		
	CF		6.85E-04	—	
Stationary Combustion - Floating Storage and Offloading Unit (Tank Inspection)	ER_{CO2}	Equation 1	74.62	g/s	Woodfibre LNG Limited
	ER_{Ch4}		—		
	ER_{N2O}		—		
	CF		1.10E-02	—	
Fugatives - Floating Storage and	ER_{CO2}	Equation 1	—	g/s	Woodfibre LNG Limited
	ER_{Ch4}		2778.00		

Data	Variable	Equation	Value	Unit	Source of data
Offloading Unit (Safety Valve Lift)	ER_{N2O}		—		
	CF		8.22E-10	—	
Stationary Combustion - Floating Storage and Offloading Unit (Emergency Power Generation)	ER_{CO2}	Equation 1	73.00	g/s	Woodfibre LNG Limited
	ER_{Ch4}		—		
	ER_{N2O}		—		
	CF		5.48E-03	—	
Mobile Combustion - Construction Equipment	Fy	Equation 2	10,267,199	L / year	U.S. EPA Exhaust and Crankcase Emissions Factors for nonroad Egine Modeling — Compression-Ignition, NR-009d, July 2010 (US EPA 2010)
Mobile Combustion - Marine	P	Equation 3	varies - see section 5.4.2	kW	Woodfibre LNG Limited
	EF	Equation 3	varies - see section 5.4.2	g/kW-h	2005 – 2006 BC Ocean-Going Vessel Emissions Inventory (The Chamber of Shipping 2007). Within The Chamber of Shipping (2007)
	LF	Equation 3	0.03 Maneuvering 0.8 Underway 1 - Auxiliary Engine	unitless	
	T	Equation 3	varies - see section 5.4.2	hours/day	Woodfibre LNG Limited
Fugitive - LNG Plant	EF	Equation 4	0.05%	percent LNG emitted/throughput LNG	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Chapter 4, Table 4.2.8
	CH_4%	Equation 4	89.91%	%	Woodfibre LNG Limited
	Q_T	Equation 4	2,100	kilotonnes/year	Woodfibre LNG Limited
Fugitive - Landfill	ER_{CO2}	Equation 5	1.60	kilotonnes/year	LandGEM (US EPA 2005) (both landfills)
	ER_{Ch4}	Equation 5	0.59	kilotonnes/year	
Electricity Consumption	E_y	Equation 6	1,550,520,000	kWh	Wooodfibre (peak capacity, and therefore very conservative estimate)
Default Parameters					

Data	Variable	Equation	Value	Unit	Source of data
Global warming potentials	GWP_{CO2}	Equation 1, 2, 4, 5 and 6	1	t CO_2e / t CO_2	IPCC Fourth Assessment Report 2007 (Solomon 2007)
	GWP_{CH4}		25	t CO_2e / t CH_4	
	GWP_{N2O}		298	t CO_2e / t N_2O	
Emission factor for mobile equipment – heavy duty diesel vehicle	EF_{CO2}	Equation 4	2.663	kg CO_2 / L	Canada National Inventory Report 1990-2012 Part 2: Table A8-11: Emission Factors for Energy Mobile Combustion Sources (Environment Canada 2014)
	EF_{CH4}		0.00011	kg CH_4 / L	
	EF_{N2O}		0.000151	kg N_2O / L	
Electricity emission factors	EF_{CO2}	Equation 7	8.1	g CO_2 / kWh	Environment Canada National Inventory Report 1990-2012 Part 3: Table A13-11: Electricity Generation and GHG Emission Details for British Columbia (Environment Canada 2014)
	EF_{CH4}		0.002	g CH_4 / kWh	
	EF_{N2O}		0.0002	g N_2O / kWh	

7.0 GREENHOUSE GAS EMISSIONS

7.1 Direct Emissions

Direct emissions were estimated for the construction and operational phases of the project. For the construction phase, direct emissions only consist of mobile equipment and the existing landfill fugitives. For the operational phase, direct emissions represent various stationary fuel combustion sources, process fugitives, landfill fugitives and mobile equipment. Table 10 and Table 11 present the direct emissions from the construction and operational phases, respectively.

Table 10: Construction Phase Direct Emissions

Source	Source Category	Annual Emissions [kt/year]				
		CO_2	CH_4	N_2O	CO_2e	% of Phase Total
Marine Vessels	Mobile Combustion	0.6	<0.1	<0.1	0.6	1.4
Construction Equipment	Mobile Combustion	27.3	<0.1	<0.1	27.8	62.3
Landfill	Landfill Fugitives	1.6	0.6	<0.1	16.2	36.3
Total		**29.6**	**0.6**	**0.0**	**44.7**	**100.0**

Table 11: Operational Phase Direct Emissions

Source	Source Category	Annual Emissions [kt/year]

		CO_2	CH_4	N_2O	CO_2e	% of Phase Total
Amine Unit Incinerator	Stationary Combustion	26.8	<0.1	<0.1	26.8	20.7
Process Flares (WWGF, LPCF, CDGF and LPWF)		10.7	<0.1	<0.1	11.4	8.8
Hot Oil Heater		37.5	<0.1	<0.1	37.5	29.0
HVAC Units		10.9	<0.1	<0.1	11.0	8.5
Emergency Power Generators		<0.1	<0.1	<0.1	<0.1	<0.1
Fugitive Natural Gas from Operations	Process Fugitives	<0.1	0.9	<0.1	23.6	18.3
Floating Storage and Offloading Unit		<0.1	<0.1	<0.1	<0.1	<0.1
Landfill	Landfill Fugitives	1.6	0.6	<0.1	16.2	12.5
Marine Vessels	Mobile Combustion	2.8	<0.1	<0.1	2.8	2.2
Total		**90.3**	**1.6**	**0.0**	**129.4**	**100.0**

The maximum annual GHG emissions scenario for the Project is expected to occur during the operational phase.

7.2 Indirect Emissions

Indirect emissions were estimated for the operational phase of the project only and represented purchased electricity. It is expected that the electricity usage will be much less during the construction phase. Additionally, the electricity estimates have been conservatively estimated based on the peak capacity of the plant.

Table 12: Operational Phase Indirect Emissions

Source	Source Category	Annual Emissions [kt/year]				
		CO_2	CH_4	N_2O	CO_2e	% of Phase Total
Purchased Electricity	Purchased Electricity	12.6	<0.1	<0.1	12.7	100.0

7.3 Conservatism in Emission Rate Calculations

Table 12 outlines the areas where conservatism was assumed in the emission rate calculations which results in an assessment that is not likely to under-predict the emissions associated with the project.

Table 13: Conservatisms in Emission Rate Calculations

Area	Conservatism

Area	Conservatism
Fugitive Landfill emissions	The emissions of CO_2 and CH_4 from the landfill are from the 2014 year using the LandGem model. This is considered conservative as the landfill is not active and the landfill gas generation will decrease over time
Mobile Marine Vessel emissions	Much of the marine vessel emissions are a result of marine vessels that are not owned by the proponent, and are therefore considered indirect Scope 3 emissions. However, they have been included as a Scope 1 direct in the annual emissions estimate for the project. This is considered conservative as otherwise Scope 3 emissions would not be included in the project GHG inventory.
Purchased Electricity	Electricity consumption was conservatively estimated based on the peak capacity of the plant.
Project Operations	All source assumed to be operating at maximum capacity as described in Table 9.

7.4 Greenhouse Gas Reporting Status

Predicted annual GHG releases have been screened for reporting under BC Reg 272/2009 and the GHGRP by first calculating the appropriate total GHG emission estimate (the screening level GHG emission estimate) in accordance with each program's respective GHG inventory boundary and guideline. The results of this screening assessment are presented in the Table 13. These emissions only include those that are required under the reporting programs (e.g. construction emissions are excluded).

Table 14: Summary of Greenhouse Gas Emissions and Screening Level Assessments for the Federal and Provincial Reporting Program

Greenhouse Gas Source	Greenhouse Gas	100-year GWP	Aggregate Source Emissions [kt/year]	Subtotal CO_2e Emissions [kt/year]
Normal				
Combustion in Stationary Sources – non-biomass	CO_2	1	85.9	85.9
Industrial Processes - Fugitives			0.1	0.1
On-site Transportation - Marine Vessels			2.8	2.8
Biomass - landfill			1.6	1.6
Combustion in Stationary Sources – non-biomass	CH_4	25	<0.1	0.8
Industrial Processes - Fugitives			0.9	23.6
On-site Transportation - Marine Vessels			<0.1	<0.1
Biomass - landfill			0.6	14.6
Combustion in Stationary Sources – non-biomass	N_2O	298	<0.1	<0.1

Greenhouse Gas Source	Greenhouse Gas	100-year GWP	Aggregate Source Emissions [kt/year]	Subtotal CO_2e Emissions [kt/year]
Industrial Processes - Fugitives			<0.1	<0.1
On-site Transportation - Marine Vessels			<0.1	<0.1
Biomass - landfill			<0.1	<0.1
			Phase Total	**129.4**
Construction*				
On-site Transportation - Marine Vessels and Construction	CO_2	1	28.0	28.0
Biomass - landfill			1.6	1.6
On-site Transportation - Marine Vessels	CH_4	25	<0.1	<0.1
Biomass - landfill			0.6	14.6
On-site Transportation - Marine Vessels	N_2O	298	<0.1	0.5
Biomass - landfill			<0.1	<0.1
			Phase Total	**44.7**
Screening level GHG emission estimate [kt CO_2e]				**129.4**
Federal reporting threshold [kt CO_2e]				**50**
Provinical reporting threshold [kt CO_2e]				**10**
Are screening level GHG emission estimates above program reporting thresholds? (Yes or No)				YES

As mentioned in Section 1.0, the inputs used to estimate the emissions are based on the detailed information about the project as presented in Section 2.0 Project Description of this environmental assessment, along with information provided by the proponent. The assumptions used to calculate the GHG emissions are conservative and may overestimate the actual emissions. Therefore, any comparison to the reporting programs should be recalculated once actual consumption data is available.

7.5 Comparison of Project Greenhouse Gas Emissions to Canadian and Global Emissions

As GHGs are considered to be a global issue, the annual GHG emissions in CO_2e for BC, Canada and globally are provided in Table 14 and Table 15. Data for BC and Canada GHG releases are provided by Environment Canada (Environment Canada 2012).

Table 15: Comparison of Project Construction Phase GHG Emissions to BC, Canadian, and Global Emissions

Source	Annual Greenhouse Gas Emissions (kt CO2e/yr)	Project Total as a Relative Percentage
Direct emissions	45	—
Indirect emissions	0	
Project Total	45	
British Columbia (2010)	61,500	0.07%
Canada (2010)	699,000	0.006%
2011 WRI Global	43,816,734	0.0001%

***Source**: Data for B.C. and Canada wide GHG emissions were obtained from the British Columbia Greenhouse Gas Inventory (B.C. Ministry of Environment, 2014) and National Inventory Report (Environment Canada, 2014). Data for global GHG emissions were obtained from the WRI (2014).*

Table 16: Comparison of Project Operational Phase GHG Emissions to BC, Canadian, and Global Emissions

Source	GHG Emissions (kt CO_2e)	Project Total as a Relative Percentage
Direct emissions	129	—
Indirect emissions	13	
Project Total	142	
British Columbia (2010)	61,500	0.23%
Canada (2010)	699,000	0.020%
2011 WRI Global	43,816,734	0.0003%

***Source**: Data for BC and Canada wide GHG emissions were obtained from the British Columbia Greenhouse Gas Inventory (BCMOE 2014) and National Inventory Report (Environment Canada, 2014). Data for global GHG emissions were obtained from the WRI (WRI 2014).*

8.0 GHG INTENSITY

The GHG intensity value for the project was estimated by taking the annual project GHG emissions and dividing it by the corresponding design throughput of LNG. Therefore, at peak capacity the project will have a GHG intensity of 0.059 t CO_2e /t LNG. This value is considered much lower than other LNG projects and can be attributed to the use of electrically powered compressor units. The following table presents a comparison to average of several LNG projects and the Pacific NorthWest LNG located in northern BC.

Table 17: GHG Intensities of Other LNG Projects

Project	GHG Intensity [t CO2e/t LNG]
Woodfibre LNG	0.059
Average from Similar Projects*	0.33

Project	GHG Intensity [t CO2e/t LNG]
Pacific NorthWest LNG*	0.27

***Note**: * - Data obtained from the Pacific NorthWest LNG Environmental Impact Statement and Environmental Assessment Certification Application (Pacific NorthWest LNG, 2014).*

9.0 REFERENCES

American Petroleum Institute, (2013); Consistent Methodology for Estimating Greenhouse Gas Emissions from Liquefied Natural Gas (LNG) Operations. July 2013.

B.C. Ministry of Environment, (2011); Reporting Regulation Guidance Document. Retrieved August 22, 2014 from http://www2.gov.bc.ca/gov/topic.page?id=7B486984E95C4667948041F3DFDC40FE.

British Columbia Ministry of the Environment, (2014); Greenhouse Gas Inventory Report 2012. Available at http://www.env.gov.bc.ca/cas/mitigation/ghg_inventory/pdf/pir-2012-full-report.pdf. Accessed July 21, 2014.

Canadian Environmental Assessment Agency (CEAA), (2003); Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners.

Environment Canada, (2012); Technical Guidance on Reporting Greenhouse Gas Emissions. Retrieved August 22, 2014 from http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=0BB4FABF-829B-41D8-B9F0-BC689637D068.

Environment Canada, (2013); National Inventory Report 1990-2011. Retrieved August 22, 2014 from http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/7383.php

Environment Canada, (2014); National Inventory Report 1990 - 2012: Greenhouse Gas Sources and Sinks in Canada. Available at https://www.ec.gc.ca/ges-ghg/3808457C-9E9E-4AE3-8463-05EE9515D8FE/NIR2014-Exec%20Sum-Web-Final.pdf. Accessed July 21, 2014.

IPCC, (2006); Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Chapter 4, Table 4.2.8 http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_4_Ch4_Fugitive_Emissions.pdf

ISO 14064-1., (2006); Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals. Retrieved August 22, 2014 from http://www.iso.org/iso/catalogue_detail?csnumber=38381.

Pacific NorthWest LNG, (2014): Environmental Impact Statement and Environmental Assessment Certificate Application, Section 7. Available from http://www.ceaa-acee.gc.ca/050/document-eng.cfm?document=98593. Accessed September 16, 2014.

Solomon, S.,D., Qin, M., Manning, Z., Chen, M., Marquis, K.B., Averyt, M., Tignor, Miller, H.L. (Eds.), (2007); Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA.

The Chamber of Shipping, (2007); 2005 – 2006 BC Ocean-Going Vessel Emissions Inventory.

US EPA (United States Environmental Protection Agency), (2005); Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide

US EPA (United States Environmental Protection Agency), (2010); Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling – Compression-Ignition, NR-009d.

Western Climate Initiative, (2011); Final Essential Requirements of Mandatory Reporting. Retrieved August 22, 2014 from http://www.westernclimateinitiative.org/news-and-updates/141-final-essential-requirements-for-mandatory-reporting-amendments-to-the-canadian-harmonization-version-second-update.

World Business Council for Sustainable Development/World Resources Institute, (2004); The Greenhouse Gas Protocol / A Corporate Accounting and Reporting Standard. Retrieved August 22, 2014, from http://www.ghgprotocol.org/standards/publications.

World Resources Institute, (2014); CAIT 2.0 – WRI's Climate Data Explorer. Available at http://cait2.wri.org/profile/World. Accessed 15 Sept 2014.

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