LNG Emissions Benchmarking

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Delphi Group

Environmental Strategies. Business Solutions.

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Executive Summary

In 2011, the Government of British Columbia (BC) developed a vision and strategy to build a new industry in Liquefied Natural Gas (LNG). Liquefaction of natural gas enables transportation to markets overseas, thereby increasing the market potential of British Columbia's abundant supply of natural gas.

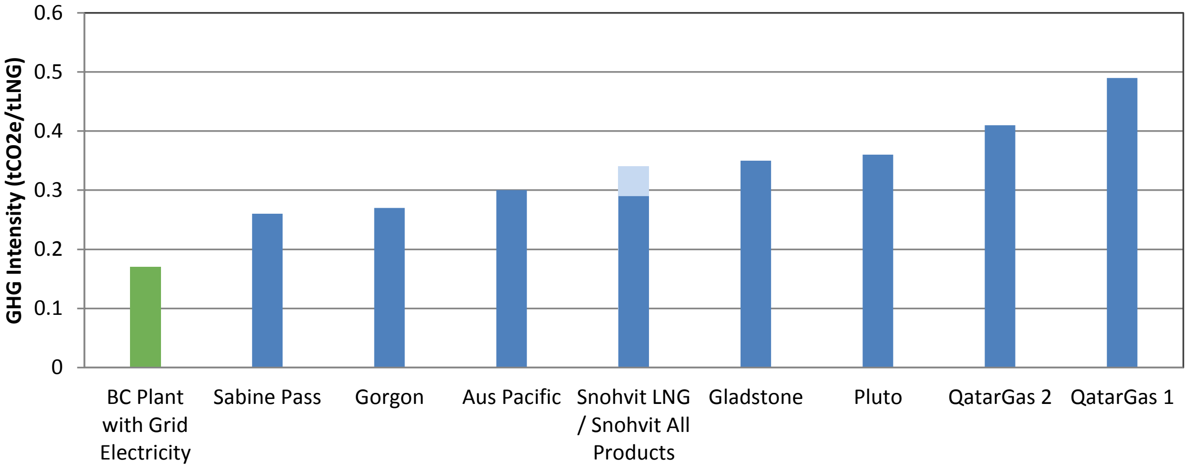
LNG production is an energy intensive process, and the purpose of this report is to benchmark the greenhouse gas (GHG) intensity of a grid electricity powered LNG production facility in BC with other planned and operational facilities worldwide. This benchmarking study focuses on the facility at which LNG is produced. GHG emissions are included for all processes within the LNG facility, but are excluded for processes that occur prior to the gas reaching the facility and for transportation and end-use once the LNG leaves the facility.

The grid-electricity powered facility in BC has been assumed to consist of 2 trains producing 12 million tonnes per annum (mtpa) of LNG. BC Hydro, the crown corporation operating the BC electricity grid, has estimated that it could provide a grid-connected LNG facility with electricity having a GHG emission factor of 200 tCO_2e/GWh without changing the GHG intensity of the grid required to meet the province's other electricity requirements.

Facilities have been included for benchmarking to represent currently installed capacity, best practice amongst facilities in construction, and best practice amongst proposed facilities. The table below provides the facilities included along with their locations and the rationale for inclusion. It is important to note that two of the facilities, Snohvit and Gorgon, incorporate Carbon Capture and Storage (CCS) as a means of GHG mitigation (Snohvit CCS is operational, Gorgon is proposed).

Facility Name	Country	Rationale for Inclusion
Qatargas 1 and Qatargas 2	Qatar	Qatar is the largest producer of LNG worldwide and has been included as a benchmark of typical emission intensity from LNG production
Snohvit	Norway	Snohvit LNG production process has the lowest GHG intensity of any facility currently in operation and includes CCS
Pluto	Australia	Recently commissioned plant with standard new facility performance
Australia Pacific	Australia	Facilities in construction that are being built incorporating efficient processes and GHG mitigation measures
Gladstone	Australia	
Sabine Pass	U.S.	This facility entering construction has the lowest proposed intensity of any of the facilities surveyed.
Gorgon	Australia	Low intensity proposed facility that plans to incorporate CCS.

The GHG intensities of the benchmarked facilities are shown in the figure below. All facilities have been adjusted to an inlet concentration of 1.5% CO_2 in the natural gas in order to account for differences in GHG emissions intensity arising from CO_2 removal. The figure indicates that an LNG facility in BC using grid electricity with an emission factor of 200 tCO_2e/GWh could have the lowest GHG intensity of production compared to all facilities surveyed. The Sabine Pass LNG facility has the next lowest GHG intensity; however, this intensity may be underestimated due to a lack of clarity around the inclusion of CO_2 removal within the facility emissions. Other facilities have higher GHG intensities, ranging from 0.27 – 0.49 $tCO_2e/tLNG$.



1 INTRODUCTION

LNG Facts At A Glance

- LNG is natural gas which has been cooled to -160°C to keep it in a liquid form.
- LNG, unlike natural gas in a gaseous form, can be shipped overseas
- Between 2000 and 2009, the volume of LNG traded, on an annual basis, increased by 77.3%.
- The largest demand growth potential moving forward exists in the Asia Pacific market, specifically in Japan and South Korea. China and India are also competing for additional natural gas supply.

BC has supplied the North American market with natural gas for more than 50 years. Over that time, the market has changed with the onset of unconventional natural gas development and supply. In just a few short years, North America's access to natural gas has increased significantly from this new supply, creating downward pressure on North American natural gas prices.

In 2011, the Government of British Columbia developed a vision and strategy to build a new industry in Liquefied Natural Gas (LNG). Liquefaction of natural gas enables transportation to markets overseas, thereby increasing the market potential of British Columbia's abundant supply of natural gas. By exporting LNG, BC intends to supply growing markets with a cleaner energy source than emissions-intensive sources such as coal and diesel.

LNG production is an energy intensive process, and the purpose of this report is to benchmark the GHG intensity of a grid electricity powered LNG production facility in BC with other planned and operational facilities worldwide. This benchmarking study focuses on the facility at which LNG is produced. GHG emissions are included for all processes within the LNG facility, but are excluded for processes that occur prior to the gas reaching the facility and for transportation and end-use once the LNG leaves the facility.

1.1 Overview and Status of BC LNG Facilities

In September 2011, the Government of BC released *Canada Starts Here: The BC Jobs Plan*. This plan sets the stage for economic growth by focusing on the province's competitive advantages, including natural resources and proximity to growing markets in Asia. *The BC Jobs Plan* included a target of three LNG facilities in operation by the year 2020. To achieve this goal, the Government of BC developed an LNG strategy, with key priorities to keep BC competitive in the global LNG market, while maintaining BC's leadership on climate change and clean energy.

With respect to specific plans for facility construction:

- Shell, announced plans to build LNG Canada with joint venture partners KOGAS, Mitsubishi and PetroChina. TransCanada was later selected to build supportive pipeline infrastructure.
- The BG Group, a major company with an established LNG portfolio, announced a partnership with Spectra Energy to jointly develop a new transportation system. The proposed pipeline will move natural gas from BC's northeast and will serve the BG Group's planned LNG facility on Ridley Island in the Port of Prince Rupert.
- PETRONAS, an experienced LNG operator, announced the Pacific Northwest LNG facility along with their acquired partnership of Progress Energy. TransCanada has been chosen to build supportive pipeline infrastructure for this plant also.
- Chevron Canada purchased an operating interest in the Kitimat LNG plant and the Pacific Trail Pipeline. Chevron will now build and operate this project along with Apache.
- Douglas Channel Energy Partnership plans to construct and operate a small scale LNG facility on the west bank of the Douglas Channel in the District of Kitimat. The project has received LNG export authorization from the National Energy Board and has executed purchase/sale agreements to provide LNG to Pacific Rim markets.

In addition to these LNG proposals, there are other industry players who are actively looking into the possibility of projects of their own, including a partnership between Nexen (recently acquired by CNOC Limited) and Inpex, as well as a recently announced partnership between AltaGas and Idemitsu Kosan.

1.2 Natural Gas Liquefaction Process

The natural gas liquefaction process involves two primary steps: treatment of the inlet natural gas to remove impurities followed by cooling/refrigeration to transform the natural gas into a liquid (LNG). In the first step, impurities such as water, hydrogen sulphide, and carbon dioxide are removed to prevent potential freezing problems in the refrigeration process and to meet LNG product quality specifications. In the refrigeration step, natural gas is cooled to approximately -162^{o}C in a heat exchange cycle using compressed refrigerant(s), such as propane, ethane, and methane.

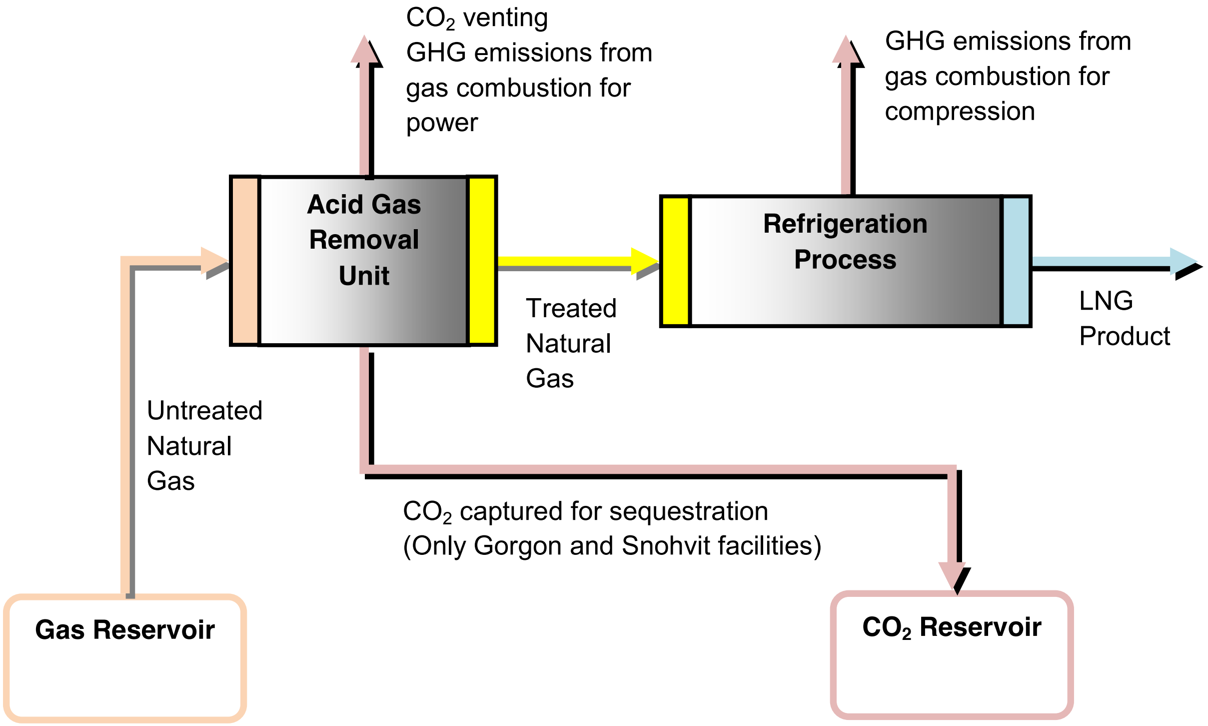


Figure 1 – Schematic of LNG production process with main emission sources.

Figure 1 shows a high-level diagram of the natural gas liquefaction process, beginning with natural gas extraction on the left. The inlet natural gas first enters a unit to remove CO_2 contained within this stream. The process of acid gas removal is sometimes done in two steps, with the first step occurring upstream and bringing the reservoir natural gas to pipeline quality and then the second step (LNG quality) occurring within the LNG facility. In most LNG plants this CO_2 is vented to atmosphere, and is thus one major source of emissions at the LNG facility. Figure 1 also shows the path taken by this CO_2 if it is to be injected in an underground reservoir – note that only one installed and operating plant in the world (Snohvit, Norway) currently incorporates carbon capture and storage (CCS). The Gorgon plant in Australia, currently in the planning phase, anticipates using CCS .

After leaving the CO_2 removal unit, the natural gas will pass through removal units for other impurities and then enter the refrigeration process. The refrigeration process may be divided into 'trains', which are processes operating in parallel to handle the total facility production capacity (the refrigerant compressors can only be sized to refrigerate a maximum amount of natural gas).

Worldwide, all currently operating plants but one (Snohvit, Norway[1]) use 'direct drive', which means that natural gas is used directly by the plant in the refrigeration step to drive the compressors. The proportion of GHG emissions from a typical LNG plant with a 1.5% CO_2 inlet concentration is shown in Figure 2.

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[1] The Snohvit plant uses natural gas generated electricity with grid electricity back-up.

The refrigeration/compression step is the largest consumer of energy and hence the largest producer of GHG emissions.

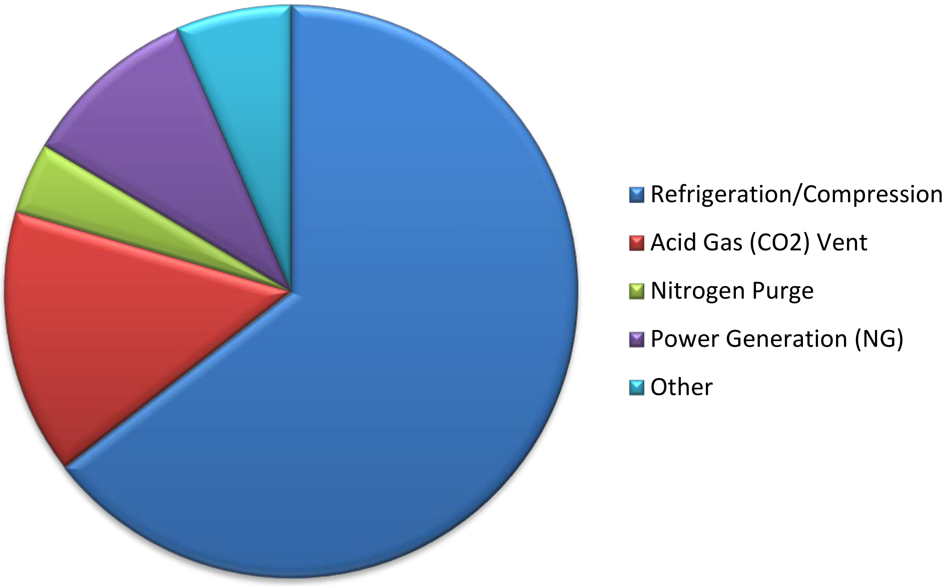

Figure 2 – Typical GHG Emission Allocations from a Natural Gas Powered LNG Facility

Another significant source of GHG emissions is the CO_2 that is vented during the purification process. Other sources of GHG emissions include electricity generated on-site (through natural gas combustion) to be used in the process, methane that is released as part of the removal of nitrogen from the inlet stream and other various smaller sources including flaring and on-site heating.

1.2.1 LNG Process Technologies

A number of different refrigeration processes are currently in use in operating LNG plants around the world. The most common processes are: ConocoPhillips' Optimized Cascade®; Air Products and Chemicals Inc.'s C3/MR™, Split MR™, and AP-X™; and, the Linde Mixed Fluid Cascade (MFCP™). These processes primarily differ in the number of cycles (heat exchange steps) and the type refrigerant(s) used. Differences in efficiency – energy used per tonne LNG produced – between the processes do exist; however, these differences are typically low. Plant equipment, such as gas turbine type, may have a greater effect on efficiency than the type of refrigeration process used. One study estimates that the Single Mixed Refrigerant process, which is considered to have low efficiency, is only 6% less efficient that the C3/MR process[2].

The GHG intensity of proposed and operational facilities are differentiated through a number of GHG mitigation options. There are three main strategies for reducing GHG emissions: incorporating energy efficient technology and processes, pumping CO_2 back into the ground that would have been vented (CCS) or changing the type of energy used. For the first strategy, there are a number of options including high-efficiency compressors, high-efficiency power generation turbines, less energy-intensive CO_2

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[2] Shukri and Barclay. (2007). Single mixed refrigerant process has appeal for growing offshore market. *LNG Journal*, pp. 35-37.

stripping processes and waste heat recovery. CCS can have a particularly large impact when the facility is processing an inlet gas with a high CO_2 concentration. The third strategy involves the electrification of the plant and the use of low emission electricity (e.g. from renewables).

2 REPORT METHODOLOGY

2.1 Benchmarking Scope

This benchmarking study focuses on the facility at which LNG is produced. GHG emissions are included for all processes within the LNG facility, but are excluded for processes that occur prior to the gas reaching the facility and for transportation and end-use once the LNG leaves the facility.

2.2 Included Facilities

Table 1 provides the facilities included within the benchmarking exercise along with a rationale for inclusion. Facilities have been included in order to provide benchmark performance of currently installed capacity, best practice amongst facilities in construction, and best practice amongst proposed facilities.

Table 1 – List of Facilities Included in the Benchmarking Analysis

Facility Name	Country	Rationale for Inclusion
Qatargas 1 and Qatargas 2	Qatar	Qatar is the largest producer of LNG worldwide and has been included as a benchmark of typical emission intensity from LNG production
Snohvit	Norway	Snohvit LNG production process has the lowest GHG intensity of any facility currently in operation and includes CCS
Pluto	Australia	Recently commissioned plant with standard new facility performance
Australia Pacific	Australia	Facilities in construction that are being built incorporating efficient processes and GHG mitigation measures
Gladstone	Australia	
Sabine Pass	U.S.	This facility entering construction has the lowest proposed intensity of any of the facilities surveyed.
Gorgon	Australia	Low intensity proposed facility that plans to incorporate CCS.

2.3 Overview of Methodology

GHG emissions were obtained for each of the facilities from publicly available GHG-specific or broader environmental impact reports. Benchmarking was conducted on an intensity basis in tonnes of CO_2 equivalent per tonne of LNG produced.

2.3.1 Key Assumptions and Limitations

Inlet CO_2 Concentrations

When natural gas is extracted from the ground, it contains CO_2 that must be separated prior to liquefaction in a step referred to as acid gas extraction. Some facilities worldwide liquefy a natural gas stream directly from the point of extraction whereas other facilities liquefy natural gas that has already undergone a separation process. Facilities in BC are expected to produce LNG from natural gas that has already been purified to pipeline quality with an expected CO_2 concentration of 1.5%.

Differences in CO_2 concentrations in the inlet gas to the LNG plant result mainly in a difference in the amount of CO_2 vented on site, but also have an effect on the energy required for acid gas extraction. GHG emissions from the facilities analyzed have been adjusted based on inflow CO_2 concentration to compare as if all inflow concentrations were 1.5% CO_2. This has been done on a mass of CO_2 vented basis only, as the reports contain insufficient information to adjust acid gas removal unit energy consumption.

Available Data

This benchmarking exercise compares performance data with projected data. As with any projected data, it may not be representative of actual facility performance after commissioning, especially if design alterations occur during construction.

Benchmarking Scope

For some facilities, it is not always possible to determine the exact scope of the published GHG emissions. Where there is uncertainty, an explanation of this uncertainty has been included in the analysis. One example of common uncertainty is that it is not always possible to determine whether a facility is including ship loading operations (loading of LNG onto ships for transportation to market) as part of their emissions or not. In the absence of clarity, we have assumed that ship loading operations are not included. Where they have been included in the documentation, we have removed them in this report.

3 ESTIMATION OF GHG EMISSIONS FROM A BC FACILITY

For the purpose of benchmarking a BC grid-electricity powered plant against other facilities, it has been assumed that this plant will consist of 2 trains producing 12 million tonnes per annum (mtpa) of LNG. This facility, rather than being powered directly by natural gas, will use electricity provided by the BC Hydro provincial electricity grid. BC Hydro, the crown corporation operating the BC electricity grid, has estimated that it could provide a grid-connected LNG facility with electricity having a GHG emission factor of 200 tCO_2e/GWh without changing the GHG intensity of the grid required to meet the province's other electricity requirements.

Specific details of energy consumption and technology selection for the BC electricity powered plant were unavailable for this study. Therefore, energy consumption has been estimated from the data published by other efficient facilities. A survey of available energy performance data suggests that an LNG facility consumes 450-500 GWh of energy for the refrigeration step per million tonnes of LNG produced[3]. Using the upper bound of this energy consumption, this would correspond to GHG emissions of 0.1 $tCO_2e/tLNG$ from grid electricity consumption.

The BC facilities will also generate GHG emissions through CO_2 venting, other power requirements and other minor sources (see Figure 2). CO_2 venting and nitrogen purge emission are a function of the concentration of CO_2 in the natural gas feed to the plant. For this analysis, it is assumed that the inlet natural gas contains 1.5% CO_2. Adding up these emission sources, a grid-connected (200 tCO_2e/GWh) LNG facility could have an estimated GHG intensity of 0.17 $tCO_2e/tLNG$ (refer to Appendix A for more detailed calculations).

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[3] Both the Sabine Pass and Snohvit facitilities analyzed in Section 4 have published energy consumption data in this range.

4 DATA AND RESEARCH RESULTS

4.1 Sabine Pass Liquefaction Project, Cameron Parish, Louisiana (Under Construction[4])

4.1.1 Plant Description

In 2012, Cheniere Energy Partners started constructing a natural gas liquefaction plant at its LNG import terminal in Louisiana. The project is expected to be completed by 2015. It will allow the terminal to both import and export LNG, depending on market conditions. Cheniere Energy anticipates constructing the facility with four trains producing 16 mtpa LNG.

4.1.2 Plant Configuration

A summary of the proposed Sabine Pass LNG plant configuration is shown below in Table 2.

Table 2 – Sabine Pass LNG plant configuration[5].

Number of Trains	4
Inlet CO_2 Concentration	Calculated from emissions data as <0.01%.
Refrigeration Process Technology	ConocoPhillips Optimized Cascade.
Refrigeration Compressor Turbine Energy Source	Natural Gas Combustion.
Refrigeration Compressor Turbine Model	General Electric PGT25+G4 aeroderivative gas turbine[6]
Electricity Generation Energy Source	Natural Gas Combustion.
Gas Turbine Generator Model	*Not Available*
Energy Efficiency and GHG Mitigation Measures	• GE Aeroderivative gas turbines selected for refrigeration compression. These turbines have very high thermal efficiency (up to 39%).

4.1.3 Energy Sources and GHG Emissions for Plant Operations

The majority of GHG emissions arise from combustion of natural gas in the turbines driving the refrigeration process (approximately 92%) and turbines for power (approximately 7.5%). This breakdown of GHG emissions is not typical for a LNG plant (see Figure 2). One possible explanation, given the extremely low calculated inlet CO_2 concentration is that the natural gas inlet stream has already undergone acid gas removal to an LNG standard prior to the facility gate. As a result, the facility will have

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[4] U.S. Department of Energy, Federal Energy Regulatory Commission. (2013). North American Import/Export Terminals. Available online: http://1.usa.gov/nkSz1M.

[5] Federal Energy Regulatory Commission. (December 2011). *Environmental Assessment for the Sabine Pass Liquefaction Project.* Available online: http://bit.ly/WqHtfr

[6] BusinessWire. (October 8, 2012). GE technology to power Cheniere Energy's LNG export facility in Louisiana. Available online: http://bit.ly/16vtlp7

low CO_2 venting emissions and a reduced energy demand for the acid gas removal unit, mercury removal unit, and dehydration system. This would explain the relatively low emissions associated with acid gas venting and power generation, as shown in the summary of GHG emissions below in Table 3.

Table 3 – GHG Emissions and Sources for the Sabine Pass LNG Plant.[7]

GHG Source	Emissions (t CO_2e for 16 mtpa plant)
Oil Heating	*Not Available*
Refrigeration Compressors	3,520,000
Power Generation	293,000
Power for Ship at Berth	*Not Available*
Backup Natural Gas Generators	824
Acid Gas Vent	688
Methane in N_2 Purge	*Not Available*
Fugitive Emissions	89,600
Flaring	3,440
TOTAL	**3,910,000**

4.1.4 GHG Emission Intensity

The Sabine Pass emissions data shown in Table 3 was adjusted for an inlet CO_2 concentration of 1.5% (refer to Appendix A for calculations). The GHG emission intensity of the facility was calculated to be **0.26 tCO_2e/tLNG**

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[7] Federal Energy Regulatory Commission (December 2011).

4.2 Australia Pacific LNG Project, Queensland, Australia

4.2.1 Plant Description

Australia Pacific LNG Pty Limited (Australia Pacific LNG), a partnership between Origin, ConocoPhillips, and Sinopec, began construction in 2012 on a LNG liquefaction project that will utilize Australia's substantial coal seam gas resources in Queensland. The LNG plant is expected to become operational in 2015. It will include four LNG trains with an installed capacity of approximately 18 mtpa.

4.2.2 Plant Configuration

A summary of the proposed Australia Pacific LNG plant configuration is shown below in Table 4.

Table 4 – Australia Pacific LNG plant configuration[8].

Number of Trains	4
Inlet CO_2 Concentration	1%
Refrigeration Process Technology	ConocoPhillips Optimized Cascade.
Refrigeration Compressor Turbine Energy Source	Natural Gas Combustion.
Refrigeration Compressor Turbine Model	General Electric LM2500-G4+ aeroderivative gas turbine
Electricity Generation Energy Source	Natural Gas Combustion.
Gas Turbine Generator Model	Solar Titan 130
Energy Efficiency and GHG Mitigation Measures	• GE Aeroderivative gas turbines selected for refrigeration compression. These turbines have very high thermal efficiency (up to 39%). • Waste heat recovery for process duties. • Boil-off gas compression to recover vapours generated during production and ship loading

4.2.3 Energy Sources and GHG Emissions for Plant Operations

The majority of GHG emissions arise from combustion of natural gas in the gas turbines driving the refrigeration process (approximately 65%), power generation turbines (approximately 17%) and the acid gas CO_2 vent (approximately 11% based on 1% CO_2 in the feed gas). A summary of GHG emissions associated with the facility is shown below in Table 5.

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[8] WorleyParsons. (March 2010). *Australia Pacific LNG Project, Volume 5: Attachments, Attachment 31: Greenhouse Gas Assessment*. Available online: http://bit.ly/Z7NGwD

Table 5 – GHG Emissions and Sources for the Australia Pacific LNG Plant[9].

GHG Source	Emissions (t CO_2e for 4.5 mtpa plant)	Emissions (t CO_2e for 9 mtpa plant)	Emissions (t CO_2e for 13.5 mtpa plant)	Emissions (t CO_2e for 18 mtpa plant)
Oil Heating	17,500	35,000	52,500	70,000
Refrigeration Compressors	890,000	1,780,000	2,670,000	3,560,000
Power Generation	100,000	200,000	300,000	400,000
Power for Ship at Berth	*130,000 (Excluded)*	*260,000 (Excluded)*	*390,000 (Excluded)*	*520,000 (Excluded)*
Backup Diesel Generators	100	200	300	400
Acid Gas Vent	145,000	290,000	435,000	580,000
Methane in N_2 Purge	60,000	120,000	180,000	240,000
Fugitive Emissions	4,000	8,000	12,000	16,000
Flaring	60,000	60,000	120,000	120,000
TOTAL	**1,276,600**	**2,493,200**	**3,769,800**	**4,986,400**

4.2.4 GHG Emission Intensity

The facility GHG emissions intensity was calculated by adjusting for an inlet CO_2 concentration of 1.5%, using the data in Table 5 for train 1[10] (refer to Appendix A for calculations). The GHG intensity was determined to be **0.30 $tCO_2e/tLNG$**.

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[9] WorleyParsons (March 2010).

[10] Note that the emissions estimates above were calculated in WorleyParsons (March 2010) by assuming a linear relationship with LNG production capacity, and therefore the emissions intensity is the same for all plant capacities in the table.

4.3 Pluto LNG Project, Western Australia, Australia

4.3.1 Plant Description

The Pluto LNG Project is located immediately south of the Karratha Gas Plant (KGP) on the Burrup Peninsula, Western Australia. The project is a joint venture between Woodside, the operator, Tokyo Gas and Kansai Electric. Production of LNG in train 1 began in May 2012 with an estimated output of 4.3 mtpa.

4.3.2 Plant Configuration

A summary of the LNG plant configuration for the first phase of the Pluto project is shown below in Table 6.

Table 6 – Pluto LNG Plant Configuration[11].

Number of Trains	1
Inlet CO_2 Concentration	2.0%
Refrigeration Process Technology	Shell FosterWheeler Worley (SFWW) C3MR
Refrigeration Compressor Turbine Energy Source	Natural Gas Combustion.
Refrigeration Compressor Turbine Model	General Electric Frame 7EA heavy duty gas turbine
Electricity Generation Energy Source	Natural Gas Combustion.
Gas Turbine Generator Model	General Electric Frame 6B gas turbine
Energy Efficiency and GHG Mitigation Measures	• Improved CO_2 separation with aMDEA technology • Waste heat recovery for process duties. • Boil-off gas compression to recover vapours generated during production and ship loading • Purchase of carbon offsets

4.3.3 Energy Sources and GHG Emissions for Plant Operations

The major sources of greenhouse gas emissions for Pluto LNG Project are gas turbines for liquefaction (50%), power generation (30%), and reservoir CO_2 (15%). A summary of GHG emissions associated with the facility is shown below in Table 7.

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[11] Woodside. (June 20, 2011). Pluto LNG Project Greenhouse Gas Abatement Program, Revision 2. Available online: http://bit.ly/YuyYjb

Table 7 – GHG Emissions and Sources for the Pluto LNG Plant[12].

GHG Source	Emissions (t CO_2e for 4.3 mtpa plant)
Oil Heating	*Not Available*
Refrigeration Compressors	804,000
Power Generation	528,000
Power for Ship at Berth	*Not Available*
Backup Diesel Generators	10,000
Acid Gas Vent	242,000
Methane in N_2 Purge	6,000
Fugitive Emissions	4,000
Flaring	29,000
TOTAL	**1,610**

4.3.4 GHG Emission Intensity

The reference document for the Pluto LNG project gives an emission intensity value of 0.31 tCO_2e / t LNG; however, this intensity includes emission reductions achieved from the purchase of carbon offsets. In order to derive a GHG intensity appropriate for the benchmarking comparison, an emission intensity was calculated by removing purchased offset credits and adjusting for an inlet CO_2 concentration of 1.5% (refer to Appendix A). The calculated emissions intensity is **0.36 tCO_2e/tLNG**.

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[12] Woodside (June 20, 2011).

4.4 Gladstone LNG Project (GLNG), Queensland, Australia

4.4.1 Plant Description

Santos Limited and its partners PETRONAS, Total, and Kogas began construction in 2010 on a LNG liquefaction and export facility on Curtis Island, near Gladstone, Queensland. The LNG facility will have an initial capacity of 3 - 4 mtpa with the potential for later expansion to 10 mtpa. The LNG facility operations are planned to commence in 2015.

Another project in the Gladstone area currently in the planning phase is the Gladstone LNG Project – Fisherman's Landing. This project is being developed by Liquefied Natural Gas Limited and will have a capacity of 3mtpa. An environmental impact statement prepared for this plant states that it will have an emissions intensity of 0.2 $tCO_2e/tLNG$, which would make it the least GHG intensive facility in the world[13].

GHG intensity comparisons with the Fisherman's Landing project cannot be made as the environmental impact statement does not specify power generation requirements, the CO_2 content of the feed gas or the frequency and volumes of gas flared. Also, at the time of writing this report, the appendix to the impact statement detailing GHG emission calculations is not available on Liquefied Natural Gas Ltd.'s website.

4.4.2 Plant Configuration

A summary of Santos Ltd.'s proposed LNG plant configuration is shown below in Table 8.

Table 8 – Gladstone LNG plant configuration[14].

Number of Trains	3
Inlet CO_2 Concentration	Not provided in reference documents. Reference documents mention the reservoir CO_2 concentration is 'very low'. The APLNG reservoir has a CO_2 concentration of 1% and it has been assumed the Gladstone project reservoir will have a similar CO_2 concentration.
Refrigeration Process Technology	ConocoPhillips Optimized Cascade
Refrigeration Compressor Turbine Energy Source	Natural Gas Combustion.
Refrigeration Compressor Turbine Model	*Not Available*
Electricity Generation Energy Source	Natural Gas Combustion.
Gas Turbine Generator Model	*Not Available*
Energy Efficiency and GHG Mitigation Measures	• GE Aeroderivative gas turbines selected for refrigeration compression. These turbines have very high thermal efficiency (up to 39%). • Use of boil-off gas in the facility as fuel rather than venting or flaring

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[13] WorleyParsons. (September 17, 2008). Gladstone LNG Project – Fisherman's Landing Environmental Impact Statement – Volume 1. Available online: http://bit.ly/ZRp64i

[14] Santos. (October 2009). Supplementary EIS Greenhouse Gas Management. Available online: http://bit.ly/16vtWr4

4.4.3 Energy Sources and GHG Emissions for Plant Operations

The major sources of greenhouse gas emissions for Gladstone LNG Project are fuel consumption in gas turbines for liquefaction and other process equipment (71%), all flaring and venting activities (20%) and power generation (9%). A summary of GHG emissions associated with the facility is shown below in Table 9.

Table 9 – GHG Emissions for the Gladstone LNG Plant[15].

GHG Source	Emissions (t CO_2e for 3 mtpa plant)	Emissions (t CO_2e for 10 mtpa plant)
Oil Heating	*Not Available*	*Not Available*
Refrigeration Compressors	825,764	2,471,724
Power Generation	102,735	319,196
Power for Ship at Berth	*Not Available*	*Not Available*
Backup Diesel Generators	*Not Available*	*Not Available*
Acid Gas Vent (Reported as Flaring and Venting)	233,570	679,642
Methane in N_2 Purge	Included in Acid Gas Vent Line	Included in Acid Gas Vent Line
Fugitive Emissions	653	1,959
Flaring	Included in Acid Gas Vent Line	Included in Acid Gas Vent Line
TOTAL	**1,162,722**	**3,472,521**

4.4.4 GHG Emission Intensity

Adjustments were not made to the reported GHG intensity values for Gladstone, as the inlet CO_2 concentration is unknown. As noted above, it has been assumed that the inlet CO_2 concentration will be close to 1% and therefore venting emissions will be similar to a plant with a 1.5% CO_2 inlet concentration. The emissions intensity of the GLNG Project is estimated to be **0.39 tCO_2e/tLNG** for the 3 mtpa process and **0.35 tCO_2e/tLNG** for the full-scale 10 mtpa process.

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[15] Santos (October 2009).

4.5 Snohvit LNG Installation, Snohvit, Norway

4.5.1 Plant Description

The Statoil owned Snohvit natural gas plant, currently in operation, is located in the Barents Sea off the northern Norwegian coast. The plant has a capacity of 4.3 mtpa LNG, 0.2 mtpa LPG (Liquefied Petroleum Gas), and 0.8 mtpa condensate (mostly hydrocarbons such as pentane, hexane, etc.).

4.5.2 Plant Configuration

The Snohvit plant utilizes a Mixed Fluid Cascade[16] refrigeration process and is powered by gas turbine electrical generators with back-up electricity provided by the grid. This set-up is different from the typical LNG plant in that the compressors run on electricity generated from natural gas, rather than energy from direct natural gas combustion. One benefit of this set-up is the decoupling of the train capacity from the drive sizes, because the electrical drive motors for the compressors can be operated almost stepless. If the compressors were to be driven directly by the gas turbines, there would be limitations because only certain sizes of gas turbines are available.

Another atypical feature of the Snohvit plant is that it captures CO_2 separated from the inlet natural gas and injects it into an underground reservoir. This offsets most of the emissions that would be associated with venting the CO_2 separated from the inlet gas in the acid gas removal unit.

The Snohvit plant also benefits from the cold climate of northern Norway, which allow both the process gas turbines and the LNG process to operate more efficiently.

A summary of the operating Snohvit LNG plant configuration is shown below in Table 10.

Table 10 – Snohvit LNG plant configuration[17].

Number of Trains	1
Inlet CO_2 Concentration	8%
Refrigeration Process Technology	Linde-Statoil Mixed Fluid Cascade
Refrigeration Compressor Turbine Energy Source	Electricity from Natural Gas Combustion with Grid-Electricity Backup.
Refrigeration Compressor Turbine Model	General Electric Nuovo Pignone MCL1404/1406 and BCL1007[18]
Electricity Generation Energy Source	Natural Gas Combustion with backup provided by the local electricity grid.
Gas Turbine Generator Model	General Electric LM 6000 gas turbine
Energy Efficiency and GHG Mitigation Measures	• Aeroderivative gas turbines selected for refrigeration compression. These turbines have very high thermal efficiency (up to 39%).

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[16] Berger, E., Forg, W., Heiersted, R.S., and P. Paurola. (2003). The MFC® (Mixed Fluid Cascade) process for the first European baseload LNG Production Plant, The Snohvit Project. Available online: http://bit.ly/10Nknjc

[17] Berger et al. (2003).

[18] StatoilHydro. Snohvit LNG, Rotating Equipment, Theory and main boosting. Available online: http://bit.ly/13YV6ak

	• Waste heat recovery. • Carbon dioxide injection sequestration in an underground reservoir.

4.5.3 Energy Sources and GHG Emissions for Plant Operations

A breakdown of GHG emissions by source is not available in public documents. The total GHG emissions emitted by the facility are given in Statoil's 2011 Sustainability Report as 964,000 tonnes CO_2 and 3,070 tonnes CH_4.[19] It should be noted that these values include emissions from the production of condensate and liquefied petroleum gas (LPG), which are not included in the emissions estimates for the other facilities discussed in this report. The emissions for the LNG production facility are not separated from emissions associated with LPG and condensate production in the Statoil data. This is addressed in the GHG intensity section below by calculating two intensities: one including the LPG and condensate produced on a LNG energy equivalent basis, and the other using only the LNG produced. A summary of GHG emissions associated with the facility is shown below in Table 11.

Table 11 – GHG Emissions for the Snohvit LNG Plant.

GHG Source	Emissions (t CO_2e for 4.3 mtpa plant)
Oil Heating	*Not Available*
Refrigeration Compressors	*Not Available*
Power Generation	*Not Available*
Power for Ship at Berth	*Not Available*
Backup Diesel Generators	*Not Available*
Acid Gas Vent	*Not Available*
Methane in N_2 Purge	*Not Available*
Fugitive Emissions	*Not Available*
Flaring	*Not Available*
TOTAL	**1,028,470**

4.5.4 GHG Emission Intensity

A GHG emission intensity in terms of LNG production at the Snohvit plant is not available in Statoil's public documents. An intensity referenced in numerous benchmarking studies of 0.22 $tCO_2e/tLNG$ was first reported in the Gorgon plant's draft environmental impact statement, released in 2005[20].This was a pre-production estimate of GHG intensity, as the Snohvit facility was then currently under construction. It was also based on the assumption that all reservoir CO_2 contained in the inlet natural gas would be captured and reinjected into an underground reservoir. However, it appears there have been problems

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[19] Statoil. (2012). Annual Report 2011, Sustainability Reporting, Environmental Data. Available online: http://bit.ly/10TlYXp

[20] Chevron Australia. (2005). Draft environmental impact statement/environmental review and management programme for the Gorgon development, Section 13: Greenhouse gas emissions – risks and management. Available online: http://bit.ly/Xb7Ent

with CO_2 injection at the Snohvit facility due to reservoir pressure buildup[21]. The quantity of CO_2 currently being injected at Snohvit is unclear as Statoil has not made this data publicly available.

Emissions intensities were calculated from data available in Statoil`s 2011 Sustainability Report, adjusting the concentration of CO_2 in the inlet natural gas to 1.5% and assuming this CO_2 is vented rather than captured and injected (refer to Appendix A for calculations). There was no information available to allocate emissions to the three product streams, so a range of intensities were calculed with the upper bound estimated by allocating all emissions to the LNG stream and the lower bound estimated by allocating emissions on an energy of product basis. The emission intensity for LNG production is therefore estimated between **0.34 tCO_2e/tLNG** and **0.29 tCO_2e/tLNG equivalent**.

4.6 Qatargas 1, 2, Qatar

4.6.1 Plant Description

Qatargas Operating Company is a venture between Qatar Petroleum, Total, ExxonMobil, ConocoPhillips, Shell, Mitsui, Marubeini, Idemitsu Kosan, and Cosmo Oil. Qatargas currently operates 7 LNG facilities with a total capacity of 42 mtpa. This section only describes two of these facilities, Qatargas 1 and Qatargas 2, as GHG emission data is not available for the other facilities. Qatargas 1 consists of three LNG trains with a total capacity of 10 mtpa and Qatargas 2 consists of 2 LNG trains with a total capacity of 15.6 mtpa.

4.6.2 Plant Configuration

A summary of the operating Qatargas LNG plants configuration is shown below in Table 12.

Table 12 – Qatargas 1 and 2 LNG plant configuration[22].

Number of Trains	Qatargas 1 – 3 Qatargas 2 – 2
Inlet CO_2 Concentration	2.1%
Refrigeration Process Technology	AP-X Hybrid Liquefaction
Refrigeration Compressor Turbine Energy Source	Natural Gas Combustion.
Refrigeration Compressor Turbine Model	Qatargas 1 – General Electric Frame 5 heavy duty gas turbine Qatargas 2 – General Electric Frame 9 heavy duty gas turbine
Electricity Generation Energy Source	Natural Gas Combustion.
Gas Turbine Generator Model	*Not Available*
Energy Efficiency and GHG Mitigation Measures	• Heat recovery

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[21] See: Stigset, M. (May 19, 2011). Statoil's reservoir for carbon injection full, Teknisk says. *Bloomberg.* Available online: http://bloom.bg/lZVtHh and Lund, P.C. (October 29, 2012). CCS in Norway Status Report. *Briefing to Global CCS Institute Japan Study Meeting.* Available online: http://slidesha.re/YuA2Ug.

[22] Qaratgas. (2012). 2011 Sustainability Report. Available online: http://bit.ly/12U4qN6

4.6.3 Energy Sources and GHG Emissions for Plant Operations

The major sources of greenhouse gas emissions for Qatargas are combustion of natural gas in turbines for power generation liquefaction compressors (68%), reservoir CO_2 venting (18%), and natural gas flaring (14%). Emissions from Qatargas 1 and 2 are shown below in Table 13.

Table 13 – GHG Emissions for the Qatargas 1 and 2 plants[23].

GHG Source	Qatargas 1 Emissions (t CO_2e for 10 mtpa plant)	Qatargas 2 Emissions (t CO_2e for 15.6 mtpa plant)
Oil Heating	*Not Available*	*Not Available*
Refrigeration Compressors	Included with Power Generation	Included with Power Generation
Power Generation	3,536,209	4,594,043
Power for Ship at Berth	*Not Available*	*Not Available*
Backup Diesel Generators	*Not Available*	*Not Available*
Acid Gas Vent	936,055	1,216,070
Methane in N_2 Purge	*Not Available*	*Not Available*
Fugitive Emissions	*Not Available*	*Not Available*
Flaring	728,043	945,832
TOTAL	**5,200,308**	**6,755,947**

4.6.4 GHG Emission Intensity

Facility specific GHG intensities were not available in public documents, so intensities were calculated from GHG emission estimates and plant capacities. These emission estimates were adjusted for a 1.5% CO_2 concentration in inlet natural gas (refer to Appendix A for calculations). The emission intensity for Qatargas 1 is **0.49 tCO_2e / t LNG** and for Qatargas 2, **0.41 tCO_2e / t LNG**.

4.7 Gorgon LNG Project, Western Australia, Australia

4.7.1 Plant Description

The Gorgon Joint Venture, which includes Chevron Australia, Shell Development Australia, Mobil Australia, Osaka Gas, Tokyo Gas, and Chubu Electric Power, is currently constructing the Gorgon LNG plant in Australia. Shipment of LNG from the facility is expected to commence in 2015. The Gorgon plant will consist of three trains with a production capacity of 15 mtpa LNG.

4.7.2 Plant Configuration

A summary of the proposed Gorgon LNG plant configuration is shown below in Table 14.

Table 14 – Gorgon LNG plant configuration[24].

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[23] Qaratgas (2012). Note that a breakdown of emissions by source for each individual plant was not available, so emissions by source were estimating using the breakdown of emissions for all plants combined.

Number of Trains	3
Inlet CO_2 Concentration	14%
Refrigeration Process Technology	Split-MR Propane Pre-Cooled Mixed Refrigerant
Refrigeration Compressor Turbine Energy Source	Natural Gas Combustion.
Refrigeration Compressor Turbine Model	General Electric Frame 7 gas turbine
Electricity Generation Energy Source	Natural Gas Combustion.
Gas Turbine Generator Model	General Electric Frame 9 gas turbine
Energy Efficiency and GHG Mitigation Measures	• Aeroderivative gas turbines selected for refrigeration compression. These turbines have very high thermal efficiency (up to 39%). • Improved CO_2 separation with aMDEA technology • Waste heat recovery • Carbon dioxide sequestration (CCS) by injection in an underground reservoir.

4.7.3 Energy Sources and GHG Emissions for Plant Operations

The major sources of greenhouse gas emissions for the Gorgon LNG Project are gas turbines for liquefaction (46%), power generation (37%), and reservoir CO_2 venting (16%). Emissions and emission sources from the Gorgon plant are shown below in Table 15.

Table 15 – GHG Emissions and Sources for the Gorgon LNG Plant[25].

GHG Source	Emissions (t CO_2e for 15 mtpa plant)
Oil Heating	10,910
Refrigeration Compressors	2,467,000
Power Generation	1,987,000
Power for Ship at Berth	*Not Available*
Backup Generators	*Not Available*
Acid Gas Vent	847,700
Methane in N_2 Purge	*Not Available*
Fugitive Emissions	18,970
Flaring	41,050
TOTAL	**5,372,630**

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[24] Chevron Australia. (2009). Gorgon Gas Development and Jansz Feed Gas Pipeline: Greenhouse Gas Abatement Program. Available online: http://bit.ly/J8smlp

[25] Chevron Australia (2009).

4.7.4 GHG Emission Intensity

For comparison to the other plant GHG intensities in this document, the reported Gorgon GHG intensity was adjusted by removing the power required to run CO_2 injection compressors, the extra power to run the acid gas removal unit, and the inlet CO_2 concentrated was adjusted to 1.5% (refer to Appendix A for calculations). The calculated GHG intensity for the Gorgon plant is **0.27 $tCO_2e/tLNG$**.

5 BENCHMARKING COMPARISON

The GHG intensities of the benchmarked facilities are shown in Figure 3.

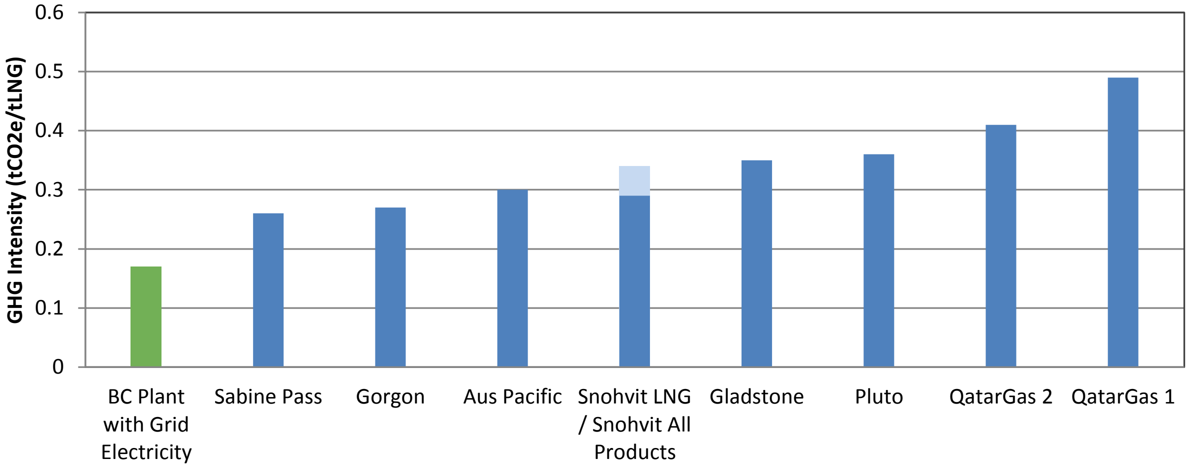

Figure 3 – GHG intensity for the LNG facilities surveyed, in $tCO_2e/tLNG$.

Emissions intensities from all facilities have been adjusted from reported values to facilitate comparison between the different facilities. The following adjustments to reported intensities have been made:

- The inlet concentration of CO_2 in the natural gas has been normalized to 1.5% in order to adjust for differences in GHG emissions intensity arising from CO_2 venting.
- For facilities with ship loading emissions reported, these emissions have been removed to enable comparison with facilities that have not reported ship loading emissions. However, if BC uses shore power provided by grid electricity for its ship loading needs, there may be an emissions advantage for grid-powered BC facilities.
- Emissions offset by the use CCS or purchase of carbon offsets have been added back to total facility emissions when calculating GHG intensities.

The figure indicates that an LNG facility in BC using grid electricity with an emission factor of 200 tCO_2e/GWh could have the lowest GHG intensity of production compared to all facilities surveyed. The Sabine Pass LNG facility has the next lowest GHG intensity; however, this intensity may be underestimated due to a lack of clarity around the inclusion of CO_2 removal within the facility emissions. Other facilities have higher GHG intensities, ranging from 0.27 – 0.49 $tCO_2e/tLNG$.

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7 APPENDIX A:
GHG INTENSITY CALCULATIONS

BC Grid-Electricity Powered Facility

Emissions from Refrigeration Compression

As discussed in Section **Error! Reference source not found.**, a survey of available energy performance data suggests that a LNG facility consumes 450-500 GWh of energy for the refrigeration step per million tonnes of LNG produced. For the grid electricity powered BC facility, it was conservatively assumed that the refrigeration energy requirement is 500GWh.

500 GWh/mtpa * 12 mtpa * 200 tCO_2e/GWh

= 1,200,000 tCO_2e

Estimating Power Generation Requirements

To estimate the power generation requirement, data from the Pluto and Gorgon plants were used, as these were the only plants benchmarked that reported facility power requirements.

Pluto Power Requirement: 108MW / 4.3 mtpa[26]

= 25.12 MW / mtpa

Gorgon Power Requirement = 384MW (total) – 15MW (acid gas removal unit) – 85MW (CCS injection power)[27]

= 284MW / 15 mtpa

= 18.93MW / mtpa

Using these power requirements, an estimate of the power requirement for the grid electricity powered BC facility was calculated. A low estimate of power requirement was calculated using the Gorgon data and a high estimate of power requirement was calculated using the Pluto data.

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[26] Woodside (June 20, 2011)

[27] See Chevron Australia (2009). This adjusts the Gorgon power requirement by removing the power required for CCS and the extra power required by the acid gas removal unit due to a very high concentration of inlet CO_2 (14%).

BC Power Requirement Low

18.93MW / mtpa * 12mtpa

= 227.16MW * 8170 hours/year operation[28]

= 1855.9 GWh

BC Power Requirement High

25.12 MW / mtpa * 12mtpa

= 301.44 MW * 8170 hours/year operation

= 2462.8 GWh

Emissions from Facility Power

A low and high estimate of facility emissions from power generation was then calculated using the grid emission factor supplied by BC Hydro.

Low: 1855.9 GWh * 200 tCO_2e/GWh

= 371,180 tCO_2e

High: 2462.8 GWh * 200 tCO_2e/GWh

= 492,553 tCO_2e

Emissions from CO_2 Venting

It was assumed that the inlet concentration of CO_2 in the feed natural gas is 1.5% and all of this CO_2 is vented to atmosphere.

12 mtpa LNG * 1.5% CO_2

= 180,000 tCO_2e

Total from Refrigeration, Power Generation, and CO_2 Venting

Low: 1,200,000 tCO_2e + 371,180 tCO_2e + 180,000 tCO_2e

= 1,751,180 tCO_2e

High: 1,200,000 tCO_2e + 492,553 tCO_2e + 180,000 tCO_2e

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[28] An assumption was made that the plant will be in operation for 340 days per year. This aligns with the assumption made in the Gorgon emissions report.

= 1,872,553 tCO_2e

Adjusting for Other Sources of Emissions

Other minor sources of emissions include methane venting in the nitrogen purge unit, fugitive emissions, flaring, and on-site heating requirements. These emissions typically make up approximately 10% of total plant emissions (refer to Figure 2). The emissions from refrigeration, power generation, and CO_2 venting were assumed to make-up 90% of total facility emissions, which were calculated as follows:

Low GHG Emissions = 1,751,180 tCO_2e / 0.90

= 1,945,755 tCO_2e

Low GHG Intensity = 1,945,755 tCO_2e / 12 mtpa

= 0.16 $tCO_2e/tLNG$

The above value represents the GHG intensity of a potential grid electricity powered facility in BC assuming a low power generation requirement.

High GHG Emissions = 1,872,553 tCO_2e / 0.90

= 2,080,614 tCO_2e

High GHG Intensity

= 2,080,614 tCO_2e / 12mtpa

= 0.17 $tCO_2e/tLNG$

The above value represents the GHG intensity of a potential grid electricity powered facility in BC assuming a high power generation requirement.

Sabine Pass

The emissions from acid gas venting have been estimated as 688 tCO_2e per 16 Mt LNG, which corresponds to an inlet CO_2 concentration of less than 0.01%[29]. In order to adjust emissions to a 1.5% inlet CO_2 concentration, first 1.5 mass% of the LNG produced was calculated as follows:

16 mtpa LNG * 1.5%[30]

=240,000 tCO_2

This value was used in the calculation of GHG emissions intensity, as described below.

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[29] The inlet CO_2 concentration was estimated by dividing the vented CO_2 (acid gas vents) by the total production of LNG.

[30] Note that this is a simplified approach since it is not adjusting for power use of the acid gas removal unit.

GHG Emissions Intensity

The GHG emission intensity was calculated using the data in Table 3 as follows:

Adjusting for inlet CO_2 concentration of 1.5%

The acid gas venting emissions from Table 3 were subtracted from the total emissions and the estimate of emissions assuming a 1.5% CO_2 inlet concentration were added back.

3.91E6 tonnes CO_2e/yr – 6.55E2 tonnes CO_2/yr + 0.24E6 tonnes CO_2/yr

= 4.15E6 tonnes CO_2e/yr

Divide GHG emissions by plant LNG capacity

4.15E6 tCO_2e /yr / 16E6 tonnes LNG/yr

= 0.26 tCO_2e/t LNG

Australia Pacific

The emissions intensity for the Australia Pacific plant was calculated by adjusting for an inlet concentration of CO_2 of 1.5%.

Adjust the Acid Gas Vent Rate

145,000 tCO_2e * 1.5

= 217,500 tCO_2e

Updated Total Emissions for Train 1

Sum the columns in Table 5 for Train 1, replacing the acid gas vent emissions with the calculated emissions for a 1.5% CO_2 inlet.

= 1,349,100 tCO_2e

Adjusted Emissions Intensity

1,276,600 tCO_2e / 4.5 Mt LNG

= 0.30 tCO_2e/tLNG

Pluto

The emissions intensity for the Pluto plant was calculated by adjusting for an inlet concentration of CO_2 of 1.5%.

Adjusting for a 1.5% Inlet CO_2 concentration

242,000 tCO_2e * (1.5%/2%) CO_2 Inlet

= 181,500 tCO_2e

Updated Emissions per Year

Sum the columns in Table 7, replacing the acid gas recovery unit emissions with the calculated emissions for a 1.5% CO_2 inlet.

= 1.55 Mt CO_2e

Calculation of GHG Intensity

1.55 Mt CO_2e / 4.3 Mt LNG

= **0.36 tCO_2e / t LNG**

Snohvit

The data available for the Snohvit plant did not break down emissions by source category or separate emissions associated with the LNG production facility. Included in the emissions reported are emissions associated with LNG, LPG, and condensate production. To account for this, two intensities were calculated, the first by dividing total emissions by LNG production, and the second by dividing total emissions by total fuel production (LNG, LPG, and condensate), expressed in terms of LNG equivalent energy content. The emissions intensity for the Snohvit plant was also adjusted for an inlet concentration of CO_2 of 1.5%, making the assumption that all CO_2 is currently injected, and thus there are no CO_2 venting emissions currently included in the reported emissions.

Total GHG Emissions

964,000 tCO_2 + 3,070 tCH_4[31] * 21 GWP

= 1,028,470 tCO_2e

Venting emissions for a 1.5% Inlet CO_2 concentration

3,150,000 tLNG produced * 1.5%

= 47,250 tCO_2

Total GHG Emissions

= 1,028,470 + 47,250 tCO_2e

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[31] Statoil (2012).

= 1,075,720 tCO_2e

Divide by LNG Produced

1,075,720 tCO_2e / 3,150,000 tLNG

= **0.34 tCO_2e/tLNG**

Including LPG and Condensate on an Energy basis

210,000 tLPG * 24 MJ/L LNG ÷ 26 MJ/L LPG

= 193,846 tLNG equivalent

520,000 tCondensate (assume all hexane) * 24MJ/L LNG ÷ 29.3MJ/L Hexane

=425,938 tLNG equivalent

1,075,720 tonnes CO_2e / (3,150,000 + 193,846 + 425,938) t LNG equivalent

= **0.29 tCO_2e/tLNG equivalent**

Qatargas 1 and 2

The emissions intensity for the Qatargas 1 and 2 plants were calculated by adjusting for an inlet concentration of CO_2 of 1.5%.

Qatargas 1

Adjust for an inlet concentration of 1.5% CO_2

936,055 tCO_2e * (1.5/2.1)

= 668,611 tCO_2e

Adjusted total emissions

=3,536,209 tCO_2e + 728,043 tCO_2e + 668,611 tCO_2e

= 4,932,863 tCO_2e

Qatargas 1 Intensity

4,932,863 tCO_2e / 10mtpa LNG

= 0.49 tCO_2e/tLNG

Qatargas 2

Adjust for an inlet concentration of 1.5% CO_2

1,216,070 tCO_2e * (1.5/2.1)

868,621 tCO_2e

Adjusted total emissions

= 4,594,043 tCO_2e + 945,832 tCO_2e + 868,621 tCO_2e

= 6,408,496 tCO_2e

Qatargas 2 Intensity

6,408,496 tCO_2e / 15.6 mtpa LNG

= **0.41 $tCO_2e/tLNG$**

Gorgon

The emissions intensity for the Gorgon plant was calculated by adjusting for an inlet concentration of CO_2 of 1.5%, removing emissions associated with power required to operate the CCS injection unit and the extra power required to operate the acid gas removal unit due to a very high inlet CO_2 concentration (14%).

Reservoir CO_2 Vented

1.5% * 15mtpa

= 150,000 tCO_2 Vented

Add the Emissions in Table 15 Replacing with New Vented CO_2 Value

= (10,910 + 2,467,000 + 1,987,000 + 150,000 + 18,970 + 41,050) tCO_2e

= 4,674,930 tCO_2e

Adjusted GHG Intensity

4,674,930 tCO_2e / 15 mtpa

= 0.3117 tCO_2e / t LNG

Subtract Power for Acid Gas Removal and CO_2 Compressors[32]

0.3117 tCO_2e / t LNG – 0.006 tCO_2e / t LNG – 0.027 tCO_2e / t LNG

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[32] Chevron Australia (2009), p. 39

=0.27 tCO_2e/tLNG