The Viability of Gas-to-Liquids in British Columbia: A Monte Carlo Cost-Benefit Analysis

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THE VIABILITY OF GAS-TO-LIQUIDS IN BRITISH COLUMBIA: A MONTE CARLO COST-BENEFIT ANALYSIS

by

Nicholas Hartley

Abstract

British Columbia's abundance of natural gas resources has opened the door to the development of many new industries within the province. This paper explores the economic viability of a gas-to-liquids (GTL) industry in B.C. by analyzing the net present value a private sector investor could expect from constructing and operating a GTL plant for 25 years in the province. A Monte Carlo simulation method is used to account for the stochastic components that will affect the net profits and cash flows of the GTL facility. High capital costs and uncertainty in future petroleum product prices are found to make a GTL facility in the province a risky investment, but with potentially high economic upside depending on investor preferences.

1. Introduction

British Columbia (B.C.) has an abundance of natural gas contained in shale and other fine grained sedimentary rocks. Technological advances and modern drilling techniques have unlocked previously inaccessible natural gas supplies, making it an increasingly plentiful and affordable energy source in the province. A National Energy Board report (NEB) released in November of 2013 estimates that the siltstones of the Montney Formation could contain 449 trillion cubic feet (Tcf) of marketable natural gas; 14.5 billion barrels of marketable natural gas liquids (NGLs), and 1.1 billion barrels of marketable oil. This report indicates that B.C.'s natural reserves could amount to 150 years of natural gas supplies to support future economic activity, strengthening the province's plans to support the development of liquefied natural gas (LNG) plants in the province's north.

LNG has been praised as a billion dollar industry that could create around 100,000 jobs and be used to pay off provincial debt. However, given the scale of incremental natural gas production taking place over the next two decades, it is important to not be limited in scope to conventional demand channels for natural gas such as electric generation and exports through LNG, but to consider other innovative gas monetization possibilities. A key part of BC's Natural Gas Strategy is to "Develop New Markets for Natural Gas", which include gas-to-liquids (GTL), methanol, and fertilizers such as ammonia. These value-added applications turn natural gas into higher value intermediate or final chemical products that can then be sold to a broad variety of markets and market types, allowing B.C. to develop new industries.

In this paper, I explore the economic viability of a GTL industry in B.C. by analyzing the net present value a private sector investor could expect from constructing and operating a GTL plant for 25 years in the province. The model involves uncertainty in a number of input parameters, namely costs and petroleum product prices that contribute to revenue, so a Monte Carlo cost-benefit simulation approach is used. The results will help to identify the risk and opportunity that a private sector GTL investor faces in B.C.

The next section provides information on the history of the GTL process and its current status in the global value added natural-gas industry. Section 3 begins to explore the potential mutual benefits that both the province and prospective investors face with the GTL opportunity. Sections four and five present the cost-benefit model and Monte Carlo approach that are employed, as well as the data and distributions that are used to account for the future uncertainty in variables affecting costs and revenues. Section six presents the results of the Monte Carlo simulation and outlines both the private and public benefits of the potential GTL project. Finally, conclusions are presented in section seven.

2. Background

An interesting aspect of GTL is the history behind the refinery process. A major shift from coal to oil occurred about a century ago, giving coal-rich and oil-poor countries like Germany a way to fuel their vehicles. Friedrich Bergius, a German chemist, developed a technique for liquefying coal under high pressure in 1913 for which he later won the Nobel Prize. Another technique was later developed by Franz Fischer and Hans Tropsch in 1923, and today the Fischer Tropsch process is the most common technology applied for the conversion of GTL.

Another country with a similar resource conundrum as Germany was South Africa because of oil embargoes due to its apartheid policy. In 1955, Sasol opened its first coal-to-liquids plant. With the exception of South Africa, the coal- and gas-to-liquids industry was essentially stagnant for more than a decade until oil prices spiked in the 1970s, after which substantial amounts of funding from the US Department of Energy was put into research. In South Africa, discovery of offshore natural gas fields provided an impetus for its national oil company to open the first gas-to-liquids plant in 1992. Today, Sasol is one of two companies to have GTL technology proven to work on a commercial scale (Shell being the other). In 2011, Sasol purchased half of Talisman Energy Inc.'s Cypress A and Farrell Creek operations in the Montney shale basin, located in northeast B.C., making this industry an important consideration for the province (Vanderklippe, 2011).

The conversion of natural gas into liquid products continues to become a more viable use for natural gas. This has been especially true in recent years due to breakthroughs in horizontal drilling and hydraulic fracturing that have drastically increased natural gas production. Prior to these breakthroughs, the cost of natural gas had generally been too high to support GTL. For these reasons, early GTL adopters could only be found in countries such as Qatar or Malaysia where large amounts of natural gas was cheap because it would otherwise be flared.

GTL technology provides an alternative value chain for producing the same products traditionally produced from oil feedstock. Therefore, GTL products are subject to the global trends and factors that influence the viabilities of developing such product markets in B.C. The technology also provides an alternative source of feedstock, such as naphtha, for producing other petrochemical products that are produced through more traditional natural gas value chains. As illustrated in Figure 1, diesel and naphtha are the common products from the GTL process, but the refining process can be designed specifically to maximize the yield of any of the GTL products. Opportunities for GTL projects to create sufficient value arise in the face of low natural gas prices and relatively high world prices for oil.

GTL technology is considered to be highly proprietary. There are significant barriers to new

entrants developing the GTL process because of the high cost of technology and the extensive patent protection of existing processes. Shell's GTL process, for instance, carries over 3,500 patents. Currently, the technology is not widely licensed. Most technology suppliers leverage their technology to gain access to gas assets. This paper therefore aims to present the potential for an international investor to invest in B.C. for a future GTL plant.
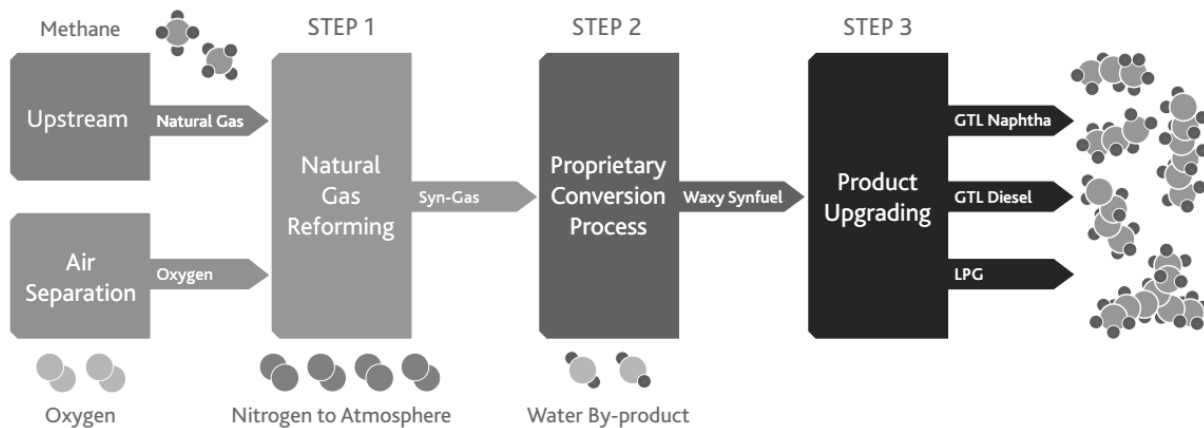
Figure 1 – The Fischer-Tropsch Process. Source: Sasol – The Canada GTL Project, 2012

It is important to recognize that GTL-based oil products differ from traditional refinery products in a number of ways. In general, due to the nature of the feedstock (natural gas) and process (significant sulfur removal during the process), the GTL oil products are essentially without sulfur, meeting key critical requirements in the North America, Europe, and other industrial jurisdictions. GTL products also show many other superior properties compared with refinery outputs. For example, GTL diesel and jet fuel have better combustion quality than traditional fuels. Therefore, GTL products tend to receive a premium compared with refinery products.

Still, the market prices of GTL-based oil products generally move in tandem with the corresponding products produced from refineries. Thus, the high capital cost of building GTL plants requires very low natural gas feedstock costs relative to the price of oil to support project economics. The installation of a GTL facility is generally located near ample gas reserves, or sufficient gas reserves to justify such an application where a pipeline or other means of removal (including flaring) are unreasonable. The largest facilities using this application are in Malaysia and Qatar, and are proposed in Uzbekistan and Louisiana in the U.S. All of these locations have abundant gas supplies where the gas demand created by the facility is not likely to impact the market price of gas in the region.

As previously mentioned, the most common technology applied for the GTL conversion is the Fischer-Tropsch process. Natural gas is broken down into its liquid components through exposure to a catalyst bed, and 'cracking' is then employed to break the liquids down into their

individual final products. A wide variety of products and cracking can be designed specifically to maximize the yield of a desired product. Shell's Pearl plant in Qatar, for instance, has a diverse product slate that includes a variety of GTL products such as diesel, naphtha, kerosene, gasoil and base oils.

The process is highly scalable, ranging from the largest plant in Qatar that produces 140,000 barrels per day (bbl/d) of transport fuels, naphtha, paraffins and lubricant oils, to recently proposed micro-scale modular units as small as 25 bbl/d. On the smaller end of this scale, the process would generally be applied to convert gaseous hydrocarbon waste into a liquid that can then be used or blended with other liquids for consumption or shipping.

There are currently only four significant GTL projects operating globally; those are located in Qatar, Malaysia, Nigeria and South Africa (Table 1). There has been some recent activity and announcements in North America regarding GTL development, the biggest of which is Sasol's announced 96,000 bbl/d plant in Louisiana which will also produce an additional 36,000 bbl/day of ethylene. Sasol has also recently completed a feasibility study and filed an environmental impact assessment with Alberta regulators to bring Canada's first GTL plant on stream by 2021 to the Alberta's Strathcona County.

Table 1 – Current GTL Configurations

Plant Configuration	Country	Status	Production (bbl/day)	Overnight Capital Costs ($/bbl/day)	Total Capital Costs ($millions USD)
Pearl	Qatar	Operational	140,000 (+120,000 coproduction)	$136,000	$19,000
PetroSA	South Africa	Operational	45,000	$68,000	$4,000
Escravos	Nigeria	Operational	33,000	$250,000	$8,400
Bintulu	Malaysia	Operational	14,700	$100,000	$1,470

GTL is an advanced petrochemical processing technology that offers attractive integration opportunities with the existing refining and petrochemical sectors and aligns with the government of B.C.'s goals for value-added natural resource development in the province. As a multi-million to multi-billion dollar investment, a GTL facility would launch a new industry that monetizes the value of B.C.'s natural gas resources, promotes economic diversification, creates

new employment opportunities in the province and generates significant revenues for all three levels of government in Canada through Federal and Provincial corporate income tax payments and municipal property tax payments.
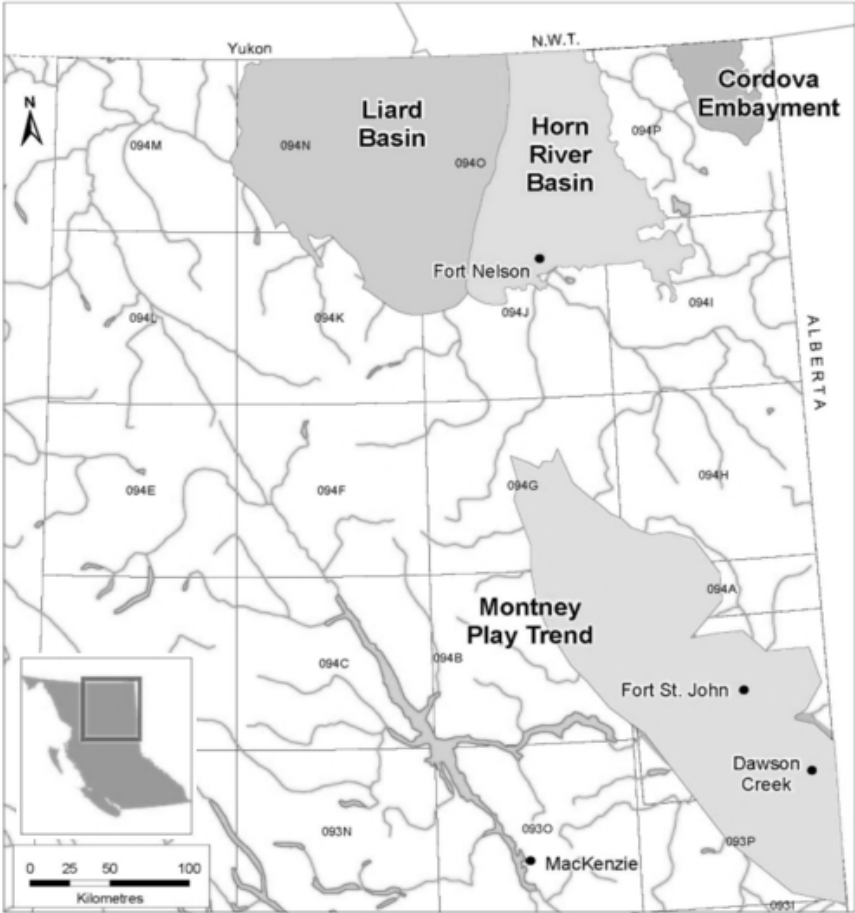
Figure 2 – Shale Gas Plays in Northeast B.C. Source: Ministry of Energy and Mines

3. The Landscape in B.C. and Western Canada

B.C. has abundant natural gas resources and is the second largest producer of natural gas in Canada. The sector employs tens of thousands of people in the province and total industry investment grew from $1.8 billion in 2000 to $7.1 billion in 2010. This brought the annual production up to 1.2 Tcf per year (a 29.5% increase since early 2000) (BC Natural Gas Strategy, 2012). Interestingly, the expectation was that there would be a shortage of natural gas in B.C. and all of North America. However, the advent of hydraulic fracturing, which allows for the recovery of shale gas, has completely turned the tables for the province. The BC Oil and Gas Commission estimated in 2012 that conventional reserves in the province amounted to 12.6 Tcf with unconventional reserves in the Horn River (11.1 Tcf) and Montney (13.4 Tcf) plays amounting to 24.5 Tcf. However, further advances in energy technology in recent years have

revealed that northern B.C. hosts an estimated 271 Tcf of natural gas within the province's share of the Montney play alone (Jang, 2014). Additional resource estimates for the Liard and Cordova basins, when available, will further add to the estimated total remaining gas reserves in the province. Figure 2 illustrates where these natural gas plays are located in Northeastern B.C.

Plans to convert natural gas into liquefied natural gas (LNG) for export have become one of the main focuses of *Canada Starts Here: The BC Jobs Plan* (Jobs Plan), bringing in as many as 75,000 full-time jobs and 39,000 construction jobs to the province. The first major LNG project in the province is a $4 billion export terminal and pipeline in Kitimat and is currently under environmental review. Project construction is expected to commence in 2015 pending receipt of the necessary regulatory approvals. In addition to this, the province has committed to working with interested investors to have three facilities in operation by 2020 and adding the production of an additional 1.9 TCF of natural gas per year (which would bring B.C.'s total production up to 3.1 TCF per year).

GTL has emerged as a commercially-viable industry over the past thirty years, but has only recently come under the spotlight in North America due to low natural gas prices, which has sparked interest among producers in GTL as a means to better monetise isolated shale gas resources. However, there is an overall sense of reluctance among natural gas producers to invest in the GTL industry, which faces a number of challenges and risks. Risks include high capital costs; volatile natural gas, crude oil and petroleum product markets; integration of upstream and downstream projects; and access to technology.

A slightly different GTL process has been developed by the Japan Oil, Gas and Metals National Corporation (JOGMEC) in collaboration with other private companies (JOGMEC, 2013). The Japan-GTL process differs from that which was developed by Sasol and Shell in that it allows for the CO_2 contained in the natural gas stream to be used directly. This innovative technology is expected to be applied primarily to untapped CO_2 containing gas fields. A 500 bbl/day demonstration plant for Japan-GTL was set up in 2006 in Japan and completed demonstrations in 2011.

The Province of B.C. and JOGMEC signed a Memorandum of Understanding (MOU) on May 16, 2012, and later extended this MOU on December 2, 2013 (JOGMEC Planning Division, 2013). Based on this MOU, JOGMEC and the Province of B.C. will continue to collaborate on developing business opportunities in B.C. for unconventional gas resources and related technologies, including GTL technology, products and services.

The LNG opportunity relies upon taking advantage of price differences in different markets around the world. B.C.'s LNG strategy in particular focuses on meeting growing demand in Asia

where natural gas prices have recently been as much as four times higher than in North America. However, a sharp fall in European and Asian gas prices in 2014 has put LNG export projects worldwide under heavy cost pressure, and even killed some off, as expected returns on investments had to be revised down along with prices. Asian spot prices fell by over 40 % in value as demand growth slowed and new supplies in the Pacific region became availbale, although prices remain around three times as expensive as in North America. Falling prices and stiff competition from other jurisdictions, such as Australia, the U.S., Qatar and Africa, have complicated B.C.'s vision for LNG that was first proposed in the Jobs Plan back in 2011.

As an alternative to LNG, GTL is much less reliant on arbitrage and could potentially bring economic benefits as its products never leave Canada. Instead, it relies on low natural gas prices relative to oil prices to become a viable investment. Uncertainty surrounding the prices of both energy sources is in fact where much of the inherent risk of GTL projects lies. However, allowing the province to better tap into the North American market with its natural gas feedstock could be seen as an advantage, rather than solely relying on overseas LNG markets.

A Canadian GTL plant would provide clean tranportation and petrochemical fuels and futher improve Canada's export security by strengthening its position as a net exporter of crude oil and petroleum products.

Taxes

For the private sector investor, the calculation of the net present value (NPV) would be incomplete if we ignore the tax implications of the project. Municipal, provincial and federal governments will collect tax from the company based on the profits that it generates. Adjustments are therefore used to calculate the after-tax cash flows for this project. For a project in B.C., the following taxes will be applicable on the project.

Carbon tax

The government of B.C. introduced a carbon tax to help reach its goal of reducing B.C.'s greenhouse gas emissions by at least 33 per cent below 2007 levels by 2020. The carbon tax was implemented on July 1, 2008, with tax rates for each fuel equal to $10 per tonne of carbon dioxide equivalent (CO_2e) emissions. The rates were increased by $5 per tonne annually until reaching $30 per tonne of CO_2e on July 1, 2012, and they will be maintained at $30 per tonne. The tax applies to almost all of the fossil fuels burned in the province. The tax does not currently include non-combustion emissions. The B.C. Ministry of Finance has noted that increasing the carbon tax rates or expanding the base to include industrial process emissions would increase costs for B.C. businesses and increase competitiveness concerns (B.C. Ministry of Finance, 2013). However, they also note that government may review and consider these

changes to the carbon tax should other jurisdictions introduce similar carbon taxes.

For the purpose of this study, I assume that all emissions from combustion and flare stacks associated with the project will be taxed at a rate of $30 per tonne of CO_2e throughout the life of the project. Emissions outlined in Sasol's Environmental Impact Assessment are projected to be 16,153 tonnes of CO_2e per day.

Provincial Income Tax

A tax regime similar to B.C.'s recently announced LNG Income tax is assumed to be imposed on the GTL facility. The LNG Income Tax rate on net income will be 5% for taxation years beginning on or after January 1, 2014 and 3.5% for taxation years beginning on or after January 1, 2017. During the period when net operating losses and capital investment are being deducted, a tax rate of 1.5% applies to the taxpayer's net income. Any tax paid at the 1.5% rate will be credited against tax payable at the higher rate. Once the net operating losses and capital investment has been depleted, the full rate of 3.5% is payable.

Municipal Property Tax

At full buildout, total municipal tax property payments are estimated to reach $49 million annually, which is the rate used in Sasol's project description.

Federal Income Tax

Under the *Income Tax Act*, the federal government levies income tax on a corporation's taxable income. As of 2012, the net federal rate on oil and gas income is 15% (PwC, 2012). This includes abatements and reductions that are designed to give provinces and territories room to impose corporate income taxes.

4. Markets for GTL products

Similar to Sasol's Alberta proposal, the products produced at the GTL facility will serve the fuel market needs of western Canada and, over the long-term, potentially market needs elsewhere in North America.

Diesel – Western Canada (B.C. in particular) is the primary market for the diesel produced in the proposed GTL plant. Diesel shortages have occurred in western Canada in recent years (Dosser, 2013). GTL diesel can be sold directly as a high-quality product or marketed as a premium refinery blend component in the western Canadian refining hub. It is assumed that its environmental advantages may serve to help it displace some of the current Western Canadian consumption of regular diesel. In response to strict tailpipe emissions limits, high fuel prices

and a growing awareness of greenhouse gas issues among both consumers and policy makers, rising demand for cars and light trucks running on diesel is forecast for the North American market. The availability of the even-cleaner burning GTL diesel may amplify this scenario.

Figure 3 illustrates the Western Canadian demand for diesel from 2003-2013. Overall, demand for diesel grew by 45% from 168,000 bbl/d in 2003 to 243,000 bbl/d in 2013 in Western Canada. This is a higher rate of growth compared to all of Canada, which grew by 26% over the same period from 409,000 bbl/d in 2003 to 513,000 bbl/d in 2013.
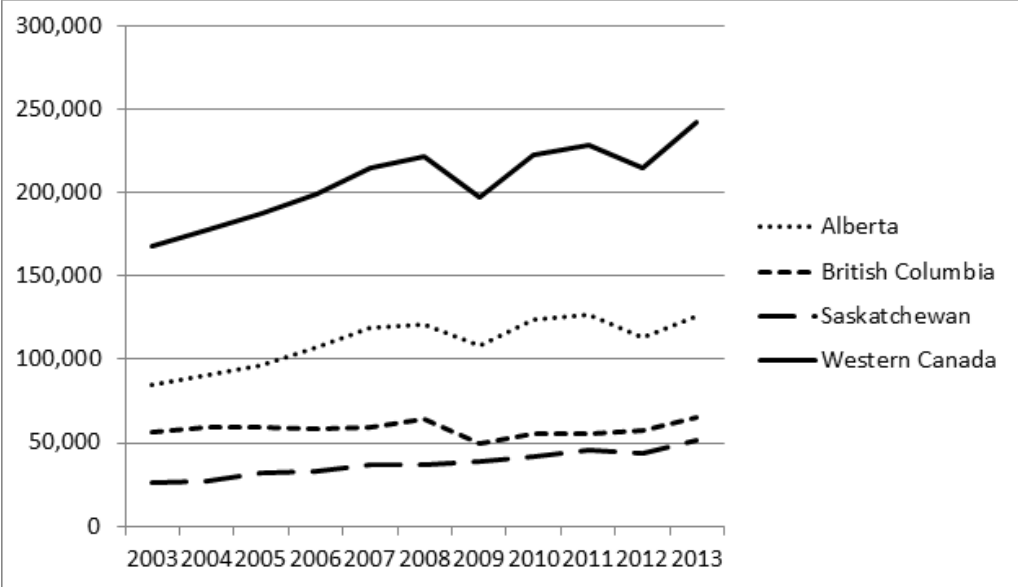

Figure 3 – Western Canadian consumption of diesel fuel (bbl/d), Source: CAPP, 2014

In Canada, shifts in demand channels affecting gasoline and diesel consumption will likely add to the growth in diesel consumption. In 2011, passenger travel accounted for 54% of the transportation demand, with freight accounting for 42% and non-industrial off-road accounting for 4%. In 2020, these shares are expected to begin to reverse, with freight accounting for 56% and passenger accounting for 40% by 2035. As gasoline is primarily used on the passenger side, and diesel in freight, this shift has implications for the use of these fuels. Over the projection period, motor gasoline consumption in transportation is forecast to decline by 0.2% per year, while diesel consumption increases 1.6% per year (NEB, 2013). Even within the passenger travel side, a shift from gasoline to diesel fuelled vehicles in North America can further increase future consumption of diesel. Diesel vehicles currently account for just 1% of new passenger car registration in the U.S. Bosch Global forecasts this share to rise to around 10% of light vehicle sales by 2018, driven by rapidly expanding range of diesel models (IHS, 2013).

Globally, forecasted demand for refined products emphasize the need for middle distillates, primarily diesel, in the transport sector. This is driven by expanding fleets of trucks and buses,

as well as diesel light-duty vehicles and cars Additional support for diesel demand will also be provided by an expected shift from fuel oil to diesel in the marine sector. Figure 4 illustrates current and projected global demand for petroleum products. Between 2013 and 2040, the product category of middle distillates is expected to increase by a total of 12.5 million bbl/d. This represents around 60% of the overall growth in demand for all liquids products (OPEC, 2014).
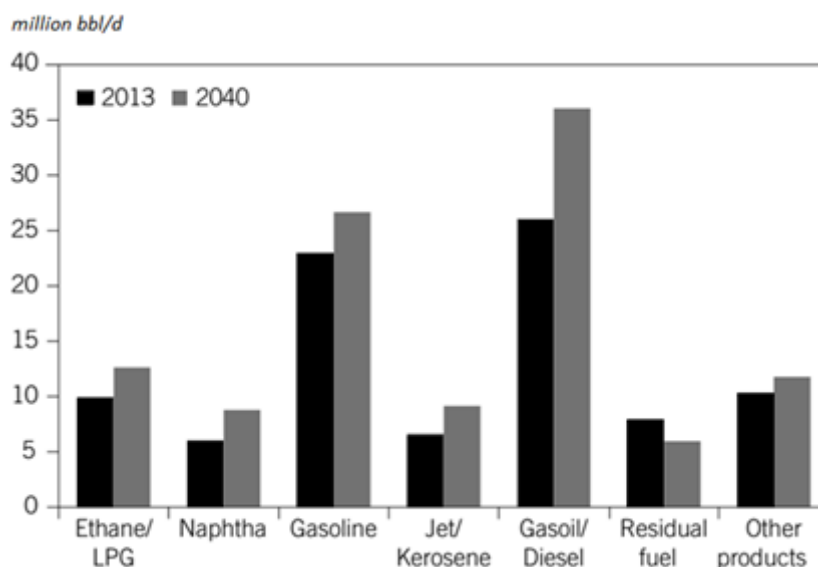

Figure 4 – Global Petroleum Product Demand, 2013 and 2040, Source: OPEC 2014

This growth will mostly be driven by emerging markets as they industrialize (Fuels Institute, 2014). As these countries undergo an oil-intensive economic expansion, diesel generally shows the strongest demand growth due to the fuel's broad uses throughout industry on top of industry-linked transportation. GTL diesel generally comes with a price premium due to its environmental advantages, although this may hinder demand for GTL diesel in developing countries that may seek cheaper alternatives. On the other hand, increasingly stringent environmental specifications for fuel combined with increasing living standards in Asia, and hence the ability for more familes to be able to afford a vehicle, provide a positive outlook for GTL diesel in these markets. GTL diesel's position in the automotive fuel sector will depend on the competitive position of compressend natural gas, LNG and electric vehicles. Whether regulatory elements will increase demand for low-emission diesel fuel in the future is a key question beyond the scope of this paper.

Naphtha - In many regions around the world, naphtha is used as a cracker feedstock for producing certain chemicals. The market for naphtha is primarily driven by increased demand for plastics as naphtha is a feedstock used in the making of ethylene, propylene, benzene and

butadiene. Naphtha produced through the GTL process is a high-value product that can be used as a bitumen diluent. Regional markets exist for GTL naphtha as a diluent for heavy oil production. To meet pipeline specifications, one third of a barrel of diluent is required for every barrel of bitumen that is to be pumped. The growing oil sands business in Alberta has resulted in a corresponding growth in the market for FT naphtha.

A 2012 report by the IHS Inc., a Colorado based company that provides information and analysis to support the decision-making process of business and governments in a number of industries, indicates that diluent demand far outstrips the available supplies in Western Canada, and future growth in bitumen production will exacerbate this situation. Currently, the supply/demand balance is tight and incremental production will require other diluent sources. An additional 450,000 bbl/d of diluent supply was projected to be needed by 2015, and this could rise as high as 780,000 bbl/d by 2020. Supply is not forecast to be sufficient, even with pipeline development for more imports and recycle. For the purposes of this study, it is assumed that the naphtha produced by the GTL facility will be sold to Alberta as both a petrochemical feedstock and pipeline diluent. Naphtha also opens up further potential value-added natural gas opportunities within B.C. should the province decide to pursue the development of its own petrochemical sector. The petrochemical sector could in fact become the primary market for the GTL naphtha should future oil pipeline projects not come to fruition, which is a possibility given the backlash that currently proposed pipeline projects are facing from local communities.

Ethylene and propylene account for approximately 56% of naphtha demand globally. Other key consumption markets in proximity to B.C. are Asia and the United States.

LPG - The GTL facility will produce relatively small quantities of liquefied petroleum gas (LPG), which comprises gaseous hydrocarbons or petroleum gases such as propane, butane and pentane that are pressurized in liquid form. While various markets exist for LPG across North America, the product could be railed to potential identified markets in Canada.

As a result of the integrated nature of North American petroleum product markets, refiners in Canada are price takers and must price their products to compete with the price of imported products delivered to Canada. Wholesale prices for petroleum products react to a broad range of factors unique to their individual markets. Product prices are influenced by the supply and demand balances as well as the prices of alternative products with which they compete. For example, propane can be used for heating, as an automotive fuel or for agricultural uses like crop drying. When all factors that influence prices come together, retail price (and to a lesser extent wholesale prices) can vary significantly between markets. Figure 5 displays the the variation between diesel wholesale prices in select Western Canadian markets.
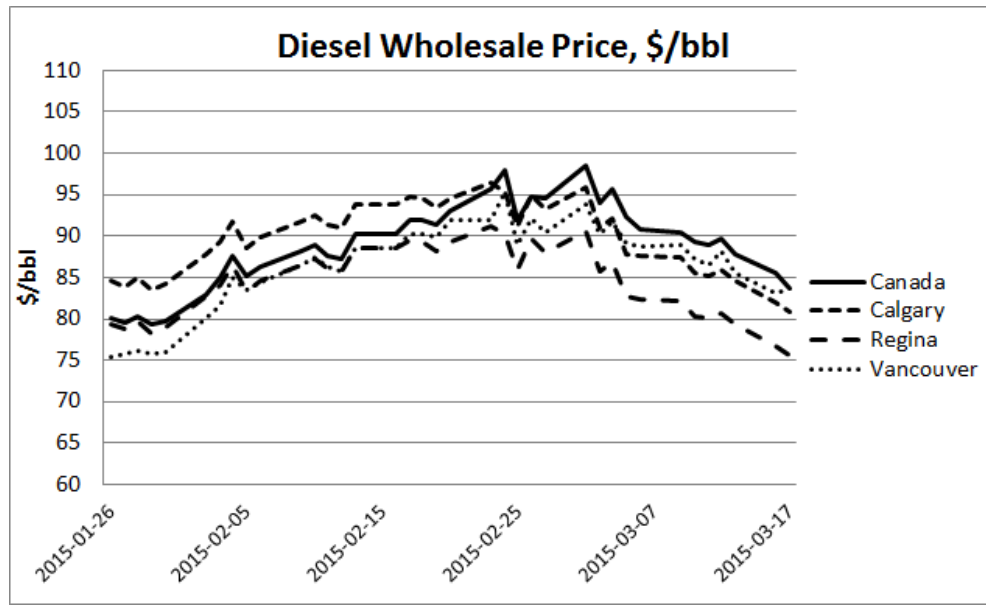
Figure 5 – Diesel Wholesale Price in Western Canadian Markets, Source: NRCAN, 2015

5. Methodology

In this section, I describe the stochastic cost-benefit analysis that will be used to determine the viability of the GTL facility. Private investors (i.e. Sasol, Shell) are used as the referent group to determine the value such companies could expect should they set up a plant in B.C.

The investment of a GTL facility in B.C. faces many uncertainties related to costs and product prices throughout the project life cycle. Therefore, it is difficult to forecast profits and cash flow. Capital and operational expenditures and petroleum product prices each play a fundamental role in the return of oil and gas projects, and project performance is very sensitive to their variation. Different methods are available to help decision makers assess the uncertainties and reduce the risk of investment opportunities in the oil and gas sector.

A Monte Carlo simulation method is used to account for the stochastic components that will affect the net profits and cash flows of the GTL facility. Monte Carlo cost-benefit analysis is a general method for estimating which is flexible and relatively simple to implement. It allows me to address the uncertainty that exists in the model's parameters by imagining all possible scenarios given the outlined distributions, and remains one of the most efficient risk analysis models for a project because it is the only method that is able to integrate the various dimensions of a problem. Compared to other methods of sensitivity analysis, the Monte Carlo method has the advantage of being based on estimated cash flows and therefore fits perfectly into the development strategies for oil and gas sector projects that focus on finding solutions that create worth. Finally, when a deterministic method is not applicable because of too few

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data, which is certainly the case for GTL facilities with only four currently operational plants (none of which happen to be in North America or similar economies to that of B.C.) that in turn provide very little information regarding their project economics, Monte Carlo simulations should be a promising solution (Belaid & De Wolf, 2009).

The simulation is run using the Excel tool Visual Basic for Applications (VBA). VBA enables faster processing for a large number of iterations in the simulation compared to a worksheet-only approach to the Monte Carlo simulation. A hybrid approach, using a combination of worksheet inputs and VBA code which interact with one another to varying degrees, is implemented to determine the most likely net present value (NPV) of a potential GTL facility in B.C. based on the limited available information. Using VBA, the variables being sampled come from the distributions described below in Section 5, as simulated by a random number generator.

The model will use 10,000 iterations to determine the net profits of a GTL plant that is similarly configured to Sasol's proposed Alberta plant, which has an expected operating life of 25 years.

The stochastic cost-benefit analysis is based on the NPV function:

$$NPV = \sum_{t=0}^{27} \frac{CF_t}{(1+r)^t}$$

where CF_t is the net cash flow in period t and r is the discount rate. Although a 25 year operating lifecycle is assumed for the plant, a projected three year construction period is also taken into account, beginning in year t=0. A number of commonly used private sector discount rates between of 8-12% are used in this analysis.

Net cash flows are derived from a basic profit function:

$$CF_t = \sum_{t=0}^{27} \left(P_t^D Q^D + P_t^N Q^N + P_t^L Q^L \right) - C_t Q^T$$

where Q^D, Q^N, Q^L, and Q^T are the per barrel quantities of diesel, naphtha, LPG and total petroleum products produced per year, respectively, from natural gas (assumed to be the same for each period according to the configuration outlined in Sasol's Alberta proposal where $Q^D = 27,521,000$; $Q^N = 10,147,000$; $Q^L = 255,500$; and $Q^T = 37,923,000$); P_t^D, P_t^N, P_t^L are the per barrel prices for diesel, naptha and LPG, respectively; and C_t is the cost of production for the GTL facility in a given year.

The cost of production for the GTL facility is given by the function:

$$C_t = K + R_t + O_t + G_t Q^G + Z_t$$

where K is the capital cost of the GTL facility; R_t is the rail transportation cost of shipping the products to local markets; O_t is the operational cost of the GTL facility; G_t is the price of natural gas used as feedstock in the GTL facility (\$/Mcf); Q^G is the quantity of natural gas feedstock used in the GTL facility (assumed to be the same for each period according to the configuration outlined in the Alberta proposal where Q^G = 360,985,000 Mcf/year); and Z_t is the total taxes imposed on the project.

Probability Distributions and Data

One of the major challenges to this analysis is simply the lack of data surrounding GTL plant costs that are available. With only four operational plants worldwide, each of which have significantly different capital expenditures (CAPEX) and production volumes, and are in very different markets than B.C., some assumptions are necessary for the analysis of a potential GTL plant.

Probability distributions are developed for each of the uncertain parameters in the NPV function. Normal, uniform and triangular distributions are used to describe the input parameters and are described in Table 2. Where applicable, correlations between variables are taken into account. In terms of the cost function, it is assumed that there are no correlations among the parameters. However, the petroleum product prices, which are refined products from crude oil, are assumed to be correlated with the price of crude oil.

Triangular distributions are used for a number of the input variables in this study. A triangular distribution is a continuous probability distribution with lower (*a*) and upper (*b*) limits and a mode (*c*), where *a* ≤ *c* ≤ *b*. This distribution is typically used as a subjective description of a population for which there is only limited sample data, which will be useful to account for the uncertainty surrounding costs and future prices. It is based on knowledge of the minimum and maximum values of a variable as well as an educated guess as to the modal value. This distribution will ensure that the outcomes of the Monte Carlo simulation come from a set of likely values.

Step/uniform distributions are used for oil and natural gas prices. In a step/uniform distribution, all values within a particular range have an equal chance of occurring, and another range of values have a different probability. All values within each separate range will have an equally likely probability of occurrence. This type of probability has been used for oil prices in the past (Zahynacz, 2013; Jaffe and Stevens, 2007).

Finally, normal distributions are used for the parameters in the diesel and LPG price equations.

Table 2 – Cost-Benefit Input Parameters

Cost-Benefit Parameters	Unit of Measurement	Type of Distribution	Distribution Parameters			Source of Data
			Min	Max	Mode[*]	
CAPEX Phase 1	$ (billions)	Triangular	6.0	9.0	8.0	Sasol Alberta
CAPEX Phase 2	$ (billions)	Triangular	5.0	7.0	6.4	Sasol Alberta
Operating Costs	$/bbl	Triangular	19.0	26.0	24.0	Sasol Alberta
Rail Costs	$/bbl	Triangular	9.0	18.0	13.5	CAPP, 2014
Crude Oil price	$/bbl	Step/Uniform	40.0	180.0	60.0 - 160.0	EIA, 2015
Diesel price	$/bbl	Normal	Derived from crude oil price			
Naphtha Price	$/bbl	Normal				
LPG Price	$/bbl	Normal				
Natural Gas Price	$/Mcf	Step/Uniform	2.0	8.0	3.0 - 7.0	EIA, 2015

*For Step/Uniform distributions, this will be a lower-higher range for most likely values

Capital Expenditures (CAPEX)

CAPEX for a B.C. based plant is based on data from Sasol's Alberta GTL plant proposal released in May of 2013. In their proposal, Sasol proposes a phased approach for the construction of the project with a production capacity of 57,950 bbl/d of GTL diesel, GTL naphtha plus LPGto be built in each phase, for a total planned capacity of 103,900 bbl/d. The production capacity for each of the products is 75,400 bbl/d of diesel; 27,800 bbl/d of naphtha and 700 bbl/d of LPG after both phases of construction are complete, with each phase accounting for the same capacity. The capital cost estimate for Sasol's project to the end of construction for phase 1 is $6-9 billion, with phase 2 estimated to cost between $5-7 billion. These values are based on Sasol's detailed cost estimate model which uses the most current cost data from engineering contractors and other economic information related to fees and rates applicable to the project. The estimate is subject to a variety of factors, including variability in world markets for steel, equipment and raw materials; worldwide currency exchange rate fluctuations; labour demand; module yard availability; construction activities underway; and weather conditions during the construction period.
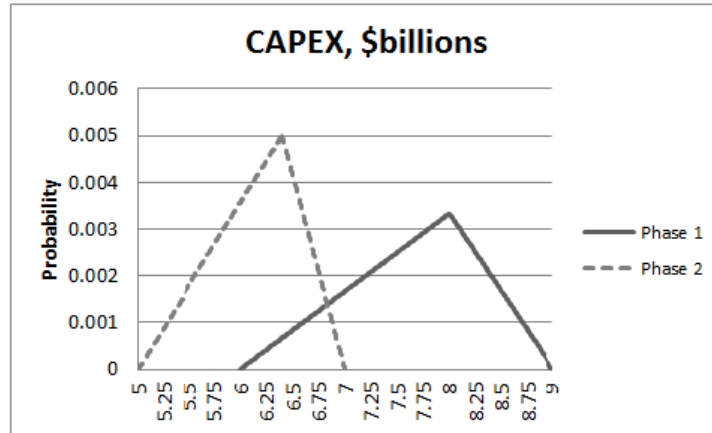
Figure 6 – CAPEX Distribution

 Sasol further uses a total CAPEX estimate of $12.5 billion for the project based on Alberta's landscape. Due to a lack of infrastructure relative to Alberta, a higher CAPEX value within Sasol's Alberta plant range is used as the most likely value. For phase 1, a most likely CAPEX of $8 billion is used, while phase 2 has a most likely value of $6.4 billion; for a total most likely CAPEX of $14.4 billion to build the project in B.C. CAPEX is assumed to be evenly spread across a three year construction period for each of the phases, starting in 2015 (so that all construction costs in years two and onwards are discounted). The plant will begin operation in 2018 at phase 1 capacity, with total capacity beginning in 2021 when phase 2 construction is complete.

Operating Costs

Operating costs are also based on data from Sasol's Alberta GTL plant proposal. In their proposal, Sasol provides a range from $19-26 per bbl for operating costs, which they note could vary depending on input costs at the time (e.g., costs for energy and labour). The most likely value is at the higher end of this range at $24/bbl to account for the generally higher wage and operating costs in B.C.
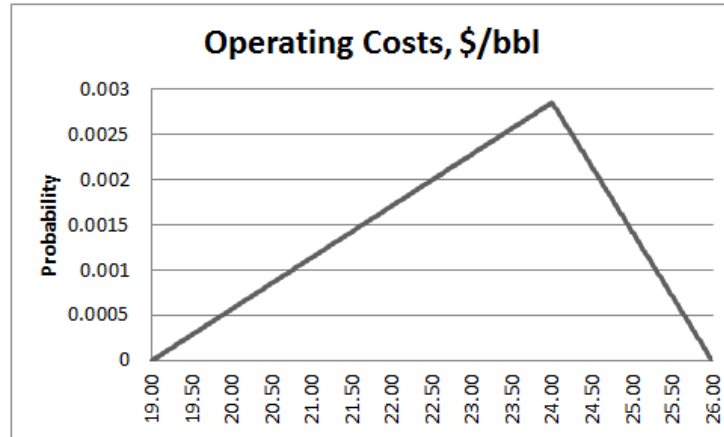
Figure 7 – Operating Costs Distribution

Rail Costs

A lack of pipeline capacity in B.C. is a major barrier to potential oil and gas sector projects in the province. Rail can provide the ability to access key markets all across North America when there are such constraints on pipeline capacity. Crude oil pipeline projects are currently proposed for B.C. (such as Enbridge's Northern Gateway Project and Kinder Morgan's Trans Mountain Pipeline Expansion), but there remains uncertainty surrounding their final investment decisions. Such pipeline projects in the future would work heavily in favour of a GTL facility in B.C., greatly reducing the costs for the project as shipping rates for petroleum products as rail costs are about twice those of pipeline transport costs.

Rail transport costs are derived from reported 2014 rates provided by the Canadian Association of Petroleum Producers (CAPP, 2014). Rates for transporting crude oil from the Alberta oil sands to the West Coast (including trucking, loading fees, rail freight, tank-car leases, and unload/terminal fees) are estimated to be in the range of about $9-18 per barrel. CAPP's range is used in this analysis, with the selected most likely value being $13.50 per barrel.
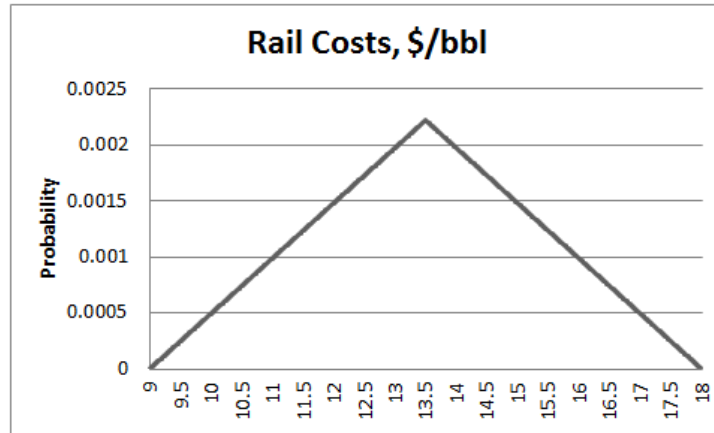
Figure 8 – Rail Costs Distribution

Petroleum Product Prices

Another challenge in this analysis is the uncertainty in petroleum product prices in both the short and long term. In the past seven months, for example, the price of oil has fallen by 60 per cent. The Monte Carlo simulation method allows for these significant and sudden fluctuations to be taken into account by selecting a range within which oil prices may fluctuate over the life of the project. Using a step/uniform distribution, a range of likely oil prices is selected, along with a broader range of extreme oil prices. The oil price will take any value between $60-160 per barrel with a probability of 90%; while there is a 10% probability that the oil price will fall between either $40-60 per barrel and $160-180 per barrel. These values are based on forecast data provided by the Energy Information Administration (EIA) to 2040, with slight adjustments made on the lower end to take into account the recent oil crash.

Figure 10 illustrates historical spot prices for crude (West Texas Intermediate), diesel and LPG from February 2007 onwards. A quick glance seemingly shows a relationship between diesel and LPG prices against the price of crude, which makes sense since the two products are refined products where crude oil is the primary input. Any downward pressure on oil prices could create a challenge for the GTL project's economics.
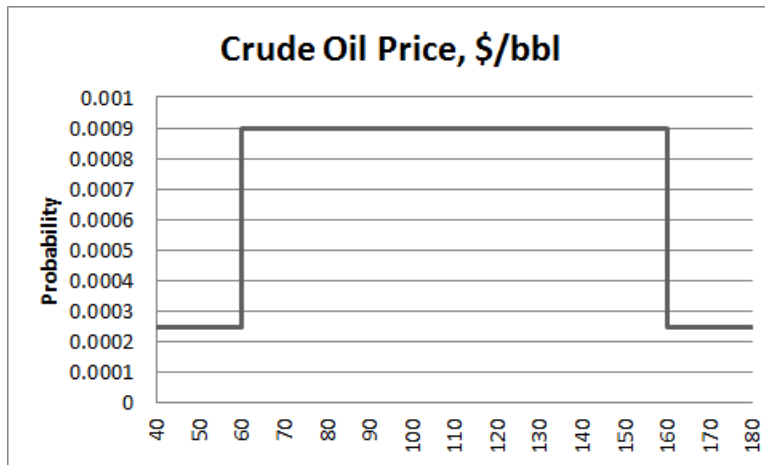
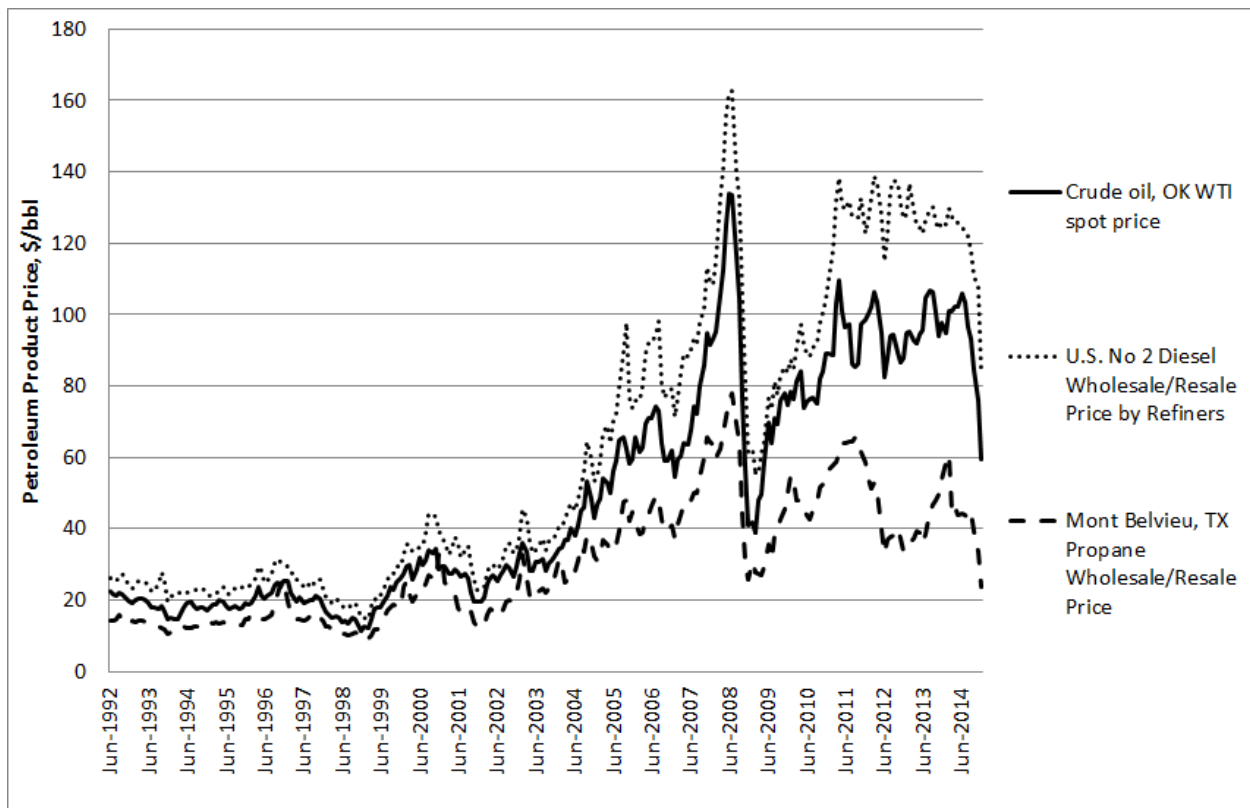*Figure 9 - Crude Oil Price Distribution*

Figure 10 – Historical Petroleum Product Wholesale Prices. Source: EIA, Indexmundi

Neither historical nor forecast data for naphtha prices are publicly available. However, a recent study on naphtha illustrates the historical price differential between gulf coast diesel and naphtha prices (Credit Suisse Securities Research & Analytics, 2013). Figure 11 shows the fluctuating diesel premium over naphtha prices, which ranged from about $0-30 over the two and a half year period used in the study. Naphtha was actually found to be more expensive than

diesel for a short time during this period. In my study, naphtha prices will be randomly generated to land in the range of $0-30 cheaper than the generated diesel prices, with a higher likelihood of the naphtha price being $15 cheaper than the diesel price.
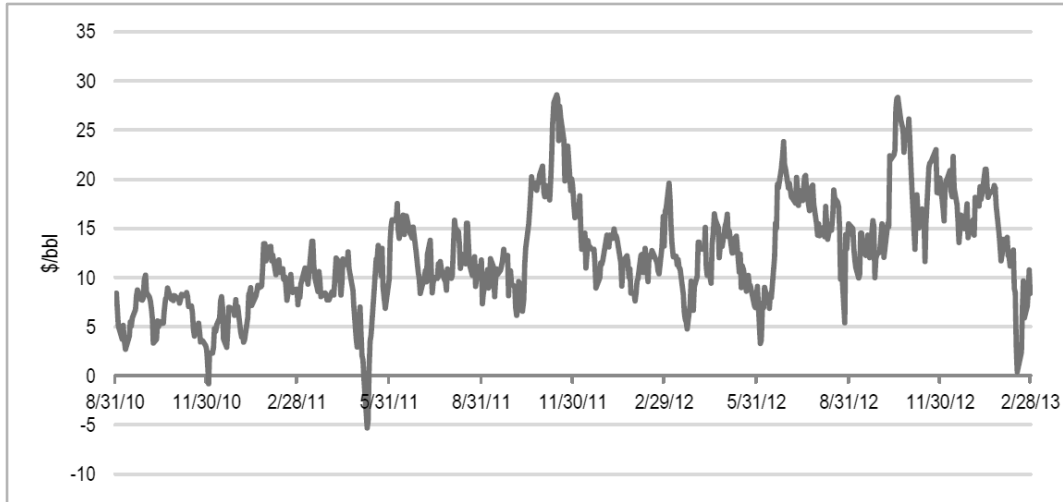

Figure 11 – Gulf Coast Diesel vs Naphtha Prices, Source: Capital Suisse R & A, 2013

Regressions are performed in an attempt to model the relationship between the two refined products' prices for which data is available against the price of crude oil, which can then be accounted for in the simulation. The regression models for diesel prices (P_t^D) and LPG prices (P_t^L) are as follows:

(1) $P_t^D = \beta_0 + \beta_1 P_t^O + u_1$ and (2) $P_t^L = \gamma_0 + \gamma_1 P_t^O + u_2$

where P_t^O is the price of crude oil, β and γ are the parameters to be estimated, and u_1 and u_2 are the regression residuals. The error terms are assumed to be correlated across the equations, so I implement a seemingly unrelated regression (SUR) model to perform the joint test $\beta_1 = \gamma_1 = 0$. SUR results from Stata are displayed in Tables 2 and 3 below.

Table 2 – Seemingly unrelated regression results

Equation	Observations	RMSE	R-sq	χ^2	P
(1) P_t^D	271	5.58819	0.9821	14832.70	0.0000
(2) P_t^L	271	6.12818	0.8678	1778.49	0.0000

Table 2 (continued) – Seemingly unrelated regression results

Equation	Coefficient	Std. Err.	z	P > |z|	95% Conf. Interval	
(1) P_t^D	β_1 = 1.28617	0.01056	121.79	0.000	1.26547	1.30687
	β_0 = -1.04623	0.62156	-1.68	0.092	-2.26446	0.17201
(2) P_t^L	γ_1 = 0.48840	0.01158	42.17	0.000	0.46570	0.51110
	γ_0 = 6.40503	0.68162	9.40	0.000	5.06908	7.74098

Table 3 – Correlation matrix of residuals

	P_t^L	P_t^L	Breusch-Pagan test of independence:
P_t^L	1.0000		
P_t^L	-0.1359	1.0000	χ^2 (1) = 5.005, Pr = 0.0253

For equation (1), the coefficient β_1 is found to be significant at the 1% level, while the constant is found to be significant at the 10% level. A standard error of 5.588 has been estimated for the regression and is used as a standard deviation for the error in the simulation. For equation (2), the coefficient γ_1 and the constant are found to be significant at the 1% level. Note that the R-squared values for equations (1) and (2) are 98% and 87% respectively, indicating that the crude oil price explains most of the variation in the wholesale price of diesel and LPG.

Table 3 illustrates that the correlation of the residuals in equations (1) and (2) is -0.1359 and that we can reject the hypothesis that this correlation is zero.

In the Monte Carlo simulation, diesel and LPG prices are randomly generated within a normal distribution for each year of each iteration, based on the regression results outlined in Table 2 above. The diesel, naphtha LPG prices that resulted from the simulation were compiled and are displayed in Figure 12.
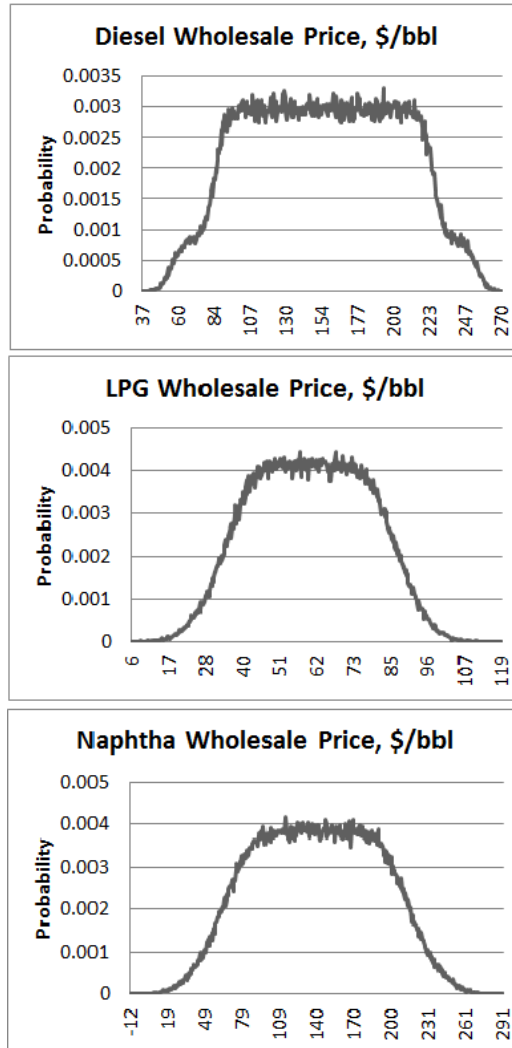
Figure 12 – Diesel, Naphtha and LPG distributions

The diesel prices are somewhat normal with values between $37.0-270.0 per barrel. The flat shape of this particular bell-curve is a result of the diesel prices being derived from the oil prices that were in turn randomly generated from a step-uniform distribution. Similarly simulated LPG and naphtha prices appear to follow a normal distribution with values between $5.8 – 118.5 and $-11.6-291.1 per barrel respectively.

Natural Gas Prices

The natural gas feedstock prices are generated similarly to the crude oil price using a step/uniform distribution. A range of likely natural gas prices is selected, along with a broader range of extreme prices. The natural has price will take any value between $3-7 per thousand cubic feet (Mcf) with a probability of 90%; while there is a 10% probability that the oil price will fall between either $2-3 per Mcf and $7-8 per Mcf. These values are also based on forecast

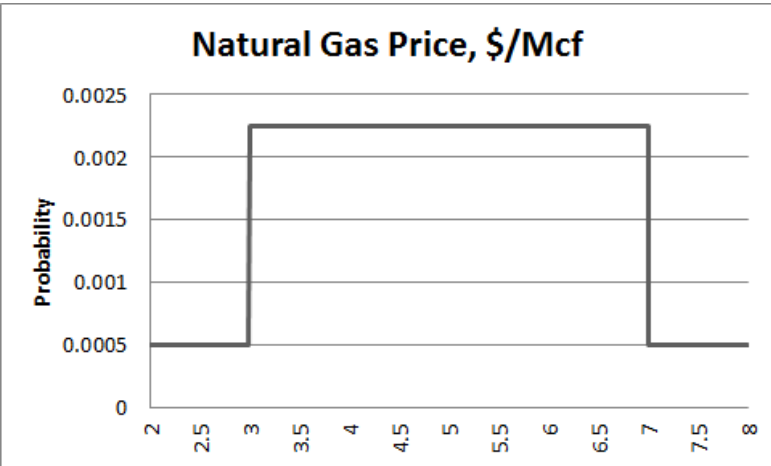data provided by the EIA to 2040.

Figure 13 – Natural Gas Price and Summary Statistics

6. Results

Figure 14 and Table 5 display the results of the 10,000 iterations that resulted from the Monte Carlo simulation at the discount rates used in this analysis. The NPV of each scenario is the result of one iteration of the model which illustrates a summation of the discounted cash flows over a 25-year lifespan of the project.

Due to the high capital costs that accrue to the project over the first six years of its life (including construction), the NPV is very sensitive to the discount rate that is selected. For instance, at a discount rate of 8%, 4.82% of the iterations were found to result in a negative NPV; at a discount rate of 12%, resulted in about 43.98% of the iterations showing a negative NPV. Further, there is a significant drop in the average NPV that is generated from using these different discount rates, from about $4.727 billion at an 8% discount rate to just $305.024 million when calculated at the 12% discount rate.

These results shed some light on the high cost, high risk nature of GTL technology that has so far gained little footing in the global energy market with just four plants currently in operation. The financial risk stems from natural gas and crude oil price volatility and the high upfront capital costs that negatively affect the viability of GTL. If a discount rate of 12% or higher is used by a potential GTL investor, the high risk and low upside to a B.C. plant that is configured to Sasol's proposed Alberta plant specifications would likely prevent them from making the decision to invest. However, at a slightly lower discount rate between 8-10%, a project of this size has a significantly more favourable NPV.
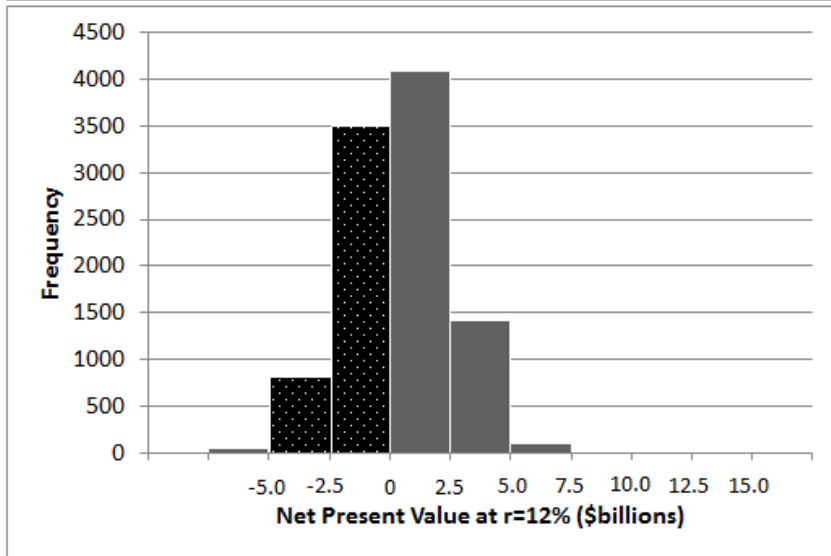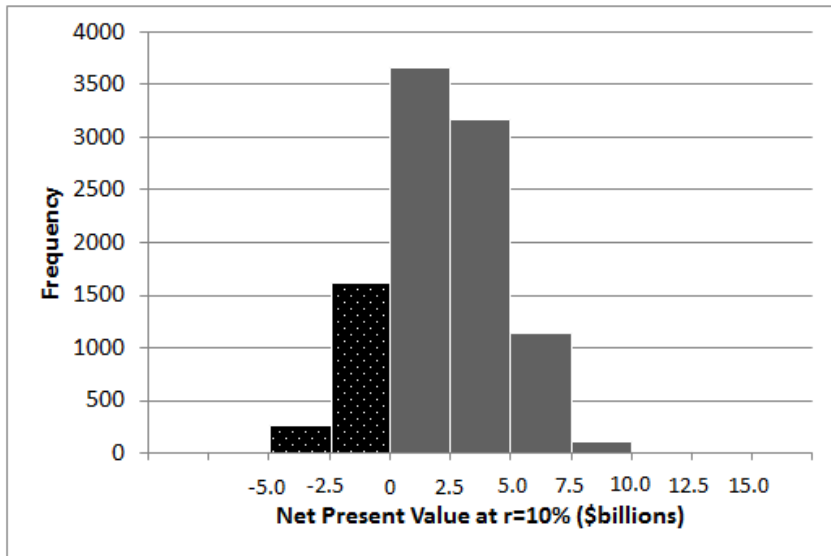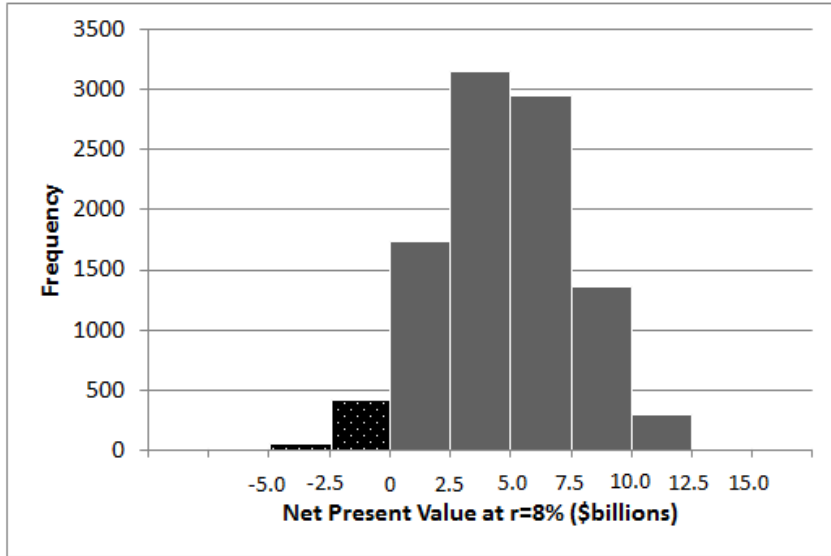
Figure 14 – Histograms of 10,000 iterations showing NPV at r=8, 10, 12%

Table 4 –Summary Statistics of NPV at different discount rates

Discount Rate	8%	10%	12%
Mean	$ 4,727,806,886	$ 2,164,843,683	$ 305,024,770
Maximum	$ 15,048,906,719	$ 11,131,861,819	$ 8,428,030,269
Minimum	-$ 6,106,102,732	-$ 6,917,506,576	-$ 7,637,778,502
Standard Deviation	$ 2,870,340,569	$ 2,431,329,369	$ 2,093,096,221
Percent of iterations where NPV<0	4.82%	18.06%	43.98%

Government Revenues

Table 4 below displays the average total and average yearly revenues that will accrue to the different levels of government over the 25-year operating life of the project. The project supports B.C. and Canada's strategic imperative to add value to its abundant natural resources. In addition to the generous contribution to employment in B.C. for both construction and operation (as outlined in section 2) as well as the royalty payments that the province can expect for its natural gas, the project contributes significantly to the fiscal balance of the three levels of government through tax payments, including:

- Municipal property tax payments averaging $49 million per year;
- B.C. corporate income taxes which average $73 million per year under the LNG Tax framework;
- Carbon tax payments which will average $166 million per year; and
- Federal corporate taxes which will average $321 million per year.

For B.C. alone, the project will contribute a total of $7.22 billion on average to the province directly through tax payments, with an additional $8.04 billion in tax payments going to the federal government over the life of the project on average.

Table 5 –Revenues to the different levels of government ($millions)

	Provincial Income Tax	Carbon Tax	Municipal Property Tax	Federal Income Tax	Total Provincial	Total
Rate	1.5% until costs recovered; 3.5% until 2037; 5% beyond 2037	$30/tonne of CO_2e	$49 million per year	15%	-	-
Average total over lifetime of project	$ 1,835.63	$4,157.00	$1,225.00	$8,036.98	$7,217.63	$15,254.61
Average total yearly payments (operational)	$73.43	$166.00	$49.00	$321.48	$288.71	$610.18

Due to the high cost environment and lack of infrastructure and labour force, B.C. may require appropriate incentive packages to entice investors to choose the province over competing jurisdictions that may be found to be more profitable. This could come in the form of lowering the carbon tax applied on this project in particular, which may be warranted given the clean burning properties of GTL products. A sort of 'well-to-wheels' analysis of the projects overall contribution to greenhouse gas emissions may be used to take into account the displacement of diesel imports with the cleaner burning product that the GTL facility will produce. At the federal level, tax breaks in the form of a higher capital cost allowance applied to the project could be instrumental to encourage the investment.

7. Conclusion

The economics of oil and gas sector investments depend on many uncertain factors. A Monte Carlo cost-benefit analysis framework can take into account multiple sources of uncertainty and their interrelationship. This paper demonstrates a VBA application of a Monte Carlo method for evaluation of the investment of a GTL facility in B.C. It generates NPV probability distributions for three different discount rates and finds that the decision to invest will likely be very dependent on the particular discount rate that is used. In the chosen range of commonly used private sector discount rates, the project's economics range from generally favourable, to quite risky with a low upside.

The proprietary nature of the GTL process will make it inherently difficult to attract one of the few investors to what has been considered a high-cost environment in B.C. For these reasons, it may be in the province's best interests to consider incentives and tax breaks that will help make it a more competitive environment to invest.

Given that one of the major barriers to a GTL investment is the high capital costs, another solution may be to think smaller. New developments in GTL technology have allowed plants to be scaled down to provide a cost-effective way to take advantage of smaller amounts of natural gas feedstock. Such plants are designed to produce anywhere from 1,000-15,000 bbl/d of liquid fuels. Their modular structure makes microchannel reactor systems very flexible. The plants can be scaled to match the size of the resource, expanded as necessary, and potentially integrated with existing facilities on refinery sites to create value from associated gas (Lipski, 2013). Therefore, these smaller scale plants have shorter construction periods, are more responsive to changing market conditions, and much less risky. Until GTL technology is further developed to potentially bring down the high upfront capital costs and developers are convinced that the divergence of gas and oil prices will be sustained in the long-term, a smaller scale GTL facility would likely be a much more feasible proposition for B.C.

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