

LOCK IN JOBS NOT POLLUTION

How British Columbia's Proposed Liquefied Natural Gas Industry
Can Create a Lasting Renewable Energy Legacy—and Why It Should

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James Glave and Jeremy Moorhouse

January 2014

Cover Photo: One of the 48 wind turbines in the 144-megawatt Dokie 1 Wind Farm, near Chetwynd, British Columbia. The Dokie 1 facility began commercial operations in February 2011 and is jointly owned by Alterra Power and Fiera Axium. Photo: Alterra Power.

Printed in British Columbia on 100 percent recycled, post-consumer paper.



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“We have set a goal to have the cleanest LNG in the world. We want our LNG plants to be principally fueled by renewables.”

The Hon. Christy Clark
Premier of British Columbia
World Economic Forum, China
September 13, 2012



“We’re trying to stay away as much as possible from having to use gas for power ... we should ... reduce gas generation by using it to firm renewables.”

The Hon. Rich Coleman
Minister of Natural Gas Development, Province of British Columbia
June 9, 2012



“Your government will bring the liquefied natural gas opportunity home, creating tens of thousands of new jobs.”

The Hon. Judith Guichon
Lieutenant Governor of the Province of British Columbia
Speech from the Throne, June 26, 2013

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1 EXECUTIVE SUMMARY

The Government of British Columbia can unlock multiple social, employment, and environmental benefits by directing and/or enabling liquefied natural gas (LNG) proponents to maximize the use of renewable energy in their planned facilities. A renewables-driven industry will create more permanent, secure jobs, produce less carbon pollution, and leave a lasting legacy of clean-power infrastructure for communities and companies in British Columbia’s North Coast region. It will do all of this while only minimally impacting competitiveness.

Compared with a business-as-usual approach—which we characterize here as a “Fossil Energy scenario”—maximizing renewable energy use by LNG facilities will increase regional permanent employment related to LNG by 45 percent, decrease carbon pollution by 33 percent, reduce smog, and build the foundations of a renewable energy economy in Northwestern British Columbia.

Further, government and industry can capture all these benefits without sacrificing competitiveness. According to our conservative assessment, the necessary technical solutions will increase the selling price of LNG of two percent relative to the standard Fossil Energy scenario.

Provincial power utility B.C. Hydro expects that LNG proponents will use electricity for 15 percent of their energy needs—around 360 megawatts (MW) of capacity at peak demand—and turn to fossil fuels to supply the rest (B.C. Hydro, 2013). This report shows that this fossil energy scenario employs fewer people and sharply increases pollution. However, by directing or enabling proponents to maximize the use of renewable

At a Glance: Maximizing Renewables in B.C. LNG



400

more permanent regional jobs



33%

decrease in climate pollution



2%

increase in LNG selling price

energy in their facilities—as this report recommends—the province can create many more permanent, secure jobs in the North Coast region.

A recent public opinion telephone survey conducted by NRG Research Group and commissioned by Clean Energy Canada suggests the public supports such a “maximum renewables” approach to LNG development. In the October 2012 survey of 600 British Columbians, respondents were advised that LNG plants could run on either pure natural gas, or a combination of natural gas and renewable energy. After learning this, 91 percent of respondents stated that it was important that the proposed plants maximize their use of renewable energy.

This public support aligns with past statements made by the Premier of British Columbia. Addressing the World Economic Forum in China in 2012, she said, “We want our LNG plants to be principally fuelled by renewables.”

The government now has a limited window within which to act. Industry proponents are already preparing sites in the coastal cities of Kitimat and Prince Rupert. Once a proponent specifies a given plant’s configuration, that developer will effectively lock in its choice for decades; a company cannot “bolt on” a cleaner power alternative at a later date. Proponents are unlikely to maximize the use of renewable energy in their plants unless provincial policy directs them to do so.

Time is therefore of the essence. We hope and expect our findings will not only inform critical ongoing negotiations between government and industry, but also inspire debate amongst British Columbians who may be concerned about the pace and scale of the proposed LNG industry and the best, most responsible path forward for the province.



Proponents are unlikely to maximize the use of renewable energy in their plants unless provincial policy directs them to do so.

2 CONTEXT: STRUGGLING TO STRIKE A BALANCE

In early 2012, the Government of British Columbia released its *Liquefied Natural Gas Strategy*. The document outlines the province's ambitions to access new overseas markets for its extensive unconventional gas reserves via a series of planned LNG facilities and terminals, creating jobs and revenue.

The proposed new fossil fuel export industry has since emerged as the province's top policy priority. Assuming industry proponents secure First Nations support, the necessary environmental approvals, and social licence, the provincial government would like to see at least three LNG plants up and running on the British Columbia coast by 2020.

In response, industry proponents have brought forward at least 17 proposals—though only a fraction of that number will likely come to fruition. To date, the National Energy Board has granted export licenses to seven companies that would like to build new LNG plants and terminals in the coastal communities of Squamish, Prince Rupert, and Kitimat.

Today, British Columbia reaps the reputational and environmental benefits of leading climate and energy policies introduced some years ago. These include a carbon tax, a ban on coal power without carbon capture, and a requirement that the province source 93 percent of its electricity from clean or renewable sources.



The 99 MW Cape Scott Wind Farm is located on northern Vancouver Island. It was developed by Sea Breeze Power Corp. and built and operated by the current owner, GDF-Suez. The project became operational in November, 2013. Photo: Dale Hilts.

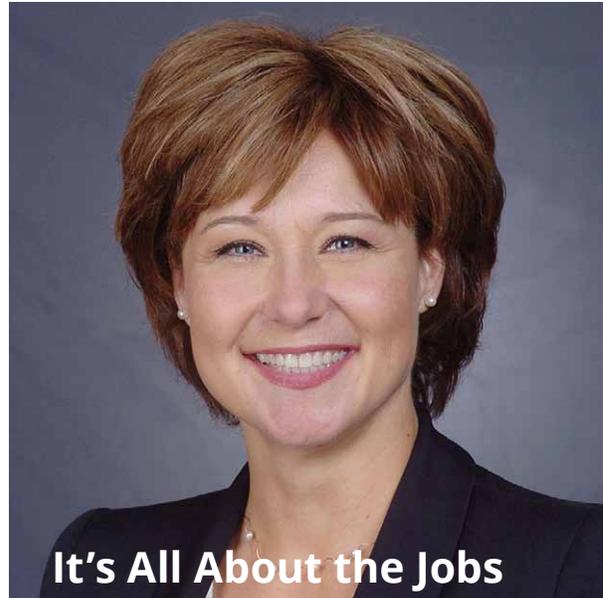
The provincial government has stressed that the proposed LNG industry will bring British Columbia many new jobs and much investment. At full build-out, the province anticipates the industry will support as many as 75,000 permanent jobs (Ministry of Energy, Mines, and Natural Gas, 2013). Given the frequency with which the government cites such job creation, in-region employment is clearly a policy priority (see sidebar: “It’s All About the Jobs”).

In September 2013, we released a report, *The Cleanest LNG in the World?* (Glave/ Moorhouse, 2013). After surveying facilities and practices across the globe to define “world’s cleanest LNG,” the study outlined the conditions under which British Columbia’s petroleum sector might produce a fuel that truly meets such a global gold standard for carbon emissions.

We concluded that without policy leadership, made-in-B.C. LNG will not be the cleanest in the world but would instead emit more than three times the carbon pollution of the current global gold standard. We based our finding not only on the emissions associated with LNG production, but on the full carbon footprint of the fuel they would produce—from wellhead to waterline.

As detailed in *The Cleanest LNG in the World*, the province can make good on its commitment to deliver a fuel that is world-leading with respect to carbon pollution, but doing so would mean requiring industry to adopt a range of technical solutions up and down the LNG production chain.

The province has been negotiating with LNG proponents for approximately the past year. The discussions centre on how best to ensure the proposed plants remain



It’s All About the Jobs

The Province of British Columbia has identified job creation as a lead driver of its proposed LNG industry. Here’s what government has been saying:

“LNG isn’t just a northern industry, but will create opportunities and jobs around the province—from direct jobs to support services to head offices. We are here to make sure that businesses and communities across B.C. benefit.”

—The Hon. Christy Clark, Premier of British Columbia, Media Release, November 14, 2013.

“The growth of our province’s natural gas sector has the ability to transform our economy and provide well-paying jobs.”

—The Hon. Rich Coleman, Minister of Natural Gas Development, Media Release, November 29, 2013.

economically viable in a competitive global fuels marketplace, while retaining social licence and ensuring adequate benefits accrue to British Columbians—both today and into the future.

We prepared *Lock in Jobs, Not Pollution* as a follow-up to *The Cleanest LNG in the World?* This report aims to further inform these ongoing conversations, and to provide industry, government, and the citizens of British Columbia with a deeper understanding of the risks, benefits, and opportunities of various approaches to powering LNG production.

“Your government will bring the liquefied natural gas opportunity home, creating tens of thousands of new jobs.”

—The Hon. Judith Guichon, Lieutenant Governor of the Province of British Columbia, Speech from the Throne, June 26, 2013.

“LNG creates an opportunity for the Government of British Columbia to collect additional revenue, create thousands of new jobs for British Columbians, and secure a brighter future for our province.”

—LNG in B.C. Awareness Quiz, Province of British Columbia, December 30, 2012.



First Nations workers assemble a section of penstock for the Kwoiek Creek run-of-river hydroelectric project. Photo: Innergex Renewable Energy.

3 IT'S WHAT'S INSIDE THAT COUNTS: INTRODUCING THE E-DRIVE

Though LNG plants are large and sophisticated industrial facilities, their inner workings are not rocket science.

The plants are effectively factory-size freezers designed to chill natural gas to minus 162 degrees Celsius—the point at which the fuel becomes liquid and transportable. As with home refrigerators and freezers that use compressors to cool air, LNG facilities use compressors to cool natural gas. Larger LNG plants such as the Gorgon Facility under construction in Australia will run six such compressors (Chevron, 2009). Taken together, these compressors effectively comprise the “heart” of a given LNG plant.

Though an LNG plant has other so-called ancillary energy requirements—think large pumps, valves and lighting—a given plant’s carbon and air pollution impacts are largely a factor of how it powers its compressors.

LNG producers can run their compressors using either electric motor drives, also known as E-drives, or gas turbine drives, also known as direct drives or D-drives. Electricity powers the former—which can be generated from renewable or fossil fuel sources—while the latter operate by burning a portion of the natural gas supply piped into the plant.

Though D-Drives are the more polluting of the two options, they are also the industry’s de facto standard. This is rooted in the industry’s history;

early LNG plants were constructed in isolated areas with poor access to electricity infrastructure. Of the 17 plant proposals now on the table in British Columbia, only Pacific Northwest Energy (principally owned by Malaysian energy conglomerate Petronas) and Woodfibre LNG (owned by Woodfibre Natural Gas) explore E-Drives as an option in their respective project descriptions (Stantec, 2013 & Golder Associates, 2013). Without provincial



The vapourizer at Freeport LNG in Quintana, Texas. Photo: Getty Images.

policy directing LNG proponents to install E-Drives, industry will very likely “lock in” to D-Drives at the expense of permanent and secure regional jobs.

In a variety of public remarks and private conversations, British Columbia’s LNG proponents have cited a number of reasons for their lack of interest in E-Drives, including cost, timelines, and perceived reliability of electricity supply.

The core technology underpinning E-Drives is neither new nor sophisticated. They are readily available from established manufacturers, such as Siemens, and are, at this moment, in reliable operation at Statoil’s Snøvit LNG plant, in Norway.

Timelines are certainly a practical consideration for proponents; however a headlong rush to reach market with old technology threatens to cast a pollution shadow that stretches for decades—as a D-Drive plant cannot feasibly be retrofitted for the cleaner alternative. As for affordability, this report finds that E-Drives powered by renewable electricity translate to a two percent cost premium in the selling price of LNG when compared with their more polluting counterparts.

The Cleanest LNG in the World? concluded that British Columbia’s petroleum industry will not be able to credibly produce the “cleanest LNG in the world” unless and until it powers its plants with E-Drives that in turn run on a combination of new renewable power, existing British Columbia grid electricity, and efficient combined-cycle natural gas generators. That assessment concluded that E-Drives would reduce emissions by the equivalent of 0.11

THE TECHNOLOGY AT THE CORE OF AN E-DRIVE IS NEITHER NEW NOR SOPHISTICATED.

tonnes of carbon dioxide per tonne of LNG produced.

Clearly, compelling employment and environmental evidence exists for the Government of British Columbia to establish policy that would require or enable the industry to maximize its use of renewable energy through E-Drive technology.



A construction worker's view of the world's largest underground LNG storage tank in Yokohama, Japan. Photo: Getty Images.

4 THE SECRET INGREDIENT: FLEXIBILITY

While E-Drive LNG plants would offer their host communities a number of tangible, measurable benefits—as outlined below—flexibility is the technology’s greatest asset.

This is because while a D-Drive LNG plant will always be powered with natural gas, the power needs of an E-Drive facility can be served with progressively cleaner sources of electricity as such options become available. For example, an efficient combined-cycle natural-gas generator can power an E-Drive LNG plant today, and tomorrow renewable energy installations can do the same job, once they are permitted and constructed. After that point, the gas generators can serve as firm on-demand power to back up the variable-output renewables.



The power needs of an E-Drive LNG facility can be served with progressively cleaner sources of electricity.

MAKING E-DRIVES COMPULSORY FOR BRITISH COLUMBIA LNG DEVELOPERS WOULD SPUR THE CREATION OF A SIGNIFICANT RENEWABLE ENERGY LEGACY

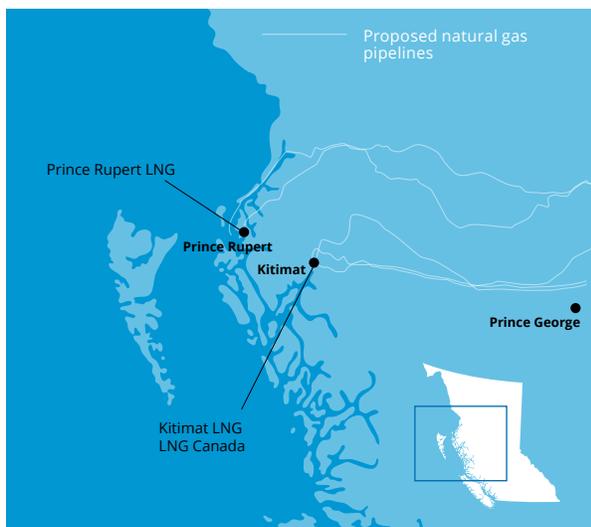
Abundant renewable energy resources exist in the general vicinity of Kitimat and Prince Rupert. Various power developers such as NaiKun Wind Energy, Alterra Power, Sea Breeze Power and Innergex Renewable Energy have proposals in with the provincial government to develop renewable resources in the North Coast region. Such generation facilities would connect to either Prince Rupert or Kitimat via transmission lines to service the region’s proposed LNG projects.

Making E-Drives compulsory for British Columbia LNG developers would not only offer critical future flexibility, but would spur the creation of a significant renewable energy legacy for future generations of British Columbians—long after today’s natural gas boom fades.

5 OUR APPROACH AND SCOPE

Our previous report, *The Cleanest LNG in the World*, assessed the full carbon footprint of British Columbia LNG production—from the natural gas fields in the province’s interior to the waterline at the ship terminals. While we remain concerned about the fuel’s carbon footprint, we limit the scope of this document to the energy needs and requirements of actual LNG production facilities.

Specifically, for discussion purposes we compared three LNG facilities proposed for Kitimat and Prince Rupert: LNG Canada (a partnership between Shell, Mitsubishi, Korea Gas Corporation, and PetroChina), Kitimat LNG (a partnership between Apache Canada and Chevron Canada), and Prince Rupert LNG (which would be owned and operated by the U.K.-based BG Group). We chose three plants because the government has indicated it would like to have that number of facilities operating by 2020. We chose this trio in particular because they are reasonably representative of the diversity of existing proposals.



We examined the public project descriptions for these three projects—and those of other LNG facilities currently being built and operated around the world. We also turned to B.C. Hydro’s assessment of renewable energy potential in the region.

To compare the impacts of one choice over the other on job creation, competitiveness and greenhouse gas emissions, we developed and modelled three scenarios:

- 1. Maximum Renewables:** In this scenario, the three LNG plants use E-Drives, which are in turn powered by a mix of renewable-energy sources (26 percent of energy), efficient combined-cycle natural gas generation (60 percent of energy), and the existing B.C. Hydro grid (14 percent of energy). We also include upgrades to the Kitimat and Prince Rupert electrical grids, and twin the existing transmission line between the Williston and Skeena substations.
- 2. Renewables Ready:** In this scenario, the three LNG plants use E-Drives, but power them with combined-cycle natural gas electricity generation.
- 3. Fossil Energy:** In this scenario, the three LNG plants use D-Drives, and meet their ancillary electricity needs via natural gas turbines using waste-heat recovery.

For each of the three scenarios, we calculated permanent, regional jobs, the cost per unit of LNG produced expressed in gigajoules (GJ), associated carbon pollution, capacity to reduce carbon pollution in the future, and the legacy infrastructure that would remain in the region after the LNG facilities eventually close down. (For a detailed technical description of our methodology, please see the Appendix.)

6 FINDINGS

Our analysis shows that, compared to a Fossil Energy scenario, maximizing renewables in British Columbia LNG facilities will increase regional permanent employment by 45 percent, decrease carbon pollution by 33 percent, and build the foundations of a clean energy economy in the North Coast region. Further, the more extensive the use of renewable power sources, the greater the corresponding decrease in air pollution.

PERMANENT, SECURE IN-REGION JOBS

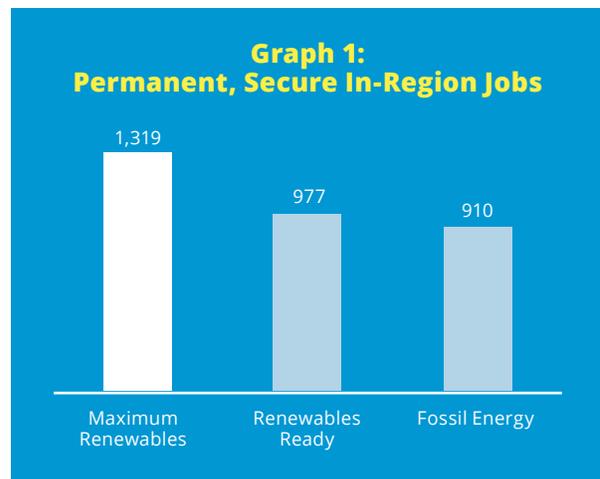
An LNG plant that maximizes its use of renewables will increase regional, secure full-time employment by 45 percent compared with the other two scenarios. If the first three LNG plants come online by 2020, as the province proposes, and if all maximize their use of renewables, an additional 400 jobs will exist between Kitimat, Prince Rupert, and Terrace.

IF THE FIRST THREE LNG PLANTS COME ONLINE BY 2020, AS THE PROVINCE PROPOSES, AND IF ALL MAXIMIZE THEIR USE OF RENEWABLES, AN ADDITIONAL 400 JOBS WILL EXIST BETWEEN KITIMAT, PRINCE RUPERT, AND TERRACE.

That translates into hundreds more people buying or renting homes, and supporting local shops and services such as grocery stores, bakeries, fitness centres, and more. Further, the jobs in question are high paying. According to renewable-energy industry sources, such

skilled positions would likely pay between \$70,000 and \$120,000 per year (Personal Correspondence, Alterra).

We estimated job numbers using LNG proponent project descriptions and B.C. Hydro estimates of employment associated with energy production (B.C. Hydro 2013).



CARBON POLLUTION

If the Shell coalition, Chevron-Apache, and the BG Group build the initial LNG facilities outlined above using fossil energy technology as proposed, the three plants would release 12.8 megatonnes of equivalent carbon dioxide per year in operation. That would create the same annual climate-disruption impact as:

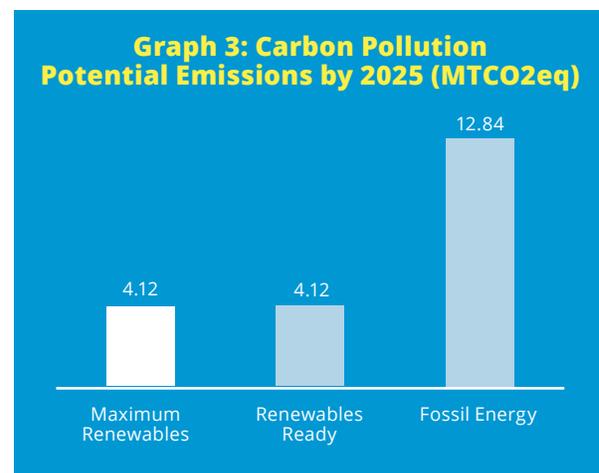
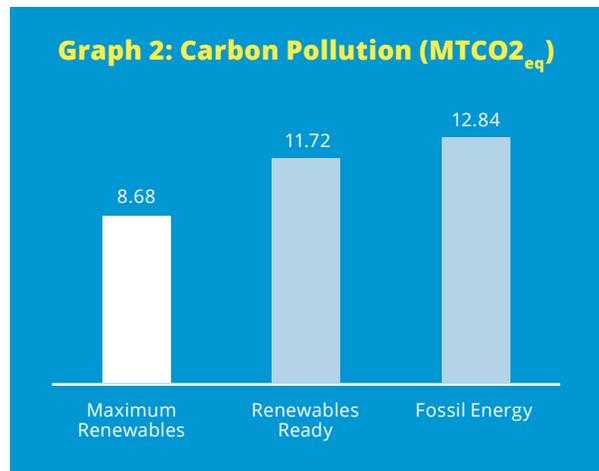
1. Adding three million more vehicles to British Columbia's roads; or
2. Building three new medium-sized (500 megawatt) coal plants.
3. Adding a new metropolitan area the size of Metro Vancouver

In contrast, a maximum renewables scenario reduces those emissions by 33 percent—to 8.6 megatonnes of equivalent carbon dioxide per year.

The Maximum Renewables and Renewable Ready scenarios can also improve in the future as more sources of cleaner energy become available—reducing the need for combined-cycle natural gas power. As new clean energy sources become available, carbon pollution in the proposed coastal LNG industry could be reduced by an additional 50 percent as shown on the next page.

In contrast, the Fossil Energy scenario closes the door to this future, and effectively binds proponents to a high-carbon plant configuration. Facilities equipped in this manner cannot further reduce their carbon pollution without a prohibitively expensive retrofit.

The carbon pollution remaining in the Maximum Renewables and Renewables Ready scenarios cannot be reduced by using renewable energy, because it is the result of carbon dioxide in the natural gas supplied to the LNG facilities. However, this carbon dioxide could be removed from the



Sea water flows in an open rack type liquefied natural gas (LNG) vapourizer at Tokyo Gas Co.'s Sodegaura plant in Sodegaura City, Chiba Prefecture, Japan. Photo: Getty Images.

gas and sequestered underground before it reaches the LNG facility using a process known as carbon capture and storage. We discuss this in our previous report, *The Cleanest LNG in the World?*

Other benefits of E-Drives extend beyond the scope of this document, but are worth touching on here. A recent report from SkeenaWild Conservation Trust examined the air-quality implications of three D-Drive LNG plants as currently proposed for Kitimat (Moorhouse, Knox, 2013). That report found that:

...each year they would burn a quantity of natural gas equivalent to two and a half times that burned annually in all of Metro Vancouver. Put another way, the three plants would collectively burn, in a confined

airshed, 60 percent of all the natural gas already burned in the entire province every year.

Clearly, beyond their carbon reduction benefits, E-Drives offer significant ecological and public health advantages to communities that would host LNG plants.

CARBON POLLUTION BY THE NUMBERS

If the three LNG plants we studied do not maximize their use of renewable energy, the additional carbon pollution would be equivalent to:



Adding one million more vehicles to B.C.'s roads



Building one new medium-sized coal plant (500 MW)

Photos: Istockphoto

LEGACY INFRASTRUCTURE

A Maximum Renewables approach would create a lasting legacy in the form of clean power production and transmission infrastructure, which would remain in the region long after LNG facilities close or become unprofitable.

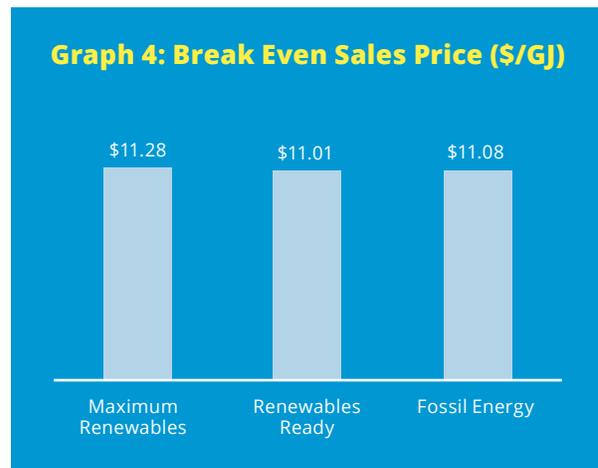
Our analysis finds that in the Northwest coast region, LNG Canada, Prince Rupert LNG, and Kitimat LNG would require 2,832 MW of electrical capacity which would require 2,265 MW of renewable installed capacity backed up by 2,265 MW of natural gas driven electricity capacity, 567 MW of grid capacity and upgrades to the Prince Rupert and Kitimat grids and twinning the Williston to Skeena transmission line.

These projects would continue to generate revenue and employment for communities in the region. Approximately 125 out of the 203 First Nations in B.C. are involved in renewable energy projects, from ownership to revenue sharing, and enjoy multiple positive benefits including jobs, income, and capacity building (Sayers, 2013). Total royalty revenues are unclear but a recent survey of 21 clean energy projects estimated First Nations royalty revenues of \$350 million over the life the projects. There are currently 130 clean energy projects in British Columbia (Kariya, 2013).

By contrast, the Fossil Energy scenario would require 2,832 MW of natural gas driven electrical and mechanical capacity inside the LNG facilities. Once the plants closed or became unprofitable, little infrastructure would remain beyond natural gas pipelines, which will be of limited value in a future lower-carbon economy.

COMPETITIVENESS

In our assessment, designing a plant to maximize renewables would add two percent to the fuel's break-even price—the minimum selling price for an LNG project to cover its costs. This increases the break-even price from \$11.08 to \$11.28 per GJ of LNG sold. As shown below, even if an LNG proponent was unable to access renewable energy today, the company could adopt E-Drives to prepare for such a future, while having a lower sales gas price.



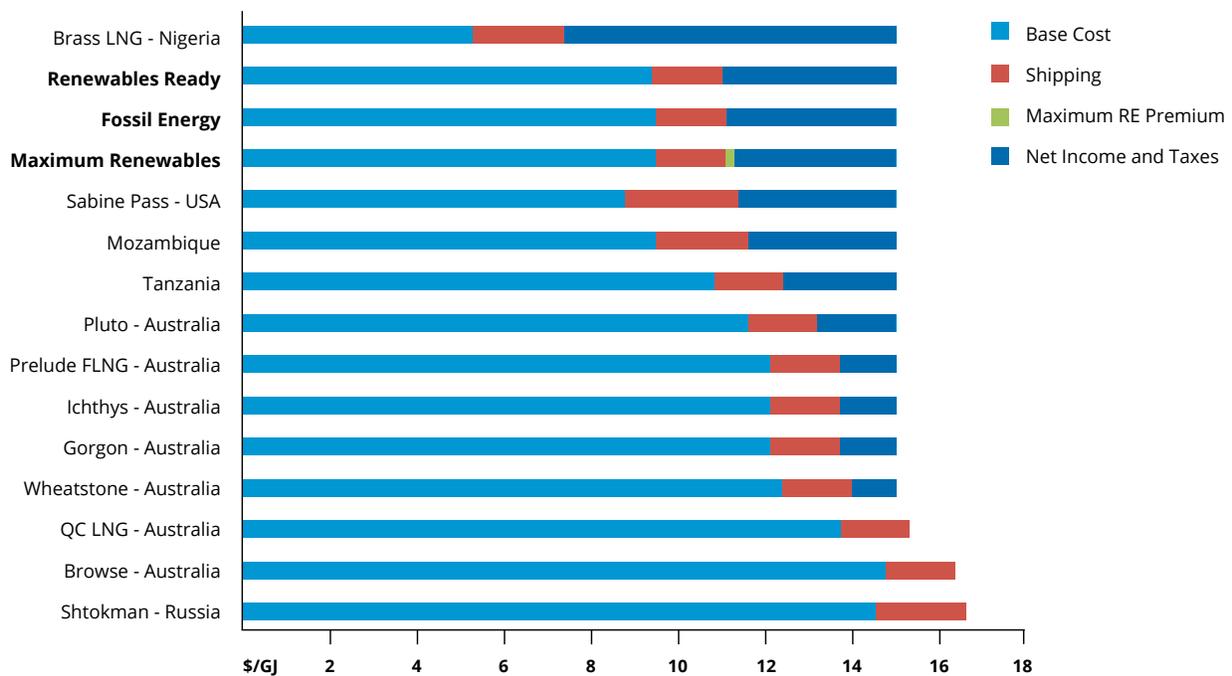
Note: The Maximum Renewables scenario costs include the incremental cost of capital, operating, fuel, twinning the transmission line between the Skeena and Williston substations and grid upgrades in the communities of Kitimat and Prince Rupert for the LNG facility energy requirements added to the estimated break-even LNG sales prices of \$11.08 per GJ (Macquarie, 2012 and Ernst & Young, 2012). The Renewables Ready scenario includes the capital, operating and fuel costs of building a combined-cycle natural gas facility and installing E-Drives at the LNG plant. It is Renewables Ready in the sense that it could accommodate renewable energy from new clean energy facilities if they are built at a later date. However, beyond that point, costs would likely rise to the Maximum Renewables point. The Fossil Energy scenario includes the cost of capital and operating for D-Drives using natural gas.

Even with a two percent premium in their fuel's selling price, British Columbia LNG projects would remain less expensive—ergo, more profitable—relative to most global competitors. The following graph shows the base costs (costs to drill, produce, process, pipeline and liquefy natural gas), shipping costs, maximum renewables premium and likely taxable income from a variety of LNG projects around the world. The Maximum Renewable scenario remains as competitive as the Fossil Energy and Renewables Ready scenarios.

The graph below presents a snapshot of LNG project costs as of 2013. Such costs can change continuously in response to dynamic variables, including but not limited to construction costs, labour costs, natural gas supply costs, natural gas demand, project timing, and carbon price. Some of these variables swamp the

incremental increase of renewable energy. For example, a \$1 per GJ change in natural gas price—which Japan experienced last year—which would reduce net income and tax revenue by 20 percent based on the graph above. The renewable energy “premium” in the Maximum Renewables scenario is approximately five percent of net income and taxes. Adopting renewable energy also allows a company to continuously improve its carbon footprint by incrementally increasing renewable energy over time and so is less sensitive to carbon price increases than the Fossil Energy scenario. Globally, wind energy prices have decreased over the last decade, decreases that are expected to continue in the future. LNG operations with E-Drives can take advantage of those falling costs.

Graph 5: Global LNG Project Price Comparison



Note: Adapted from (Ernst & Young, 2013) by converting to GJ, and assuming a sales price of \$15 per GJ (MacQuarie, 2012).

7 CONCLUSION AND RECOMMENDATION

This report demonstrates that if the Government of British Columbia requires LNG proponents to principally power their facilities with renewable energy using E-Drives, the province will create more permanent and stable regional jobs and significantly less carbon pollution, without significantly impacting the proposed sector's competitiveness.

Taking such action will not only create more jobs, it will help advance the province considerably closer to its long-stated goal of producing the "cleanest LNG in the world." This will in turn help strengthen the social licence that both government and industry need to ensure the industry develops without risk of interruption or delay.

We acknowledge there are impacts associated with renewable energy infrastructure development and would expect that any proponents would mitigate or eliminate any potential ecosystem impacts, seek maximum benefits for First Nations communities, and accommodate wherever possible the preferences of impacted nearby communities.

Given the multiple benefits outlined above—and given that the E-Drive technology does not present a heavy or unfair burden on the sector—we recommend the provincial government implement policy that would direct or enable LNG proponents to maximize the use of renewable energy through E-Drives in their planned facilities.



An LNG tanker off the coast of Australia. Photo: Reuters.

8 APPENDIX - DETAILED DISCUSSION OF RESULTS

This appendix summarizes the jobs and cost calculations for two LNG power scenarios. Scenario 1 includes renewable electricity generation backed up by combined-cycle gas turbines and the B.C. Hydro grid. Scenario 2 considers D-Drives with heat recovery to generate electricity. Below we summarize methodology, results by Scenario, Data Sources and Calculations.

METHODOLOGY

We built off existing studies and information whenever possible and filled the gaps with new analysis when required. The following are our key assumptions, followed by our specific approach for the cost and jobs calculations.

- **LNG facility:** The analysis is based on the energy required for three LNG facilities in Kitimat and Prince Rupert: LNG Canada, Prince Rupert LNG and Kitimat LNG. Combined, these facilities could produce 63 million tonnes per annum (MTA) of LNG. Since these facilities have yet to make final decisions on how they will be powered, and there is only preliminary data on the quantity of energy they will require, we estimated total power required at 45 MW per MTA for compression and ancillary requirements (Morgan, 2012). Prince Rupert LNG's power requirements are 38 MW per MTA, while LNG Canada's are between 50 and 56 MW per MTA depending on energy efficiency assumptions (AECOM, 2013; Stantec Consulting, 2013).
- **Renewable generation type:** B.C. Hydro's resource option report estimates 2.5 Gigawatt hours of wind energy potential in Northwestern British Columbia, with an average unit cost of energy at point of interconnection of \$132 per megawatt-hour (B.C. Hydro, 2013a). There are other energy opportunities in the region as well—including run-of-river hydroelectricity—but since the wind resource is relatively abundant, we consider only wind.
- **Renewable generation location:** We did not pick a specific location for renewable energy resources, but all would be located on the North Coast.
- **Discount rate:** We assumed a 10 percent discount rate for electricity generation and transmission projects and 15 percent discount rate for capital expenditures at the LNG facility. LNG projects have a higher risk profile than electricity generating projects and transmission lines, and we assume a higher discount rate.
- **Cost of gas:** We assumed natural gas to feed the LNG facilities costs \$4 per gigajoule, which includes production, processing and transmission.
- **Break even price of gas:** We assume a break even price of gas of \$11.08 per GJ based on break even cost estimates by Ernst & Young and Macquarie (Ernst & Young Global Ltd., 2013; Macquarie, 2012).
- **Carbon cost:** We impose a \$30 per tonne carbon tax and an LNG facility performance standard. The performance standard levies a penalty of \$25 per tonne of CO₂eq for every tonne of CO₂eq above 0.14 tonnes CO₂eq per tonne LNG. The 0.14 tonne

CO₂eq per tonne LNG is from our combined cycle and renewable energy scenario in *The Cleanest LNG in the World?*

- **Grid cost:** We set the cost of grid electricity to \$95 per MW hour, which is the marginal cost of electricity on the B.C. grid based on the addition of the proposed Site C Hydroelectric Project (B.C. Hydro, 2013b).
- **Cost calculation:** Costs are calculated using simple levelized cost of electricity.
- **Combined cycle energy efficiency:** 58 percent, which includes the cold climate efficiency advantage afforded LNG operators located in northern regions.
- **D-Drive with heat recovery and steam generated electricity:** 50.6 percent.
- **Lifespan:** We assume energy generating technologies have a 25-year lifespan, LNG facilities 25 years and transmission lines have a 50-year lifespan.

JOBS CALCULATION METHODOLOGY

We calculated jobs based on B.C. Hydro estimates (B.C. Hydro, 2013a) per generation type and then checked the results with industry experts in British Columbia. We consider only direct jobs during the operation phase of the LNG projects and associated energy production. Data sources are available in the Data Sources section.

COST CALCULATION METHODOLOGY

We used a simple levelized cost of energy (sLCOE) for each scenario. We used B.C. Hydro cost estimates for wind and combined-cycle power production in British Columbia and supplemented information gaps. Data sources are available in the Data Sources section.

LEVELLIZED COST CALCULATIONS

This equation converts capital costs into annual payments using a capital recovery factor and then adds the annual capital cost to annual operating and energy costs. We add the costs for each portion of the energy system (such as production and transmission) and then divide the total by MWhr produced per year to arrive at a cost per MWhr of energy.

Equation:

$$sLCOE = \frac{\sum(CRF * CC + OC + EC)}{MWhr}$$

Where:

Capital Recovery Factor (CRF)

$$CRF = \frac{d}{(1 - (1 + d)^{-n})}$$

CC = Capital Cost
 OC = Operating Cost
 EC = Energy Cost
 MWhr = Annual Megawatt hours of energy
 d = Discount rate
 n = Lifespan of technology

RESULTS BY SCENARIOS

Scenario 1: Maximum Renewables

In this scenario, we use a mix of wind – 2,265 MW installed capacity at a 0.33 capacity factor, combined cycle – 2,265 MW installed capacity at a 0.75 percent capacity factor and grid electricity – 567 MW capacity at peak requirements, to power the prospective LNG facility. The scenario includes E-Drives at the LNG facilities, grid upgrades in Kitimat and Prince Rupert and twinning the transmission line between the Skeena Substation and Williston Substations. The following tables summarize costs in millions and jobs for this scenario.

Costs	Wind Farm	Transmission Line	B.C. Hydro Grid	Combined-Cycle Power Plant	E-Drive
Capital	\$2,590.82	\$198.00	\$-	\$858.74	\$28.65
Operating	\$38.36	\$5.94	\$-	\$276.03	\$0.27
Life Cycle	\$313.20	\$25.91	\$107.97	\$367.12	\$3.16
Jobs	Wind Farm	Transmission Line	B.C. Hydro Grid	Combined-Cycle Power Plant	E-Drive
Jobs (FTE)	271.24	107.59		128.24	61.86

The total levelized cost is \$94.88 per MWhr. FTE: Full Time Equivalent.

Scenario 2: Renewable Ready

In this scenario the LNG facilities install E-Drives with electricity provided by natural gas fired combined-cycle turbines with an installed capacity of 2,832 MW.

Costs	Combined-Cycle Power Plant	E-Drive
Capital	\$3,220.27	\$85.94
Operating	\$1,028.42	\$0.80
Life Cycle Costs	\$1,370.03	\$14.10
Jobs	Combined-Cycle Power Plant	E-Drive
Jobs (FTE)	160.30	61.86

The total levelized cost for this scenario is \$55.79 per MWhr.

Scenario 3: Fossil Energy

In this scenario, the LNG facility is powered by D-Drive natural gas turbines; heat recovery and steam generation produce electricity. The combined system has an installed capacity of 2,832 MW including both electrical and mechanical power.

Costs	
Capital	D-Drive \$3,220.27
Operating	\$1,172.87
Life Cycle Costs	\$1,633.32
Jobs	
Jobs (FTE)	D-Drive 53.43

The total levelized cost for this scenario is \$67.05 per MWhr. FTE: Full Time Equivalent.

DATA SOURCES

Summary of cost data sources

Component	Assumptions
Cost – Combined-cycle capital, operating, maintenance, fuel	Combined-cycle capital and operating costs from B.C. Hydro – (2013) Fuel cost calculated based on cost of natural gas and efficiency in assumptions.
Cost – Wind capital, operating, maintenance,	B.C. Hydro Resource Assessment, North Coast Wind. Estimates confirmed with Alterra Energy, Personal Communication
Cost – grid	Estimate of Site C cost \$95 per MWhr (B.C. Hydro 2013a)
Cost – Electric motor	1/3 cost of single cycle power generation from (B.C. Hydro)
Transmission capacity	Golder Associates Ltd. (2007) For transmission to Kitimat British Columbia Transmission Corporation. (2007) For system upgrades in Kitimat Twinning transmission between Skeena and Williston substations (B.C. Hydro estimated at 3 percent of capital cost Silverstein, A. (2011)

Summary of data sources for jobs

Information Required	Sources
Jobs direct – Wind	B.C. Hydro Resource Assessment (B.C. Hydro 2013a) supported by discussion with renewable energy industry
Jobs direct – Combined-cycle	B.C. Hydro Resource Assessment (B.C. Hydro 2013a) Backed up by discussion with renewable energy industry

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