

# **British Columbia LNG Greenhouse Gas (GHG) Life Cycle Analysis**

Discussion Draft

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**Prepared for:**

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# EXECUTIVE SUMMARY

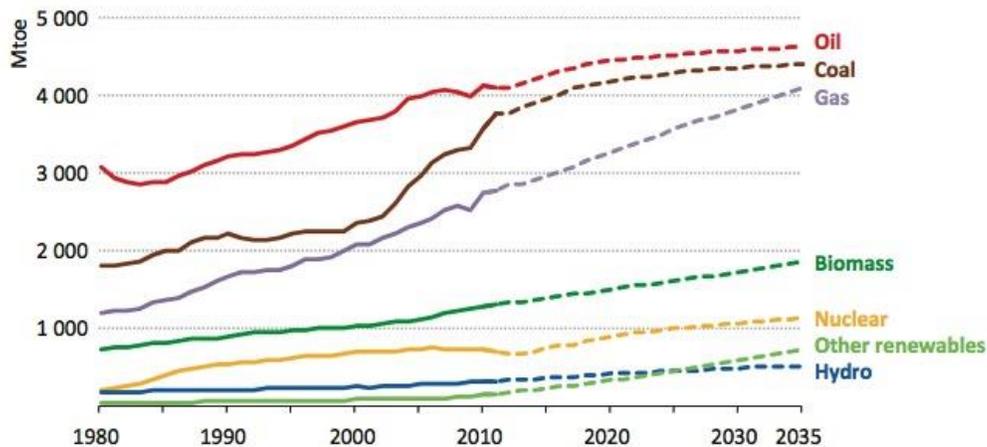
In September 2011, the BC Government released its *Canada Starts Here: The BC Jobs Plan*, which included a target to bring at least one liquefied natural gas (LNG) terminal online by 2015, with three LNG facilities in operation by the year 2020.

This project assesses the greenhouse gas (GHG) emissions impact of British Columbia’s natural gas export value chain from the wellhead to various consumer markets overseas, assuming BC begins shipping LNG product within the next three years (by 2017). GLOBE’s research is based on available international energy reports and public data supplied by the BC Government, Statistics Canada, and Environment Canada, as well as GHG life cycle models developed by Natural Resources Canada (GHGenius Model) and Argonne Labs in the United States (GREET Model).

The assessment involved an examination of the country partners and markets that are associated with potential LNG infrastructure projects in BC, with the aim to determine whether the export of LNG, originating in BC and exported globally, will have a positive or negative full life cycle impact on overall global GHG emissions.

## Global Energy Demand and Supply

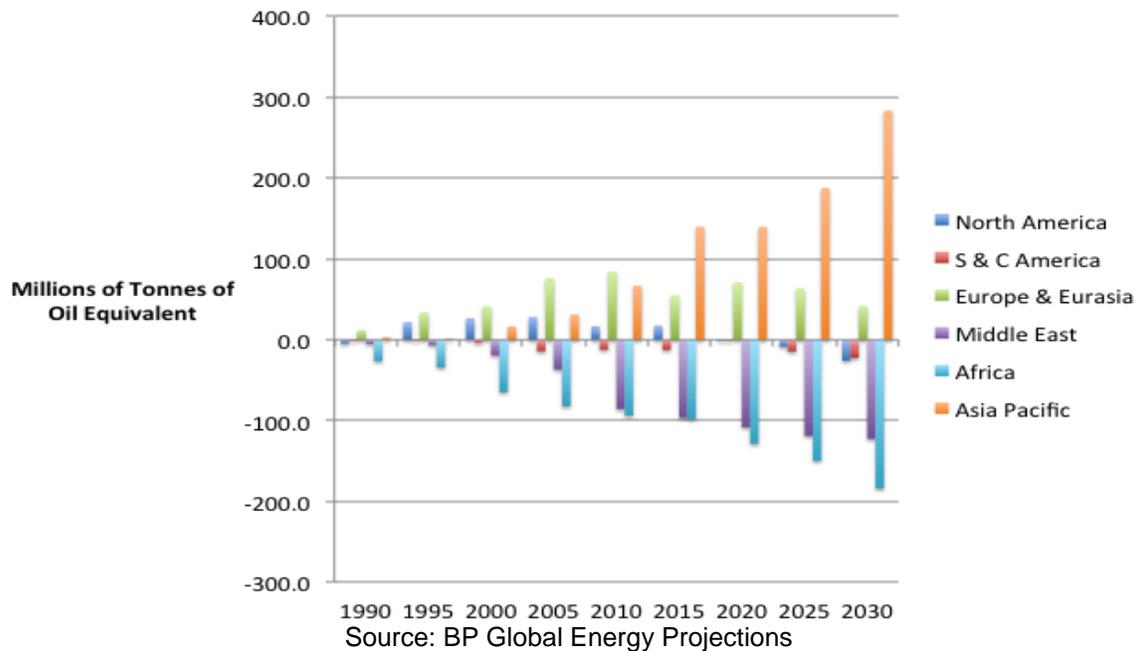
The future markets for natural gas in Asia, as reported by the International Energy Agency (IEA) and the United States Energy Information Office, forecast highly bullish natural gas markets over the next two decades, with the likelihood that much of this natural gas will be used to replace coal-fired power generation. The IEA, based on its *New Policies Scenario*, projects that there will be a growing global demand for natural gas, while the demand for other fossil fuels (in particular coal and oil) and nuclear power levels off by 2035.



Source: International Energy Agency, World Energy Outlook, 2013

Figure: World primary energy demand by fuel in the *New Policies Scenario*.

The Asia Pacific region is short in the supply of natural gas relative to demand (as illustrated in the figure below). While GLOBE cannot definitively conclude that all natural gas purchases in Asia will be used to replace coal, predictions by reputable sources including the IEA, suggest that this will largely be the case.



**Figure: Global natural gas demand minus supply projections.**

## BC's Natural Gas Value Chain GHG Emissions

GLOBE estimated the full life cycle GHG emissions for BC's natural gas overseas export value chain. This value chain includes natural gas production at the wellhead; processing (treatment and compression); distribution to LNG facilities (transportation by pipeline); liquefaction at LNG facilities; ocean transportation; and consumption (combustion) by end users.

Two emissions scenarios were prepared: (1) a standard or "traditional" LNG plant with upstream emissions based on the GHGenius model; and (2) a "clean" LNG plant that utilizes renewable electricity, state-of-the-art practices, and carbon capture and storage (CCS) as part of its facility.

While proponents have yet to develop LNG projects along the BC coastline, the proposed LNG plants can achieve very significant efficiencies for reduced GHG emissions due to the use of electric drive compressors that, in turn, run on a combination of new renewable power, existing BC grid hydro electricity, and efficient combined-cycle natural gas generators.

There is also the potential for using CCS technologies. These technologies do not necessarily involve the more traditional practice of storing CO<sub>2</sub> in rock caverns or depleted gas and/or oil wells, but may also include technologies and/or processes that allow for CO<sub>2</sub> to be converted into useful products such as biofuel, biochemicals, bioplastics, and building materials. There are a number of CCS technology options that can be explored in British Columbia for lowering overall upstream GHG emissions.

For scenario one, the “traditional” LNG plant scenario, the GHGenius model provided a well-to-waterline GHG emissions ratio of approximately 0.75 tonnes of CO<sub>2</sub>e per tonne of LNG (tCO<sub>2</sub>e / tLNG) produced, assuming that no CCS technologies are employed. For scenario two, the “clean” LNG plant scenario, GLOBE Advisors assumed that the proposed LNG plants in BC will be developed in-line with current “best-in-class” LNG projects, as well as CCS technology, and as such, could produce well-to-waterline GHG emissions of approximately 0.38 tCO<sub>2</sub>e / tLNG, equal to a 50 per cent reduction over the “traditional” plant scenario.

Average LNG tanker transportation emissions from BC to Asian markets amount to an estimated additional 0.08 tCO<sub>2</sub>e / tLNG. Consequently, delivering BC’s LNG product to customers overseas results in approximately 0.83 tCO<sub>2</sub>e / tLNG produced under the “traditional” LNG plant scenario and 0.46 tCO<sub>2</sub>e / tLNG from the “clean” LNG plant scenario.

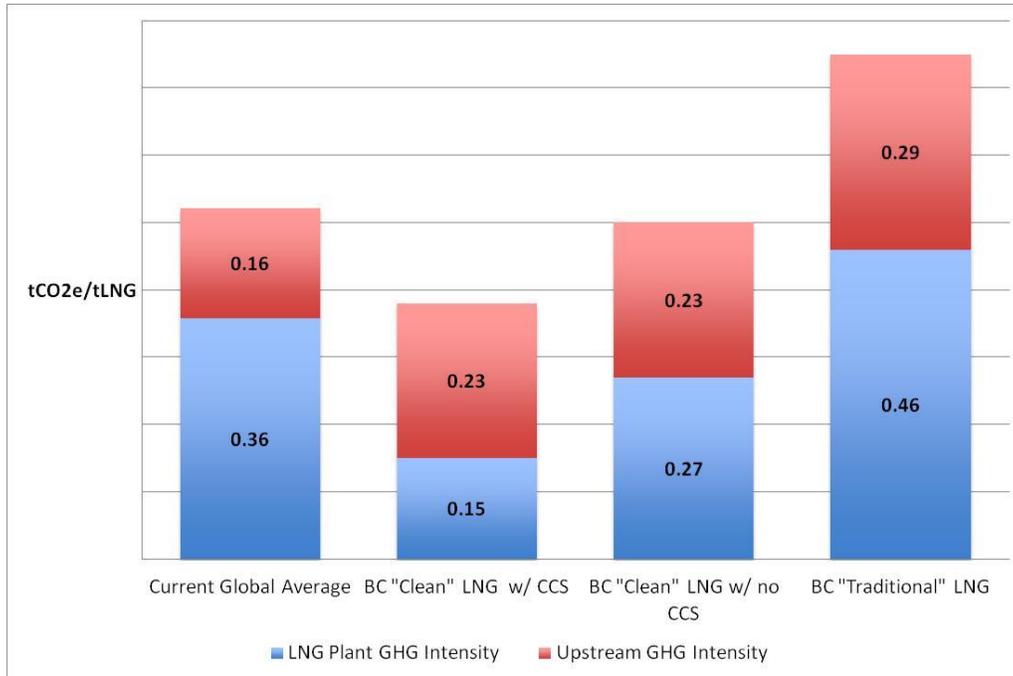
The wellhead to customer GHG emission factors are a relatively small components of the full life cycle of natural gas when combustion factors are included based on the customer burning natural gas for producing electrical power. As such, the full life cycle GHG emissions from wellhead to overseas customer ranges from 2.95 tonnes of CO<sub>2</sub>e per tonne of LNG produced (scenario 1) to 3.32 (scenario 2), as shown in the table below.

**Table: Full life cycle GHG emissions for the overseas export and consumption of BC natural gas to Asian markets for both “traditional” and “clean” LNG plant operations.**

|  | “Traditional” LNG Plant<br>GHG Emission Rate<br>(tCO <sub>2</sub> e / tLNG) | “Clean” LNG Plant<br>GHG Emission Rate<br>(tCO <sub>2</sub> e / tLNG) |
|--|---|---|
| <b>Exploration &amp; Wellhead</b>                  |   |   |
| Fuel distribution and storage                      | 0.07  | 0.06  |
| Fuel production                                    | 0.07  | 0.06  |
| Feedstock recovery                                 | 0.09  | 0.08  |
| Gas leaks and flares                               | 0.07  | 0.04  |
| <b>Subtotal</b>                                    | <b>0.29</b>   | <b>0.23</b>   |
| <b>LNG Plant</b>                                   |   |   |
| CO <sub>2</sub> , H <sub>2</sub> S removed from NG | 0.12  | 0.01  |
| Liquefaction at LNG Plants                         | 0.33  | 0.14  |
| <b>Subtotal</b>                                    | <b>0.46</b>   | <b>0.15</b>   |
| <b>Well-to-Water Upstream with CCS</b>             |   | <b>0.38</b>   |
| <b>Well-to-Water with no CCS</b>                   | <b>0.75</b>   | <b>0.50</b>   |
| <b>Tanker Emissions</b>                            | <b>0.08</b>   | <b>0.08</b>   |
| <b>Customer Combustion Emissions</b>               | 2.49  | 2.49  |
| <b>Total Life Cycle Emissions with CCS</b>         |   | <b>2.95</b>   |
| <b>Total Life Cycle Emissions without CCS</b>      | <b>3.32</b>   | <b>3.07</b>   |

LNG plant emissions of 0.15 tonnes of GHG per tonne of LNG produced (or a 58 per cent reduction from a “traditional” LNG plant powered by fossil fuels) is both possible and plausible, as the LNG plants in BC can employ near-zero emission clean electricity to power the compressors.

The figure below compares the global average well-to-waterline GHG emissions for various LNG plants around the world, equal to 0.52 tCO<sub>2</sub>e / tLNG, to hypothetical LNG plants in British Columbia under three scenarios: (a) the BC “clean” LNG plant emissions factor of 0.38 tCO<sub>2</sub>e / tLNG with the application of CCS technologies ; (b) the BC “clean” LNG plant factor with no CCS that results in plant and upstream emissions of 0.50 tCO<sub>2</sub>e / tLNG; and (c) the “traditional” LNG plant well-to-waterline emissions factor of 0.75 tCO<sub>2</sub>e / tLNG based on the GHGenius model.



Source: GLOBE Advisors and Australia Pacific LNG Project Volume Greenhouse Gas Assessment by LNG Facility (Worley Parsons)

**Figure: Global average well-to-waterline GHG emissions intensity compared to three BC LNG plant well-to-waterline GHG emissions scenarios.**

As illustrated in the figure above, the BC “traditional” LNG plant factor, based on GHGenius, results in emissions in excess of the current global average while the BC “clean” LNG plant factor with CCS would result in significantly less GHG emissions.

## Impact of BC's LNG Exports on Global GHG Emissions

A fundamental question is whether or not natural gas being exported from BC will be consumed as an alternative to other fuel sources, and in particular, as a replacement for coal. When natural gas is used to replace coal and/or natural gas being sourced from other locations with higher life cycle GHG emissions, it has an overall positive impact on reducing global GHG emissions and local air pollutants.

Natural gas is a particularly attractive fuel for countries and regions that are urbanizing and seeking to satisfy rapid growth in energy demand, such as China and India. These countries will largely determine the extent to which natural gas use expands over the next 25 years.<sup>1</sup> Research suggests that natural gas imported by Asian economies is expected to largely replace existing or planned thermal coal power and, hence, will provide an overall reduction in CO<sub>2</sub> equivalent emissions due to the lower combustion emissions of natural gas over coal.

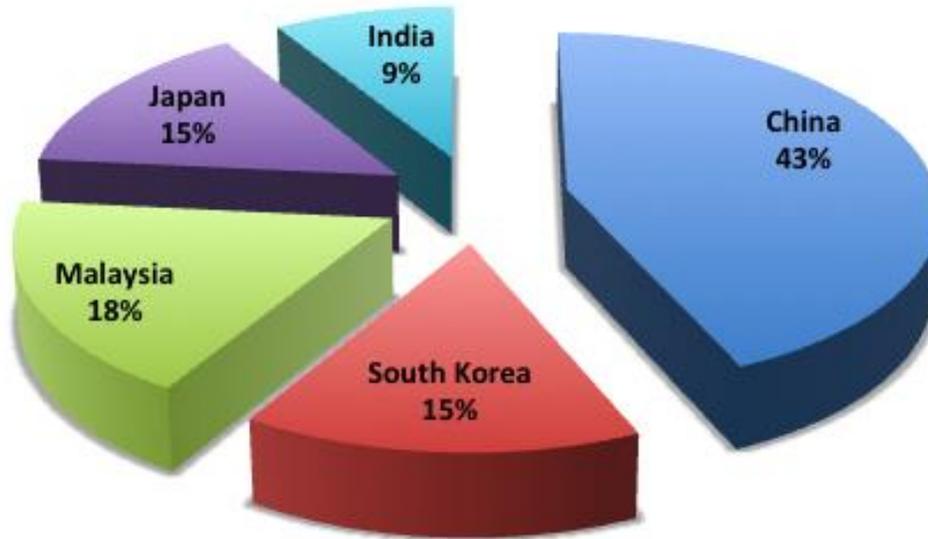
In order to determine the overall impact on global GHG emissions from the export of BC's natural gas to Asia, an examination of energy consumption trends for each market was carried out. This assessment provided the conclusion that natural gas exports from BC would, for the most part, replace coal and to a lesser degree, natural gas coming from other sources, with the exception of Malaysia where natural gas would most likely replace diesel used for power generation (see table below).

**Table: Impact of BC's natural gas exports on energy consumption in select Asian markets.**

| Country     | Impact on Energy Consumption                                 |
|-------------|--|
| China       | Mixture of replacing coal and natural gas from other sources |
| Japan       | Mixture of replacing coal and LNG from other sources         |
| South Korea | Mixture of replacing coal and LNG from other sources         |
| India       | Mixture of replacing coal and natural gas from other sources |
| Malaysia    | Replace diesel power   |

<sup>1</sup> See: <http://www.iea.org/newsroomandevents/pressreleases/2011/june/name.20306.en.html>

This assessment was further linked to the projected distribution of BC's LNG exports to economies in Asia based on projected Asian market demand scenarios by the IEA, as well as the planned LNG infrastructure project investments in BC (see figure below). It was assumed that by 2021, 67 per cent of the proposed LNG projects in BC would be operational, producing approximately 88 million metric tonnes per annum (mmtpa) of LNG.



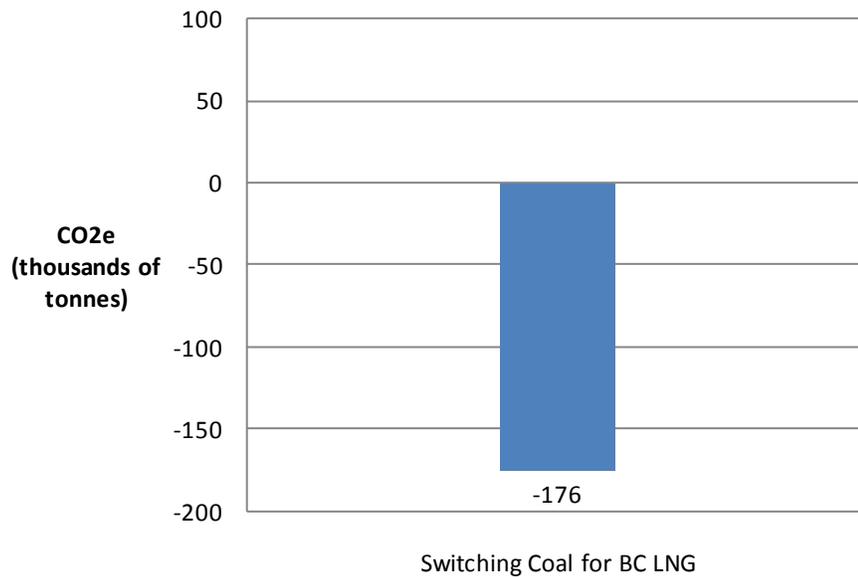
Source: IEA World Outlook 2013 and various BC LNG infrastructure websites

**Figure: Estimated distribution of BC's LNG exports to countries in Asia.**

## Natural Gas Switching Scenarios

GLOBE Advisors examined the impact on global GHG emissions of two scenarios where natural gas from BC is exported as LNG to Asian markets for consumption.

The “*Full Coal Switching*” scenario looks at the GHG emissions impact of having natural gas from BC completely replace coal-powered electricity production and/or serve as an alternative to the construction of new coal-fired power facilities. The GHG emissions avoided by Asian markets consuming 88 mmtpa of LNG produced in BC could amount to an annual reduction of 176 million tonnes of CO<sub>2</sub>e over the GHG emissions from the same amount of energy produced by the combustion of thermal coal.



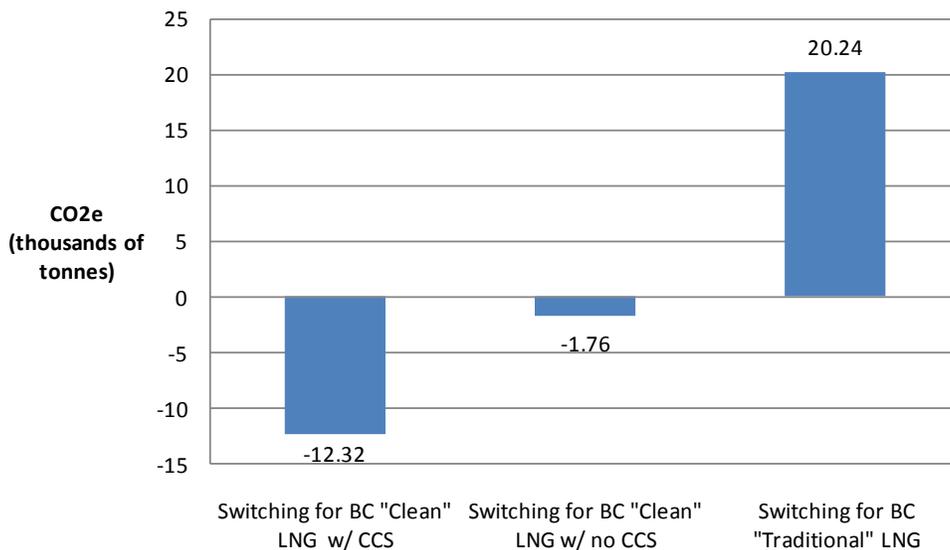
Source: GLOBE Advisors

**Figure: Annual GHG emissions impact of having BC natural gas completely replace coal-powered electricity production under the *Full Coal Switching* scenario (assuming LNG production of 88 mmtpa).**

The “*Full Natural Gas Switching*” scenario looked at the impact on global GHG emissions of having natural gas exported from BC to Asian markets replace natural gas coming from other global suppliers where the global LNG average well-to-waterline GHG emissions was compared to BC’s hypothetical LNG well-to-waterline GHG emissions.

In the *Full Natural Gas* switching scenario, achieving the “clean” LNG plant well-to-waterline factor of 0.38 tCO<sub>2</sub>e / tLNG produced could result in a fairly significant reduction of global GHG emissions – in the range of 12.4 million tonnes of CO<sub>2</sub>e per year (based on BC’s estimated annual production level of 88 mmtpa by 2021). If BC’s LNG plants apply renewable energy and upstream best practices but no CCS technology, the reduction in global GHG emissions would be 1.8 million tonnes of CO<sub>2</sub>e per year for the production of 88 mmtpa of LNG in BC. Nonetheless, even in the absence of CCS, lower global GHG emissions occur when “clean” BC natural gas replaces LNG produced elsewhere.

The net CO<sub>2</sub>e savings based on BC natural gas replacing natural gas sourced from global suppliers (using the global average) is shown in the figure below.<sup>2</sup> Note that where BC’s natural gas under the “traditional” LNG plant scenario replaces natural gas with the global average GHG emissions factor, a net increase in global CO<sub>2</sub>e emissions occurs.



Source: GLOBE Advisors

**Figure: Annual GHG emissions impact of having BC natural gas replace natural gas supplied by natural gas with the global average GHG emissions footprint under the *Full Natural Gas Switching* scenario (assuming LNG production of 88 mmtpa).**

<sup>2</sup> **Note to reader:** Marine transportation GHG emissions are not included in this comparison as these vary based on the consumer market and global supplier. However, the difference in transportation emissions between global suppliers is relatively small, particularly when compared with the full life cycle emissions.

## Conclusions

Based on a review of secondary sources and global trends in energy demand and supply, GLOBE Advisors believes that the most realistic outcome for natural gas exported from BC to Asian markets will be a combination of switching out / replacing both thermal coal *and* natural gas product from other global suppliers (with the exception of Malaysia where it may go primarily to replacing diesel).

The scenarios discussed in this report provide three examples where, on a full life cycle basis, there is a net reduction of global GHG emissions from the export of BC's natural gas to overseas markets in Asia. These scenarios include the replacement / substitution of thermal coal in Asian markets and the replacement or substitution of LNG coming from other global suppliers (assuming the global average for life cycle GHG emissions) with LNG produced in BC under the two "clean" LNG plant examples. Our analysis shows that "clean" natural gas from BC could result in significantly reduced global GHG emissions depending on which scenario is achieved.

In the case where it acts as a substitute for natural gas from other global suppliers, it is particularly important to consider whether or not the upstream life cycle GHG emissions for the supply of natural gas coming from other global markets (i.e., shale and coal bed plays in Russia, China, Australia, and elsewhere) and, in some cases the related LNG plant facilities, is more or less carbon intensive than the natural gas being exported from British Columbia. This is a difficult question to answer, as BC has not yet built LNG plants and the GHG emissions described in this report are only hypothetical at this stage.

At the end of the day, the total net benefit that will come from exporting BC's natural gas to Asian markets in terms of its ability to reduce overall global GHG emissions will depend largely on how much coal is displaced.

Where it serves as a substitute for natural gas from other sources, keeping the BC well-to-waterline factor below the global average (currently estimated to be 0.52 tCO<sub>2</sub>e / tLNG) would result in a net benefit in terms of reducing global GHG emissions. Achieving the well-to-waterline GHG emissions factor of 0.38 tCO<sub>2</sub>e / tLNG could result in a significant reduction of global GHG emissions.

British Columbia has an opportunity to produce some of the cleanest LNG in the world, in part by reducing fugitive emissions and flaring, but particularly by encouraging action during LNG production at the plant. British Columbia can achieve LNG plant production GHG emission factors that are better than the current Canadian "industry standard" and global average by applying renewable power, modern and efficient technology such as electric drive compressors, and CCS solutions where feasible.

# **INTRODUCTION**

This project assesses the greenhouse gas (GHG) emissions impact of British Columbia's natural gas export value chain from the wellhead to various consumer markets overseas. The key question is "*will the development and export of LNG, originating in BC and exported globally, have a positive or negative impact on overall global GHG emissions?*"

Many believe that natural gas is a bridge fuel to the low carbon economy, as it burns cleaner than other fossil fuels. Some, however, challenge this view. They argue that while natural gas burns cleaner at the consumer stage, it can produce considerable GHG emissions at the exploration and production stage, mostly due to fugitive gases, which may be under-reported. Their position is that if these fugitive gases were counted accurately, natural gas could produce similar or even higher GHG emissions than coal, diesel, and petrol.

Producing LNG for export involves the actual liquefaction facility, as well as the full upstream chain of production that includes gas extraction, processing, and transportation. The LNG producers will source some of their gas from unconventional shale deposits, some of which have a higher carbon dioxide content than conventional deposits. This shale gas would be piped across the province, and liquefied at different locations, which, without mitigation measures, may increase the carbon footprint of the final product.

To what extent will BC's LNG be replacing higher or lower GHG intensive fuels? To get at the crux of this question, a detailed examination of the end user of potential natural gas exports from British Columbia is required through the examination of the country partners and markets that are associated with potential LNG infrastructure projects in BC.

In this research, GLOBE examines the realities of BC's natural gas GHG emissions based on available data produced by BC Stats, Statistics Canada, and Environment Canada, as well as GHG life cycle models developed by Natural Resources Canada and Argonne Labs in the United States. GLOBE also examined the potential GHG life cycle of natural gas in British Columbia from the wellhead to the overseas consumer, assuming BC begins shipping LNG product within the next five year timeframe.

GLOBE also examined future markets for natural gas in Asia as reported by the International Energy Agency (IEA) and the United States Energy Information Office. These reports strongly forecast highly bullish natural gas markets over the next two decades and the likelihood that much of this natural gas purchases will replace coal power. GLOBE cannot definitively conclude that all Asian natural gas purchases will replace coal, although this occurrence should be mostly accurate. Subsequently, the analysis puts forward scenarios where varying amounts of coal are being replaced by natural gas such as 25 percent, 50 percent, and 100 percent.

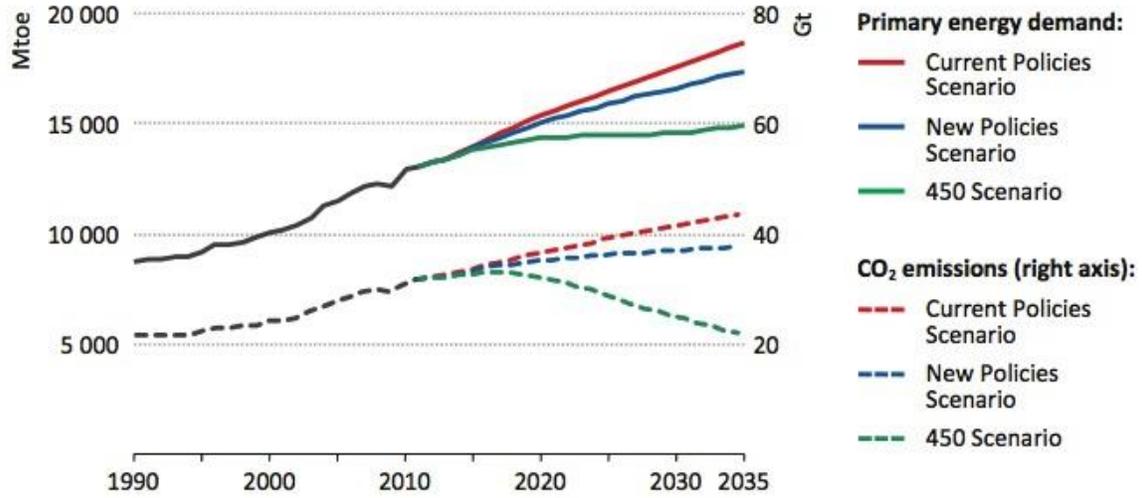
This report is not a detailed engineering study but rather, is meant to serve as a document to help inform policy makers by putting the lifecycle GHG emissions for BC's LNG production into a global perspective. Please note that GLOBE uses the term GHG emissions to include CO<sub>2</sub> equivalent emissions. These two terms GHG and CO<sub>2</sub>e are used interchangeably in this document.

**PART 1:  
GLOBAL ENERGY DEMAND, SUPPLY & GHG  
EMISSION SCENARIOS**

This section provides an overview based on existing sources for global medium and long-term energy and greenhouse gas (GHG) emission scenarios where BC is not exporting LNG to overseas markets.

## Global Market for Energy

The International Energy Agency's 2013 global forecasts for energy demand and associated CO<sub>2</sub> emissions are illustrated in Figure 1 below.



Note: Mtoe = Million tonnes of oil equivalent; Gt = gigatonnes.

Source: International Energy Agency, World Energy Outlook, 2013

**Figure 1: World primary energy demand and related CO<sub>2</sub> emissions by scenario**

This forecast provides scenarios for the continuation of current energy policies (*Current Policy Scenario*), *New Policies Scenario* where governments are committed to increased energy efficiency and lower GHG emissions, and the *450 Scenario*, which is a “scenario presented in the World Energy Outlook that sets out an energy pathway consistent with the goal of limiting the global increase in temperature to 2 degrees Celsius by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO<sub>2</sub>”.<sup>3</sup>

<sup>3</sup> See: <http://www.iea.org/publications/scenariosandprojections/>

More specifically, the global forecast for energy-related CO<sub>2</sub> emissions is shown by fuel type in Figure 2 below.

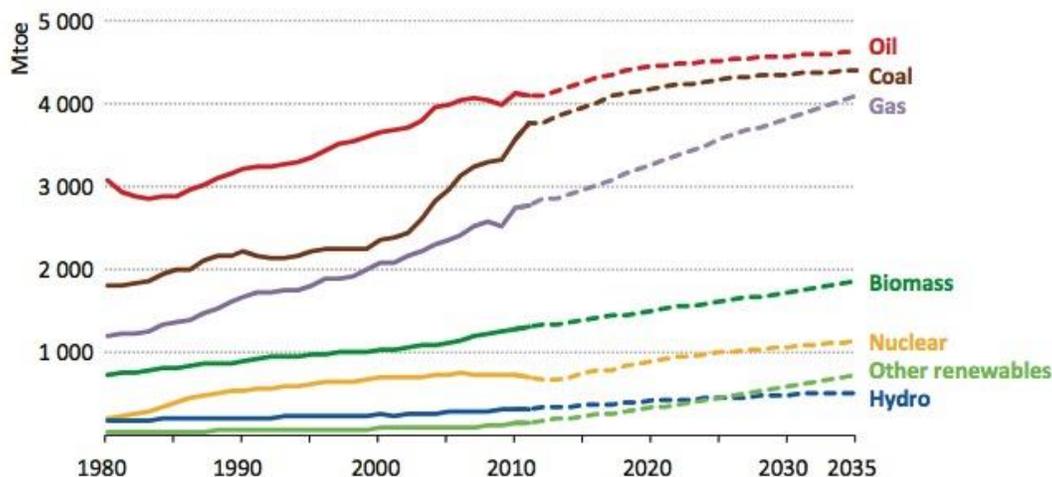
|                                      |               |               | New Policies Scenario |               | Current Policies Scenario |               | 450 Scenario  |               |
|--------------------------------------|---------------|---------------|-----------------------|---------------|---------------------------|---------------|---------------|---------------|
|                                      | 2000          | 2011          | 2020                  | 2035          | 2020                      | 2035          | 2020          | 2035          |
| Coal                                 | 2 357         | 3 773         | 4 202                 | 4 428         | 4 483                     | 5 435         | 3 715         | 2 533         |
| Oil                                  | 3 664         | 4 108         | 4 470                 | 4 661         | 4 546                     | 5 094         | 4 264         | 3 577         |
| Gas                                  | 2 073         | 2 787         | 3 273                 | 4 119         | 3 335                     | 4 369         | 3 148         | 3 357         |
| Nuclear                              | 676           | 674           | 886                   | 1 119         | 866                       | 1 020         | 924           | 1 521         |
| Hydro                                | 225           | 300           | 392                   | 501           | 379                       | 471           | 401           | 550           |
| Bioenergy*                           | 1 016         | 1 300         | 1 493                 | 1 847         | 1 472                     | 1 729         | 1 522         | 2 205         |
| Other renewables                     | 60            | 127           | 309                   | 711           | 278                       | 528           | 342           | 1 164         |
| <b>Total (Mtoe)</b>                  | <b>10 071</b> | <b>13 070</b> | <b>15 025</b>         | <b>17 387</b> | <b>15 359</b>             | <b>18 646</b> | <b>14 316</b> | <b>14 908</b> |
| <i>Fossil fuel share</i>             | 80%           | 82%           | 80%                   | 76%           | 80%                       | 80%           | 78%           | 64%           |
| <i>Non-OECD share**</i>              | 45%           | 57%           | 61%                   | 66%           | 61%                       | 66%           | 60%           | 64%           |
| <b>CO<sub>2</sub> emissions (Gt)</b> | <b>23.7</b>   | <b>31.2</b>   | <b>34.6</b>           | <b>37.2</b>   | <b>36.1</b>               | <b>43.1</b>   | <b>31.7</b>   | <b>21.6</b>   |

\* Includes traditional and modern biomass uses. \*\* Excludes international bunkers.

Source: International Energy Agency, World Energy Outlook, 2013

**Figure 2: World primary energy demand and energy-related CO<sub>2</sub> emissions by fuel type and scenario**

This forecast is shown graphically for the *New Policy Scenario* in Figure 3. Note that globally, the IEA predicts under its *New Policies Scenario* that there will be a growing demand for natural gas, while the demand for other fossil fuels and nuclear power begins to level off by 2035. In the IEA's *450 Scenario* and its *Golden Age of Gas Scenario*<sup>4</sup>, natural gas demand actually pushes the share of coal in the energy mix into decline and overtakes it by 2030.



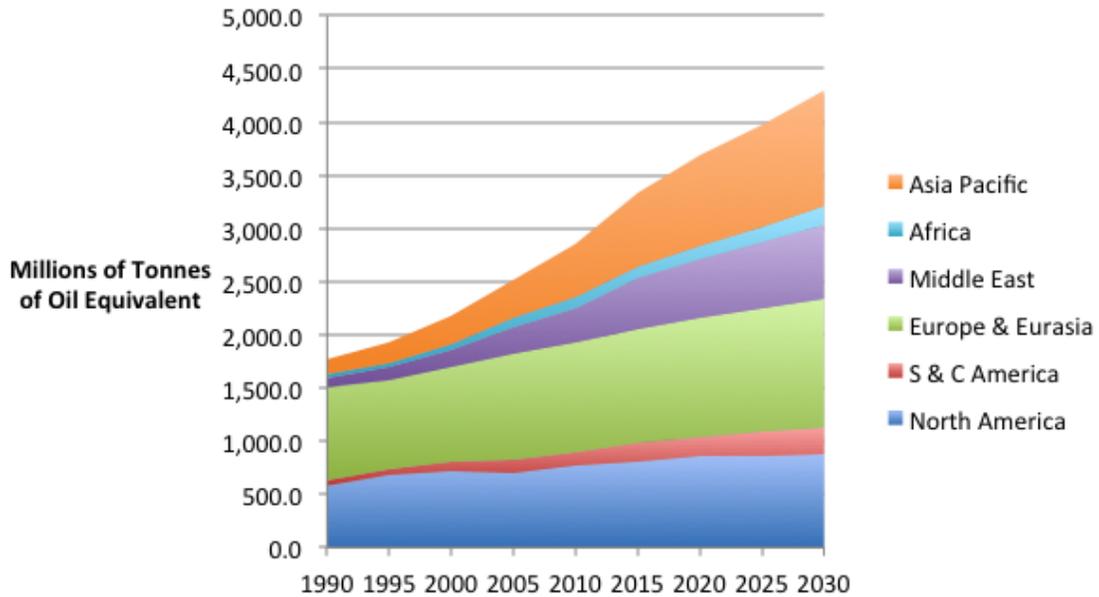
Source: International Energy Agency, World Energy Outlook, 2013

**Figure 3: World primary energy demand by fuel in the *New Policies Scenario*.**

<sup>4</sup> See: [http://www.worldenergyoutlook.org/media/weowsite/2011/WEQ2011\\_GAG\\_FactSheet.pdf](http://www.worldenergyoutlook.org/media/weowsite/2011/WEQ2011_GAG_FactSheet.pdf)

## Global Market Demand for Natural Gas

Demand for liquefied natural gas (LNG) is heating up around the world, with demand projections to 2030 showing exponential growth – especially in Asian economies (Figure 4). These economies, however, will not be producing sufficient natural gas to meet their demand, as is illustrated in the following section on global supply.



Source: BP Global Energy Projections

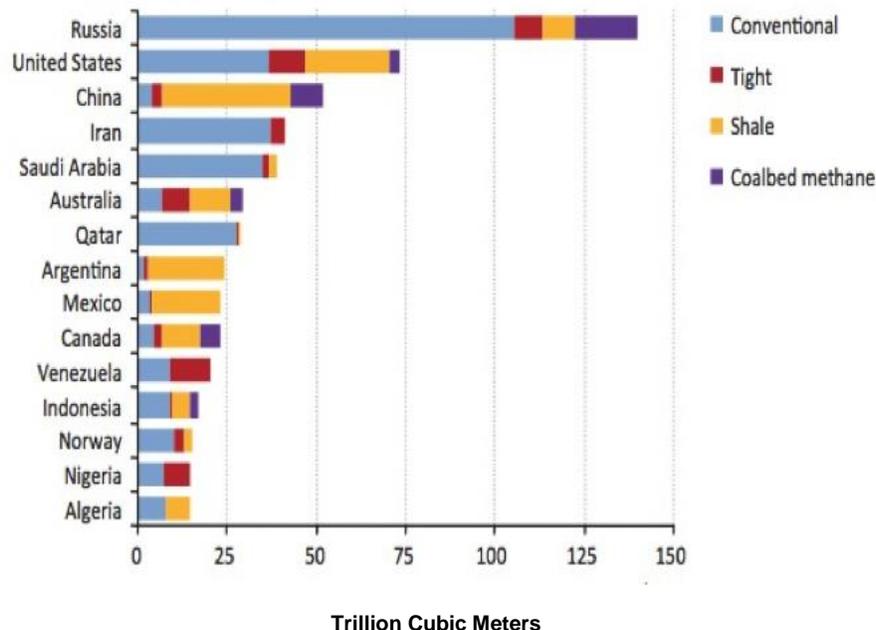
**Figure 4: Natural Gas Demand Projections**

## Global Supply of Natural Gas & LNG Infrastructure

In its *Special Report on Unconventional Gas, Golden Rules for a Golden Age of Gas*, the International Energy Agency (IEA) concluded that “*natural gas is poised to enter a golden age, but will do so only if a significant proportion of the world's vast resources of unconventional gas - shale gas, tight gas, and coalbed methane - can be developed profitably and in an environmentally acceptable manner....Yet a bright future for unconventional gas is far from assured: numerous hurdles need to be overcome, not least the social and environmental concerns associated with its extraction.*”<sup>5</sup>

Producing unconventional gas is an intensive industrial process, generally imposing a larger environmental footprint than conventional gas development. More wells are often needed and techniques such as hydraulic fracturing are usually required to boost the flow of gas from the well. The scale of development can have major implications for local communities, land use, and water resources. Serious hazards, including the potential for air pollution and for contamination of surface and groundwater, must be successfully addressed. Greenhouse gas emissions must be minimized, both at the point of production, and throughout the entire natural gas supply chain. Improperly addressed, these concerns threaten to curb, if not halt, the development of unconventional resources.

The IEA report discussed natural gas supply opportunities for several regions around the globe. These are illustrated in Figure 5. The top five overall natural gas supply countries include Russia, the United States, China, Iran, and Saudi Arabia. However, China, the United States, Argentina, Mexico, and Australia have the largest potential supplies of shale gas and tight gas. Canada is positioned slightly behind Australia in shale and tight gas supplies.

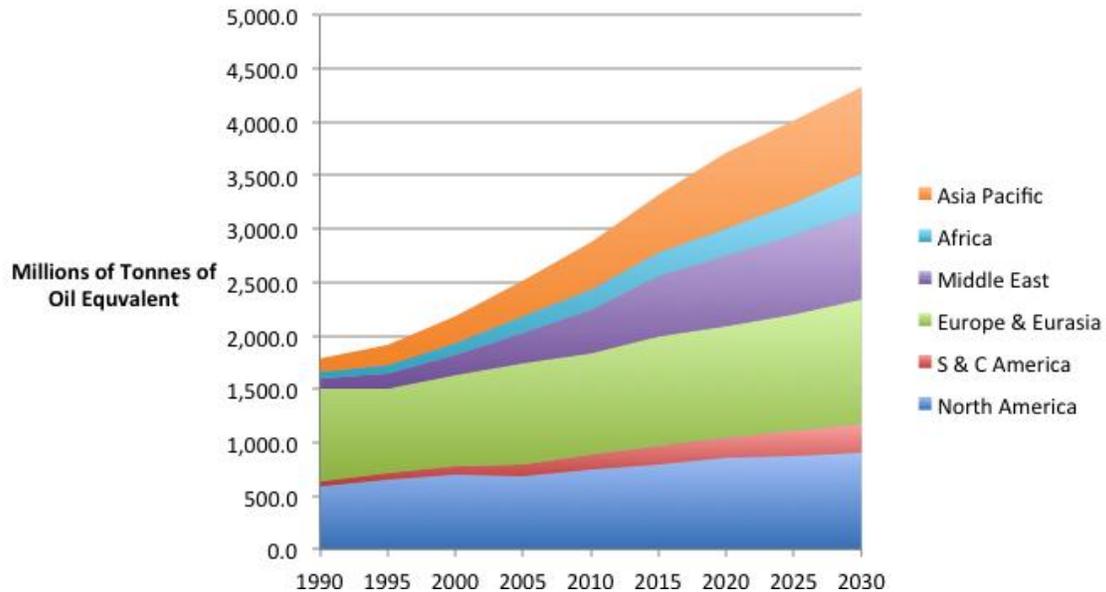


Source: International Energy Agency, *Golden Rules for a Golden Age of Gas*

**Figure 5: Remaining recoverable natural gas reserves in the top 15 countries (end-2011)**

<sup>5</sup> International Energy Agency in a Special Report on Unconventional Gas, *Golden Rules for a Golden Age of Gas*.

LNG exporters in Australia, Russia, Malaysia, and Qatar have been quick to respond to the demand for natural gas Asia. The chart in Figure 6 below shows natural gas supply projections by major geographic region to 2030. This supply is forecast to grow significantly in all regions of the globe. As such, competitors are already on track to develop much of the necessary infrastructure to fulfill the needs of this expanding market and are responding by locking in multiyear supply contracts.



Source: BP Global Energy Projections

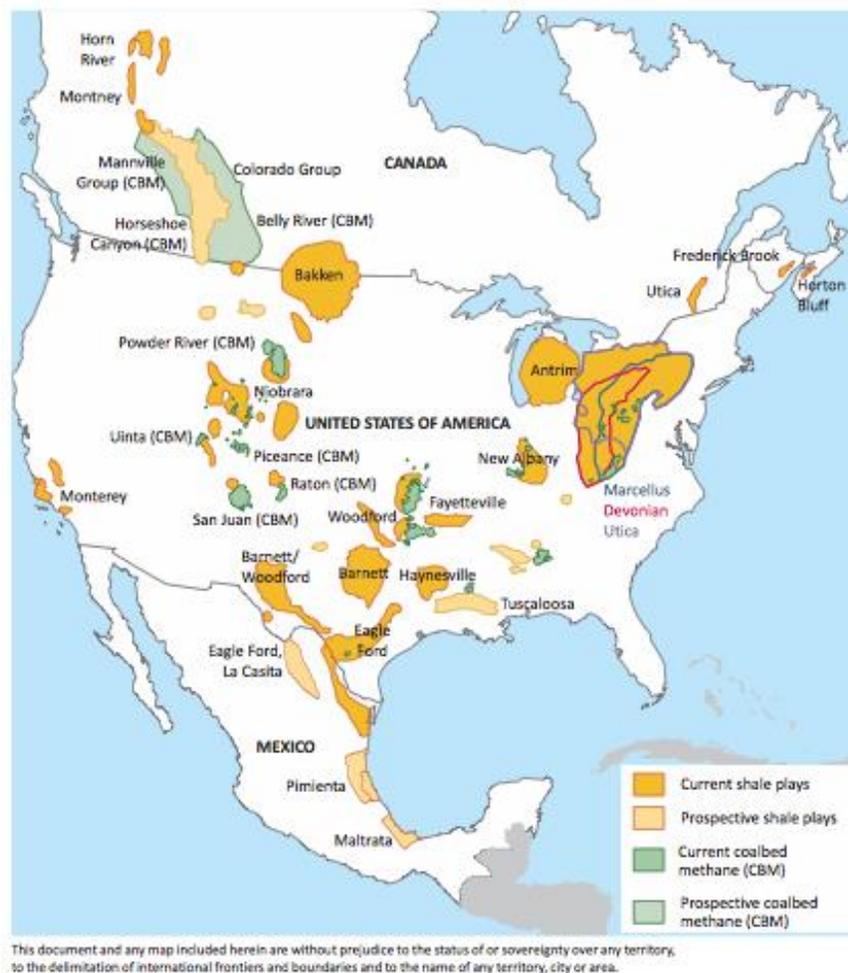
**Figure 6: Natural gas supply projections to 2030.**

## North American Supply of Unconventional Natural Gas

The Canadian Association of Petroleum Producers (CAPP) have forecast that the majority of future natural gas production in Canada will be unconventional gas including tight gas, shale gas, and coalbed methane. In fact, CAPP is forecasting that in Western Canada, including BC, conventional gas will decline and production of unconventional gas will significantly grow. In short, in most non-OPEC countries, the future of gas is in the unconventional play. Therefore, a brief discussion of unconventional reserves by global region follows below.

The IEA has published in its Golden Age of Gas report a map of the recoverable shale gas reserves for North America (see Figure 7). Significant supplies of current and prospective shale plays are located in the Peace River Region of Alberta and British Columbia, the Bakken Region in the Dakotas, Mid-Eastern United States, and in Texas. The Mexican shale gas plays are located in that country's East Coast. In BC, the Horn River and Montney are the dominant unconventional natural gas plays, which are of the shale gas variety.

The IEA reports that for the United States only 65% of tight gas, 45% of coalbed methane and 40% of shale gas resources are accessible.



Source: International Energy Agency, 2013

**Figure 7: Major unconventional natural gas resources in North America.**

## European Supply of Unconventional Natural Gas

The IEA has published in its Golden Age of Gas report a map of the recoverable shale gas reserves in Europe (see Figure 8). Unconventional supplies of natural gas in Europe are of interest to BC as these supplies may compete with BC as a supplier to Asian markets.



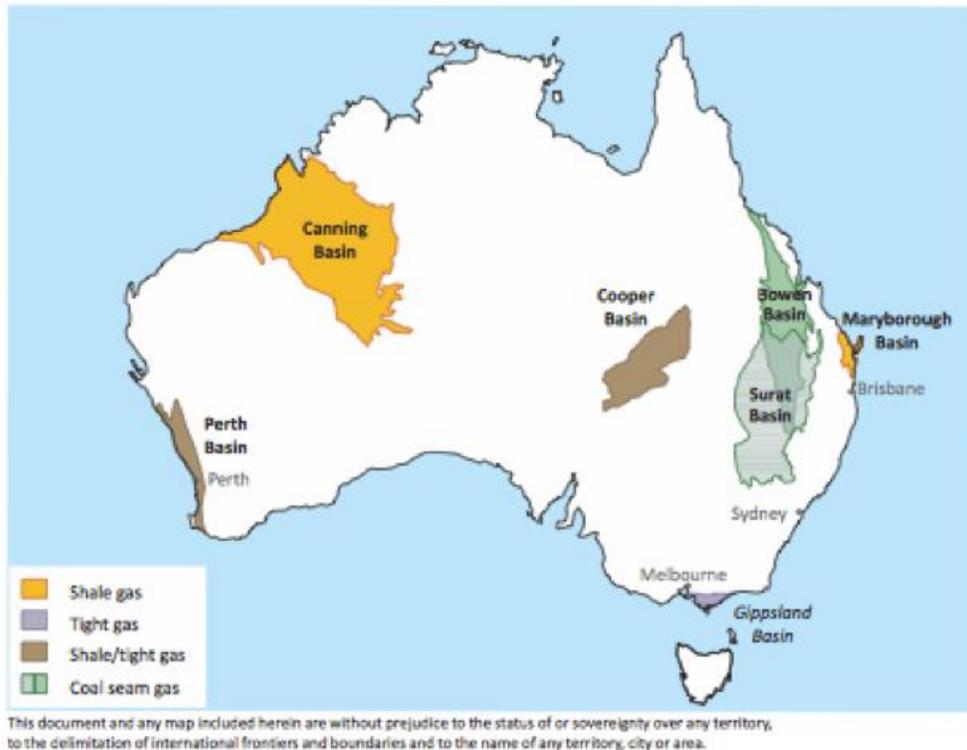
This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Source: International Energy Agency, 2013

**Figure 8: Major unconventional natural gas resources in Europe.**

## **Australian Supply of Unconventional Natural Gas**

The IEA has published in its Golden Age of Gas report a map of the recoverable shale gas reserves for Australia (see Figure 9). In Australia, only 40% of coalbed methane and none of the shale gas resources are assumed to be accessible. Development of both types of resources has already become controversial in Australia. About 5 bcm of coalbed methane was produced in Australia in 2010 and there are three large-scale projects underway to build LNG plants fed by coalbed methane. The restriction to 40% of available resources essentially amounts to no new projects being authorized beyond those announced.

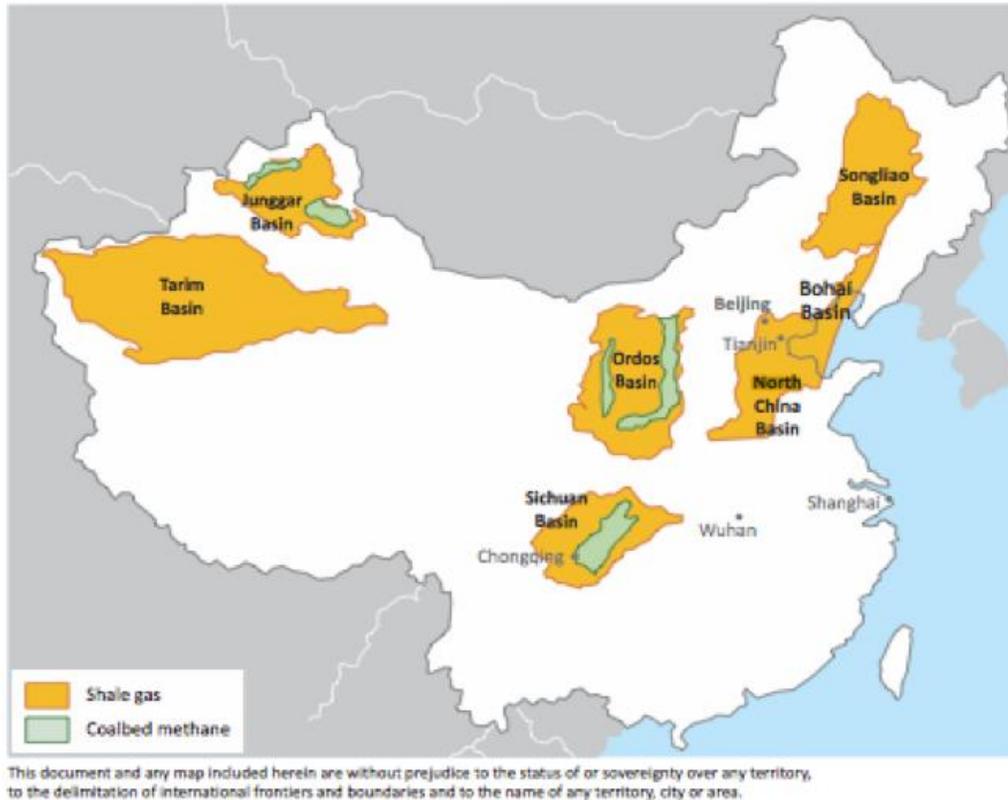


Source: International Energy Agency, 2013

**Figure 9: Major unconventional natural gas resources in Australia.**

## Chinese Supply of Unconventional Natural Gas

The IEA has published in its Golden Age of Gas report a map of the recoverable shale gas reserves for China (see Figure 10). For China, the IEA report that only 40% of the coalbed methane and 20% of the shale gas resources are assumed to be accessible. Public acceptance is likely to be a lesser influence in China than in other countries.



Source: International Energy Agency, 2013

**Figure 10: Major unconventional natural gas resources in China.**

For the rest of the world, the IEA reports that no new unconventional gas resources are assumed to be developed (for which GLOBE uses percentages of about half of those in the United States to reflect similar dynamics, but the smaller part of the resources so far developed).

While Russia has significant conventional supplies of natural gas, unconventional resources are not expected to play a significant role. It is fair, however, to assume that natural gas from Russia will be in direct competition with LNG being exported from BC to Asian markets.

One issue is whether or not the shale and coalbed plays in Asia and Australia are more GHG intensive than the activities in British Columbia. Longer pipeline distances to the LNG plant will result in somewhat higher fugitive emissions. Similarly, older LNG plants will likely be less efficient and emit higher amounts of GHG emissions than more modern, process-efficient or “cleaner” plants.

## Global Demand for Natural Gas Relative to Supply

North America, including BC, has substantial excess supply of natural gas relative to its demand and the Asia Pacific Region is short of supply relative to demand (as illustrated in Figure 11). Taking a supply / demand view of the Asia Pacific region through 2030, there is still a projected gap in supply to meet projected demand, especially when taking into account the huge growth expected in China and India.

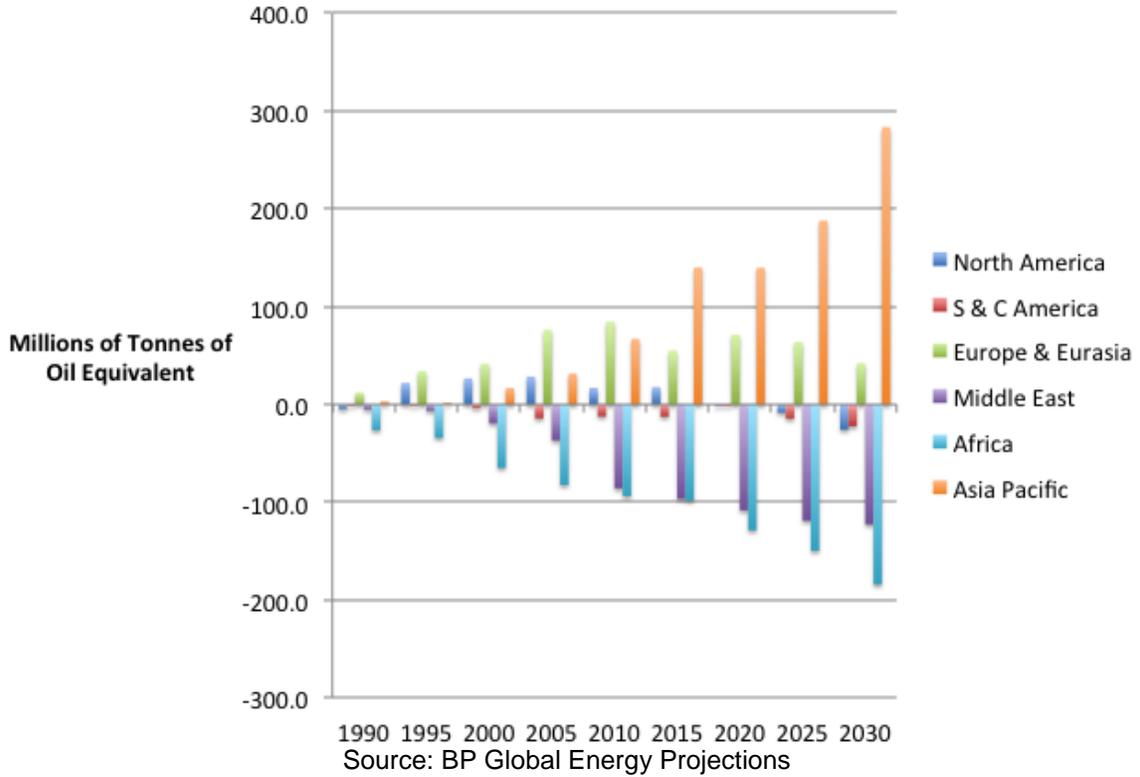
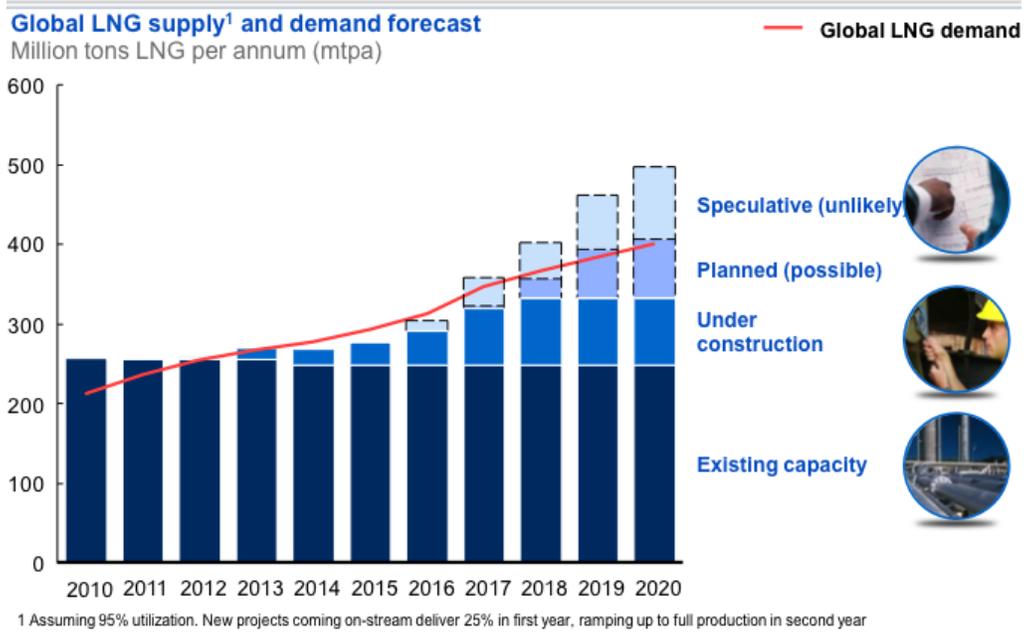


Figure 11: Natural Gas Demand Minus Supply Projections

Figure 12 illustrates the global LNG supply and demand forecast. Global demand for LNG is expected to be in the range of 400 million tons per annum (MMTPA) by 2020.



Source: LNG Growth and Opportunities in Thailand, Ptt Group

**Figure 12: Global LNG Supply and Demand Forecast**

**PART 2:  
BC's NATURAL GAS VALUE CHAIN GHG  
EMISSIONS**

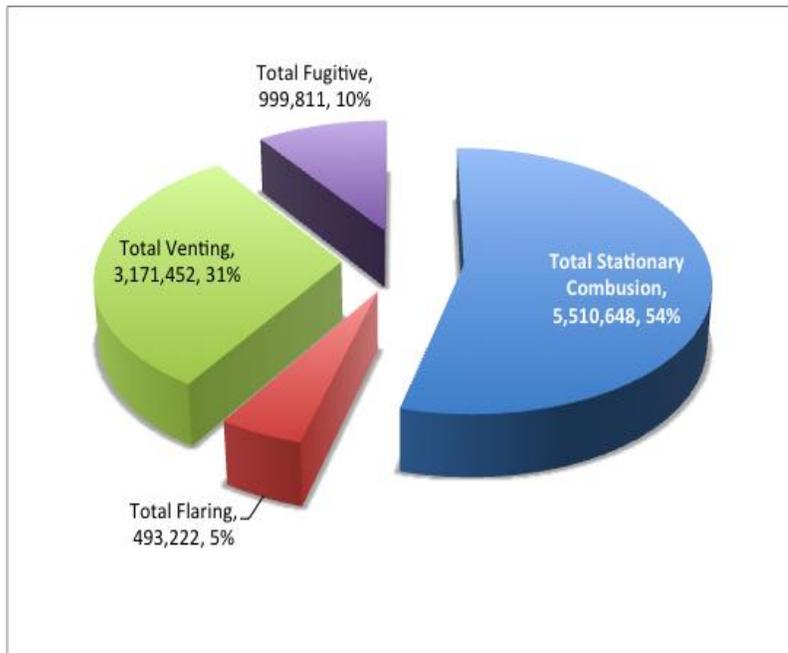
This section shows estimates for the life cycle GHG emissions for BC's natural gas overseas export value chain. As illustrated in the sidebar, this value chain includes natural gas production at the wellhead; processing (treatment and compression); distribution to LNG facilities (transportation by pipeline); liquefaction at LNG facilities; ocean transportation; regasification at LNG facility; distribution to users (transportation by pipeline); and consumption (combustion) by end users.

**Side Bar Figure: BC's natural gas value chain from wellhead to consumer (combustion).** Source: Clean Energy Canada



### BC's GHG Emissions by Reporting Facility

British Columbia publishes a report annually on GHG emissions by reporting facility. In 2012, 46 per cent of GHG emissions released by the oil and gas sector (including pipelines and distribution channels) were from gas that was vented, flared, or from fugitive releases (see Figure 13).

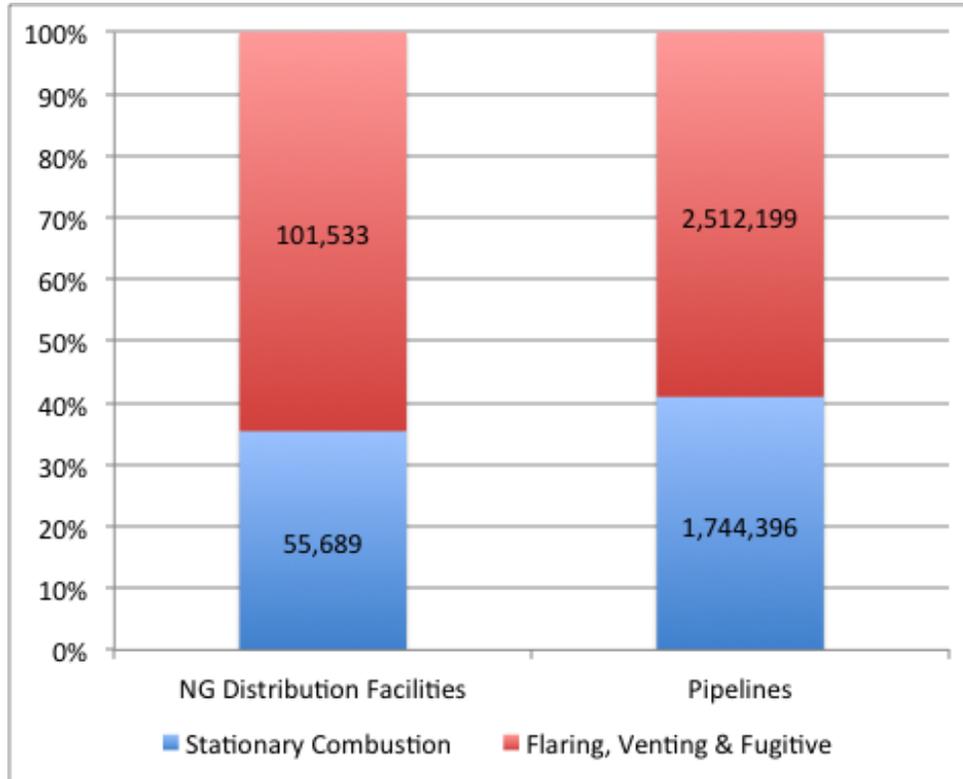


Source: BC report on GHG emissions by annual reporting facility 2012, linear facilities

**Figure 13: Greenhouse gas emissions in tonnes and per cent from linear facilities in British Columbia (conventional oil and gas extraction), 2012**

## BC's GHG Emissions from Natural Gas Extraction & Pipeline Transport

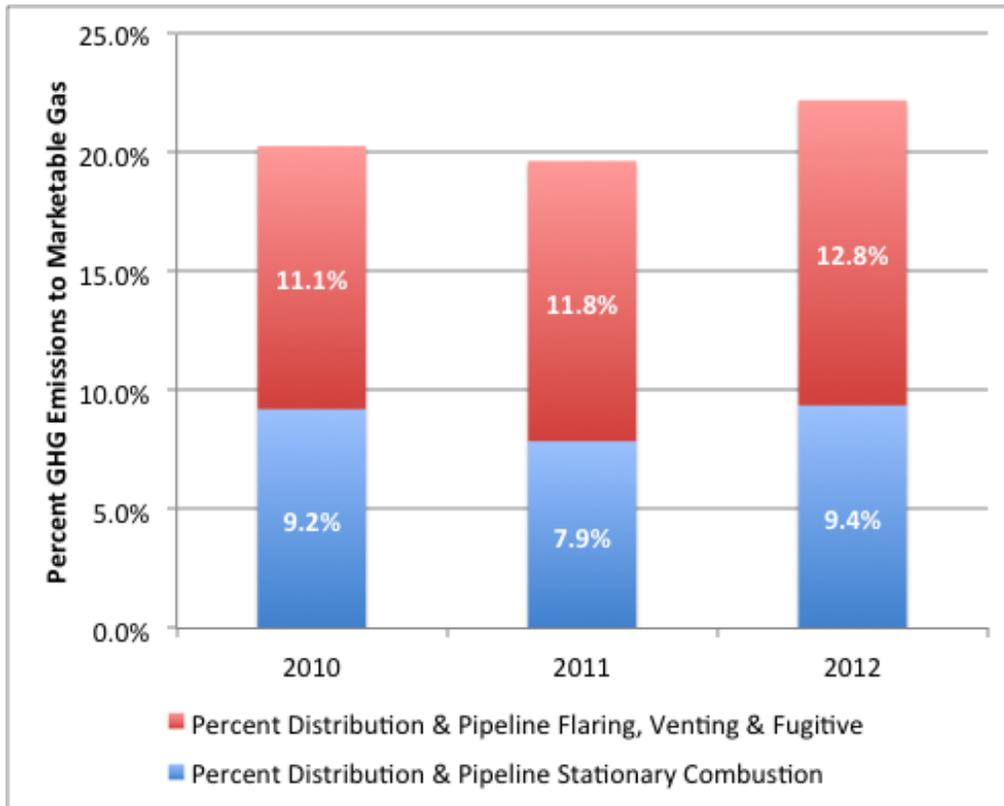
The BC report on GHG emissions by annual reporting facility also provides data on GHG emissions by both natural gas distribution and pipeline facilities. Figure 14 shows the amount of GHG emissions in tonnes of CO<sub>2</sub> equivalent reported by both distribution and pipeline facilities in 2012.



Source: BC report on GHG emissions by annual reporting facility 2012, linear facilities

**Figure 14: GHG emissions in tonnes and percent type by natural gas distribution and pipeline facilities in British Columbia, 2012**

Figure 15 shows flaring, venting, and fugitive emissions as a percentage of marketable gas for distribution and pipeline facilities from 2010 to 2012.



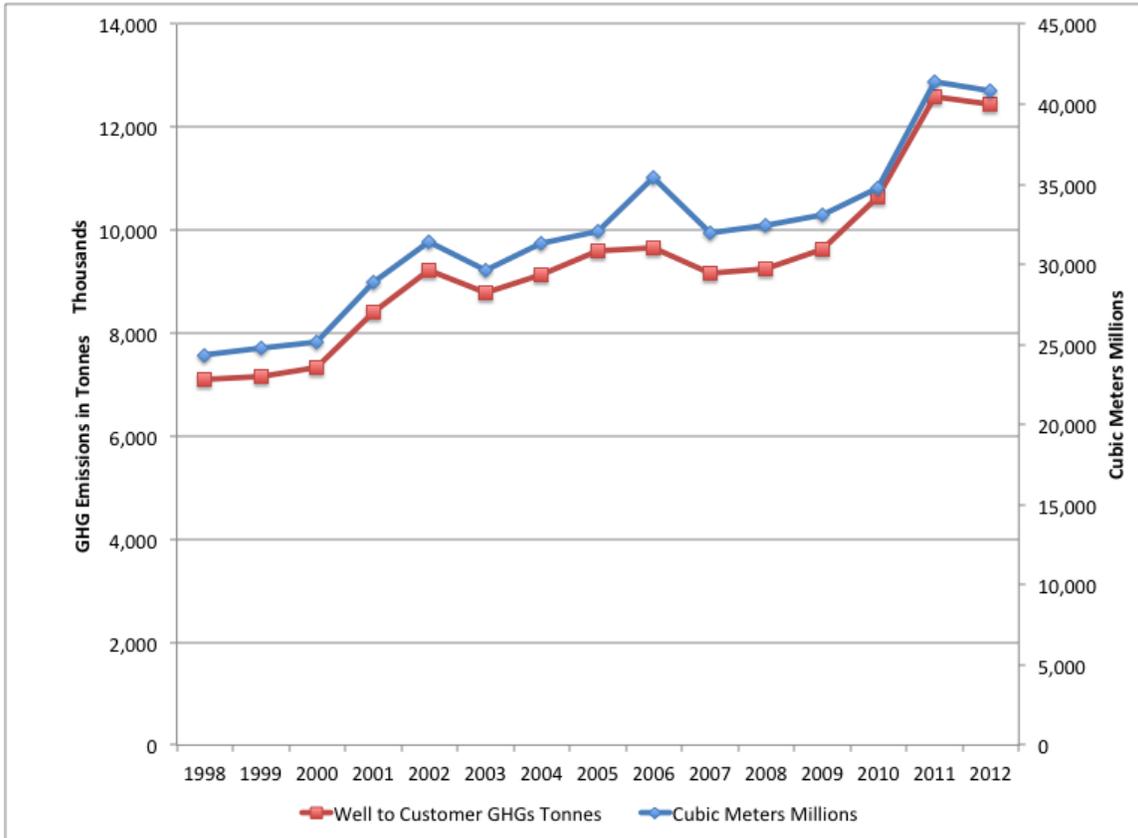
Source: BC report on GHG emissions by annual reporting facility 2012, linear facilities

**Figure 15: Percentage of GHG emissions to marketable gas, distribution, and pipeline facilities in British Columbia, 2010 to 2012.**

In order to reduce GHG emissions, project developers could use a combination of strategies and tools such as electrification—using electricity instead of natural gas to process natural gas and to power water pumps (rather than diesel)—and low-bleed valves and plunger lifts, which reduce leaks and venting. It is also important to limit the impact from black carbon (residual burn).

Flaring, venting, and fugitive releases of natural gas are significant for pipelines based on the BC survey. In terms of limiting pipeline losses and related GHG emissions, ensuring regular inspection and maintenance is critical. Project developers when constructing pipeline routes must also consider the one-time but material impact of removing trees that would normally act as carbon sinks.

Figure 16 shows the production of natural gas in BC and estimated GHG emissions associated with this production from 1995 to 2012. These emission estimates are derived from the algorithms published in GHGenius model for BC. As a point of reference, CO<sub>2</sub> equivalent emissions are also reported based on the BC large plant survey.<sup>6</sup> In 2012, BC produced approximately 40 billion cubic meters of natural gas. The potential for expanded production and related GHG emissions growth due to LNG projects coming online over the next decade is examined in more detail later in this section.



Source: Table 131-0001 Supply and disposition of natural gas, annual (cubic metres x 1,000,000) and CO<sub>2</sub> equivalent emission rates from the BC GHGenius model.

**Figure 16: British Columbia production of natural gas in millions of cubic meters and GHG emissions in tonnes, 1998 to 2012.**

<sup>6</sup> British Columbia Reporting Regulation Emissions Report, 2012.

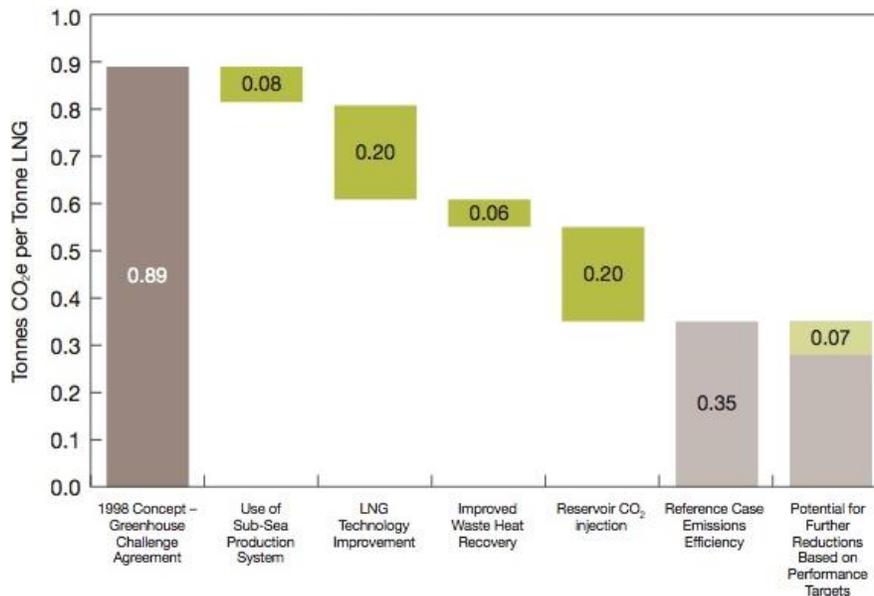
## BC's GHG Emissions from LNG Plant Production

Liquefied natural gas plants are essentially industrial-sized refrigerators that run massive power-consuming condensers to cool incoming natural gas to -162 degrees Celsius. The liquefaction process also involves removal of certain components, such as dust, acid gases, helium, water, and heavy hydrocarbons, which could cause difficulty downstream.

The processing and compression of LNG involves energy and if this energy is a fossil fuel, it contributes to the life cycle GHG emissions. LNG facilities may burn natural gas to run these condensers directly. However, they can also be operated by electricity, which may use lower carbon energy sources including wind, hydro, and also natural gas burned in an efficient “combined-cycle” power plant.

While proponents have yet to develop LNG projects along the BC coastline, an opportunity exists to develop them using technology and processes that allow for best-in-class production and, in turn, lower GHG emissions. Using renewable zero emissions electricity to power these LNG plants has the potential to substantially reduce the GHG footprint of the plant. Examining the GHG emissions impact of existing LNG plants around the world can help to determine the standard that BC can aim for in order to minimize overall life cycle GHG emissions.

In Australia, the Gorgon LNG plant is a state of the art facility that has improved its GHG emissions substantially due to “changes in process technology, improved waste heat recovery on the gas turbines resulting in a significant reduction in the use of supplementary boilers and heaters, and significantly reduced GHG emissions by the injection of reservoir CO<sub>2</sub> into the subsurface”.<sup>7</sup> Figure 17 illustrates how the Gorgon LNG plant achieved substantial reductions in GHG emissions from an original concept target of 0.89 tonnes of GHGs per tonne of LNG produced down to 0.35 tonnes. A further reduction of .07 tonnes of GHG emissions is currently being targeted.

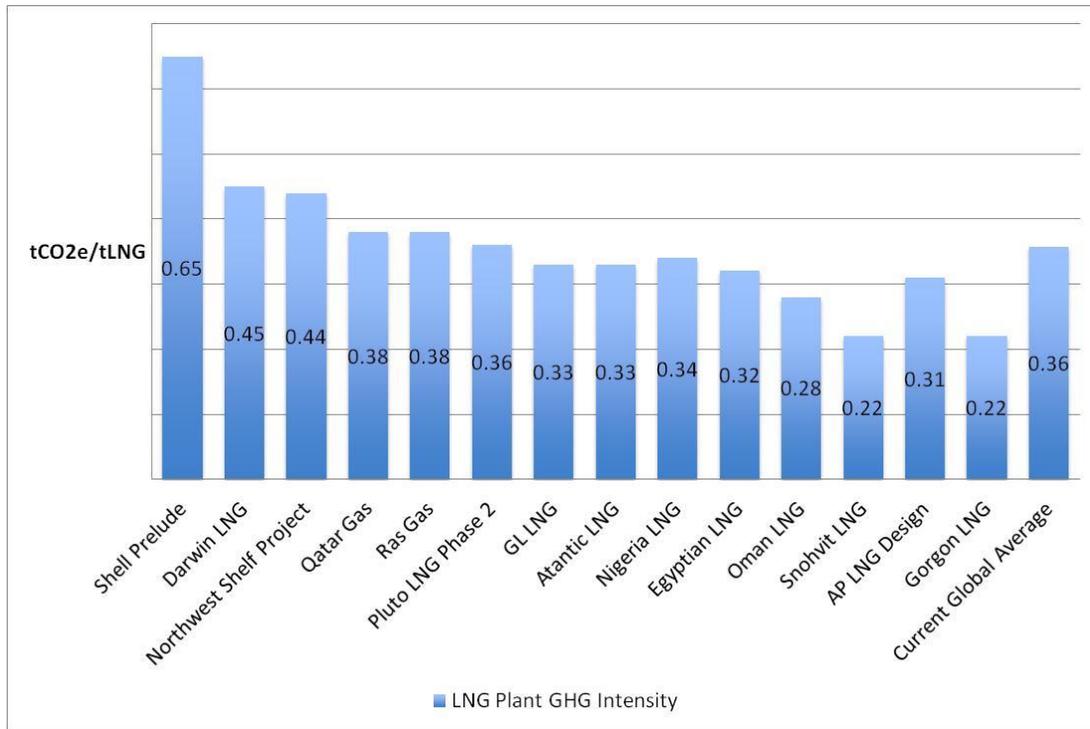


Source: Draft Environmental Impact Statement/Environmental Review and Management Programme for the Gorgon Development, Chapter 13, Greenhouse Gas Risks and Management

**Figure 17: Emissions efficiency improvements, Gorgon LNG plant, Australia.**

<sup>7</sup> Draft Environmental Impact Statement/Environmental Review and Management Programme for the Gorgon Development, Chapter 13, Greenhouse Gas Risks and Management.

GLOBE Advisors also reviewed the GHG emissions from several additional LNG production plants across the globe (as illustrated in Figure 18).



Source: Australia Pacific LNG Project Volume 5: Attachments, Attachment 31: Greenhouse Gas Assessment - LNG Facility, WorleyParsons

**Figure 18: GHG emissions intensity of select international LNG plants.**

The GHG emissions factors in Figure 18 represent the LNG plant compression and releases of CO<sub>2</sub> embedded in the natural gas. The Snohvit LNG plant, for example, has a relatively low emission factor of 0.22 tonnes per tonne of LNG produced. This plant captures and stores the CO<sub>2</sub> that is embedded in the natural gas.

The average GHG emission ratio for these plants is 0.36 tonnes of CO<sub>2</sub> equivalent per tonne of LNG produced. These LNG plants are powered from different fuels and technologies and hence, caution must be exercised in making a definitive comparison to British Columbia. In addition, some plants employing carbon capture and storage technologies have greater and easier access to rock caverns to store CO<sub>2</sub> than others, which makes a comparison of CO<sub>2</sub> equivalent intensities highly spurious amongst these international plants.

This information is useful, however, as the range of GHG emission factors illustrate the potential savings that are made possible through the use of more efficient technologies and, in some cases, carbon capture and storage. GLOBE Advisors believes that the LNG plants that will be built in BC can achieve very significant efficiencies for reduced GHG emissions due to the use of electric drive compressors that, in turn, run on a combination of new renewable power, existing British Columbia grid hydro electricity, and efficient combined-cycle natural gas generators. There is also the potential for using carbon capture and storage (CCS) technologies designed to cleanse the embedded CO<sub>2</sub> from the methane.

These potential CCS technologies do not necessarily involve the more traditional practice of storing CO<sub>2</sub> in rock caverns or depleted gas and/or oil wells. Various ways of storing carbon could include:

- **Algae / Biofuel Production**
  - Algae thrives on carbon dioxide. Algae farming with CO<sub>2</sub> is probably the most mature technology, and the first fuel-producing plants are already going online.
- **Converting into Plastics**
  - Captured CO<sub>2</sub> to produce polycarbonate plastics, like those used in CDs and DVDs. The idea is to take carbon dioxide emissions, and instead of sequestering them in the ground, trap them in resilient products. This approach makes sense, but because it relies largely on sequestering carbon in disposable products, like plastic forks and water bottles. So, basically, we'd be sequestering carbon every time we threw away plastic.
- **Sodium Bicarbonate (Baking Soda) Production**
  - Captures CO<sub>2</sub> as it exits power plant smokestacks and mixes it with sodium hydroxide to form baking soda. This process, called SkyMine, also removes heavy metals and dangerous pollutants and converts the CO<sub>2</sub> into sodium bicarbonate. Baking soda has a variety of uses on the commercial market, and this process could help make carbon capture more economically viable. Even if the baking soda is not sold, because it is solid it is immensely easier to store it in old mines or landfills than it would be to sequester gaseous CO<sub>2</sub> beneath the ground.
- **Calcium Carbonate / Concrete Production**
  - A new process called GreenCarbon, which, at the base of things, turns carbon dioxide into useful stuff. The GreenCarbon process mixes the CO<sub>2</sub> with crushed calcium minerals, one of the most abundant elements in the earth's crust. The end result is calcium carbonate, an industrial chemical that's used in thousands of applications, from PVC to paper to toothpaste and, in its pure form, as wall board and chalk.
- **Other Fuel Production**
  - The carbon dioxide would be super heated to around 1,200 C and mixed with water to create various hydrocarbons of the sort is already burning in cars. The idea is to use leftover heat from nuclear or utility-scale solar thermal power generating plants. The process basically reverses combustion, and is only economically viable if the energy can come from cheap, clean sources.

A plethora of CCS technologies including those discussed above could be explored in BC.

GLOBE Advisors carefully examined GHG emission ratios developed for the GHGenius and GREET models and prepared a set of emission ratios (tonnes of GHG emissions per tonne of LNG produced) for a traditional LNG plant (based on GHGenius model results), as well as for a plant that utilizes renewable electricity and state-of-the-art practices for carbon capture and storage as part of its facility. These emission ratios are illustrated in Table 1 below.

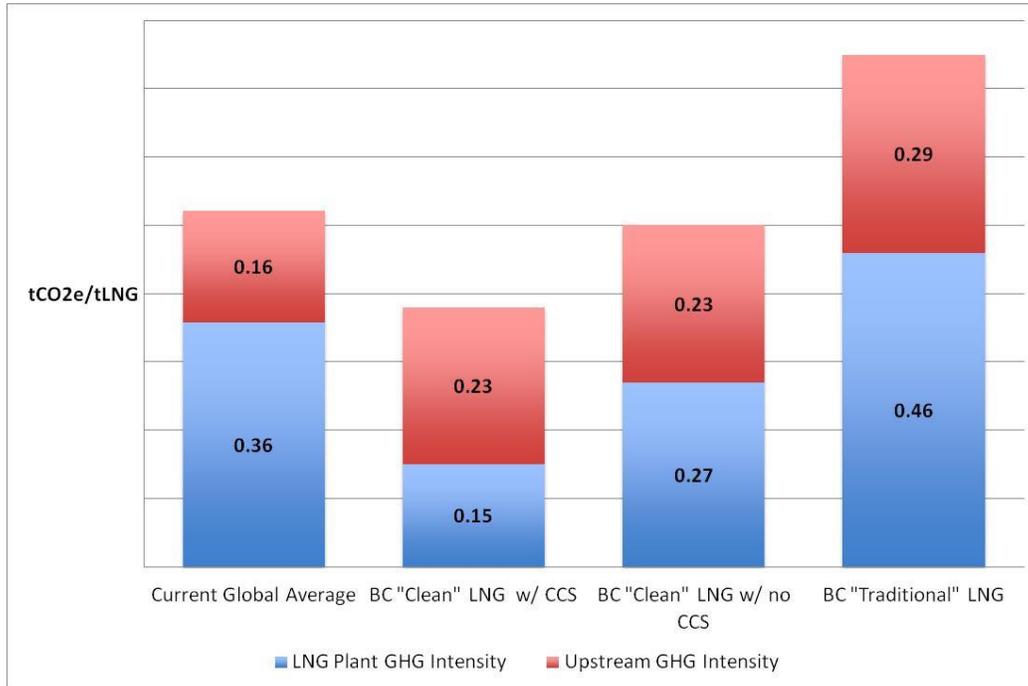
**Table 1: Wellhead to waterline GHG emission factors for both “traditional” and “clean” LNG plants in BC.**

|  | <b>Traditional Plant GHG Emission Factor</b> | <b>Clean Plant GHG Emission Factor</b> |
|--|--|--|
| <b>Exploration &amp; Wellhead</b>                  |  |  |
| Fuel distribution and storage                      | 0.07   | 0.06                                   |
| Fuel production                                    | 0.07   | 0.06                                   |
| Feedstock recovery                                 | 0.09   | 0.08                                   |
| Gas leaks and flares                               | 0.07   | 0.04                                   |
| <b>Subtotal</b>                                    | <b>0.29</b>                                  | <b>0.23</b>                            |
| <b>LNG Plant</b>                                   |  |  |
| CO <sub>2</sub> , H <sub>2</sub> S removed from NG | 0.12   | 0.01                                   |
| Liquefaction at LNG Plants                         | 0.33   | 0.14                                   |
| <b>Subtotal</b>                                    | <b>0.46</b>                                  | <b>0.15</b>                            |
| <b>Well-to-Water Upstream with CCS</b>             | <b>0.75</b>                                  | <b>0.38</b>                            |
| <b>Well-to-Water with no CCS</b>                   | <b>0.75</b>                                  | <b>0.50</b>                            |

Based on the GHGenius model, a traditional LNG plant in BC that does not utilize “clean” practices (including renewable power supplemented by CCS) will produce well-to-water GHG emissions of approximately 0.75 tCO<sub>2</sub>e / tLNG. However, if LNG plants in BC utilize renewable power for compressing the natural gas and, conceivably, employ CCS technologies to capture the embedded CO<sub>2</sub>, a well-to-water emissions factor of 0.38 tonnes per tonne of LNG product is achievable.<sup>8</sup> Using some combination of renewable energy technology and/or CCS can achieve well-to-water emissions somewhere in between 0.75 and 0.38 tCO<sub>2</sub>e / tLNG produced.

<sup>8</sup> GLOBE includes the exploration, production, distribution, and LNG facilities in its upstream emissions.

As illustrated in Figure 19, the global average for upstream GHG emissions combined with LNG plant emissions (well-to-water ratio) for various LNG projects around the world is 0.52 tCO<sub>2</sub>e / tLNG produced. Included in this graph are three GHG emission factors that represent hypothetical LNG plants in British Columbia under three scenarios. These scenarios include the “traditional” plant emissions factor of 0.75 tCO<sub>2</sub>e / tLNG based on the GHGenius model, the “clean” plant emissions factor of 0.38 tCO<sub>2</sub>e / tLNG that includes application of CCS technologies, and a hybrid scenario that does not include CCS and results in plant emissions of 0.50 tCO<sub>2</sub>e / tLNG.



Source: GLOBE Advisors and Australia Pacific LNG Project Volume 5: Attachments, Attachment 31: Greenhouse Gas Assessment - LNG Facility, WorleyParsons

**Figure 19: Global average well-to-waterline GHG emissions intensity compared to three BC LNG plant well-to-waterline GHG emissions scenarios.**

GLOBE Advisors believes that a target of 0.15 tonnes of GHG emissions per tonne of LNG produced (or a 58 per cent reduction from a “traditional” LNG plant powered by fossil fuels) is both possible and plausible, as the LNG plants in BC can employ near-zero emission clean electricity to power the compressors. This improvement in emission efficiency is in-line with the Gorgon targets that were achieved in Australia.<sup>9</sup>

Liquefied natural gas plants in BC have the potential to produce some of the lowest well-to-waterline value chain GHG emissions if both renewable electricity and CCS technologies are applied. However, without the application of CCS, BC plants would be marginally less GHG emissions intensive than the global average. If LNG plants in BC do not employ renewable energy and new technologies in order to reduce emissions, then the traditional emission rate of 0.75 tCO<sub>2</sub>e / tLNG would be considerably higher than the global average of 0.52 tCO<sub>2</sub>e / tLNG produced.

<sup>9</sup> The CO<sub>2</sub> venting and possible capture and sequestration is assumed to occur at the LNG plant phase similar to what has been reported for the international examples including the Gorgon Plant. An argument can be made that CO<sub>2</sub> venting occurs at the upstream phase; however, this does not change the overall life cycle CO<sub>2</sub> intensity.

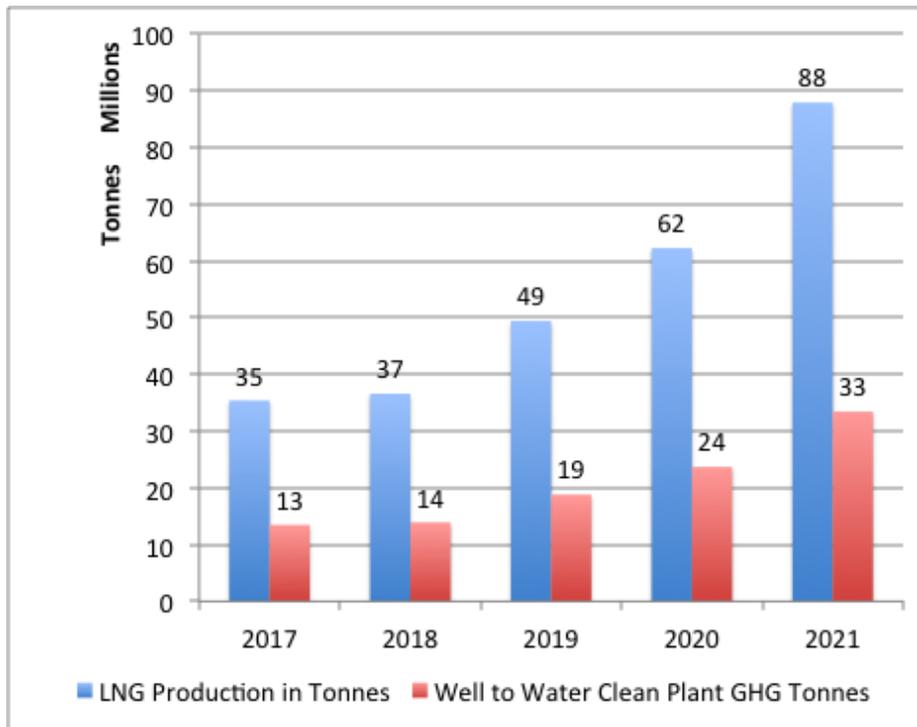
At present, there are a total of ten LNG projects proposed for development in British Columbia. Table 2 provides an overview of each project's proposed capacity and its current status. If all of these projects were to proceed to full potential capacity, approximately 131 million metric tonnes per annum (mtpa) of LNG would be produced and available for export to overseas markets.

**Table 2: Overview of forecast LNG infrastructure projects in BC, 2017 to 2021.**

| Project Name<br>(Location)   | Project Lead & Partners  | Potential Capacity<br>(mtpa) | Current Status          |
|--|--|------------------------------|-------------------------|
| <a href="#">Douglas Channel Energy Project</a><br>(Kitimat)                  | <b>BC LNG Export Co-Operative</b><br>Haisla Nation<br>Golar LNG                                      | 0.9                          | Export license approved |
| <a href="#">LNG Canada</a><br>(Kitimat)                                      | <b>Shell Canada Ltd.</b><br>Korea Gas Corp. (KOGAS),<br>Mitsubishi Corp.,<br>PetroChina Company Ltd. | 24                           | Export license approved |
| <a href="#">Kitimat LNG</a><br>(Kitimat)                                     | <b>Apache Canada Ltd.</b><br>Chevron Canada Ltd.   | 15                           | Export license approved |
| <a href="#">Prince Rupert LNG</a><br>(Prince Rupert)                         | <b>BG Group</b><br>Spectra Energy Natural Gas<br>Transportation System                               | 14                           | NEB currently reviewing |
| <a href="#">Pacific Northwest LNG</a><br>(Prince Rupert)                     | <b>Progress Energy Canada Ltd.</b><br>Petroleum Nasional Berhad<br>(Petronas)<br>JAPEX               | 18                           | NEB currently reviewing |
| <a href="#">Imperial Oil / Exxon Mobil</a><br>(Prince Rupert or Kitimat)     | <b>Imperial Oil</b><br>Exxon   | 30                           | NEB currently reviewing |
| <a href="#">AltaGas Idemitsu Joint Venture</a><br>(Prince Rupert or Kitimat) | <b>AltaGas</b><br>Idemitsu Kosan Co. Ltd.  | 2.3                          | NEB currently reviewing |
| <a href="#">Woodfibre LNG</a><br>(Squamish)                                  | Woodfibre Natural Gas Ltd.   | 3                            | NEB currently reviewing |
| <a href="#">Aurora LNG</a><br>(Prince Rupert)                                | <b>CNOOC</b><br>Inpex<br>JGC Corp.   | 12                           | NEB currently reviewing |
| <a href="#">Kitsault Energy LNG</a><br>(Kitsault)                            | Kitsault Energy  | 15                           | Feasibility phase       |
| <b>Total Proposed LNG Production in BC (MMTPA)</b>                           |  | <b>131.2</b>                 |                         |
| <b>Estimated LNG Production in BC by 2021 (131.2 MMTPA X 67%)</b>            |  | <b>87.9</b>                  |                         |

Realistically, not all ten of the proposed LNG projects listed in the table above will proceed to full capacity. In this report, GLOBE Advisors worked with an assumption that two-thirds (67 per cent) of the total capacity proposed for construction will come on stream by 2021. In this regard, once constructed and operational, these LNG projects will produce 87.9 million metric tonnes of LNG per annum (mtpa).

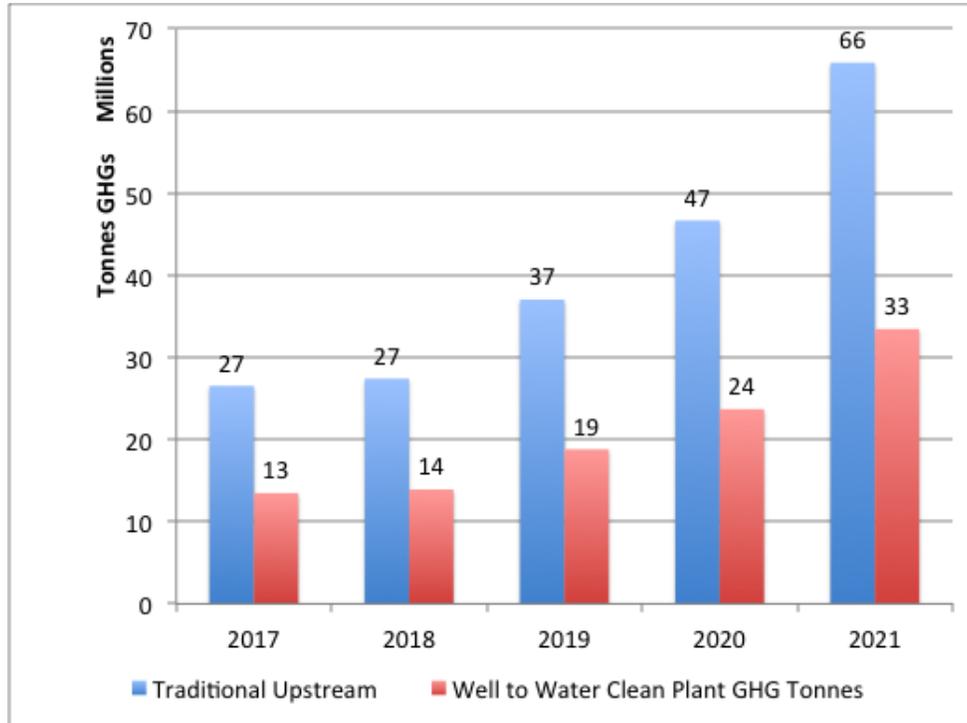
Figure 20 shows the expected production of natural gas and associated GHG emissions from 2017 to 2021, as the estimated LNG plant production in BC begins to come on stream. Under this scenario, approximately 33 million tonnes of GHG emissions (CO<sub>2</sub> equivalent) would be produced in 2021 as the life cycle GHG emissions from wellhead to waterline, assuming that LNG plants in BC utilize “cleanest” practices for plant operations and upstream management of GHG emissions. LNG production units are in millions of metric tonnes and GHG emissions are in tonnes of CO<sub>2</sub>e.



Source: GLOBE Advisors

**Figure 20: British Columbia projected production of LNG and related GHG emissions in Tonnes, 2017 to 2021 (based on estimated 67% of proposed LNG infrastructure construction proceeds to full operation).**

Figure 21 shows the relevant tonnes of GHG emissions (CO<sub>2</sub> equivalent) for a LNG plant in BC using the “cleanest” production processes relative to GHG emissions of LNG produced in BC from a “traditional” plant, based on 88 mmtpa of LNG produced.

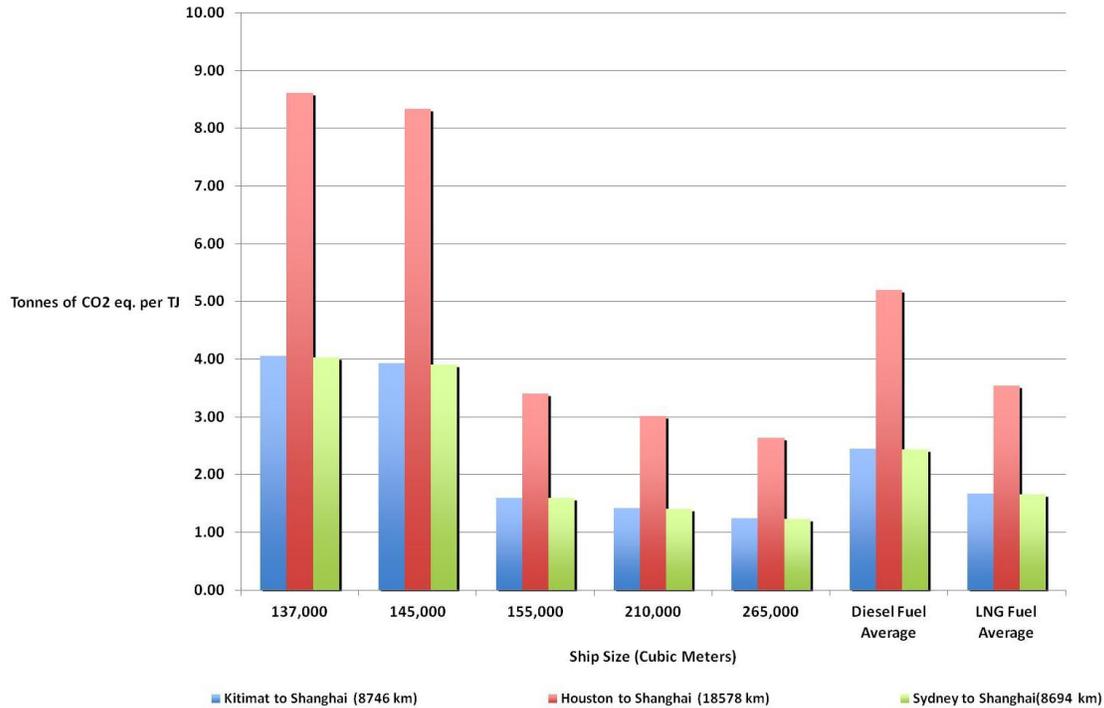


Source: GHGenius and GLOBE Advisors

**Figure 21: Well to waterline GHG emissions for a “traditional” LNG plant in BC (modeled with GHGenius) compared with a “clean” LNG plant.**

## GHG Emissions from LNG Tanker Transportation

Tanker shipping accounts for a certain level of GHG emissions and these emissions should be included in the full life cycle analysis. Shipping emissions occur during the consumption of fuel used to power the propulsion engine. The amount of GHG emissions from LNG tankers depends on the distance shipped, the type of fuel consumed (diesel or natural gas), and the size of the tanker. Figure 22 shows various LNG tanker emission factors based on these three variables.

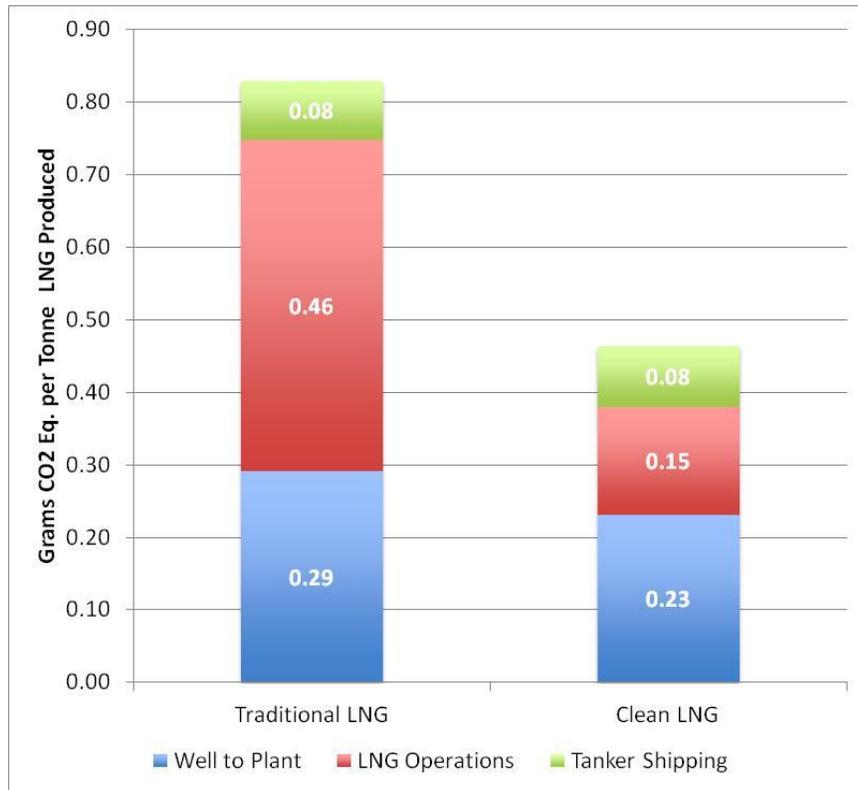


Source: University of Queensland, Life Cycle Assessment (LCA) of Liquefied Natural Gas (LNG) and its environmental impact as a low carbon energy source.

**Figure 22: GHG emission factors by distance shipped, tanker size, and fuel type.**

The route from Kitimat, BC, to Shanghai, China, for example, is considerably lower than from Houston, Texas. As a consequence, so are the related GHG emissions. The distance from Kitimat, BC, and Sydney, Australia, are nearly identical and as such, so are the GHG emissions from marine transportation given similar vessels are used. It should be noted that GHG emissions are further reduced when bunker or diesel fuel is switched for cleaner LNG fuel used to power ship transportation.

Figure 23 shows these GHG emission factors for both a “traditional” LNG plant (based on the GHGenius model) and for the potential “clean” plant (based on GLOBE’s target for best-in-class operations).

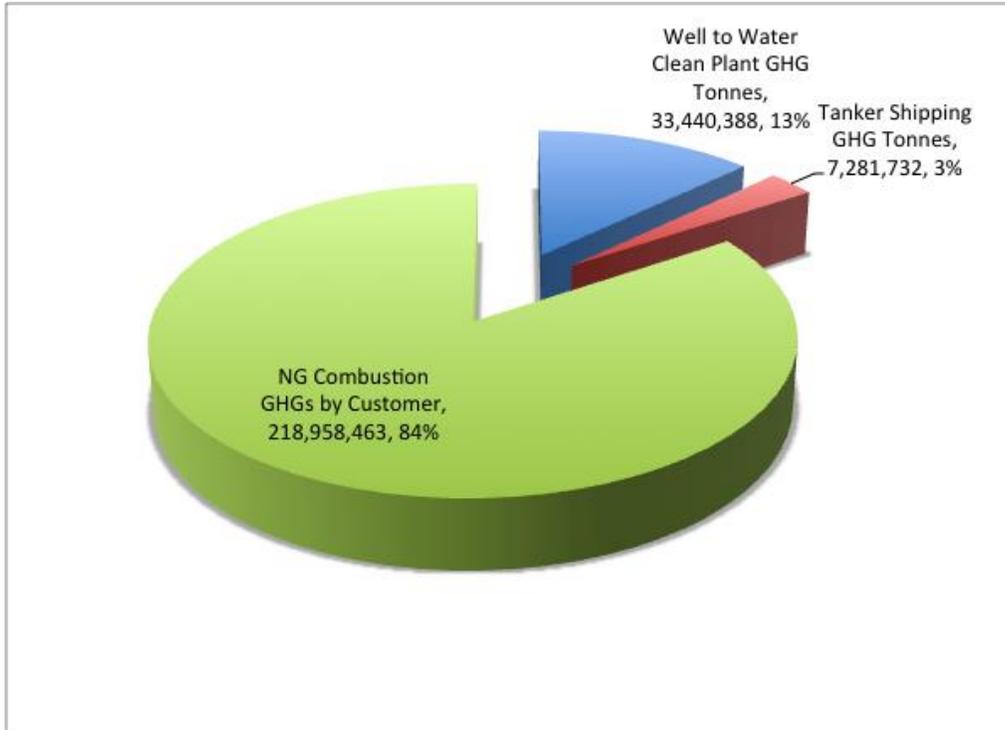


Source: GHGenius and GLOBE Advisors

**Figure 23: GHG emission factors for “traditional” and “clean” LNG plants in BC.**

## BC's GHG Life Cycle Emissions from Wellhead to the Customer

Figure 24 shows the potential GHG emissions (CO<sub>2</sub> equivalent) in tonnes and percentages for the full natural gas and LNG life cycle based on export of 88 mmtpa of LNG from BC to Asian markets.



Source: GLOBE Advisors and GHGenius

**Figure 24: GHG emissions impact for the full life cycle of BC natural gas and LNG from the wellhead to the customer, tonnes of CO<sub>2</sub> (based on 88 MMTPA production)**

GLOBE Advisors has assumed that the proposed LNG plants in BC will have been developed in-line with current best-in-class “clean” LNG projects and as such, will produce approximately 0.38 tonnes CO<sub>2</sub>e per tonne of LNG. The tanker transportation emissions amount to a further 0.08 tonnes CO<sub>2</sub>e per tonne of LNG production. Thus, delivering the product to the customer results in 0.46 tonnes of GHG emissions for every tonne of LNG produced.

However, the wellhead to market GHG emission factors pale in comparison with the full life cycle of BC's natural gas when combustion factors are included, based on the customer burning BC's natural gas product for electrical power (as illustrated in Figure 26 above). As illustrated, BC's upstream GHG emissions from wellhead to waterline are equal to 16 per cent of total life cycle GHG emissions.

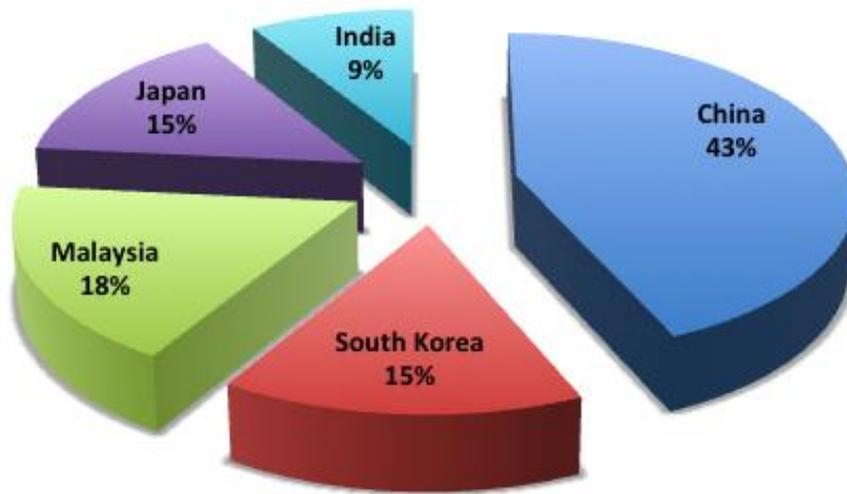
**PART 3:  
IMPACT OF BC's LNG EXPORTS ON GLOBAL GHG  
EMISSIONS**

This section addresses the issue of whether or not natural gas being exported from BC will be consumed as an alternative to fuel from other sources, and in particular, as a replacement to coal.

The question being addressed is to what extent will BC's LNG be replacing higher GHG intensive fuels. Replacing coal with natural gas has the potential to reduce GHG emissions substantially. This analysis requires a more detailed examination of the end user of BC's LNG exports.

### Estimated LNG Exports by Country

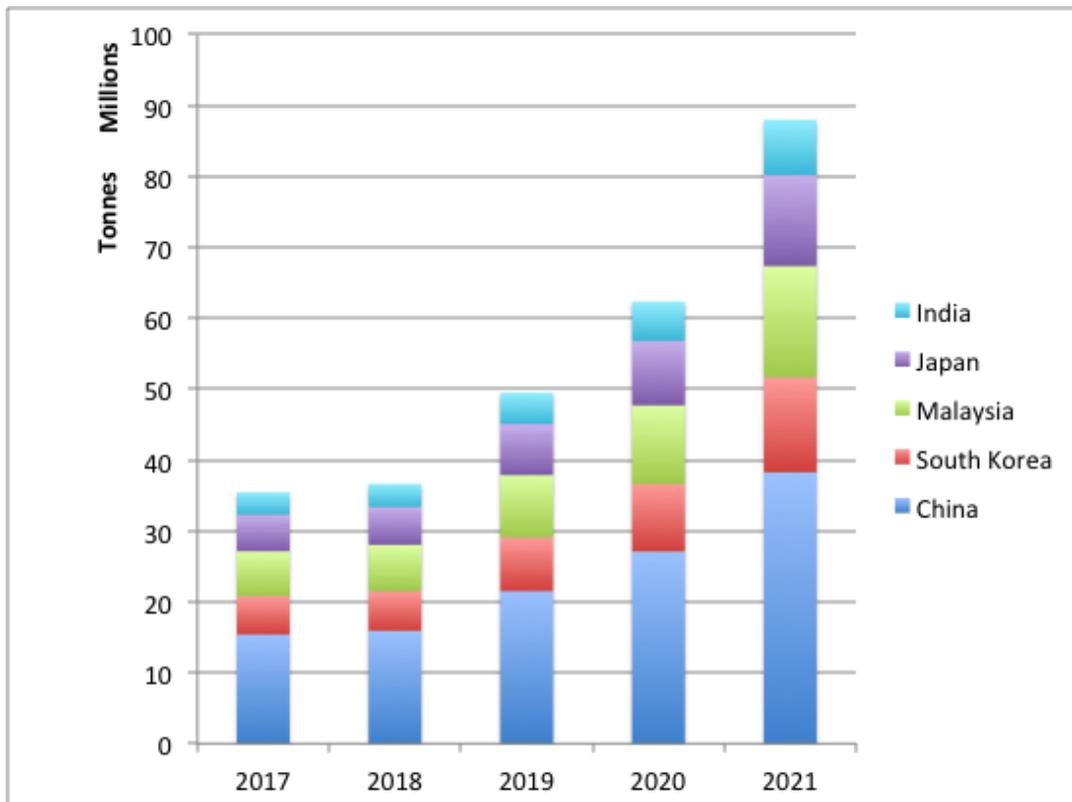
GLOBE Advisors estimated the distribution of British Columbia's LNG exports to Asian economies based on examining proposed LNG plant investment shares by various Asian partners, as well as on projected demand recently published in the International Energy Agency's World Outlook for 2013. These estimated shares are illustrated in Figure 25 below.



Source: International Energy Agency and various BC LNG infrastructure websites on investor partners

Figure 1725: Distribution of BC's LNG exports to Asian countries.

British Columbia’s potential LNG export capacity by country is shown in Figure 26. As illustrated, China is the dominant economy for receiving LNG exports from British Columbia based on the current proposed projects.



Source: International Energy Agency and BC LNG infrastructure projects based on investor partners.

**Figure 26: Potential LNG exports to Asian countries, 2017 to 2021 (in mmtpa).**

Table 3 shows the ten proposed LNG projects and their major partners, mostly from Asia. Based on these partners, GLOBE has provided an anecdotal discussion of possible GHG impacts within the various customer markets in the following section.

**Table 3: Target Country Markets of Forecast LNG Projects in BC, 2017 to 2021**

| Project Name<br>(Location)   | Project Lead & Partners  | Target Country /<br>Region | Impact on Energy<br>Consumption                              |
|--|--|----------------------------|--|
| <a href="#">Douglas Channel Energy Project</a><br>(Kitimat)                  | <b>BC LNG Export Co-Operative</b><br>Haisla Nation<br>Golar LNG            | Asia                       | Mixture of replacing coal and natural gas from other sources |
| <a href="#">LNG Canada</a><br>(Kitimat)                                      | <b>Shell Canada Ltd.</b>   | Asia                       | Mixture of replacing coal and natural gas from other sources |
|  | Korea Gas Corp. (KOGAS)  | South Korea                | Mixture of replacing coal and LNG from other sources         |
|  | Mitsubishi Corp.   | Japan                      | Mixture of replacing coal and LNG from other sources         |
|  | PetroChina Company Ltd.  | China                      | Mixture of replacing coal and natural gas from other sources |
| <a href="#">Kitimat LNG</a><br>(Kitimat)                                     | <b>Apache Canada Ltd.</b><br>Chevron Canada Ltd.                           | Asian utility companies    | Mixture of replacing coal and natural gas from other sources |
| <a href="#">Prince Rupert LNG</a><br>(Prince Rupert)                         | <b>BG Group</b><br>Spectra Energy Natural Gas<br>Transportation System     | China                      | Mixture of replacing coal and natural gas from other sources |
|  |  | Japan                      | Mixture of replacing coal and LNG from other sources         |
|  |  | South Korea                | Mixture of replacing coal and LNG from other sources         |
|  |  | India                      | Mixture of replacing coal and natural gas from other sources |
| <a href="#">Pacific Northwest LNG</a><br>(Prince Rupert)                     | <b>Progress Energy Canada Ltd.</b><br>Petroleum Nasional Berhad (Petronas) | Malaysia                   | Replace diesel power   |
|  | JAPEX  | Japan                      | Mixture of replacing coal and LNG from other sources         |
| <a href="#">Imperial Oil / Exxon Mobil</a><br>(Prince Rupert or Kitimat)     | <b>Imperial Oil</b><br>Exxon   | Asia and other markets     | Mixture of replacing coal and natural gas from other sources |
| <a href="#">Woodfibre LNG</a><br>(Squamish)                                  | n/a  | Asia and other markets     | Mixture of replacing coal and natural gas from other sources |
| <a href="#">AltaGas Idemitsu Joint Venture</a><br>(Prince Rupert or Kitimat) | <b>AltaGas</b><br>Idemitsu Kosan Co. Ltd.                                  | Japan                      | Mixture of replacing coal and LNG from other sources         |
| <a href="#">Aurora LNG</a><br>(Prince Rupert)                                | <b>CNOOC</b>   | China                      | Mixture of replacing coal and natural gas from other sources |
|  | Inpex  | Indonesia                  | Replace diesel power   |
|  | JGC Corp.  | Japan                      | Mixture of replacing coal and LNG from other sources         |
| <a href="#">Kitsault Energy LNG</a><br>(Kitsault)                            | Kitsault Energy  | Asia and other markets     | Mixture of replacing coal and natural gas from other sources |

## BC's Natural Gas Life Cycle Impact on Global GHG Emissions

As a fossil fuel, GHG emissions are emitted when natural gas is burned. However, the GHG emissions associated with burning natural gas are lower than for most other fossil fuels.

When natural gas is used to replace coal and/or natural gas being sourced from other locations with higher life cycle GHG emissions, it will have an overall positive impact on reducing global GHG emissions and local air pollutants.

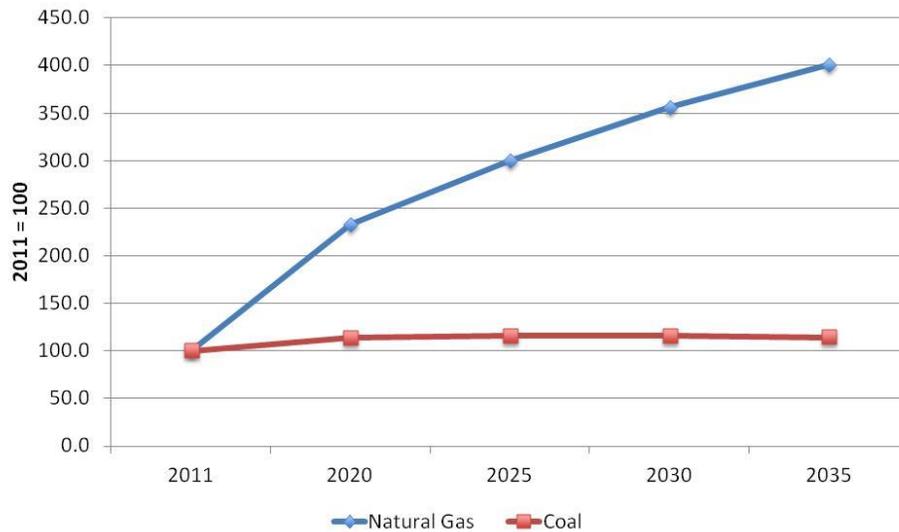
Natural gas is a particularly attractive fuel for countries and regions that are urbanizing and seeking to satisfy rapid growth in energy demand, such as China and India. These countries will largely determine the extent to which natural gas use expands over the next 25 years.<sup>10</sup>

As described earlier in this report in the section on the projected global demand for natural gas, the natural gas imported by Asian economies is expected to largely replace existing or planned coal thermal power and, hence, will provide an overall reduction in CO<sub>2</sub>e emissions due to lower combustion emissions of natural gas over coal.

A more detailed examination of BC's primary markets for the export of LNG and the related impacts on local GHG emissions within each market follows below.

### China

Based on the IEA's *New Policies Scenario*, the demand for natural gas in China is expected to quadruple by 2035, while the demand for coal is expected to remain relatively constant (see Figure 27).



Source: IEA 2013 World Energy Outlook, *New Policies Scenario*

**Figure 27: Demand for natural gas and coal in China, 2011 to 2035.**

<sup>10</sup> See: <http://www.iea.org/newsroomandevents/pressreleases/2011/june/name.20306.en.html>

At the same time, China is experiencing a serious shortage in natural gas. The problem is particularly acute in northern China, where its air is polluted and where officials are trying to end large-scale use of coal for heating and power generation. The country's domestic supply of natural gas cannot meet demand. "China's demand was 143.8 billion cubic meters, of which 40 billion had to be imported. It is estimated that China's dependence on imported natural gas will exceed 35 per cent by 2015."<sup>11</sup>

The efforts to reduce coal usage in the Beijing-Tianjin-Hebei region are unprecedented. "On August 25, the Beijing Environmental Protection Bureau issued guidelines demanding that 137 boilers of about 4,900 tons of steam capacity in six urban districts switch from coal to gas from this year to 2015, thus reducing coal consumption by 1.2 million tons. Nearly all industrial and corporate boilers in the entire city were told to switch from coal to gas by 2016."<sup>12</sup>

According to the United States Energy Information Administration, "natural gas usage in China has also increased rapidly in recent years, and China has looked to raise natural gas imports via pipeline and liquefied natural gas (LNG). China is also the world's largest top coal producer and consumer and accounted for about half of the global coal consumption, an important factor in world energy-related CO<sub>2</sub> emissions."<sup>13</sup>

Natural gas exports to China and the rest of Asia will be substantial. This power will, however, be produced with fewer GHG emissions than through the use of other fossil fuels (coal, diesel, etc.). Note that the IEA in an interview with the Press regarding the 2013 World Outlook Report rejected calls for British Columbia to forgo the production and export to Asia of LNG due to concerns that the province would not meet its own GHG reduction targets. Growing LNG imports in China and elsewhere should reduce the need for coal-fired electricity, leading to a global reduction in GHG emissions.

GLOBE Advisors believes that the strong Chinese demand for natural gas will coincide with a lower emphasis on coal thermal power due to the strong pressure to reduce pollution and CO<sub>2</sub> equivalent emissions as part of its 12<sup>th</sup> Five-Year Plan and future Five-Year Plans.

## ***Japan***

Japan is currently the world's largest importer of LNG. In light of the country's lack of sufficient domestic hydrocarbon resources, Japanese energy companies are actively pursuing participation in upstream oil and natural gas projects overseas and provide engineering, construction, financial, and project management services for energy projects around the world. Coal continues to account for a significant share of total energy consumption, although natural gas is increasingly important as a fuel source.

"Because of its limited natural gas resources, Japan must rely on imports to meet its natural gas needs. Japan began importing LNG from Alaska in 1969, making it a pioneer in the global LNG trade. Due to environmental concerns, the Japanese government has encouraged natural gas consumption in the country. Japan is the world's largest LNG importer, holding about 33 per cent of the global market in 2011."<sup>14</sup>

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<sup>11</sup> See: <http://english.caixin.com/2013-11-29/100611459.html>

<sup>12</sup> Ibid

<sup>13</sup> See: <http://www.eia.gov/countries/cab.cfm?fips=CH>

<sup>14</sup> Ibid

With respect to nuclear power, since the Fukushima disaster, nuclear power production may decrease in Japan. Japan shut down all 50 commercial reactors in the wake of the 2011 earthquake and tsunami that triggered a nuclear crisis at the Fukushima plant. Two reactors were restarted in July of 2012, but were taken offline again in September 2013 for inspections, leaving the country without any nuclear power.

Coal has been the dominant replacement of power in Japan since the shutdown of nuclear power facilities in that country. As such, GLOBE Advisors has assumed that increased natural gas usage will be used to replace coal power that is currently being consumed, or natural gas sourced from other less “clean” sources.<sup>15</sup> As such, fuel switching from coal or “dirtier” natural gas to “cleaner” natural gas imported from BC when the LNG plants become operational (starting in 2017) will have positive impacts on reducing GHG emissions in Japan.

However, according to senior Japanese energy officials, nuclear power is expected to remain a key part of Japan’s energy profile, despite the safety concerns raised by the Fukushima disaster.<sup>16</sup> Prime Minister Shinzo Abe has openly backed a return to the widespread use of atomic energy, but the Japanese public remains divided, with opponents citing continued safety fears. The amount to which Japan returns to sourcing its power from nuclear plants may have an affect on the overall GHG benefits from natural gas imported from BC if it is used to replace nuclear.

## **Malaysia**

According to the IEA, 37 per cent of the country’s energy consumption is met by natural gas and 18 per cent by coal. Thirty-nine per cent is being met by oil; 4 per cent by biomass and waste; and 2 per cent by hydroelectric power.

Malaysia was the world’s second largest exporter of LNG after Qatar in 2012. Malaysia’s state-owned Petronas dominates the natural gas sector. The company has a monopoly on all upstream natural gas developments, and it also plays a leading role in downstream activities and the LNG trade. The power sector consumes about 74 per cent of the Malaysia’s natural gas market sales, and demand for power is expected to increase. Rising domestic demand and LNG export contracts place pressure on the gas supply. Malaysia is actively investing in reservoir development to meet these needs.

To a large extent, growing LNG imports will be effectively replacing coal and/or oil power, although some natural gas imports will represent incremental power. For these opportunities, BC natural gas can have a positive impact on reducing global GHG emissions, particularly if its natural gas is “cleaner” than the global average.

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<sup>15</sup> See: <http://www.eia.gov/countries/analysisbriefs/cabs/Japan/pdf.pdf>

<sup>16</sup> See: <http://www.japantoday.com/category/national/view/nuclear-power-still-key-to-japan-energy-mix-officials>

## **South Korea**

South Korea is one of the top energy importers in the world. In 2011, the country was the second largest importer of LNG, the third largest importer of coal, and the fifth largest importer of crude oil. South Korea has no international oil or natural gas pipelines, and relies exclusively on tanker shipments of LNG and crude oil. According to the IEA, natural gas accounts for 17 per cent of total energy consumption; petroleum 42 per cent; coal 29 per cent; and nuclear 13 per cent.

South Korea is the second largest importer of LNG in the world after Japan. “South Korea consumed 1.6 trillion cubic feet (Tcf) of natural gas in 2011, which was an increase of more than 125 per cent from 2001. The city gas network – serving residential, commercial, and industrial consumers – accounted for the majority (54 per cent in 2011) of natural gas sales, while power generation companies made up nearly all of the remaining shares.”<sup>17</sup>

South Korea has four LNG regasification facilities, with a total capacity of 4.5 Tcf per year. Nearly an additional 1 Tcf of regasification capacity had been added since 2010.

With respect to electricity generation, 69 per cent comes from conventional thermal sources, 30 per cent came from nuclear power, and 1 per cent from renewable sources. It uses coal for a significant amount of its electricity generation (approximately 50%) and coal consumption has grown in the last few years. South Korea also has 14 new nuclear facilities planned for 2025, six of which are currently under construction.

These figures provide strong opportunities for natural gas power to replace thermal coal power to some extent. It is assumed that exports of natural gas from BC to South Korea will likely replace coal and, as such, will have an overall net benefit to reducing global GHG emissions.

## **India**

In 2011, India was the fourth largest energy consumer in the world after the United States, China, and Russia. India's largest energy source is coal, followed by petroleum and traditional biomass (e.g., burning firewood and waste).

The power sector is the fastest growing area of energy demand, increasing from 23 per cent to 38 per cent of total energy consumption between 1990 and 2009. An estimated 25 per cent of the population lacks basic access to electricity.

There is a strong need to balance the demand for electricity with environmental concerns and shift away from thermal power, which should bode well for future LNG exports from BC to India and have an overall net benefit to reducing global GHG emissions.<sup>18</sup> GLOBE Advisors believes that switching from coal to natural gas will become a reality as a result of this strong need for cleaner energy in India.

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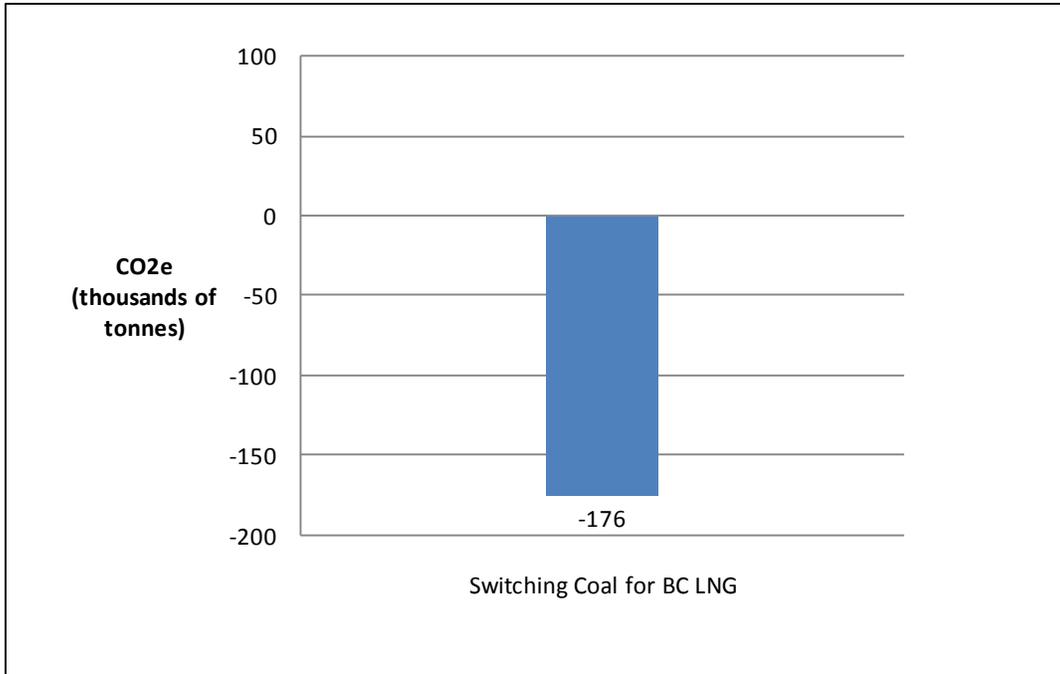
<sup>17</sup> See: <http://www.eia.gov/countries/cab.cfm?fips=KS>

<sup>18</sup> See: <http://www.eia.gov/countries/cab.cfm?fips=IN>

## Natural Gas Switching Scenarios

GLOBE Advisors examined the impact on global GHG emissions of two scenarios where natural gas from BC is exported as LNG to Asian markets.

The first scenario looks at the GHG emissions impact of having natural gas from BC completely replace coal-powered electricity production and/or serve as an alternative to the construction of new coal-fired power facilities. In this “*Full Coal Switching*” scenario, the GHG emissions avoided from combustion of natural gas over coal alone amounts to an annual savings of 176 million tonnes of CO<sub>2</sub>e in 2021, a fairly significant savings in overall global GHG emissions as illustrated in Figure 28 below.



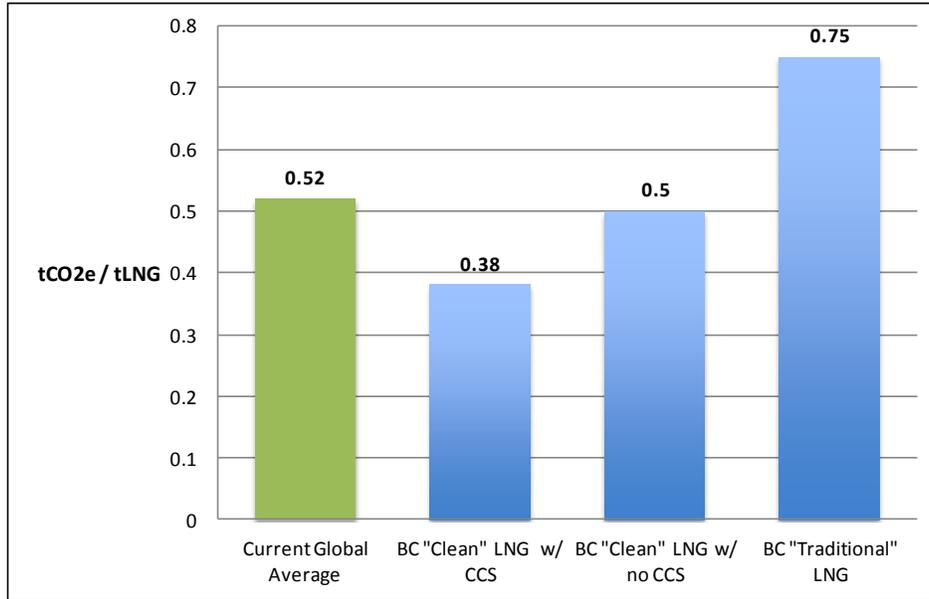
Source: GLOBE Advisors

**Figure 28: Annual GHG emissions impact of having BC natural gas completely replace coal-powered electricity production under the *Full Coal Switching* scenario (assuming LNG production of 88 mmtpa).**

These GHG emissions savings were calculated by subtracting the total GHG emissions that are produced from the combustion of the LNG produced in BC from the GHG emissions that would have otherwise been produced from burning the equal amount of coal used to generate the same amount of power (in terajoules).

The second scenario looked at the impact from having natural gas exported from BC to Asian markets replace natural gas coming from other global suppliers. Under this “*Full Natural Gas Switching*” scenario, the global average for LNG value chain GHG emissions was compared to BC’s hypothetical LNG production scenarios.

The well-to-waterline GHG emission factors for the “clean” LNG plant and the “traditional” LNG plant scenarios against the global GHG emissions average are illustrated in Figure 29.



Source: GLOBE Advisors

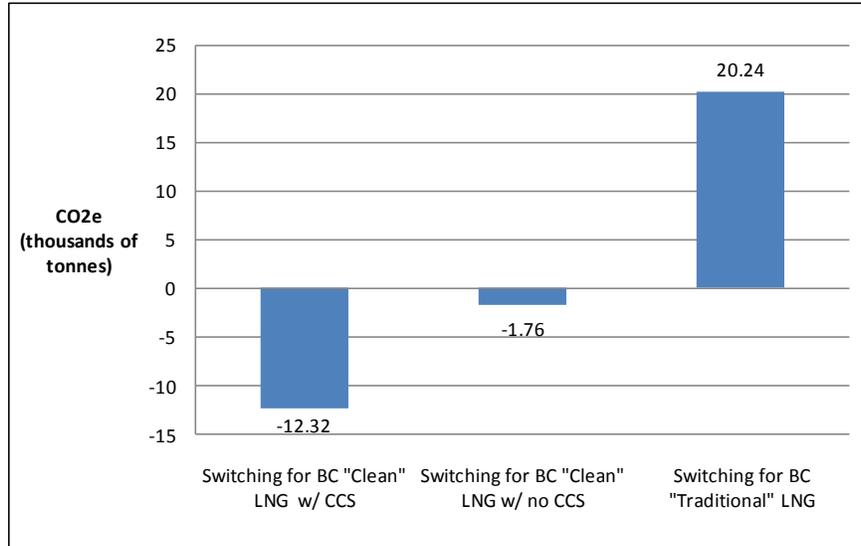
**Figure 29: CO<sub>2</sub>e emission factors for various well-to-waterline LNG plant scenarios in BC against the international average (tCO<sub>2</sub>e / tLNG).**

Achieving the “clean” LNG plant well-to-waterline factor of 0.38 tCO<sub>2</sub>e / tLNG produced, there would be a reduction of global GHG emissions in the range of 12.4 million tonnes of CO<sub>2</sub>e per year (based on BC’s estimated annual production level of 88 mmtpa by 2021), which is the difference between the “clean” LNG plant well-to-waterline emissions of 33.4 million tonnes of CO<sub>2</sub>e and the 45.8 million tonnes of CO<sub>2</sub>e that would be produced for an equal amount of LNG using the global average life cycle emissions value of 0.52 tCO<sub>2</sub>e / tLNG.

If BC’s LNG plants apply renewable energy and upstream best practices without CCS technology, the reduction in global GHG emissions is lower at 1.8 million tonnes of CO<sub>2</sub>e per year for the production of 88 mmtpa of LNG in BC. Nonetheless, even in the absence of CCS, lower GHG emissions occur when BC natural gas replaces the same product produced elsewhere.

On the other hand, if the LNG plants in BC adopt the “traditional” LNG plant average of 0.75 tCO<sub>2</sub>e / tLNG produced (in line with the GHG emissions factor published by the GHGenius model), then BC natural gas that replaces gas from other global suppliers would actually add to overall global CO<sub>2</sub>e emissions by a factor of 20.2 million tonnes per annum (based on applying the global average life cycle GHG emissions factor of 0.52 tCO<sub>2</sub>e / tLNG).

The net CO<sub>2</sub>e savings based on BC natural gas replacing natural gas sourced from global suppliers (applying the global average) is shown in Figure 30.<sup>19</sup> Note that the “traditional” LNG plant scenario, based on the GHGenius model, would actually result in additional CO<sub>2</sub>e emissions relative the average global LNG plant GHG emissions factor.



Source: GLOBE Advisors

**Figure 29: Annual GHG emissions impact of having BC natural gas replace natural gas supplied by natural gas with the global average GHG emissions footprint under the *Full Natural Gas Switching* scenario (assuming LNG production of 88 mmtpa).**

<sup>19</sup> **Note to reader:** Marine transportation GHG emissions are not included in this comparison as these vary based on the consumer market and global supplier. However, the difference in transportation emissions between global suppliers is relatively small, particularly when compared with the full life cycle emissions.

## **CONCLUSIONS**

In developing this natural gas impact model, GLOBE Advisors examined BC’s entire natural gas value chain from the wellhead to the industrial customer. A fundamental question is “will the development and export of LNG, originating in BC and exported to overseas markets, result in an overall increase or decrease in global GHG (CO<sub>2</sub>e) emissions?”

The answer to this question depends largely on the extent that BC natural gas replaces coal power. In fact, the IEA’s Chief Economist rejected calls for British Columbia to forgo the production and export to Asia of LNG due to concerns that the province would not meet its own GHG reduction targets, referencing that growing LNG imports in China and elsewhere could reduce the need for coal-fired electricity, leading to a global reductions in carbon dioxide emissions.<sup>20</sup>

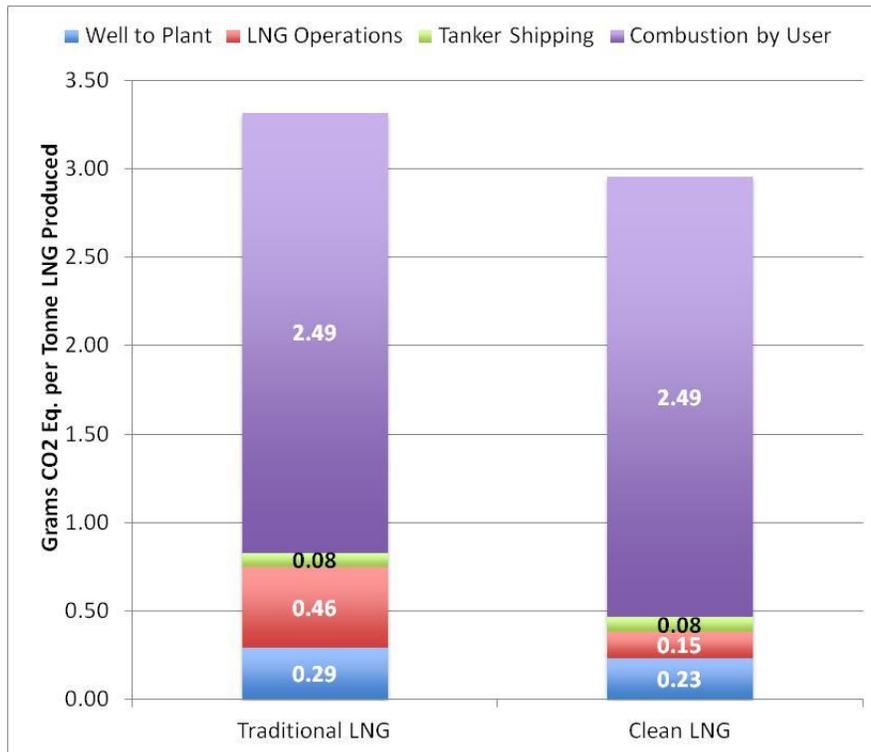
The full life cycle GHG emissions from wellhead in BC to overseas customers ranges from 2.95 tCO<sub>2</sub>e / tLNG produced to 3.32 (as shown in Table 4 below).

**Table 4: Full life cycle GHG emissions for the overseas export and consumption of BC natural gas to Asian markets for both “traditional” and “clean” LNG plant operations.**

|  | “Traditional” LNG Plant<br>GHG Emission Rate<br>(tCO <sub>2</sub> e / tLNG) | “Clean” LNG Plant<br>GHG Emission Rate<br>(tCO <sub>2</sub> e / tLNG) |
|--|---|---|
| <b>Exploration &amp; Wellhead</b>                  |   |   |
| Fuel distribution and storage                      | 0.07  | 0.06  |
| Fuel production                                    | 0.07  | 0.06  |
| Feedstock recovery                                 | 0.09  | 0.08  |
| Gas leaks and flares                               | 0.07  | 0.04  |
| <b>Subtotal</b>                                    | <b>0.29</b>   | <b>0.23</b>   |
| <b>LNG Plant</b>                                   |   |   |
| CO <sub>2</sub> , H <sub>2</sub> S removed from NG | 0.12  | 0.01  |
| Liquefaction at LNG Plants                         | 0.33  | 0.14  |
| <b>Subtotal</b>                                    | <b>0.46</b>   | <b>0.15</b>   |
| <b>Well-to-Water Upstream with CCS</b>             |   | <b>0.38</b>   |
| <b>Well-to-Water with no CCS</b>                   | <b>0.75</b>   | <b>0.50</b>   |
| <b>Tanker Emissions</b>                            | <b>0.08</b>   | <b>0.08</b>   |
| <b>Customer Combustion Emissions</b>               | 2.49  | 2.49  |
| <b>Total Life Cycle Emissions with CCS</b>         |   | <b>2.95</b>   |
| <b>Total Life Cycle Emissions without CCS</b>      | <b>3.32</b>   | <b>3.07</b>   |

<sup>20</sup> Article from The Globe and Mail, November 17, 2013. See: <http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/oil-sands-not-a-major-source-of-climate-change-says-iea-economist/article15480326/>

Figure 31 below illustrates the full life cycle GHG emission factors for both a “traditional” LNG plant (based on GHGenius value of 0.75 tCO<sub>2</sub>e / tLNG) and for an LNG plant in BC using the “cleanest” production factor of 0.38 tCO<sub>2</sub>e / tLNG, assuming 88 mmtpa of LNG is exported to Asia. The vast majority of these full life cycle GHG emissions occur when the customer burns the gas to produce electricity.



Source: GHGenius and GLOBE Advisors

**Figure 31: Full life cycle GHG emission factors for 88 mmtpa of LNG exported from BC to Asia, produced by a “traditional” LNG plant and a plant using current “clean” production best practices.**

The scenarios discussed in this report provide three examples of where, on a full life cycle basis, there is a net reduction of global GHG emissions due to either replacing thermal coal in Asian markets, or from the replacement / substitution of LNG coming from other global suppliers (assuming the global average for life cycle GHG emissions) with LNG produced in BC under the “clean” plant assumptions.

Based on its review of secondary sources and global trends in energy demand and supply, GLOBE Advisors feels that the most realistic outcome for natural gas exported from BC to Asian markets will be a combination of switching out / replacing both thermal coal *and* natural gas product from other global suppliers (with the exception of Malaysia where it may go primarily to replacing diesel). GLOBE believes that a high proportion of BC LNG exports to Asia can realistically replace existing or planned coal power.

In the case where it acts as a substitute for natural gas from other global suppliers, it is particularly important to consider whether or not the upstream life cycle GHG emissions for the supply of natural gas coming from other global markets (i.e., shale and coal bed plays in Russia, China, Australia, and elsewhere) and, in some cases the related LNG plant facilities, is more or less carbon intensive than the natural gas being exported from British Columbia. This is a difficult question to answer, as BC has not yet built LNG plants and the GHG emissions described in this report are only hypothetical at this stage.

Based on comparing the GHGenius and GREET models, BC has the potential for lower per unit upstream emissions than many parts of the world and, given the province's predominantly hydro-powered electricity grid, may be able to power much of the proposed LNG plant operations using a clean electricity mix. In addition, the well-to-waterline GHG emissions target rate proposed in this report of 0.38 tCO<sub>2</sub>e / tLNG produced is close to the GHG emissions rate of select "best-in-class" LNG plants around the world (in Australia and Norway), albeit these plants are not comparable in nature since they mostly source their natural gas from deep sea locations.

An important issue on the level of upstream emissions in BC pertains to the amount of carbon dioxide gas that is embedded in the methane. The Pacific Institute for Climate Solutions (PICS) reported that "raw natural gas extracted from shale deposits in the Horn River Basin contains approximately 11-12% CO<sub>2</sub>, considerably higher than the average content of 2-4.5% for BC's conventional natural gas reservoirs (NEB, 2009b; CAPP, 2004; CAPP, 2010) and the even lower 1% CO<sub>2</sub> content of the Montney fields (based on an update to the GHGenius model). Typically, commercial gas sold to market customers can contain no more than 2% CO<sub>2</sub> to ensure adequate heating value and for pipeline restrictions. When excess CO<sub>2</sub> is removed at natural gas processing facilities, it is usually vented to the atmosphere".

This information suggests that carbon capture and storage (CCS) may play an important role to keeping BC's natural gas GHG footprint as clean as the global best standard. Effective CCS technology requires suitable storage locations (e.g., depleted wells), with the CO<sub>2</sub> being transported to these storage facilities if none are near the processing and LNG facilities. This could add substantially to project costs. Alternatively, innovative technologies could be employed to convert the CO<sub>2</sub> to usable carbon-based products (see discussion on innovative "carbon recycling" technologies on page 21).

At the end of the day, the total net benefit that will come from exporting BC's natural gas to Asian markets in terms of its ability to reduce overall global GHG emissions will depend largely on how much coal is replaced. Where it serves as a substitute for natural gas from other sources, the well-to-waterline GHG emissions footprint would have to be kept lower than the global average of 0.52 tCO<sub>2</sub>e / tLNG in order to maintain a net benefit. For BC, this will mean achieving better plant production than the current "industry standard" by applying renewable power where possible, best-in-class / efficient technology such as electric drive compressors, and preferably CCS solutions.

## Appendix A: Methodology

GLOBE Advisors worked with the British Columbia life cycle module of the GHGenius Model, which has been developed for Natural Resources Canada. GHGenius focuses on the life cycle assessment (LCA) of current and future fuels for transportation and stationary applications. A summary for natural gas and other fuels is shown Table A1. Table A1 shows that gasoline and highway diesel emit substantially more CO<sub>2</sub> equivalent GHG emissions than any of the natural gas categories.

**Table A1: CO<sub>2</sub>-Equivalent Emissions per Unit of Energy Delivered to End Users by Stage and Feedstock/Fuel Combination (Grams per GJ, British Columbia 2010)**

|   | Gasoline | Hwy diesel | LPG     | CNG     | NG to   | NG to    | NG to    | NG to       | NG to    |
|---|----------|------------|---------|---------|---------|----------|----------|-------------|----------|
|   | Oil      | Oil        | NG      | NG      | Power   | Industry | Commerce | NG pipeline | NG field |
| <b>Fuel dispensing</b>                                | 19.1     | 19.5       | 19.6    | 183.9   | 0.0     | 0.0      | 0.0      | 0.0         | 0.0      |
| <b>Fuel distribution and storage</b>                  | 402.5    | 411.2      | 661.5   | 1,275.6 | 1,144.1 | 1,144.1  | 1,271.2  | 444.9       | 0.0      |
| <b>Fuel production</b>                                | 10,385.5 | 7,909.0    | 2,566.7 | 1,345.8 | 1,339.3 | 1,341.1  | 1,341.2  | 1,339.0     | 1,338.8  |
| <b>Feedstock transmission</b>                         | 78.8     | 80.5       | 0.0     | 0.0     | 0.0     | 0.0      | 0.0      | 0.0         | 0.0      |
| <b>Feedstock recovery</b>                             | 11,936.5 | 12,194.0   | 1,729.5 | 1,653.6 | 1,645.7 | 1,647.9  | 1,646.3  | 1,644.1     | 1,644.1  |
| <b>Land-use changes, cultivation</b>                  | 427.5    | 427.5      | 0.0     | 0.0     | 0.0     | 0.0      | 0.0      | 0.0         | 0.0      |
| <b>Gas leaks and flares</b>                           | 2,190.4  | 2,185.7    | 636.3   | 2,378.0 | 654.4   | 1,133.5  | 1,149.8  | 564.9       | 508.0    |
| <b>CO<sub>2</sub>, H<sub>2</sub>S removed from NG</b> | 0.0      | 0.0        | 638.3   | 641.2   | 638.1   | 638.9    | 639.0    | 637.9       | 637.8    |
| <b>Emissions displaced</b>                            | -189.7   | -189.7     | 0.0     | 0.0     | 0.0     | 0.0      | 0.0      | 0.0         | 0.0      |
| <b>Total</b>  | 25,250.6 | 23,037.8   | 6,251.9 | 7,478.0 | 5,421.6 | 5,905.6  | 6,047.5  | 4,630.8     | 4,128.7  |

Source: GHG Genius BC Model

Table A2 illustrates GHG emissions on a per centage basis. Note that gas leaks and flares are proportionally much higher for the natural gas categories than for gasoline and highway diesel.

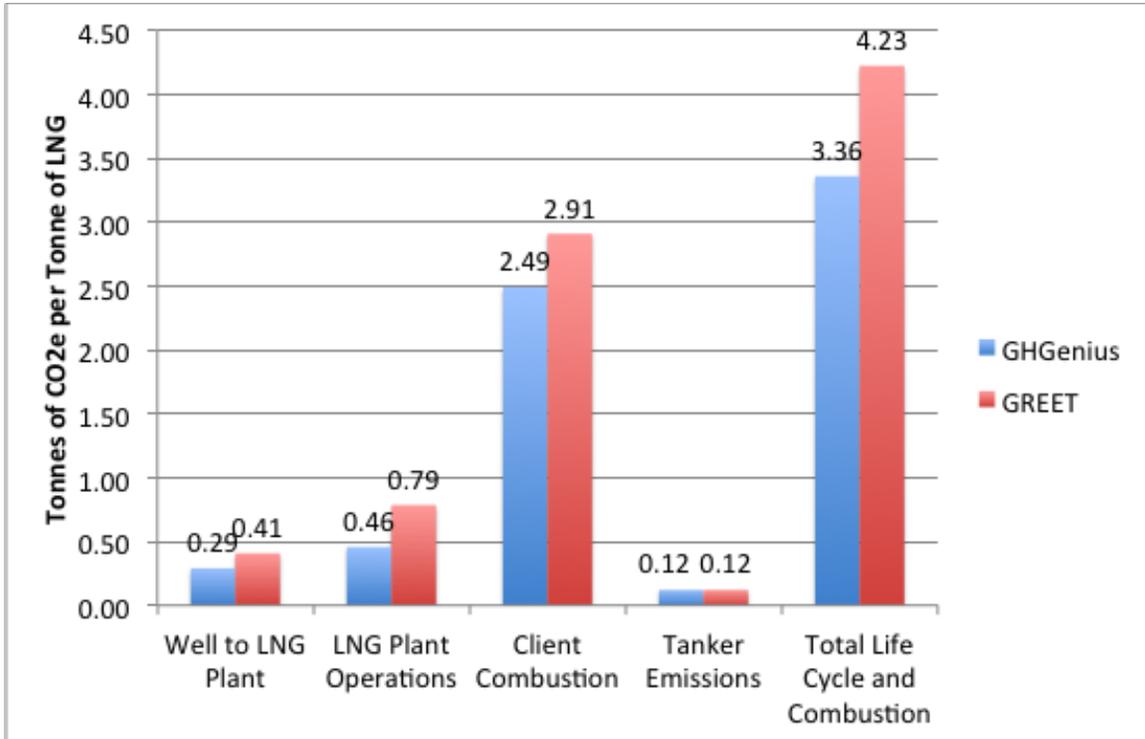
**Table A2: Per centage of CO2-Equivalent Emissions per Unit of Energy Delivered to End Users by Stage and Feedstock/Fuel Combination (Grams per GJ, British Columbia 2010)**

|                                      | Gasoline | Hwy diesel | LPG    | CNG    | NG to  | NG to    | NG to    | NG to       | NG to    |
|--------------------------------------|----------|------------|--------|--------|--------|----------|----------|-------------|----------|
|                                      | Oil      | Oil        | NG     | NG     | Power  | Industry | Commerce | NG pipeline | NG field |
| <b>Fuel dispensing</b>               | 0.1%     | 0.1%       | 0.3%   | 2.5%   | 0.0%   | 0.0%     | 0.0%     | 0.0%        | 0.0%     |
| <b>Fuel distribution and storage</b> | 1.6%     | 1.8%       | 10.6%  | 17.1%  | 21.1%  | 19.4%    | 21.0%    | 9.6%        | 0.0%     |
| <b>Fuel production</b>               | 41.1%    | 34.3%      | 41.1%  | 18.0%  | 24.7%  | 22.7%    | 22.2%    | 28.9%       | 32.4%    |
| <b>Feedstock transmission</b>        | 0.3%     | 0.3%       | 0.0%   | 0.0%   | 0.0%   | 0.0%     | 0.0%     | 0.0%        | 0.0%     |
| <b>Feedstock recovery</b>            | 47.3%    | 52.9%      | 27.7%  | 22.1%  | 30.4%  | 27.9%    | 27.2%    | 35.5%       | 39.8%    |
| <b>Land-use changes, cultivation</b> | 1.7%     | 1.9%       | 0.0%   | 0.0%   | 0.0%   | 0.0%     | 0.0%     | 0.0%        | 0.0%     |
| <b>Fertilizer manufacture</b>        | 0.0%     | 0.0%       | 0.0%   | 0.0%   | 0.0%   | 0.0%     | 0.0%     | 0.0%        | 0.0%     |
| <b>Gas leaks and flares</b>          | 8.7%     | 9.5%       | 10.2%  | 31.8%  | 12.1%  | 19.2%    | 19.0%    | 12.2%       | 12.3%    |
| <b>CO2, H2S removed from NG</b>      | 0.0%     | 0.0%       | 10.2%  | 8.6%   | 11.8%  | 10.8%    | 10.6%    | 13.8%       | 15.4%    |
| <b>Emissions displaced</b>           | -0.8%    | -0.8%      | 0.0%   | 0.0%   | 0.0%   | 0.0%     | 0.0%     | 0.0%        | 0.0%     |
| <b>Total</b>                         | 100.0%   | 100.0%     | 100.0% | 100.0% | 100.0% | 100.0%   | 100.0%   | 100.0%      | 100.0%   |

Source: GHG Genius BC Model

The GHG emission intensity ratios that were applied in this report were derived from the GHGenius lifecycle model that was developed specifically for British Columbia by Natural Resources Canada. The lifecycle results from the wellhead to the waterline were lower than what has been reported by some other reports, including Clean Energy Canada and the Pembina Institute. Subsequently, GLOBE Advisors ran its production numbers through the American GREET lifecycle model as a point of comparison.

The following Figure illustrates and compares the GHG emission results based on both the British Columbia GHGenius model and the American GREET model. The GREET GHG emissions per tonne ratios are slightly higher than the GHGenius rates.<sup>21</sup>



**Figure A1: GHG Ratios, CO2 Equivalent Tonnes per Tonne of LNG for GHGenius and GREET Models**

<sup>21</sup> The tanker emission factor was based on neither GHGenius nor GREET, but it is included in the chart in order to show complete life cycle emissions.