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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 tCO₂e/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).

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

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% CO₂ in the natural gas in order to account for differences in GHG emissions intensity arising from CO₂ removal. The figure indicates that an LNG facility in BC using grid electricity with an emission factor of 200 tCO₂e/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 CO₂ removal within the facility emissions. Other facilities have higher GHG intensities, ranging from 0.27 – 0.49 tCO₂e/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°C in a heat exchange cycle using compressed refrigerant(s), such as propane, ethane, and methane.
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.

\(^1\) 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.

Another significant source of GHG emissions is the CO\textsubscript{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\textsuperscript{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\textsubscript{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\textsubscript{2}

stripping processes and waste heat recovery. CCS can have a particularly large impact when the facility is processing an inlet gas with a high CO₂ 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

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

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 CO₂ equivalent per tonne of LNG produced.

2.3.1 Key Assumptions and Limitations

Inlet CO₂ Concentrations

When natural gas is extracted from the ground, it contains CO₂ that must be separated prior to liquefaction in a step referred to as acid gas extraction. Some facilities worldwide liquify a natural gas stream directly from the point of extraction whereas other facilities liquify 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 CO₂ concentration of 1.5%.
Differences in CO\textsubscript{2} concentrations in the inlet gas to the LNG plant result mainly in a difference in the amount of CO\textsubscript{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\textsubscript{2} concentration to compare as if all inflow concentrations were 1.5% CO\textsubscript{2}. This has been done on a mass of CO\textsubscript{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 tCO₂e/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 tCO₂e/tLNG from grid electricity consumption.

The BC facilities will also generate GHG emissions through CO₂ venting, other power requirements and other minor sources (see Figure 2). CO₂ venting and nitrogen purge emission are a function of the concentration of CO₂ in the natural gas feed to the plant. For this analysis, it is assumed that the inlet natural gas contains 1.5% CO₂. Adding up these emission sources, a grid-connected (200 tCO₂e/GWh) LNG facility could have an estimated GHG intensity of 0.17 tCO₂e/tLNG (refer to Appendix A for more detailed calculations).

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\(^3\) Both the Sabine Pass and Snohvit facilities 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 Construction4)

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 configuration5.

<table>
<thead>
<tr>
<th>Number of Trains</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet CO₂ Concentration</td>
<td>Calculated from emissions data as &lt;0.01%.</td>
</tr>
<tr>
<td>Refrigeration Process Technology</td>
<td>ConocoPhillips Optimized Cascade.</td>
</tr>
<tr>
<td>Refrigeration Compressor Turbine Energy Source</td>
<td>Natural Gas Combustion.</td>
</tr>
<tr>
<td>Refrigeration Compressor Turbine Model</td>
<td>General Electric PGT25+G4 aeroderivative gas turbine6</td>
</tr>
<tr>
<td>Electricity Generation Energy Source</td>
<td>Natural Gas Combustion.</td>
</tr>
<tr>
<td>Gas Turbine Generator Model</td>
<td>Not Available</td>
</tr>
<tr>
<td>Energy Efficiency and GHG Mitigation Measures</td>
<td>• GE Aeroderivative gas turbines selected for refrigeration compression. These turbines have very high thermal efficiency (up to 39%).</td>
</tr>
</tbody>
</table>

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 CO₂ 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...

low CO₂ 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.

<table>
<thead>
<tr>
<th>GHG Source</th>
<th>Emissions (t CO₂e for 16 mtpa plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Heating</td>
<td>Not Available</td>
</tr>
<tr>
<td>Refrigeration Compressors</td>
<td>3,520,000</td>
</tr>
<tr>
<td>Power Generation</td>
<td>293,000</td>
</tr>
<tr>
<td>Power for Ship at Berth</td>
<td>Not Available</td>
</tr>
<tr>
<td>Backup Natural Gas Generators</td>
<td>824</td>
</tr>
<tr>
<td>Acid Gas Vent</td>
<td>688</td>
</tr>
<tr>
<td>Methane in N₂ Purge</td>
<td>Not Available</td>
</tr>
<tr>
<td>Fugitive Emissions</td>
<td>89,600</td>
</tr>
<tr>
<td>Flaring</td>
<td>3,440</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3,910,000</td>
</tr>
</tbody>
</table>

4.1.4 GHG Emission Intensity

The Sabine Pass emissions data shown in Table 3 was adjusted for an inlet CO₂ concentration of 1.5% (refer to Appendix A for calculations). The GHG emission intensity of the facility was calculated to be **0.26 tCO₂e/tLNG**.

---

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.

<table>
<thead>
<tr>
<th>Number of Trains</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet CO\textsubscript{2} Concentration</td>
<td>1%</td>
</tr>
<tr>
<td>Refrigeration Process Technology</td>
<td>ConocoPhillips Optimized Cascade.</td>
</tr>
<tr>
<td>Refrigeration Compressor Turbine Energy Source</td>
<td>Natural Gas Combustion.</td>
</tr>
<tr>
<td>Refrigeration Compressor Turbine Model</td>
<td>General Electric LM2500-G4+ aeroderivative gas turbine</td>
</tr>
<tr>
<td>Electricity Generation Energy Source</td>
<td>Natural Gas Combustion.</td>
</tr>
<tr>
<td>Gas Turbine Generator Model</td>
<td>Solar Titan 130</td>
</tr>
</tbody>
</table>
| 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\textsubscript{2} vent (approximately 11% based on 1% CO\textsubscript{2} in the feed gas). A summary of GHG emissions associated with the facility is shown below in Table 5.

---

Table 5 – GHG Emissions and Sources for the Australia Pacific LNG Plant\textsuperscript{9}.

<table>
<thead>
<tr>
<th>GHG Source</th>
<th>Emissions (t CO(_2)e for 4.5 mtpa plant)</th>
<th>Emissions (t CO(_2)e for 9 mtpa plant)</th>
<th>Emissions (t CO(_2)e for 13.5 mtpa plant)</th>
<th>Emissions (t CO(_2)e for 18 mtpa plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Heating</td>
<td>17,500</td>
<td>35,000</td>
<td>52,500</td>
<td>70,000</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>890,000</td>
<td>1,780,000</td>
<td>2,670,000</td>
<td>3,560,000</td>
</tr>
<tr>
<td>Compressors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Generation</td>
<td>100,000</td>
<td>200,000</td>
<td>300,000</td>
<td>400,000</td>
</tr>
<tr>
<td>Power for Ship at</td>
<td>130,000 (Excluded)</td>
<td>260,000 (Excluded)</td>
<td>390,000 (Excluded)</td>
<td>520,000 (Excluded)</td>
</tr>
<tr>
<td>Berth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backup Diesel</td>
<td>100</td>
<td>200</td>
<td>300</td>
<td>400</td>
</tr>
<tr>
<td>Generators</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acid Gas Vent</td>
<td>145,000</td>
<td>290,000</td>
<td>435,000</td>
<td>580,000</td>
</tr>
<tr>
<td>Methane in N(_2)</td>
<td>60,000</td>
<td>120,000</td>
<td>180,000</td>
<td>240,000</td>
</tr>
<tr>
<td>Purge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fugitive Emissions</td>
<td>4,000</td>
<td>8,000</td>
<td>12,000</td>
<td>16,000</td>
</tr>
<tr>
<td>Flaring</td>
<td>60,000</td>
<td>60,000</td>
<td>120,000</td>
<td>120,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td><strong>1,276,600</strong></td>
<td><strong>2,493,200</strong></td>
<td><strong>3,769,800</strong></td>
<td><strong>4,986,400</strong></td>
</tr>
</tbody>
</table>

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 \textsuperscript{10} (refer to Appendix A for calculations). The GHG intensity was determined to be \textbf{0.30 tCO\(_2\)e/tLNG}.  

\textsuperscript{9} WorleyParsons (March 2010).

\textsuperscript{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

<table>
<thead>
<tr>
<th>Number of Trains</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet CO₂ Concentration</td>
<td>2.0%</td>
</tr>
<tr>
<td>Refrigeration Process Technology</td>
<td>Shell FosterWheeler Worley (SFWW) C3MR</td>
</tr>
<tr>
<td>Refrigeration Compressor Turbine Energy Source</td>
<td>Natural Gas Combustion.</td>
</tr>
<tr>
<td>Refrigeration Compressor Turbine Model</td>
<td>General Electric Frame 7EA heavy duty gas turbine</td>
</tr>
<tr>
<td>Electricity Generation Energy Source</td>
<td>Natural Gas Combustion.</td>
</tr>
<tr>
<td>Gas Turbine Generator Model</td>
<td>General Electric Frame 6B gas turbine</td>
</tr>
</tbody>
</table>
| Energy Efficiency and GHG Mitigation Measures | • Improved CO₂ 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 CO₂ (15%). A summary of GHG emissions associated with the facility is shown below in Table 7.

---

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

<table>
<thead>
<tr>
<th>GHG Source</th>
<th>Emissions (t CO$_2$e for 4.3 mtpa plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Heating</td>
<td>Not Available</td>
</tr>
<tr>
<td>Refrigeration Compressors</td>
<td>804,000</td>
</tr>
<tr>
<td>Power Generation</td>
<td>528,000</td>
</tr>
<tr>
<td>Power for Ship at Berth</td>
<td>Not Available</td>
</tr>
<tr>
<td>Backup Diesel Generators</td>
<td>10,000</td>
</tr>
<tr>
<td>Acid Gas Vent</td>
<td>242,000</td>
</tr>
<tr>
<td>Methane in N$_2$ Purge</td>
<td>6,000</td>
</tr>
<tr>
<td>Fugitive Emissions</td>
<td>4,000</td>
</tr>
<tr>
<td>Flaring</td>
<td>29,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,610</td>
</tr>
</tbody>
</table>

4.3.4 GHG Emission Intensity

The reference document for the Pluto LNG project gives an emission intensity value of 0.31 tCO$_2$e / 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$_2$e/tLNG.

---

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$_2$/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$^{14}$.

<table>
<thead>
<tr>
<th>Number of Trains</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet CO$_2$ Concentration</td>
<td>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.</td>
</tr>
<tr>
<td>Refrigeration Process Technology</td>
<td>ConocoPhillips Optimized Cascade</td>
</tr>
<tr>
<td>Refrigeration Compressor Turbine Energy Source</td>
<td>Natural Gas Combustion.</td>
</tr>
<tr>
<td>Refrigeration Compressor Turbine Model</td>
<td>Not Available</td>
</tr>
<tr>
<td>Electricity Generation Energy Source</td>
<td>Natural Gas Combustion.</td>
</tr>
<tr>
<td>Gas Turbine Generator Model</td>
<td>Not Available</td>
</tr>
<tr>
<td>Energy Efficiency and GHG Mitigation Measures</td>
<td>• GE Aeroderivative gas turbines selected for refrigeration compression. These turbines have very high thermal efficiency (up to 39%).</td>
</tr>
<tr>
<td></td>
<td>• Use of boil-off gas in the facility as fuel rather than venting or flaring</td>
</tr>
</tbody>
</table>

---


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.\(^\text{15}\)

<table>
<thead>
<tr>
<th>GHG Source</th>
<th>Emissions (t CO(_2)e for 3 mtpa plant)</th>
<th>Emissions (t CO(_2)e for 10 mtpa plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Heating</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>Refrigeration Compressors</td>
<td>825,764</td>
<td>2,471,724</td>
</tr>
<tr>
<td>Power Generation</td>
<td>102,735</td>
<td>319,196</td>
</tr>
<tr>
<td>Power for Ship at Berth</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>Backup Diesel Generators</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>Acid Gas Vent (Reported as Flaring and Venting)</td>
<td>233,570</td>
<td>679,642</td>
</tr>
<tr>
<td>Methane in N(_2) Purge</td>
<td>Included in Acid Gas Vent Line</td>
<td>Included in Acid Gas Vent Line</td>
</tr>
<tr>
<td>Fugitive Emissions</td>
<td>653</td>
<td>1,959</td>
</tr>
<tr>
<td>Flaring</td>
<td>Included in Acid Gas Vent Line</td>
<td>Included in Acid Gas Vent Line</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,162,722</td>
<td>3,472,521</td>
</tr>
</tbody>
</table>

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\(_2\)e/tLNG for the 3 mtpa process and 0.35 tCO\(_2\)e/tLNG for the full-scale 10 mtpa process.

\(^{15}\) 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 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 CO₂ 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 CO₂ 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>
<thead>
<tr>
<th>Table 10 – Snohvit LNG plant configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Trains</strong></td>
</tr>
<tr>
<td><strong>Inlet CO₂ Concentration</strong></td>
</tr>
<tr>
<td><strong>Refrigeration Process Technology</strong></td>
</tr>
<tr>
<td><strong>Refrigeration Compressor Turbine Energy Source</strong></td>
</tr>
<tr>
<td><strong>Refrigeration Compressor Turbine Model</strong></td>
</tr>
<tr>
<td><strong>Electricity Generation Energy Source</strong></td>
</tr>
<tr>
<td><strong>Gas Turbine Generator Model</strong></td>
</tr>
<tr>
<td><strong>Energy Efficiency and GHG Mitigation Measures</strong></td>
</tr>
</tbody>
</table>

17 Berger et al. (2003).
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$_4$. 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>
<thead>
<tr>
<th>GHG Source</th>
<th>Emissions (t CO$_2$e for 4.3 mtpa plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Heating</td>
<td>Not Available</td>
</tr>
<tr>
<td>Refrigeration Compressors</td>
<td>Not Available</td>
</tr>
<tr>
<td>Power Generation</td>
<td>Not Available</td>
</tr>
<tr>
<td>Power for Ship at Berth</td>
<td>Not Available</td>
</tr>
<tr>
<td>Backup Diesel Generators</td>
<td>Not Available</td>
</tr>
<tr>
<td>Acid Gas Vent</td>
<td>Not Available</td>
</tr>
<tr>
<td>Methane in N$_2$ Purge</td>
<td>Not Available</td>
</tr>
<tr>
<td>Fugitive Emissions</td>
<td>Not Available</td>
</tr>
<tr>
<td>Flaring</td>
<td>Not Available</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,028,470</td>
</tr>
</tbody>
</table>

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$_2$e/tLNG was first reported in the Gorgon plant’s draft environmental impact statement, released in 2005. 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

---

with CO₂ injection at the Snohvit facility due to reservoir pressure buildup. The quantity of CO₂ 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 CO₂ in the inlet natural gas to 1.5% and assuming this CO₂ 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 calculated 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 tCO₂e/tLNG and 0.29 tCO₂e/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, Marubeni, 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.

| Number of Trains | Qatargas 1 – 3  
|------------------|------------------  
| Inlet CO₂ 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  
| Electricity Generation Energy Source | Qatargas 2 – General Electric Frame 9 heavy duty gas turbine  
| Gas Turbine Generator Model | Not Available  
| Energy Efficiency and GHG Mitigation Measures | • Heat recovery  

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$^{23}$.

<table>
<thead>
<tr>
<th>GHG Source</th>
<th>Qatargas 1 Emissions (t CO$_2$e for 10 mtpa plant)</th>
<th>Qatargas 2 Emissions (t CO$_2$e for 15.6 mtpa plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Heating</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>Refrigeration Compressors</td>
<td>Included with Power Generation</td>
<td>Included with Power Generation</td>
</tr>
<tr>
<td>Power Generation</td>
<td>3,536,209</td>
<td>4,594,043</td>
</tr>
<tr>
<td>Power for Ship at Berth</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>Backup Diesel Generators</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>Acid Gas Vent</td>
<td>936,055</td>
<td>1,216,070</td>
</tr>
<tr>
<td>Methane in N$_2$ Purge</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>Fugitive Emissions</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>Flaring</td>
<td>728,043</td>
<td>945,832</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5,200,308</td>
<td>6,755,947</td>
</tr>
</tbody>
</table>

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$_2$e / t LNG and for Qatargas 2, $0.41$ tCO$_2$e / 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$^{24}$.

---

$^{23}$ 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sup>25</sup>.

<table>
<thead>
<tr>
<th>GHG Source</th>
<th>Emissions (t CO&lt;sub&gt;2&lt;/sub&gt;e for 15 mtpa plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Heating</td>
<td>10,910</td>
</tr>
<tr>
<td>Refrigeration Compressors</td>
<td>2,467,000</td>
</tr>
<tr>
<td>Power Generation</td>
<td>1,987,000</td>
</tr>
<tr>
<td>Power for Ship at Berth</td>
<td>Not Available</td>
</tr>
<tr>
<td>Backup Generators</td>
<td>Not Available</td>
</tr>
<tr>
<td>Acid Gas Vent</td>
<td>847,700</td>
</tr>
<tr>
<td>Methane in N&lt;sub&gt;2&lt;/sub&gt; Purge</td>
<td>Not Available</td>
</tr>
<tr>
<td>Fugitive Emissions</td>
<td>18,970</td>
</tr>
<tr>
<td>Flaring</td>
<td>41,050</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5,372,630</td>
</tr>
</tbody>
</table>

<sup>25</sup> 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 CO₂ injection compressors, the extra power to run the acid gas removal unit, and the inlet CO₂ concentrated was adjusted to 1.5% (refer to Appendix A for calculations). The calculated GHG intensity for the Gorgon plant is 0.27 tCO₂e/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 tCO₂e/tLNG.](image)

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 CO₂ in the natural gas has been normalized to 1.5% in order to adjust for differences in GHG emissions intensity arising from CO₂ 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 tCO₂e/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 CO₂ removal within the facility emissions. Other facilities have higher GHG intensities, ranging from 0.27 – 0.49 tCO₂e/tLNG.
6 References


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.

\[
500 \text{ GWh/mtpa} \times 12 \text{ mtpa} \times 200 \text{ tCO}_2\text{e/GWh} = 1,200,000 \text{ tCO}_2\text{e}
\]

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\(^26\)

\[
= 25.12 \text{ MW / mtpa}
\]

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

\[
= 284\text{MW} / 15 \text{ mtpa}
\]

\[
= 18.93\text{MW} / \text{ mtpa}
\]

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.

\(^{26}\) 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
18.93 MW / mtpa * 12 mtpa
= 227.16 MW * 8170 hours/year operation
= 1855.9 GWh

BC Power Requirement High
25.12 MW / mtpa * 12 mtpa
= 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 tCO₂e/GWh
= 371,180 tCO₂e

High: 2462.8 GWh * 200 tCO₂e/GWh
= 492,553 tCO₂e

Emissions from CO₂ Venting
It was assumed that the inlet concentration of CO₂ in the feed natural gas is 1.5% and all of this CO₂ is vented to atmosphere.

12 mtpa LNG * 1.5% CO₂
= 180,000 tCO₂e

Total from Refrigeration, Power Generation, and CO₂ Venting

Low: 1,200,000 tCO₂e + 371,180 tCO₂e + 180,000 tCO₂e
= 1,751,180 tCO₂e

High: 1,200,000 tCO₂e + 492,553 tCO₂e + 180,000 tCO₂e

---

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 tCO₂e

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 CO₂ venting were assumed to make-up 90% of total facility emissions, which were calculated as follows:

Low GHG Emissions = 1,751,180 tCO₂e / 0.90
= 1,945,755 tCO₂e

Low GHG Intensity = 1,945,755 tCO₂e / 12 mtpa
= 0.16 tCO₂e/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 tCO₂e / 0.90
= 2,080,614 tCO₂e

High GHG Intensity
= 2,080,614 tCO₂e / 12mtpa
= 0.17 tCO₂e/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 tCO₂e per 16 Mt LNG, which corresponds to an inlet CO₂ concentration of less than 0.01%29. In order to adjust emissions to a 1.5% inlet CO₂ concentration, first 1.5 mass% of the LNG produced was calculated as follows:

16 mtpa LNG * 1.5%30
=240,000 tCO₂

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

---

29 The inlet CO₂ concentration was estimated by dividing the vented CO₂ (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 CO₂ 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% CO₂ inlet concentration were added back.

\[
3.91 \times 10^6 \text{ tonnes CO}_2\text{e}/\text{yr} - 6.55 \times 10^2 \text{ tonnes CO}_2\text{e}/\text{yr} + 0.24 \times 10^6 \text{ tonnes CO}_2\text{e}/\text{yr} = 4.15 \times 10^6 \text{ tonnes CO}_2\text{e}/\text{yr}
\]

Divide GHG emissions by plant LNG capacity

\[
\frac{4.15 \times 10^6 \text{ tCO}_2\text{e}/\text{yr}}{16 \times 10^6 \text{ tonnes LNG/yr}} = 0.26 \text{ tCO}_2\text{e/t LNG}
\]

Australia Pacific

The emissions intensity for the Australia Pacific plant was calculated by adjusting for an inlet concentration of CO₂ of 1.5%.

Adjust the Acid Gas Vent Rate

\[
145,000 \text{ tCO}_2\text{e} \times 1.5 = 217,500 \text{ tCO}_2\text{e}
\]

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% CO₂ inlet.

\[
= 1,349,100 \text{ tCO}_2\text{e}
\]

Adjusted Emissions Intensity

\[
\frac{1,276,600 \text{ tCO}_2\text{e}}{4.5 \text{ Mt LNG}} = 0.30 \text{ tCO}_2\text{e/t LNG}
\]

Pluto

The emissions intensity for the Pluto plant was calculated by adjusting for an inlet concentration of CO₂ of 1.5%.
Adjusting for a 1.5% Inlet CO₂ concentration

242,000 tCO₂e * (1.5%/2%) CO₂ Inlet

= 181,500 tCO₂e

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% CO₂ inlet.

= 1.55 Mt CO₂e

Calculation of GHG Intensity

1.55 Mt CO₂e / 4.3 Mt LNG

= 0.36 tCO₂e / 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 CO₂ of 1.5%, making the assumption that all CO₂ is currently injected, and thus there are no CO₂ venting emissions currently included in the reported emissions.

Total GHG Emissions

964,000 tCO₂ + 3,070 tCH₄⁳¹ * 21 GWP

= 1,028,470 tCO₂e

Venting emissions for a 1.5% Inlet CO₂ concentration

3,150,000 tLNG produced * 1.5%

= 47,250 tCO₂

Total GHG Emissions

= 1,028,470 + 47,250 tCO₂e

---

⁳¹ Statoil (2012).
\begin{align*}
1,075,720 \text{ tCO}_2\text{e} \\
\text{Divide by LNG Produced} \\
1,075,720 \text{ tCO}_2\text{e} / 3,150,000 \text{ tLNG} \\
= 0.34 \text{ tCO}_2\text{e/tLNG}
\end{align*}

\textit{Including LPG and Condensate on an Energy basis}

\begin{align*}
210,000 \text{ tLPG} \times 24 \text{ MJ/L LNG} / 26 \text{ MJ/L LPG} \\
= 193,846 \text{ tLNG equivalent} \\
520,000 \text{ tCondensate (assume all hexane)} \times 24\text{MJ/L LNG} / 29.3\text{MJ/L Hexane} \\
= 425,938 \text{ tLNG equivalent} \\
1,075,720 \text{ tonnes CO}_2\text{e} / (3,150,000 + 193,846 + 425,938) \text{ t LNG equivalent} \\
= 0.29 \text{ tCO}_2\text{e/tLNG equivalent}
\end{align*}

\textit{Qatargas 1 and 2}

The emissions intensity for the Qatargas 1 and 2 plants were calculated by adjusting for an inlet concentration of CO\textsubscript{2} of 1.5%.

\textbf{Qatargas 1}

\textit{Adjust for an inlet concentration of 1.5% CO\textsubscript{2}}

\begin{align*}
936,055 \text{ tCO}_2\text{e} \times (1.5/2.1) \\
= 668,611 \text{ tCO}_2\text{e} \\
\text{Adjusted total emissions} \\
= 3,536,209 \text{ tCO}_2\text{e} + 728,043 \text{ tCO}_2\text{e} + 668,611 \text{ tCO}_2\text{e} \\
= 4,932,863 \text{ tCO}_2\text{e} \\
\textbf{Qatargas 1 Intensity} \\
4,932,863 \text{ tCO}_2\text{e} / 10\text{mtpa LNG} \\
= 0.49 \text{ tCO}_2\text{e/tLNG}
\end{align*}

\textbf{Qatargas 2}
Adjust for an inlet concentration of 1.5% CO$_2$

1,216,070 tCO$_2$e * (1.5/2.1) 

868,621 tCO$_2$e

Adjusted total emissions

= 4,594,043 tCO$_2$e + 945,832 tCO$_2$e + 868,621 tCO$_2$e 

= 6,408,496 tCO$_2$e

Qatargas 2 Intensity

6,408,496 tCO$_2$e / 15.6 mtpa LNG 

= 0.41 tCO$_2$e/t LNG

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$_2$e 

= 4,674,930 tCO$_2$e

Adjusted GHG Intensity 

4,674,930 tCO$_2$e / 15 mtpa 

= 0.3117 tCO$_2$e / t LNG

Subtract Power for Acid Gas Removal and CO$_2$ Compressors$^{32}$

0.3117 tCO$_2$e / t LNG – 0.006 tCO$_2$e / t LNG – 0.027 tCO$_2$e / t LNG

$^{32}$ Chevron Australia (2009), p. 39
=0.27 tCO₂e/tLNG