Challenges and Opportunities for the

Production of Ethanol from

MPB Killed Biomass in Interior BC.

Stuart Sinclair

B.Sc., University of Alberta 1991

Project Submitted In Partial Fulfillment Of

The Requirements for The Degree Of

Master Of Business Administration

The University of Northern British Columbia

April 2009

1. ABSTRACT

The short-term over supply of biomass feedstock in the Interior of British Columbia resulting from the Mountain Pine Beetle (MPB) infestation has created a mix of challenges and opportunities for the development of a biofuel industry. Several challenges include: the current economic downturn, difficulty in obtaining financing, insufficient government support, lack of security of long term biomass supply, and technological limitations. There are also several opportunities, which need to be maximized in order for this biofuel industry to succeed. They include: the growing market demand for biofuel, new approaches to biomass utilization, high value co-products, inter-industry synergies and utilizing short-term availability of beetle killed wood, which offers cost and time savings as well as higher yield capacity.

This project was designed to identify the opportunities for, and the barriers for biofuel production, specifically ethanol, to determine if it would be a potential component to a successful rural economic development plan, while at the same time providing additional salvage opportunities for dead pine stands in the Interior of BC. The results indicate that the dead pine biomass does provide significant short-term opportunities, however persistent technological barriers, uncertain economic times and long term fibre supply issues still present barriers that need to be overcome.

2. CONTENTS

2.1 Table of Contents

2.2 List of figures

2.3 List of tables

3. ACKNOWLEDGEMENTS

I would like to thank the many individuals who have assisted with this project. First, I would like to express my appreciation to Dr. Paul Bowles for his guidance and patience during this project. I would also like to thank Ibrahim Karidio for his enthusiasm and initial direction. I would also like to acknowledge my committee member Bryan Bogdanski, the MBA program administration, professors, and my cohorts for their patience, dedication and support.

I would also like to thank Fiona Lamprecht for her world class editing skills and keeping me motivated through this project. Most importantly I would like to thank my wife, Jeannie Sinclair, for her continuing support and encouragement throughout the entire MBA program.

4. BACKGROUND

4.1 Introduction

An increasing social and economic demand for biofuels has presented the Interior of British Columbia with the opportunity to use its abundance of dead pine biomass for the production of ethanol for use as a transportation fuel. Public policy, such as the *2003 Climate Change Plan for Canada,* has encouraged advances in biofuel technology by setting targets to reduce green house gases (GHG) through increased use of ethanol blended gasoline. As a result, the technology employed in the manufacture of transportation fuel from biomass has gained momentum as the leading technology to produce ethanol from lignocellulosic (plant biomass composed of cellulose, and lignin) feedstock.

Once the Mountain Pine Beetle (MPB) infestation in the British Columbia (BC) Interior has run its course, close to 1.4 billion cubic metres of wood, and over 13.5 million hectares of forest will have been killed (Mountian Pine Beetle 2008). The potential economic, social, and environmental impacts of this catastrophic insect infestation are just beginning to be realized. The importance of finding alternate uses for this dead fibre, once it is no longer of use to the lumber and pulp industries, is significant in minimizing the short and long term economic and social impacts on the communities of Interior BC and the province of BC as a whole. The provincial government, which is responsible for the stewardship of the forested lands in BC, has had limited success in providing incentives, opportunities and leadership towards significant economic use of this surplus fibre. Despite this abundance of surplus woody fibre from dead pine trees (hereon referred to as *biomass*), there are several barriers to the development of a sustainable biofuel industry in the province of BC in general, and more specifically the Interior Region of British Columbia. This paper will provide an overview of these challenges, as well as potential opportunities that exist in the utilization of the abundance of MPB killed biomass for commercial scale lignocellulosic ethanol production in Interior BC. There are several possible alternative uses for the dead pine fibre, such as pellet production and cogeneration of heat and power. However, this project focuses specifically on the potential of ethanol as an end use in the form of transportation fuel.

This project provides a general background and discussion of the importance of ethanol production as a potential use for dead pine by reviewing literature and conducting interviews with industry members. In order to provide an understanding of biofuels, an overview of first and second generation ethanol production and the biomass-to-fuel pathways for second generation ethanol production are presented. Following this overview of technologies, government policy is reviewed, along with incentives and how society's concerns over greenhouse gas emissions (GHG) may be addressed by lignocellulosic ethanol production.

Once the background is provided, the discussion moves to detailing the challenges facing lignocellulosic ethanol production, beginning with the economic interdependencies and how global economies and oil price uncertainty impact investment decisions. Additional challenges are then identified including issues around biomass supply and consumption, MPB shelf life, feedstock availability and pricing, biochemical technology barriers, and finally financing. Once the challenges are explained, the focus shifts to determining the opportunities for successful commercial production of ethanol in the Interior of BC. On the product demand side, a significant opportunity is for ethanol to be blended into gasoline and used as transportation fuel. These opportunities are explored and compared to the current biomass utilization, costs and availability. Further evidence is explored regarding the unique opportunities provided by the benefits of MPB killed wood for use in ethanol production, including cost and time savings and higher yield capacity. Finally, the discussion explores obtaining value from co-products as well as gaining inter-industry synergies by adopting a biorefinery model.

Conclusions and recommendations from the research and interview findings are summarized after the discussion under the general categories of ethanol demand, fibre supply, technology and economic interdependencies. The recommendations provide a course of action that can be implemented to overcome the various challenges and capitalize on the time sensitive opportunities provided by MPB fibre. This course of action required for a successful lignocellulosic ethanol industry in Interior BC includes taking the lead on sustainability, investing in risk reduction, seizing the short-term biomass surplus opportunity, enhancing government support and maximizing value with synergies and partnerships. Ultimately, it is hoped that all of these recommendations will contribute to the development of an alternate strategy for economic development in BC.

4.2 Objectives

In the process of reviewing literature and in consultation with industry participants, this study has the following objectives:

1. Provide an overview of challenges and opportunities that exist for the commercialization of lignocellulosic ethanol in Interior BC.
2. Identify a possible course of action and requirements for the development of a successful commercial biofuel industry in Interior BC.
3. Contribute to the development of an alternate strategy for economic development in BC.

4.3 Importance of this study

The 34 forestry dependent communities of Interior BC are a large economic driver for the province, historically providing between $600 million to $1.1 billion in direct annual revenue to the provincial government in stumpage alone (Ministry of Forests and Range 2009). The Urban Futures Institute conducted an analysis in 2005 that showed the forest industry accounted for 32% of British Columbia's economic base, and the Interior BC forest industry accounts for 60% of the forest sector, or approximately 19% of the province's economic base (Baxter 2005). The economic and social impact of the MPB to these communities and the Province of BC over the next decade will be significant. If we are unable to find economically viable alternatives to utilizing biomass from dead pine trees, then the survival of these communities and the economic well being of the province is threatened.

One potential alternative is utilizing the surplus dead pine biomass to develop a biofuel industry using cellulosic ethanol technology. A successful biofuel industry would provide several benefits, including a reduction of environmental impacts associated with the use of fossil fuels, economic diversification through increased rural development, and reforestation of MPB killed pine forests (Walburger, *et al.* 2006). The estimated 200 million cubic metres of MPB-killed timber that will not be utilized by the current forest industry presents an opportunity for the cellulosic ethanol industry (Pedersen 2003). It remains to be seen, however, whether this surplus of dead trees is a sustainable fibre supply, or at least sufficient enough to be considered a fibre source for the commercial production of ethanol in Interior BC.

4.4 Methodology

Research for this project was based on consultation of primary and secondary data sources. Interviews were conducted with ethanol industry participants from BC to collect firsthand information, and this primary data was used to supplement a literature review of various secondary data sources.

Interviews were conducted in person or via telephone with participants from across the lignocellulosic ethanol industry including existing forest industry incumbents, provincial government, and ethanol researchers and producers. Each interview consisted of a specific list of questions focused on collecting insight into the particular challenges faced by the biofuel industry in establishing commercial lignocellulosic ethanol production in the Interior of BC. A total of 5 interviews was undertaken and the results are presented without explicit attribution to the individuals. All interviews were approved by the UNBC Research Ethics Board. The secondary source of information for this project was a review of the literature available on biological lignocellulosic ethanol production and the BC MPB epidemic.

Data collected from interviews and the literature review was used to determine the status of the lignocellulosic ethanol production technology and to identify possible barriers or challenges, as well as opportunities that exist for commercial production from MPB killed trees in Interior BC. All aspects relating to the subject were reviewed, including:

1. Macroeconomics and market trends affecting the biofuel industry.
2. The status and limitations of biological technologies used to produce lignocellulosic ethanol.
3. The medium and long term supply trend of woody biomass feedstock in Interior BC.
4. The trends in biomass feedstock cost and pricing in Interior BC.
5. Challenges in obtaining financing for lignocellulosic ethanol plants.
6. The market demand for ethanol produced in BC and Interior BC.
7. Industry support in the form of government policies and incentives.
8. Opportunities in terms of biomass utilization.
9. Possible inter-industry synergies, such as in the Biorefinery model.

4.5 Quantity and spatial distribution of MPB biomass

Figure 1 provides an alarmingly clear visual illustration of the widespread spatial distribution of the MPB attack in BC. Although this indicates a large potential supply of feedstock for biofuel or bioenergy production, much of it may be uneconomical to access (Stennes & McBeath 2006). Of the 200 million cubic metres or 140 million tonnes (bone dry) estimated to not be utilized by the existing forest industry, only approximately 11 million tonnes (bone-dry) of MPB killed forest biomass would be available as feedstock for lignocellulosic ethanol production according to the BC Ministry of Forests and Range. This total volume of dead wood equals about 2.5 million bone-dry tonnes of MPB killed biomass annually for the duration of the current outbreak that could be made available to the ethanol industry (Mabee 2008).

It is important to consider where these dead pine forests are situated in relation to potential plant locations. One interviewee pointed out that the spatial distribution of surplus MPB killed stands will be in the back end of valleys, furthest away from existing infrastructure as the close, less expensive MPB killed stands will have already been harvested by the forest industry. The surplus dead pine stands are expected to be 100 to 130 km or greater from any potential plant site, which will significantly increase hauling and delivered biomass costs to over $100/tonne (Girvan & Hall 2008).

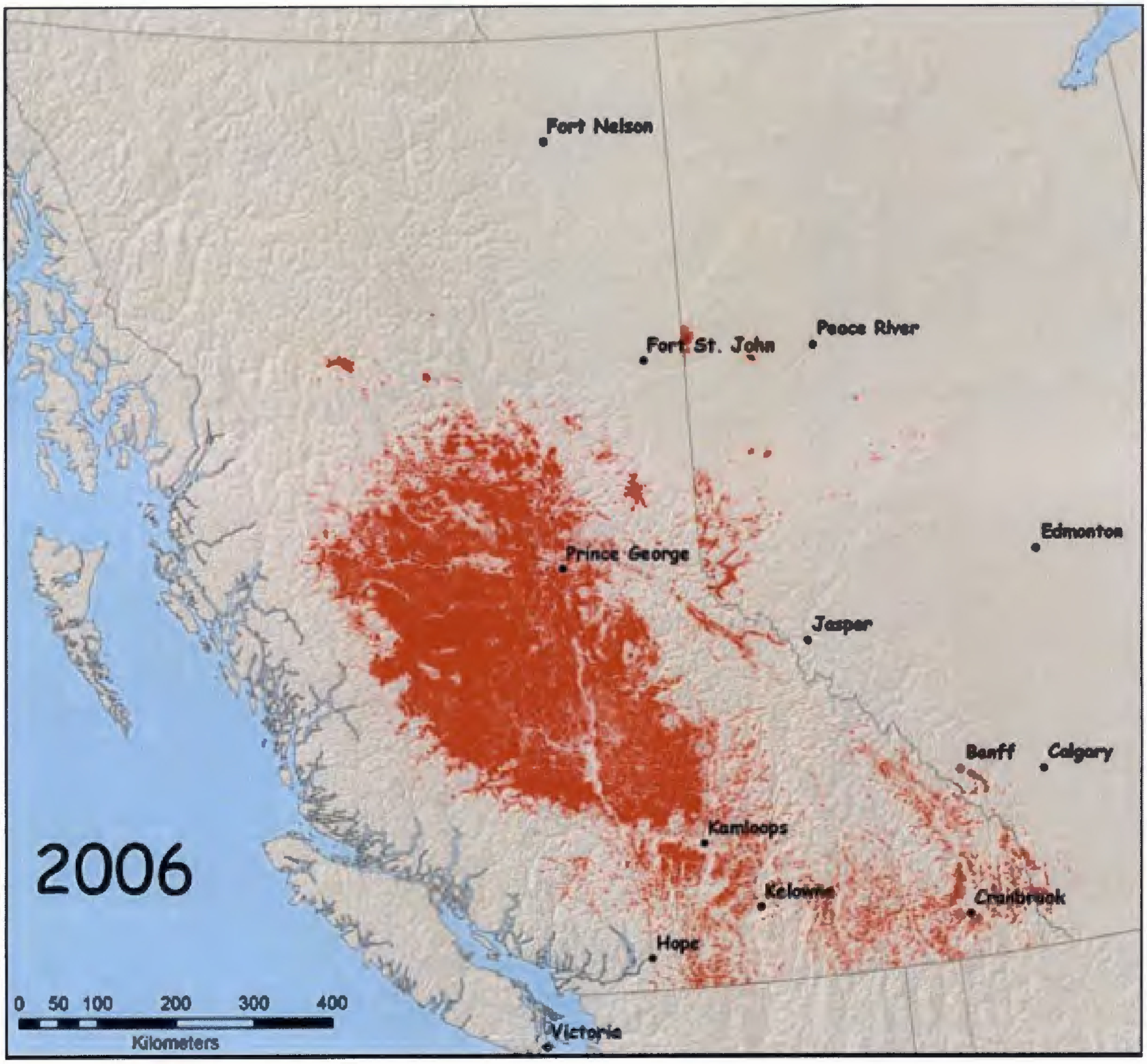

Figure 1. Spatial distribution of the MPB attack in BC (Mountian Pine Beetle 2008)

The Ministry of Forests and Range (MOFR) conducted a study in fall 2007 to estimate the potential tenure opportunity for bioenergy (see Table 1). The MOFR considered forest stewardship requirements, available low grade timber, and current Allowable Annual Cut (AAC) as a means to determine potential biomass AAC levels. Preliminary estimates show a supply of biomass feedstock within the Interior of BC.

However, these rough estimates did not consider the spatial distribution of the dead pine stands and the possibility of overlapping tenure conflicts.

Timber Supply Area	Potential AAC available for 20-year bioenergy tenures	Potential biomass available for 20 yr bioenergy tenures
Quesnel	725,000 m3/year	350,000 tonnes/year
Williams Lake	700,000 m3/year	400,000 tonnes/year
100 Mile House	225,000 m3/year	130,000 tonnes/year
Merritt	200,000 m3/year	117,000 tonnes/year
Kamloops	200,000 m3/year	117,000 tonnes/year
Lakes	300,000 m3/year	176,000 tonnes/year
Morice	225,000 m3/year	130,000 tonnes/year
Prince George	**1,300,000 m3/year**	**765,000 tonnes/year**
• Prince George district • Vanderhoof district • Fort St. James district	Nil 300,000 m3/year 1,000,000 m3/year	
INTERIOR TOTAL	**3,875,000 m3/year**	**2,280,000 tonnes/year**

Table 1. Timber supply areas and correlating potential AAC (MOFR 2007).

Complex models have been created to better understand the impacts MPB and current forest industry harvesting and utilization have on overall biomass fibre supply for the Interior of BC and the province as a whole. One such model, the BC Fibre Model, built by Jim Girvan and Murray Hall can be used to forecast net biomass by region and for the province. Figures 2 and 3 illustrate snapshots of the biomass situation in BC as depicted through the lens of Girvan and Hall's BC Fibre Model. In this model, biomass is defined as part of the AAC that is either harvested or not and not currently used by the existing forest industry. By using forecasted log consumption rates of the lumber and pulp and paper industry, it is possible to determine what the remaining available biomass is over time.

The BC Fibre Model was created with input from the MOFR to define assumptions made in forecasting forest industry activity. It is a very complicated forecast, but one that is believed to provide the most credible picture of available biomass within the framework of the government endorsed AAC.

Key assumptions over time include:

- Shelf life,
- Fall down in the AAC as a result of the MPB progression,
- Sawmill rationalization in the face of saw log shortages and
- Pulp mill response to falling residual chip and hog fuel supplies.

Figure 2 summarizes the net available biomass in the Prince George region, which includes the Prince George Timber Supply Area (TSA) and the Mackenzie TSA. The chart shows cumulative forest biomass on the right axis and net available on the left axis. From this chart, it is evident that biomass accumulates for a number of years within the region and then falls off dramatically as the AAC is reduced. By 2022, a deficit position is expected, since it was assumed that operation of the biomass consuming pulp mills would continue in the face of reduced sawmill activity (Girvan & Hall 2008).

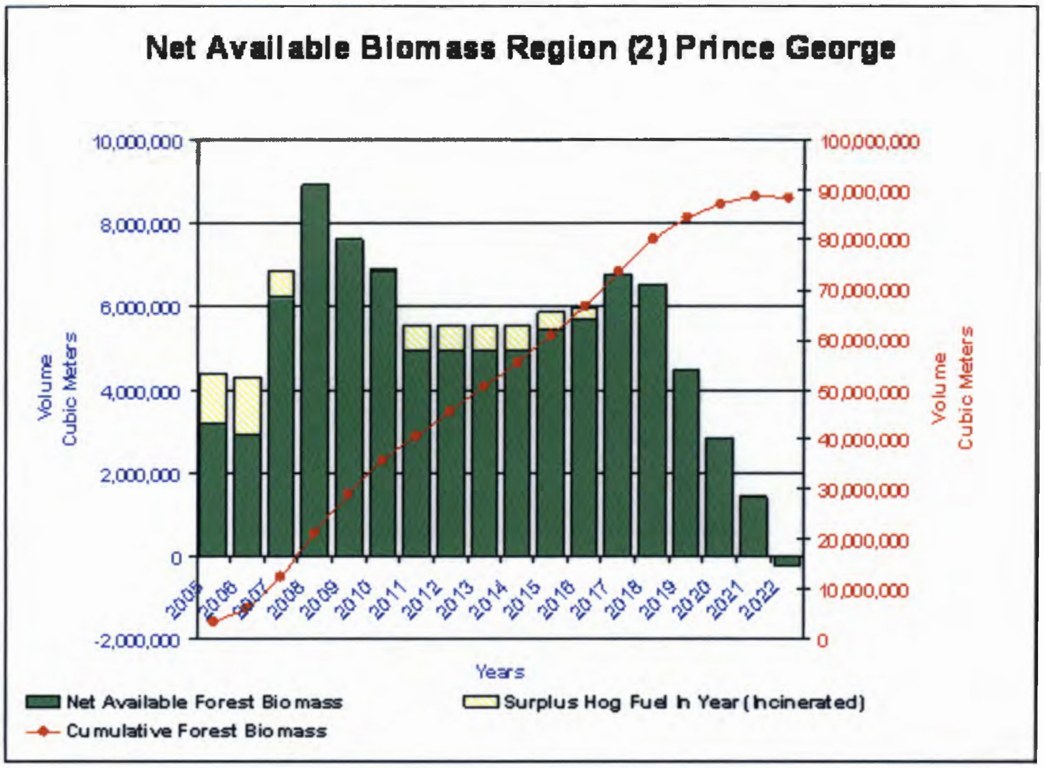

Figure 2. Net available biomass for the Prince George region (Girvan & Hall 2008).

According to Girvan and Hall, additional accumulative fibre supply due to MPB will only be increasing to around 2020. Overall biomass supply is expected to have a short-lived peak (at approximately 85 million cubic metres) with volume declining from this point forward as dead stands become uneconomical to harvest and existing under utilized residuals are used by the pulp and paper industry. Beginning in 2020 commercial ethanol producers will be faced with a significant barrier in that they will need to compete with the pulp and paper and/or power industries for available fibre.

It is evident that for the 15 Interior BC Timber Supply Areas that have been impacted by MPB (including Prince George and Quesnel), the current level of biomass supply is not sustainable, and unless existing biomass-consuming pulp, paper and power industries reduce production levels, a fibre supply shortage is likely to occur sometime after 2020. The authors of this initial BC Fibre Model are hoping to incorporate cost of biomass and to have a revision completed sometime in 2009 (Girvan & Hall 2008).

4.5 Overview of first and second generation ethanol production

There are different types or 'generations' of ethanol which vary according to production processes and type of feedstock used. First generation ethanol production uses agricultural products, including grains such as corn. Second generation biofuels use non-food crop biomass containing lignocellulose, a complex matrix that incorporates cellulose, hemicellulose, and lignin, which forms the structural components of plants and trees (Atchison 1993; Sjöström 1993).

The development and expansion of first generation biofuel production was one response to rising fuel prices over the past decade and the growing concern regarding greenhouse gas emissions. In Canada, the production of first generation ethanol from food grains is approximately 422 million litres/year (Canadian Renewable Fuels Association 2008). The use of food crops for the production of ethanol has become an issue in recent years, as increased demand for corn and wheat has caused grain prices to dramatically increase across the globe. These price increases have caused widespread speculation and social concern that food crops once available to feed people are now going into fuel production. Recent fluctuations in commodity prices have compounded the pressure on the first generation corn-based ethanol industry. Despite the drop in oil prices, many corn ethanol producers remain bound to fixed contracts for delivery of high priced corn and it is estimated that 40 out of 120 corn ethanol plants in the United States may file for bankruptcy in the first quarter of 2009 (Lakers 2008). Commercial production of second generation or lignocellulosic biofuel is claimed to be potentially more viable, and less costly than first generation biofuel as it uses diverse and abundant—sometimes difficult to dispose of—feedstock, while not diverting food away from the animal or human food chain, and thus addressing the "food versus fuel" debate (Decker 2009). However, second generation lignocellulosic ethanol is likely to suffer the same vulnerability to fluctuating commodity prices as first generation ethanol.

4.6 Biomass-to-fuel pathways for second generation ethanol production

Second generation biofuel or lignocellulosic ethanol can be produced using two different technological pathways, one biochemical and the other thermo-chemical. Neither pathway appears to be technically or commercially superior to the other and both are under continual research and development, and are yet to be fully proven on a commercial scale. However, the biochemical pathway for lignocellulosic ethanol production is currently being proposed by several ethanol industry members in BC because these biological processes present greater opportunities to further reduce costs and make it significantly cheaper than thermo-chemical processes (Sims *et al.* 2008). Due to the significant potential upside of the biochemical pathway and the prevalence of the number of industry participants exploring its use in Interior BC, this production process was the focus for this project.

Figure 3 shows a diagrammatic representation of the biochemical process pathways in the production of lignocellulosic ethanol with a magnification of the pretreatment effect on wood and forest residues. Lignocellulosic ethanol is produced from a process that involves pretreatment, hydrolysis, and fermentation of the resulting sugars from cellulosic sources such as wood residue, wood chips, agricultural residues, and grasses. An effective combination of pretreatment, hydrolysis, and fermentation is key to economical production of ethanol. Pretreatment is conducted by either a series of thermo-mechanical or thermo-chemical treatments that impact the efficiency of downstream processing steps. Once the cellulose and hemicellulose is released from the lignin, it is ready to be converted to hexoses and pentoses in the enzymatic stage. The final stage of fermentation of the five and six carbon sugars into ethanol is achieved by either Separate Hydrolysis and Fermentation (SHF) or Simultaneous Saccharification and Fermentation (SSF). SSF has been found to be highly effective in the production of ethanol, as the enzymatic and fermentation processes can occur in the same vessel while at the same time reducing capital costs (Schwietzke 2008).

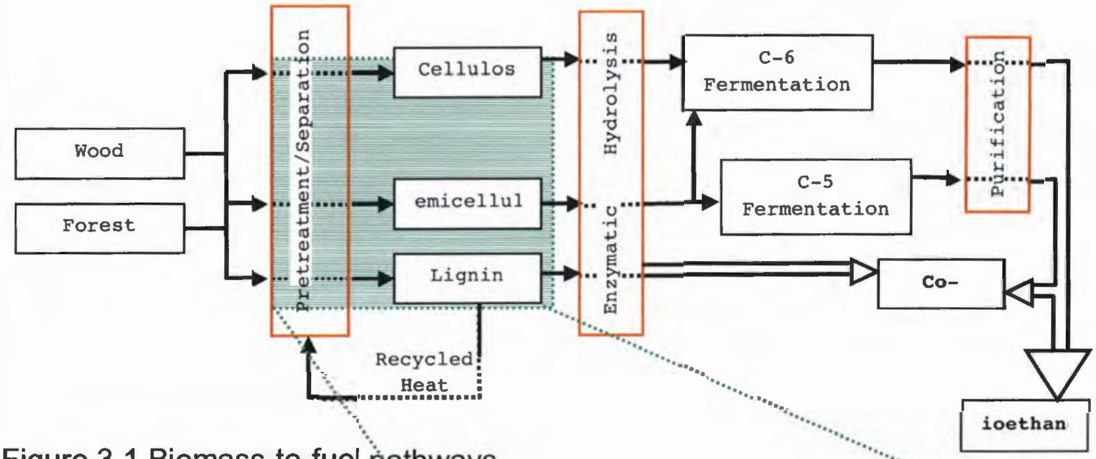

Figure 3.1 Biomass-to-fuel pathways.

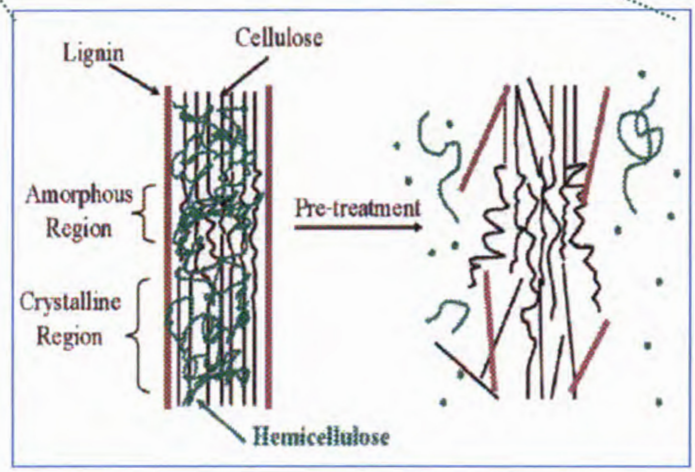

Figure 3.2. Magnification of pretreatment effect on lignocellulosic material (From Hsu *et al.* 1980)

Figure 3. Biomass-to-fuel pathways for second generation biofuels showing pretreatment effect.

4.7 Government policy and greenhouse gas emissions

The federal governments of Canada, the United States, Australia, and the European Union have imposed trade barriers in the form of import taxes on ethanol, which have reduced the overall international trade in ethanol. Inter-provincial trade barriers exist within Canada, further reducing the overall domestic trade of ethanol. In British Columbia, incentive for ethanol blended gasoline only applies to ethanol produced in BC. These trade barriers, tax exemptions and subsidies encourage ethanol production and use, however government support is rationalized not only to support the ethanol industry is in its infancy, but also to reduce greenhouse gas (GHG) emissions.

Biofuels such as lignocellulosic ethanol can help reduce GHG emissions and provide opportunities and employment for forest dependent communities in the Interior of BC. These positive aspects associated with lignocellulosic ethanol production will allow the provincial and federal government to continue developing policies and programs that promote the industry. These programs include excise tax exemptions on fuel, tax credits, capital grants, and other subsidies for biofuel production, consumption and research. Although these measures are aimed at encouraging ethanol production and use, they may also misrepresent the true market supply and pricing (Walburger *et al.* 2006).

Given the history of reliance of the ethanol industry on government support, any trend to move away from this support will place uncertainty around investment into lignocellulosic ethanol. Whether or not the government can provide tax exemptions, subsidies and mandated usage targets indefinitely is unclear and most likely dependent on free trade agreements, and the level of subsidies in ethanol producing countries such as the United States and Brazil. However, uncertainty around government support in the long run is a risk that should be considered as a potential barrier to the investment in second generation ethanol production.

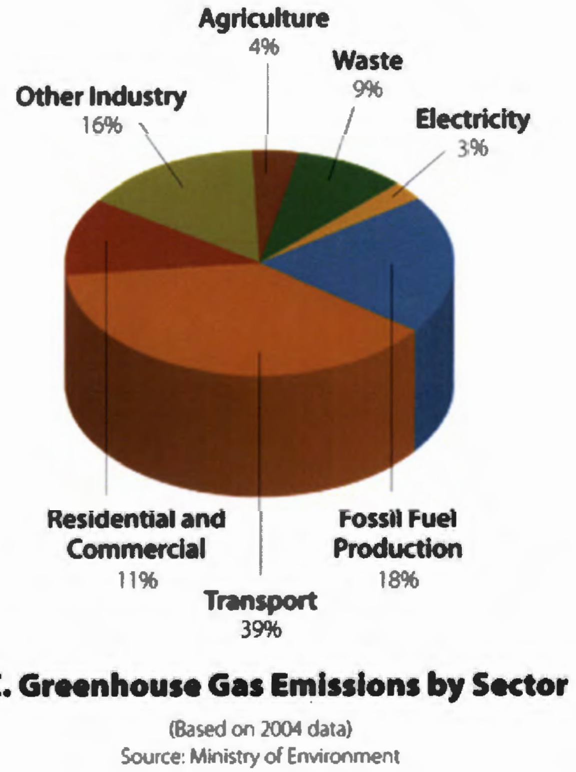

Figure 4. BC GHG emissions by sector (*The BC Energy Plan 2007*).

Figure 4 shows that the transportation sector in BC produces approximately 40% of provincial GHG emissions and therefore the use of renewable biofuels such as ethanol as transportation fuel provides a significant opportunity to reduce overall GHG emissions in BC.

Canada is a net exporter of energy and therefore does not need a biofuel industry to ensure its energy security. However, it is necessary to look at other rationales to support an ethanol/biofuel industry. These include reducing GHG emissions, increasing forestry and farming incomes, and promoting rural development. The effectiveness of reducing GHG emissions by production of ethanol from first generation biofuels is questionable, as the overall reduction in carbon emissions is limited and there are less expensive ways to reduce GHG emissions (Auld 2008). Only countries like Brazil, with the lowest average cost of producing ethanol from sugar cane, have a reasonably competitive CO_2 reduction per tonne compared with other methods of reducing GHG emissions. With lower feedstock costs, second generation ethanol production has a better chance of reducing the cost per tonne of CO_2 to a competitive level. If conversion yields can be achieved on a commercial scale, second generation ethanol production may provide support to the GHG reduction rationale (Walburger *et al.* 2006).

There have been several recent changes to Canadian federal and provincial subsidies designed to encourage the production and use of ethanol as a transportation fuel. Until April 2008, the federal gasoline excise tax of $0.10 per litre was not imposed on the portion of ethanol blended in gasoline. This program was replaced with a producer credit program that provides up to $0.10 CAD/litre directly to the ethanol producer. This producer tax credit program is graduated and the amount of the subsidy is based on the industry profitability. As the industry becomes more profitable, the amount of the tax credit declines.

The Ethanol Expansion Program (EEP) is another federal program aimed at increasing production and consumption of ethanol, with the goal to reduce transportation-related GHG emissions. Between 2003 and 2005, the EEP has provided contributions toward the construction financing of new or expanded fuel ethanol production facilities in Canada (Ethanol Expansion Program 2003). The Ethanol Expansion Program was part of the *Climate Change Plan for Canada*, which was created to meet the targets set in the Kyoto Protocol (Walburger *et al.* 2006). The federal government has also set a 5% ethanol content requirement be blended into all gasoline sold in Canada by 2010. Similar to the United States, Canada has imposed a $0.0492 CAD/litre import tariff on all ethanol imported, except from NAFTA counties. This import tariff increases the price of ethanol imported from cheap producers like Brazil.

Apart from these programs, the federal government committed $1.5 billion in the 2007 federal budget to provide incentives for the production of alternative fuel. $500 million of this funding was used to launch the NexGen Biofuels Fund that is managed by Sustainable Development Technology Canada (SDTC). This fund is focused on the production of second generation biofuels from biomass including cellulosic ethanol by funding demonstration facilities. The fund provides up to 40% funding of 'first of its kind' demonstration plants in Canada that produce renewable fuels that have been proven in pre-commercial pilot projects (News Room 2007). These funds have also been used to set up the BC Bioenergy Network that has recently awarded $1.82 million to Lignol Innovations Ltd. This financial support will be used to develop

Lignol's fully integrated biorefinery pilot plant located in Burnaby BC (BC BioEnergy Network 2009).

The British Columbia Provincial Government's bioenergy strategy is aimed at "establishing BC as a world leader in bioenergy development" and in so doing, promoting the production of liquid biofuels to meet Renewable Fuel Standards and displace conventional fossil fuels (*BC Energy Plan 2007*). To help achieve this, there is currently a provincial subsidy providing 14.5 cents/litre for E85 fuel, which must contain 85% ethanol, and the ethanol must be produced in BC (Natural Resources Canada, 2008). In addition, the province of BC was one of the first jurisdictions in North America to introduce a carbon tax on all fossil fuels in July 2008. This carbon tax is applied to all fossil fuel types consumed in the province including a 2.41 cents/litre on gasoline, which is scheduled to increase to increase to 7.24 cents /litre by 2012 (Ministry of Finance 2008). Biofuel and renewable energy, including ethanol are not subject to the carbon tax and can be considered an additional subsidy.

Life-cycle emissions of biofuels compared with that of liquid and gaseous fossil fuels in the transport sector show biodiesel and ethanol could yield significant reductions in GHG emissions. Engines would require no modifications to run ethanol-petroleum or ethanol-diesel blends up to 15% or any biodiesel-diesel blend (Calais and Sims 1999). Dr. Tom Beer and Dr. Tim Grant's full-cycle analysis of GHG emissions from light vehicles found that hybrid electrical vehicles produce the lowest level of GHG emissions overall and are better health-wise and for the environment. The migration to electric vehicles is inevitable, but is considered a longer term prospect that should not be prohibitive for the immediate demand for ethanol for blended biofuels required for the first step in the hybrid vehicle direction. The demand for transportation fuels, and thus ethanol, will continue long into the future, after the economic opportunity for surplus MPB killed biomass available in the Interior BC has been realized with its use as biofuel feedstock. Thus, the expected demand for ethanol is not a limiting factor for the commercial production of lignocellulosic ethanol from MPB killed timber in Interior BC.

5. CHALLENGES

In order to determine the challenges for the commercial production of ethanol from MPB killed timber in Interior BC, aspects relating to the subject were reviewed. This review included the status of the current technology, the market or demand of ethanol biofuel, the biomass feedstock supply available from MPB killed forests, government policies and incentive programs, and market and commodity trends.

5.1 Economic interdependencies

5.1.1 Global economic downturn

The global economic downturn that began with the fall of the housing market in The United States in 2007 has resulted in an estimated 50% reduction in the capacity of lumber production in Interior BC. The US housing crisis and resulting worldwide financial crisis are global economic issues that have a direct impact on the production of ethanol in Interior BC. The reduction in lumber production has greatly reduced the amount of chips and the availability of other biomass residuals. This, combined with tightened capital markets and large corporate losses in the forest sector reduces the likelihood of an industry incumbent, or a new market entrant, to start a new ethanol venture, at least until an economic market recovery occurs - by which time optimal timing for utilization of MPB biomass would likely have passed.

Long term and short-term fossil fuel price trends and fluctuations are also seen as a potential barrier to the success of the industry. As seen in the US corn ethanol industry, wild crude oil price fluctuations can cause the industry to over expand and then collapse as the price of oil tumbles. Most business models for lignocellulosic ethanol production estimate crude oil prices between $70- $80 USD per barrel when determining expected cash flow. These estimates, which may have seemed reasonable for the past 5 years until oil prices crashed in the fall of 2008, are now called into question. Nevertheless, long term trends indicate that crude oil prices will gradually return to the estimated price range (see Figure 5).

Production interdependencies are already a key to the success of the current wood pellet industry in Interior BC. However, the current economic downturn has forced the forest industry in BC and across Canada to curtail production. Thus, biomass feedstock supply for the wood pellet industry has also been reduced, which further magnifies the interdependencies between biomass and primary forest products in the context of this economic downturn. The majority of wood pellets produced in Interior BC are exported to Europe for power production and long-term contracts for pellet volumes were based on the traditional volume of residual fibre supply from sawmills. This decrease in biomass supply with the same level of demand has caused the price of biomass feedstock to rise and the pellet industry has started to seek other options to secure biomass supply. One of these options, although not ideal, is to collect biomass from the forest, grind it and truck it directly to the pellet plant. This feedstock interdependency is a significant barrier to entry for any ethanol producer in the current economic downturn as available residue fibre has decreased significantly.

5.1.2 Biofuel competition

Competition from low cost first generation biofuels such as the import of ethanol from Brazil should also be considered a potential challenge to the success of a cellulosic ethanol production in Interior BC. Brazil is currently the largest exporter and lowest cost producer of biofuel ethanol in the world. In 2005, Brazil produced 18.2 billion litres of ethanol from sugarcane (Tokgoz 2006). The cost of ethanol from Brazil in 2006 was $0.23-0.29 USD per litre, which is significantly lower than the estimated cost range of $0.35 -1.30 USD for cellulosic ethanol produced in Interior BC (Northwind Ethanol 2008; Sims 2008). In 2007, Canadian ethanol imports were approximately 500 million litres or 60% of our domestic ethanol production. Canada applies a $0.0492 USD/litre import tariff on ethanol from countries outside of NAFTA, which increases the price of import ethanol, however not significantly enough to reduce its competitive pricing.

5.1.3 Oil price fluctuations

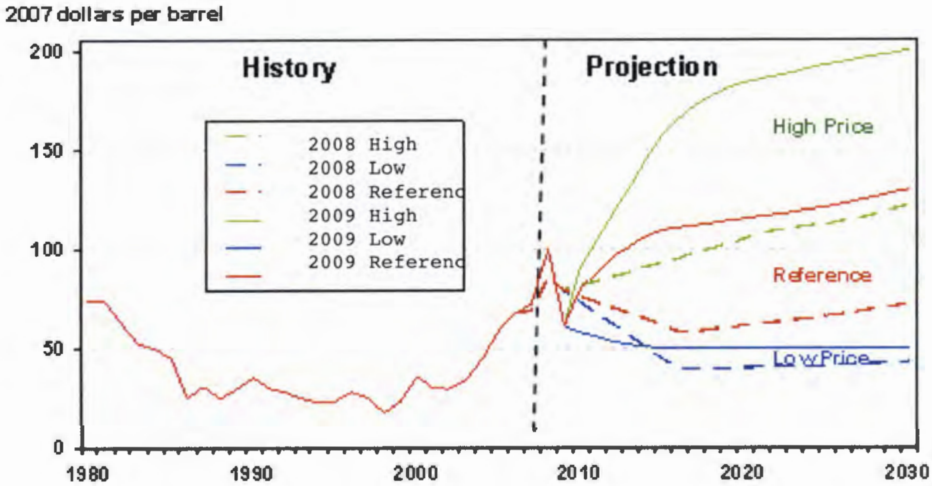

Figure 5. Oil price predictions (US Department of Energy 2008)

As seen in Figure 5, since 1998 oil prices have increased due to a combination of growing demand for petroleum products, increasing instability in the Middle East, and natural disasters that have adversely affected productivity. Increases in global crude oil prices contribute to higher transportation fuel prices in Canada. Despite the higher prices, total gasoline and diesel demand continued to increase between 2002 and 2008. By the first half of 2008, however, consumers began responding to higher fuel prices by changing their consumption pattems, which in turn started to reduce the transportation demand. As such, it can be assumed that any significant long term increase in transportation fuel prices will continue to have a negative impact on the Canadian economy (Canadian National Energy Board 2009).

Predictions of oil prices vary in the literature depending on the time of writing. However, all authors agree to a continual rise in long term oil prices. Higher prices are expected once the global economy recovers and the supply of low cost oil is expected to continue to diminish as demand from emerging economies remains strong. According to the US Energy Information Administration (EIA), world crude oil prices will average $60 USD/bbl in 2009 and begin to rise slowly as the global ecomomy and oil demand recover. By 2030 the average price of crude oil is expected to be $130 USD/bbl (2007 US dollars) (US Department of Energy 2008). Oil price predictions carry a huge level of uncertainty which creates price uncertainty for ethanol and inturn makes investment decision into ethanol production difficult.

Probably the most significant detriment to the profitable production of lignocellulosic ethanol in BC in the next couple of decades is the cost of production relative to gasoline, ethanol's primary substitute. Competitiveness of ethanol relative to gasoline is dependent on the price of crude oil verses the price of biomass feedstock. If the price of crude oil rises and the price of feedstock drops, then ethanol becomes competitive. However, if the reverse occurs, it is not competitive. This dependency on global trends in commodity prices of crude oil makes investment in second generation ethanol a somewhat high risk venture.

5.2 Biomass supply and consumption

5.2.1 Biomass supply issues

Key issues with any energy source are its physical availability and access to it. The importance of location of the biomass for lignocellulosic ethanol production is no different. Interviews confirmed potential barriers identified in the literature regarding variations on fibre supply issues. All participants concur that long term fibre supply will not be available from the current solid wood industry in the form of residuals, as these fibre sources are for the most part already being utilized. Also the amount of sawlogs and biomass available to the industry will be decreasing in the medium term (Girvan & Hall 2008). The industry participants realize biomass feedstock will need to be sourced either directly from the forest or from partner processing plants. Participants also provided a range of $30 to $60/tonne that they would be able to pay for their biomass feedstock and remain financially viable. They also expressed that fibre price and supply security over a 20 to 25 year planning horizon would be key to their success. Participants suggested the amount of fibre that would be required to support a commercial ethanol plant ranged from 60,000 to 350,000 tonne of fibre per year. The relationship between local biomass feedstock prices and global crude oil price was also verified as a potential barrier to the lignocellulosic ethanol industry.

5.2.2 Biomass consumption issues

In order to determine if a lignocellulosic ethanol plant would have a sustainable fibre supply in Interior BC, a review of the estimated consumption is required. The biomass consumption estimates provided in the literature and through the interview process vary widely, and the main reason for this is the discrepancy between conversion technologies and differing opinion on what size plant would be required to be commercially feasible. Table 2 shows the wide range in plant size estimates and respective amounts of cubic metres of wood required.

Plant type	Plant capacity Litre/year	Plant Biomass consumption Tonne/year	Cubic Metres of wood required/year*
Demonstration Plant	40,000-500,000	100-1,200	170-2040
Commercial	25-50 Million	60,000-120,000	102,000-205,000
Large Commercial	150-250 Million	350,000-600,000	600,000-1,020,000

Table 2. Expected biomass feedstock requirements (Sims 2008)

**Assumed ethanol conversion plant efficiency at 4,00l/dry tonne (litres per tonne of cellulosic feedstock) and 1.7 cubic metre/tonne of biomass at 20-25% moisture content*

A comparison between the estimated amount of biomass available and the amount required to operate a commercial scale lignocellulosic ethanol plant indicates that sufficient supply is available in Interior BC. However, the temporal and spatial distributions of this biomass supply are a significant risk to success. The 85 million cubic metre surplus of biomass in the Prince George Region created by the MPB infestation will only be economically harvestable as long as the trees remain standing, which is until approximately 2020 (Girvan & Hall 2008). If construction of an ethanol plant were to begin as early as June 2010, and assuming one year for construction and commissioning the plant, there would only be approximately eight years to take advantage of the dead pine surplus volume before it starts to decline and become uneconomical to harvest.

5.2.3 Shelf life of MPB biomass

The huge surplus of biomass in BC is in the form of lodgepole pine (*Pinus contorta*) trees, one of the most dominant softwood species in western Canada, which are in various stages of attack by the MPB. These trees suffer fibre loss and decay becoming unsuitable for structural materials and present dangerous forest fire hazard to surrounding communities (Eng *et al.* 2005). The extensive damage to pine forests is not only a fire hazard; it threatens the future health of the BC forestry industry and the viability of the 34 forestry dependant communities in the Interior of the province (Baxter 2005). From 1998 – 2007 (inclusive), the MPB killed an estimated 620 million cubic metres of pine in BC, which is almost half of the total of BC's merchantable mature lodgepole pine – approximately 1.8 billion cubic metres with an estimated mortality rate of 80% by 2013. The resulting 1.4 billion cubic metres of dead pine will only remain marketable for a short period of time (maximum 5 - 20 years). The widespread distribution of the MPB attack shown in Figure 1 indicates how important correct management of these dead pine stands will be for the economic well-being of the province.

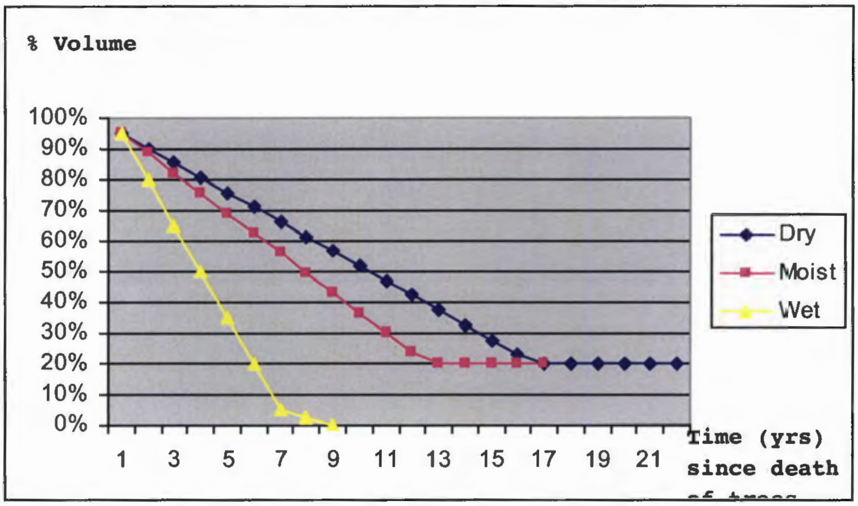

Figure 6. Shelf life of dead pine trees in Interior BC (Girvan & Hall 2008).

The shelf life, taken into account by Girvan and Hall's BC Fibre Model, is the length of time a pine stand remains economically viable to harvest. Many factors affect economic shelf life including site and stand characteristics, as well as distance from the mill. As shown in Figure 6, there is a relationship between soil moisture and the rate of wood deterioration. In wetter sites, the dead pine trees may rot and fall over within a few years after death. In drier areas they may remain standing for 20 years or more. In either case, once a tree falls over, it will very quickly lose any remaining value. Most pine leading stands are on well drained, relatively low nutrient sites where pine outperforms other species. In most cases, pine trees are expected to remain standing for 15 years or more after death. In this study, it was assumed that after 20 years the pine stand was either harvested or had become uneconomical to harvest due to the dead pine trees falling over and losing their value.

5.3 Biomass feedstock costs and pricing

Biomass feedstock pricing is very much dependent on its supply and how far producers need to haul fibre to the plant in conjunction with the demand for other forest products including lumber, pulp and paper, and wood pellets. Traditional fibre prices for the pulp industry in Interior BC have ranged between \$60 CAD/tonne for wood chips/residuals from saw mills to \$140 CAD/tonne or \$75 CAD/m^3 for delivered logs from the forest. Currently in the Prince George region, biomass is being collected from harvesting residuals that are left as roadside debris piles. These piles are collected, ground and trucked to a pellet plant in Prince George for an estimated cost of \$40-\$50/tonne with an air-dried moisture content ranging between 20-25%. However, these roadside debris piles will not be available indefinitely. From approximately 2020, when biomass supply in Interior BC is expected to begin to decrease, fibre supply contract prices will most certainly increase above \$100 CAD/tonne. The ethanol industry should therefore take into account this expected fibre shortage and price increase and perhaps find ways to avoid relying on competing with existing industry. The trend in fibre supply and pricing is dependent on the demand for other forest products including lumber, pulp and paper and wood pellets. These existing industries are expected to provide competition for biomass feedstock. With the sinking supply from 2020 onward, competition and prices for fibre will only increase. Unless the current ethanol conversion technologies become more cost effective, they will not have the ability to pay the higher biomass feedstock prices.

Biomass tends to have relatively low energy density compared to fossil fuels. Air-dried biomass has approximately 10-15 GJ/tonne, whereas coal is double or approximately 20-25 GJ/tonne (Sims 2008). This low energy density of biomass is further hampered by its moisture content, which makes it difficult and costly to transport, handle and store. Air-dried biomass can still contain up to 25% moisture, which over a short haul distance may not impact price per GJ of delivered energy, but this becomes a significant issue when designing plant size. In order to reduce production costs to an economically feasible level, the plant must be of a significant size. Estimates from players in the ethanol industry indicate that a cost effective plant will need to produce 100 million litres/year, which equals inputs of 250,000 to 300,000 tonnes of biomass. Keeping in mind, this biomass will need to be hauled from a distance up to 100 - 130kms away from the plant. These costs and logistics are often overlooked in the development of a facility that depends on a steady supply of biomass feedstock (Fulton 2004). If it is not assumed that harvesting feedstock from MPB infested stands will be forced further and further away from the plant, road construction and transportation costs may increase so significantly and even cancel out any assumed economies of scale. Therefore, a realistic view of the energy density and spatial distribution of biomass earmarked for commercial lignocellulosic ethanol production is crucial in evaluating the costs of this feedstock over the lifespan of the plant.

5.4 Biochemical technology

Individuals interviewed in this study highlighted suboptimal efficiencies in current process integration and individual technologies to be significant barriers. Each separate component of the pretreatment, hydrolysis, and fermentation processes are proven technologies, however, the overall process is not yet proven and requires additional technology and control systems to ensure the development of a cost effective commercial scale plant (Sims *et al.* 2008). Scalability of existing technology is also an issue as construction costs for a demonstration plant is half of that for a full sized commercial plant, and therefore investors are unwilling to invest in a demonstration plant and yet, at the same time, are reluctant to invest in a commercial plant if the overall process is not proven at a scale that makes it efficient.

Challenges in the commercialization of lignocellulosic ethanol present themselves not only in improving the overall process synergies, but also in the fundamental effectiveness of pretreatment stage technology. For example, the stubborn nature of the lignin and its ability to reattach itself to the cellulose during the pretreatment stage means that if the lignin is still present on the cellulose, the enzymes are unable to access and convert the cellulose into sugar. Current research is focusing on determining which types of pretreatment most efficiently match which hydrolysis and fermentation technology in order to reduce enzyme costs and increase fermentation yields. There is also a need to improve process economics and synergies by creating opportunities to capture co-products that could contribute to the revenue stream. The end product focus is ethanol, however lignin can be viewed as either a byproduct that must be disposed of or a co-product that can be burned to provide energy inputs into the process or sold as a commodity.

Once enzymatic hydrolysis is complete, the six carbon sugars are fermented into ethanol using proven yeast fermentation processes. The five carbon sugars, however, are more difficult to ferment, which presents another opportunity to find enzymes that can effectively utilize both hexoses and pentoses to produce increased ethanol yields. Based on a review of the literature, it is estimated that current ethanol yields from lignocellulosic feedstock range between 0.12 and 0.32 L/kg (undried), depending upon the efficiency of five carbon sugar conversion (Mabee 2006).

The variability of forest based biomass feedstock is another potential barrier to the commercial production of ethanol due to the high sensitivity of pretreatment performance to varieties of different biomass feedstocks. There is a huge variation between trees in different areas and at different stages of MPB attack. A variety of different fungi can also colonize the trees after attack (Kim *et al.* 2005), and moisture and other environmental factors can differ widely. These factors make it difficult to determine what the properties of a particular sample of biomass will be, and emphasize the importance of having a robust process that is effective for a variety of feedstocks with variable characteristics. The use of more consistent agricultural residuals as biomass feedstock is, however, not a solution for reasons already mentioned, but most importantly because it represents a small opportunity compared to the supply of forest-based biomass in Interior BC.

All processes that convert cellulosic biomass into ethanol require significant energy and chemical inputs. Specifically, high energy inputs occur during the pretreatment stage where large amounts of electricity, steam, chemicals, and/or heat are required. The success of ethanol production is directly impacted by the cost of these energy inputs and conversion efficiencies. Depending on the pretreatment process, lignin may be available as a co-product that can be burned to produce steam and power, thus reducing energy inputs significantly. Other options include co-development of an ethanol plant at an existing pulp mill site that already produces steam, heat and electricity. However, if these options are not available, then fluctuating energy and chemical costs and high overall process costs are considered to be a significant barrier to commercial scale cellulosic ethanol production. Greater energy and chemical efficiencies are not only cost effective, but also improve the ethanol's lifecycle and carbon footprint.

Production cost estimates for first and second generation ethanol differ in the literature and within the ethanol industry. However, most sources agree that the current technologies for second generation ethanol are approximately three times more expensive per litre then first generation technology. A cost range of $0.80-1.00 USD/litre by the International Energy Agency includes most estimates found in the literature (Sims *et al.* 2008). These higher production costs may be reduced through conversion improvement, however the lower cost feedstock for second generation ethanol make, it the long term viable form of ethanol production.

5.5 Securing financing

Ethanol producers face challenges obtaining start-up capital from traditional financing institutions, as bioenergy initiatives—least of all first-of-a-kind commercial scale operations—have a less favourable risk rating compared with more well-established energy technologies. The first commercial scale lignocellulosic ethanol plants are currently either in construction or commissioning phases with companies like Iogen in Canada, Diversa/Celunol in USA and Abengoa in Spain. The capital costs for a medium sized commercial plant that produces 50 to 150 million litres of ethanol per year is estimated between $125-250 million (Sims *et al.* 2008). Northwind Ethanol is currently constructing a demonstration plant in Prince George that will use wood residue to produce ethanol. Northwind is assuming a two-phase plant with total capital costs of $40 million USD producing 75 million litres of ethanol per year (Northwind Ethanol 2008). These numbers seem optimistic, however, they provide a benchmark for Interior BC. It should also be noted that significant cost overruns during plant construction are not uncommon and therefore a 50% contingency surplus should be considered reasonable. The type of feedstock used and the plant operators' expertise play the largest role in the selection of pretreatment process type (Sims *et al.* 2008). Although there is currently no significant difference in capital cost between the different pretreatment systems, according to research conducted by Ralph Sims *et al.*, the use of relatively high cost technology presents an area of opportunity to reduce capital costs per litre.

The lack of operating commercial lignocellulosic ethanol plants worldwide increases the perceived high risk of such an investment and this risk, in turn, increases financing costs. Since lignocellulosic ethanol production is an emerging sector with unknown and untested production costs, lenders are unable to identify and understand the risks. Most ethanol projects are financed by a combination of equity and debt. Raising the debt portion can be a challenge for numerous reasons including the current lack of market access to capital. Lending institutions that provide debt financing are generally not involved in sharing the profits generated and therefore focus on reducing the potential losses to their participation. As a result, lenders tend to focus on the downside or what could go wrong with the project. In the current constrained debt market, lenders will prioritize opportunities that provide the best returns for the least risk. With the unproven commercial viability and current fluctuating commodity prices the ethanol industry does not currently fall into that category.

New sectors require lenders to become comfortable with the risks or at least the perception of the risks. As such, the first projects are the most difficult to finance since there is no track record or proven success that lenders can rely on. Most commercial lignocellulosic ethanol companies find the current lack of access to debt financing a considerable market barrier and may call for increased government funding as has been seen in the US with the corn ethanol industry.

All business plans view a portion of equity financing as an important portion of the overall capital structure of a business. Added to the negative perception of this industry being "bleeding edge" or not yet proven, the reduction in commodity prices and significant market and investor uncertainty means that equity financing is not currently an attractive option for start-up ethanol companies.

6. OPPORTUNITIES

6.1 Market demand for ethanol blended transportation fuel

"The gradual move away from oil has begun. Over the next 15 to 20 years we may see biofuels providing a full 25% of the world's energy needs" (Iler 2007). At a time of increasing concern over the environmental impact of using fossil fuels and when energy analysts predict a period of unpredictable oil markets, the argument for more carbon neutral supply diversification is strong.

Looking at specifically the transportation fuel end use of biofuel and its growing demand in British Columbia, The *BC Energy Plan* has set the target of a 5% average renewable fuel standard for diesel in the province by 2010. This supports the federal target stated in Bill C33, of increasing ethanol content of gasoline to 5% by 2010 (*The BC Energy Plan 2007*). Even though the establishment of targets for ethanol consumption in other jurisdictions has often been over ambitious and the goals are usually not met by the target dates (Walburger *et al.* 2006), accelerated growth in demand for biofuel going forward is undeniable. BC's gross gasoline consumption in 2007 was 4,749 million litres (Energy consumption and disposition 2008), and if BC gasoline consumption remains at this level and the 5% ethanol target is to be met, BC will require 237 million litres of ethanol per year.

According to the International Institute for Sustainable Development, Canada produced approximately 422 million litres of ethanol in 2006, and if planned plants are built we will have the capacity to produce 3 billion litres of ethanol by 2010. However, it is expected that actual production capacity will be approximately half of this value, which is close to the 2009 ethanol production capacity in Canada of 1.8 billion litres per year according to the Canadian Renewable Fuels Association. Currently there is no commercial ethanol production in the province of BC, and of the 1.8 billion litres a year produced in Canada, only 2 million litres are from second generation biomass fuels (Canadian Renewable fuels Association 2008). Even with other Canadian provinces supporting the federal ethanol targets found in Bill C33 it is expected that national ethanol production will not meet this target and BC will fall far short.

One of the significant opportunities for the commercial production of ethanol from wood fibre is the market demand and price trends of energy, and more specifically, the forecasted increasing demand and pricing of transportation fuels like gasoline refined from crude oil. With Canada's vast size and widely dispersed population and business centers, transportation fuel is critical to our economy. In 2006, 2,492,000 Terajoules (TJ) of energy were consumed to fuel transportation, which is (as indicated in Figure 6) approximately a third of all the energy used in Canada (National Energy Board 2009). Transportation fuel sources require high energy-to-weight value in order to make them feasible to be transported by the vehicle that is consuming them. The conversion of biomass to fuels such as ethanol provides for the greatest concentration of fuel energy and increased energy-to-weight value.

Other (current) uses for biomass including the production of electricity, heat, or wood pellets are far less energy-efficient. Interior BC has low population densities and large distances to markets or urban centers, hence the conversion of dead MPB biomass into a high density, high value product that can be efficiently transported makes ethanol an excellent bioenergy alternative for the province.

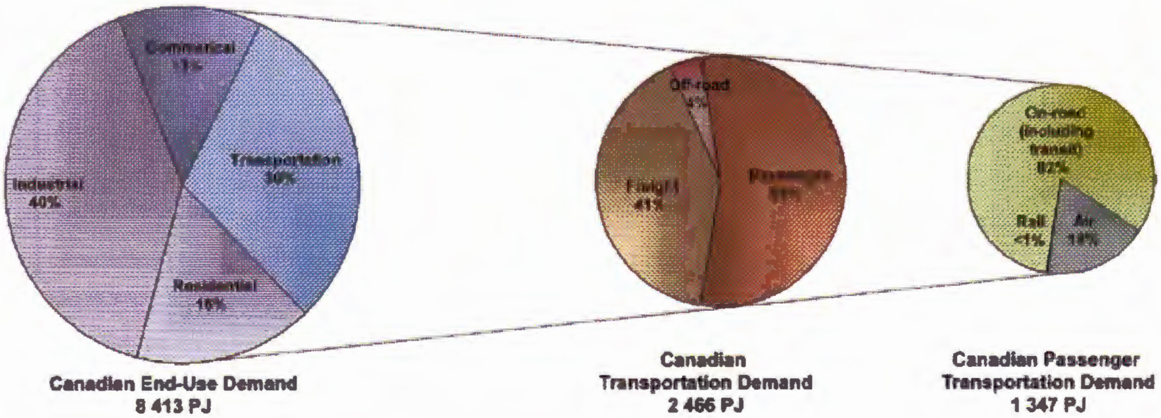

Figure 7. Energy usage (Office of Energy Efficiency, Natural Resources Canada)

Figure 7 shows a diagrammatic representation of energy use in Canada with transportation making up 30% of the total demand. British Columbia has the potential to produce enough biomass resources to provide over 50% of our current fossil energy needs, i.e. 920 PJ/yr (Layzell 2006). This amount of energy is equal to approximately 32 million dry tonnes of biomass per yr [Mt(dry)/yr]. BC could therefore produce enough biomass resources to cover the entire annual energy requirement of transportation in Canada. In the Interior of BC, forest biomass is the largest biomass resource and therefore has the greatest biofuel feedstock supply potential. As previously discussed, the migration to hybrid and electric vehicles is inevitable in the longer term, but it should not be prohibitive for the immediate demand for ethanol for blended biofuels. The demand for transportation fuels, and thus ethanol, will be strong enough in the next couple of decades – enough time to reap the economic reward of harvesting and processing the surplus biomass available in Interior BC. Thus, the expected demand for ethanol is not a limiting factor for the commercial production of lignocellulosic ethanol from MPB killed timber in Interior BC.

6.2 Biomass utilization

6.2.1 Changes to the appraisal of biomass

The accumulation of biomass in the form of sawdust and other sawmill residues originally had a negative value due to the associated disposal costs. The resultant dismissive "if you can haul it, you can have it" approach to biomass feedstocks spearheaded the opportunistic wood pellet industry. However, as the biomass industry has matured and competition for this biomass has increased, the value has also increased. Once these on-site or remote site biomass sources are used up, other biomass residues must be sourced from the forest, which is a more costly activity (Sims *et al.* 2008).

6.2.2 Residual biomass availability

The BC forest industry is a leader in the handling and processing of wood and biomass from the forest, including a number of different types of residual cellulosic biomass, which may be diverted to ethanol production. The growing forest is well inventoried, however the amount of forest residual material suitable for lignocellulosic ethanol production is less well documented (Mabee 2008). A 2005 analysis of BC's residual biomass resource completed for the BC Bioproducts Association estimates that even though residual biomass is currently being sourced by the existing bioenergy industry from the primary forest product industry, such as lumber mills and pulp and paper mills, about 1.8 million tonnes of mill residues are not currently used in BC and could be available for bioconversion purposes. This highlights the fact that the current supply chain has potential to be optimized and to further reduce the overall cost of waste disposal that has historically increased production costs in the forest industry.

6.3 Benefits of MPB biomass for ethanol production

There may be multiple benefits associated with the use of MPB killed versus healthy pine biomass feedstocks. These include lower stumpage rates and superior bioconversion.

6.3.1 Lower stumpage rate

The cost of MPB killed wood is typically much lower than comparable healthy wood. Stumpage rates as low as $0.25 CAD/m^3 have been assessed for low grades of MPB killed wood (BC Ministry of Forests 2004). University of British Columbia was involved in part of a US Department of Energy funded Consortium for Applied Fundamentals and Innovation (CAFI) project, which used techno-economic models to analyze process costs of generating bioethanol (Wyman *et al.* 2006). The total cost breakdown in the production of ethanol was found to be made up of costs associated with various inputs or processes including biomass, pretreatment, processing, enzymes, distillation and others such as waste treatment, boiler, utility, and storage costs. Biomass cost usually includes stumpage as well as the feedstock handling component. The biggest cost (up to 50%) is the cost of enzymes for hydrolysis. The second biggest cost contributor is that of biomass (up to 30%), followed closely by capital costs associated with plant construction (Wingren *et al.* 2005). Absolute production costs are very difficult to predict accurately, however the CAFI project was able to make estimates of minimum ethanol selling prices ranging between 0.35 - 0.44 cents per litre depending on the pretreatment selected. However, none of these costs can be accurately gauged until the various demonstration projects currently under construction around the world are completed and begin providing real operational data (Mabee 2008). However, since biomass feedstock costs can make up as much as a third of the total ethanol production cost, the reduced stumpage rate for MPB killed wood provides a possible opportunity for the lignocellulosic ethanol industry in Interior BC.

6.3.2 Superior bioconversion

In addition to the lower feedstock cost, MPB killed biomass has been shown to be capable of relatively fast hydrolysis with lower enzyme loadings. A 2008 report for UBC Forest Products Biotechnology indicates the initial rate of enzymatic hydrolysis of standing dead MPB-killed trees is higher than that of harvested healthy pine. "The extensive destruction to chemical structure of beetle-killed lodgepole pine have devastated the economical value of these timbers for house or furniture, however, it is this unique property that can prove beneficial for wood to ethanol bioconversion especially during enzymatic hydrolysis." (Mabee 2008). The report continues to say that compared with healthy wood, the degradation of the drier MPB killed wood fibres—aided perhaps by the presence of colonizing microorganisms—allows the wood to be more easily broken down and causes higher sugar recoveries during pretreatment. The MPB killed feedstock also boasts a higher hydrolysis conversion.

In the experimental work described by Mabee, "beetle-killed lodgepole pine subjected to organosolv pretreatment reached 100% hydrolysis (measured as conversion of cellulose to glucose) over 24 hours. At the same timepoint, healthy pine biomass had only reached 85% hydrolysis. An additional 24 hours of processing time was required for the healthy pine biomass to reach equivalent cellulose conversion." (Mabee 2008). Therefore it was concluded that quicker hydrolysis of MPB feedstock will result in the effective processing cost being reduced. Total operating costs associated with hydrolysis could be reduced by up to 50%, due to both processing time and enzyme loading effectively being reduced by half (Mabee 2008). Mabee also reported that the cost of enzymes could likely very soon be reduced dramatically, as commercial biorefineries utilizing cellulosic feedstocks begin to demand significant quantities.

It is important to consider that Mabee's calculations of overall costs exclude a 10% saving from electricity credits. The value of lignin co-products is a crucial factor in making the lignocellulosic ethanol production process economically viable. In fact in ideal circumstances, the co-product value could even cover the bioconversion costs of ethanol completely. The assumption is that low stumpage value MPB killed biomass feedstock is used. Regular market value for healthy pine biomass could easily double the cost of the process. Depending on the ultimate cost of enzymes, MPB killed biomass may be processed with a savings of between 4 - 25% of total process costs when compared to healthy pine biomass (Mabee 2008). This could represent a major incentive to utilize MPB killed biomass for lignocellulosic ethanol production in Interior BC.

6.4 Looking beyond ethanol for value

6.4.1 Development of co-products

The development of process efficiencies is contingent on the development of high value co-products from lignin and hemicellulose, while the cellulose component is exploited for the production of ethanol. In order to maximize all outputs in the highly sensitive bioconversion processes, it is necessary to develop a compromise between the optimal conditions for each step. For example, the recovery of cellulose, hemicellulose, and lignin in the pretreatment as well as the ease of the enzymatic hydrolysis, and the usefulness of the recovered lignin for use in co-products such as antioxidants and other new applications (Mabee 2008).

Researchers still hope to discover a cost effective super-microbe that could complete all steps in the process (remove the lignin, breakdown the cellulose and hemicellose and ferment the sugars) all in one tank. Instead of waiting for such a technological breakthrough, researchers should recognize the potential of the MPB's higher efficiency ethanol bioconversion capacity, and how to capitalize on this short-term abundant supply in Interior BC. And since high value lignin co-products can economically justify ethanol production, further research focus should be prioritized on developing these products. The processing of lignocellulosic ethanol alongside co-products would take place in a commercial biorefinery, the model of which is discussed in more detail in the next subsection.

6.4.2 The biorefinery model

Interviews conducted with ethanol industry producers revealed that the biorefinery model is one way of increasing potential success by not only producing ethanol but refining other co-products that help diversify revenue streams. This approach has also been well documented in the literature and it clearly identifies the interdependencies that exist between different industries and economic sectors. Further exploration of this model is required to explain this opportunity to help overcome challenges for ethanol production in Interior BC.

The biorefinery model is based on a symbiotic relationship between the forest industry and chemical companies working together to actively explore a new, environmentally friendly way of achieving sustainable growth through integrated value streams and process efficiencies. In this model, for example, pulp mills would gasify biomass materials to create synthesis gas and then convert the syngas into a variety of green fuels and chemical feedstocks (Inside Green Business 2007).

When relating the biorefinery model (refer to Figure 8) directly to the ethanol industry, the production, capturing and marketing of multiple co-products from the ethanol production process provides additional opportunities to increase revenue streams. For example, (and as indicated in the lignin–heat feedback loop in Figure

3.1 Biomass-to-fuel pathways) additional cost reduction potential can be found in the capturing of heat and energy produced either as a co-product from the production of ethanol or from other forest industry processes. The pulp and paper industry is already a large independent power producer in the province of BC, which could become more economically and environmentally sustainable if these new synergies were explored.

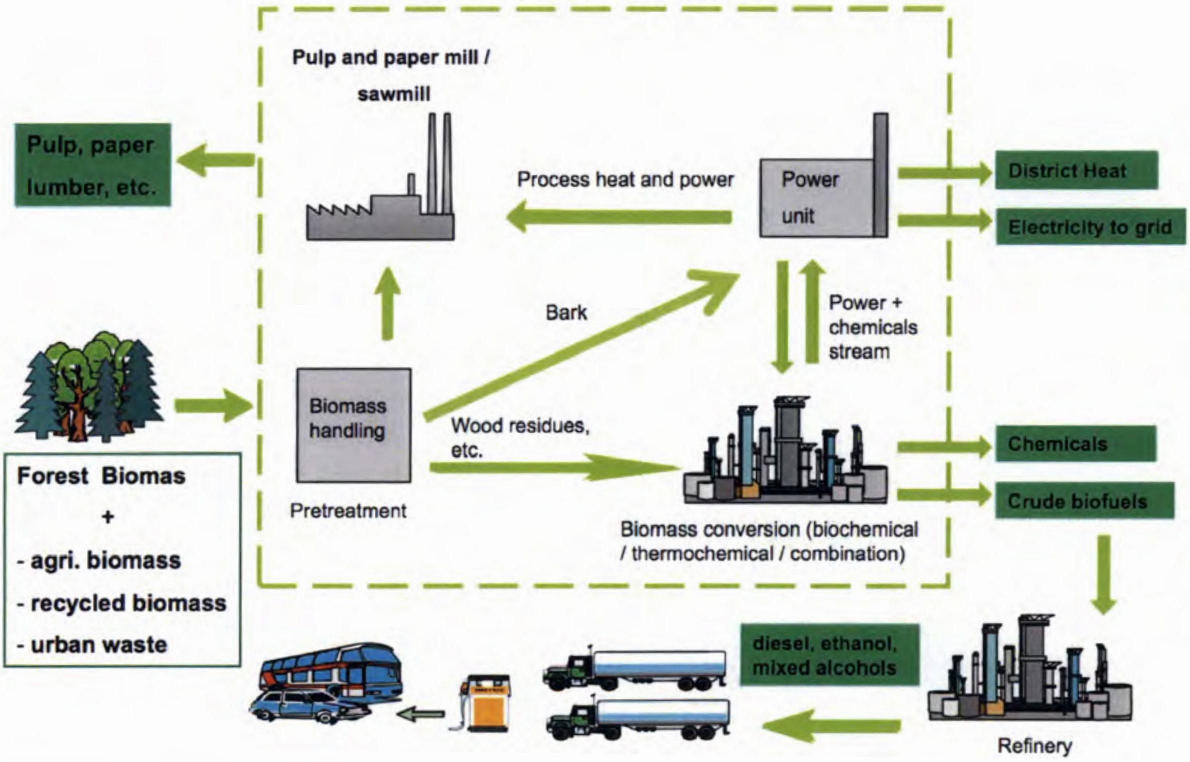

Figure 8. Integrated forest industry biorefinery (Hetemäki, 2007)

Similar to the concept of the petroleum refinery, a biorefinery can make co-products that include different fuel types, chemicals, and high value materials. Biorefineries can produce finished products such as lignin that is used as an emulsifier or binding agent and can be found in paints and many different industrial applications.

Biorefineries can also produce intermediates like resins that are used in the plywood and panel board industries.

Lignol Energy Corporation, based in Vancouver, BC, is approaching cellulosic ethanol production from the biorefinery model. Lignol believes a significant barrier to succeeding with a commercial lignocellulosic biorefinery is the poor economics when ethanol is the only revenue stream (Arato *et al.* 2005). The majority of lignocellulosic ethanol production processes use steam explosion or other mechanical pretreatment methods to release the lignin and expose the cellulose for enzymatic hydrolysis. These aggressive pretreatment techniques reduce the potential to recover valuable co-products like lignin. Without extra revenues from co-products, the ethanol plant must rely solely on ethanol revenue, which necessitates the development of a larger ethanol plant to achieve economies of scale. Lignol believes these larger plants are a challenge to the industry as a greater amount of capital and financing risk are needed to reach commercialization (Arato *et al.* 2005). In the Lignol biorefinery model, ethanol production only accounts for 25 - 35% of the total potential revenue stream. Information for the potential co-products from a biorefinery are listed in Table 3 in the Appendix section. Lignol recognizes the importance of reducing enzyme costs and believes they can achieve greater than 90% theoretical production yield of ethanol from their process.

Several pilot or demonstration biorefinery plants are in the process of development. However, there is only one fully commercial biorefinery existing in Sarpsborg Norway, which uses lignocellulosic feedstock in the form of spruce logs. This Norwegian biorefinery is operated by Booregaard and its main products are Lignin, Specialty Cellulose, Vanillin, Yeast, Bio Ethanol, and Omega-3 products (Borregaard Products from natural sources 2008). Although the Biorefinery model requires significant development and adaptation to a specific set of circumstances, it is believed that a number of niche products could be produced including pharmaceuticals, drugs, and essential oils. The development of biorefineries to produce biofuels and other industrial chemicals would not only increase the robustness of the lignocellulosic ethanol industry by helping protect itself against price fluctuations in biomass feedstock and crude oil, but it will diversify and extend the forest products industry and create new markets and opportunities for economic growth in BC.

7. CONCLUSIONS

Evidence gathered from reviewing published data and firsthand interviews with key stakeholders supports the premise of this thesis. There are significant challenges and opportunities for commercial production of lignocellulosic ethanol from MPB killed timber in Interior BC. In summary, these challenges and opportunities are organized into the following 4 main categories:

- Ethanol demand
- Biomass supply
- Technology
- Interdependencies

7.1 Ethanol demand [Opportunity]

The demand for ethanol is not a limiting factor, but a significant and growing opportunity for the commercial production of lignocellulosic ethanol from MPB killed timber in Interior BC. Blended ethanol gasoline targets of 5% have been set for BC and Canada, and BC will require 237 million litres of ethanol per year. With no current commercial production of ethanol in BC, this demand will remain. Long term social and economic demand for biofuels will continue to increase with the global trend towards reducing our dependency on fossil fuels and reducing GHG emissions. The provincial and federal governments will continue to develop policies and programs, which are in line with global trends to push technological advances in biofuel and thus promote the commercialization of lignocellulosic ethanol. If BC achieves the bioenergy leadership it aspires to, then the province should not only meet the local demand for biofuel, but there is also a significant opportunity for BC to export lignocellulosic ethanol.

7.2 Biomass supply [Opportunity/Challenge]

Biomass fibre supply is both a challenge and an opportunity for a few reasons. The surplus of cheaper, quicker and higher ethanol yielding MPB killed biomass is a huge opportunity. However, the challenge is that this opportunity is short-lived; the MPB biomass is not sustainable in the long term, but should not be overlooked for its potential economic contribution to the province of BC.

A comparison between the estimated amount of biomass available and the amount required to operate a commercial scale lignocellulosic ethanol plant indicates that sufficient supply is available in Interior BC. However, long term biomass supply is considered a challenge because independent ethanol producers will have to compete with the pulp, paper and power industries that have a significant head start in securing a long term biomass supply. In addition, biomass feedstock costs will increase significantly over the lifespan of any lignocellulosic ethanol plant. Not only will the cheap supply of close and easy to obtain fibre be consumed rapidly by the existing forest industry, but the MPB biomass surplus is estimated to begin to diminish in 2020, thus risking long term sustainability of commercial ethanol plants.

7.3 Technology [Challenge]

Lack of advancement in lignocellulosic ethanol conversion technology is a serious challenge. The lignocellulosic ethanol industry in BC is still in its infancy and not yet succeeding in making the leap from demonstration plant to large scale commercialization. Significant challenges include shortfalls in biochemical technology, which require improving the effectiveness of the pretreatment process, decreasing enzyme costs, improving overall process integration and efficiencies, as well as researching viable co-products. Despite documented findings regarding the cost savings derived from using MPB feedstock, pilot projects that are underway have not yet proven a way to produce ethanol that is cost effective enough to offset the capital costs of a commercial scale plant, thereby exacerbating the uncertainty for debt and equity financing.

7.4 Economic interdependencies [Challenge/Opportunity]

Both challenges and opportunities exist in the economic interdependencies between various players in the forest, chemical, bioenergy and transportation sectors. Interviews were conducted with participants from across the BC lignocellulosic ethanol industry from large forest industry incumbents, medium and small sized ethanol producers, and government. Interview results demonstrate there is room for more collaboration between the stakeholders in the ethanol industry in BC. Each organization, whether it is research, government or industry appears to be operating independently with a "silo mentality" on in-house research into improving processes and technology. There is fierce competition within the ethanol industry to develop commercially viable technology that will increase ethanol recovery from wood fibre to an economic level. Unfortunately, with this type of approach, individual ethanol producers tend to keep technology or process innovation to themselves as a competitive advantage, while at the same time waiting for someone else to take the difficult first steps.

Even with this protectionist approach to technology and process development, the majority of participants believe that there are opportunities for interdependencies across industries and sectors to be recognized and optimized through partnerships for overall economic success. Proposed partnerships may exist on a business-to-business level with forest industry incumbents partnering with the petrochemical industry and an ethanol technology provider. Several participants called for a partnership between government and industry on the research and development side with the formation of a 'BC Biofuel Center of Excellence' for the development and research of biomass energy alternatives. The University of Northern British Columbia (UNBC) is considered by many as a natural choice for such a center due to its location and its ability to leverage academic expertise.

8. RECOMMENDATIONS

Identified challenges and opportunities facing the lignocellulosic ethanol producers presents a balanced view of the emerging, yet vulnerable ethanol industry in Interior BC. The following recommendations suggest how to address some of the challenges identified and maximize opportunities that currently exist. This will provide a series of possible actions and requirements for the development of a successful commercial biofuel industry in Interior BC, which may in turn contribute to the development of an alternate strategy for the region's economic development.

8.1 Take the lead on sustainability

The BC government should take the lead and prioritize the development of a sustainable commercial lignocellulosic ethanol industry in accordance with their *BC Energy Plan* objective of becoming the bioenergy leader in Western Canada as the "BC Biofuel Center of Excellence". This will help facilitate strategic partnerships between existing forest industry incumbents, government, and ethanol producers. It will only take one successful commercial operation to demonstrate the technology, thereby increasing investor confidence and “blazing the trail” for other incumbents in the province to follow. It will also be worthwhile developing market opportunities for BC produced lignocellulosic ethanol – locally and for export out of the province. The BC provincial government has announced the creation of the “Wood Innovation and Design Centre” at UNBC to promote new expertise in wood building products, focusing on engineered wood products and other structural uses for wood. This is a step in the right direction that needs to be capitalized upon immediately in order to meet the fast approaching expiration of MPB biomass opportunity.

8.2 Seize the short-term MPB biomass surplus opportunity

Timing is definitely the most critical consideration when it comes to addressing these recommendations and securing optimum social and economic benefits. MPB biomass is a short term, non-sustainable feedstock with a very limited shelf life and steadily perishing value. Any lignocellulosic ethanol production facility implemented to utilize MPB killed biomass would gain a short-term subsidy in terms of reduced processing costs. However, within approximately 10 years, the supply of MPB killed wood will start to diminish and the ethanol industry will have to turn to other feedstocks. In the long term, the lignocellulosic ethanol industry in BC will have plenty of sustainable feedstock sources from the well managed forests in the interior as well as biomass residue from the existing forest products value chain (Mabee 2008). However, the industry must gain a cost competitive advantage if it is going to be able to access these long term feedstock resources.

In the short term, MPB biomass should not be overlooked. There is still a significant supply of MPB killed biomass with demonstrated advantages compared to healthy wood biomass. It is highly suitable to serve as an initial, short-term feedstock to establish a bioethanol industry within BC. If we are unable to initiate economically viable alternatives, such as utilizing MPB killed fibre for commercial lignocellulosic ethanol production, then the survival of forestry dependent communities and the economic well being of the province is threatened. The BC government and investors should not wait for recently afflicted global economic markets to turn around before applying resources and financing for technology solutions necessary in order to overcome current limitations and process inefficiencies. It is critical that this readily available supply of MPB killed feedstock be harnessed for commercial lignocellulosic ethanol production as soon as possible in order to contribute to the economic well being of the province.

8.3 Invest in risk reduction

Risk perception needs to be addressed through policy measures and technical support measures, so that conditions for financing become more favourable. The best way to reduce risk is to eliminate unknowns, therefore the ethanol industry should invest resources in overcoming limitations of biological technologies as well as quantifying and qualifying medium to long term cost and supply of woody biomass feedstock. The emerging biofuel industry should learn from best practices in current biomass industries, such as the wood pellet industry, which have succeeded with similar dependencies on reducing costs associated with biomass transportation, storage and handling. Besides reducing risk, technological advancement will reduce costs and foster the emergence of an array of co-products. More research is required to further evaluate co-products potential for increasing value in the form of expanding markets that are currently occupied by niche products. Resources and funding should also be put towards perfecting the scalability of existing technology in demonstration plants to ensure the development of cost effective commercial scale lignocellulosic ethanol plants. This will help reduce risks associated with this emerging industry and more importantly, ensure sustainability of the BC biofuel industry and the BC economy as a whole.

The 2007 United Nations paper on sustainable bioenergy reiterated the fact that as the emerging industry develops, quality control of the ethanol, blended fuel and co-products will be critical, particularly in the early stages of market development. Regulatory processes such as standards and certification/assurance systems will have to be put in place to ensure sustainability and to protect consumer experience and market confidence. This will require capacity building and testing systems that are not cost prohibitive.

8.4 Enhance government support

The BC government will have to find the right mix and effective administration of instruments to support an emerging lignocellulosic ethanol industry. This may include tax incentives, coupled with consumption mandates, production subsidies and import restrictions. In order to continue the support of the development of ethanol production and consumption including ethanol produced from second generation biofuels, it is recommended that the BC government take the following steps:

1) Work together with other provinces to remove inter-provincial barriers to trade of ethanol, to allow the industry to develop in BC with the prospects of exporting more easily.
2) Provide long term commitment to current tax incentives and mandated targets for ethanol blended gasoline.
3) Continue to provide funding for research and development activities related to the production and marketing of biofuel, including development of markets for co-products such as lignin.

The various forms of federal and provincial subsidies provided to the ethanol producers are key to the development of this emerging industry. In order for the lignocellulosic ethanol industry to continue to evolve and overcome its challenges, subsidies will need to be implemented and continued into the future.

8.5 Maximize value with synergies and partnerships

"To create and maintain the bioenergy value chain, all players must operate in synchrony to deliver the product. This can be a challenge when new industries are developing and when the costs, benefits, and interests of actors within the chain differ. Thus, parallel support for the whole value chain must be considered" (UN-Energy 2007).

The best option for government to encourage new commercial ethanol plants is public-private partnership funding dedicated to financing energy efficient and renewable energy investments in the economy. Public funds could hedge the risk or give guarantees while private investors physically provide the actual loans or credits.

In addition to securing financing, any successful commercial cellulosic ethanol plant in Interior BC will need to develop strong partnerships with petrochemical refinery and forest industry players. Stakeholders should work together to create inter-industry synergies and avoid competing for resources. By maximizing synergies, particularly across the forest and petrochemical industries, the production, capturing and marketing of multiple co-products from the ethanol production process provides additional opportunities to increase revenue streams.

Participants concurred that it may be most cost effective to retrofit existing infrastructure or to co-locate new and old infrastructure. A holistic 'biorefinery model' approach to overcoming barriers, by incorporating all stakeholders and maximizing efficiencies and business partnerships, would help create value from the full cycle of all types of wood products including chips, pellets, and biomass. In order to be successful, the lignocellulosic ethanol industry should avoid 'reinventing the wheel' and take advantage of sections of the supply chain already in place in Interior BC. This can be achieved by seeking out partnerships with feedstock suppliers in order to benefit from management, harvesting, transportation, storage and delivery of forest biomass feedstock already established by an efficient forest industry. One example of such an opportunity is the petrochemical refinery in Prince George, which is currently blending corn ethanol into gasoline.

The nature of interdependencies that exist in the biomass industry that are necessary for the whole supply-chain to function optimally require up front capital pooling, research/technology-sharing, risk-sharing and profit-sharing in order obtain critical mass and, in turn, support the sustainability of the provincial economy as a whole.

9. REFERENCES

Arato, C., Pye, K., & Gjennestad, G. (2005). *The Lignol Approach to Biorefining of Woody Biomass to Produce Ethanol and Chemicals.* Vancouver: Humana Press Inc.

Auld, D. (2008). The Ethanol Trap:Why Policies to Promote Ethanol as Fuel Need Rethinking. Toronto: C.D. Howe Institute.

Baxter, R. B. (2005). *Regions & Resources: The Foundation of British Columbia's Economic Base* . Vancouver: The Urban Futures Institute .

BC Bioenergy Network. (2009, 02 04). *News/Events*. Retrieved 02 14, 2009, from BC BioEnergy Network: http://www.bcbioenergy.ca/_news/2009-02-04-PR-Lignol-BCBN.pdf

BC Ministry of Forests. (2004). *Interior Appraisal Manual.* Victoria, British Columbia : Governement of BC, Revenue Branch.

Borregaard Products from natural sources. (2008, 01 28). Retrieved 01 25, 2009, from Borregaard:
http://www.borregaard.com/eway/default.aspx?pid=227&trg=MainPage_5913&MainPage_5913=10009:0:

Calais, P., & Sims, R.A . (1999). *A comparison of life-cycle emissions of liquid biofuels and liquid and gaseous fossil fuels in the transport sector. Renewable Energy Transforming Business.* Perth: Murdoch University.

Canada Green Building Council. (2006). Retrieved 11 19, 2008, from http://www.cagbc.org/leed/certified_buldings/index.htm

Canadian National Energy Board. (2009). *Energy Briefing Note, Canadian Energy Demand: Passenger Transportation.* Calgary, Alberta: Government of Canada.

Canadian Renewable fuels Association. (2008, 12). Retrieved 02 14, 2009, from Industry Information: http://greenfuels.org/lists.php

Decker, J. (2009, 01 22). *Going Against the Grain: Ethanol from Lignocellulosics* . Retrieved 03 03, 2009, from Renewable Energy World:

http://www.renewableenergyworld.com/rea/news/article/2009/01/going-against-the-grain-ethanol-from-lignocellulosics-54346

Energy Sources . (2006). Retrieved 02 09, 2009, from Natural Resources Canada: http://www.nrcan.gc.ca/eneene/sources/pripri/aboapr-eng.php

Eng, M. F. (2005). *Provincial Level Projection of the Current Mountain Pine Beetle Outbreak: An overview of the Model (BCMPB v2) and Results of Year 2 of the Project.* Victoria, BC : Canadian Forest Service Mountain Pine Beetle Intiative, BC Forest Service.

Ethanol Expansion Program (EEP). (2003). Retrieved 01 10, 2009, from Natural Resources Canada: http://oee.nrcan.gc.ca/transportation/fuels/ethanol/eep.cfm?attr=8

Fulton, T. H. (2004). *Biofuels for Transportation an International Perspective.* Paris: OECD/IEA.

Girvan, J., & Hall, M. (2008). *BC Fibre Model User Guide* . Victoria: Jim Girvan of M.D.T. Ltd. and Murray Hall of Murray Hall Consulting Ltd.

Hetemaki, L. (2007). Retrieved 03 01, 2009, from Finish Forest Research Institute (Melta): http://www.metla.fi/hanke/50168/pdf/hetemaki-iufro-saariselka-2007.pdf

Inside Green Business. (2007, 01 10). *New Biorefinery Model Would Link Chemical,Forestry Companies.* Retrieved 03 01, 2009, from Tri-Inc.net : http://www.tri-inc.net/common/New%20Biorefinery%20Model%20Would%20Link%20Chemical,%20Forestry%20Companies.pdf

Lakers, M. (2008, 11 19). *PlugNews*. Retrieved 01 15, 2009, from EthanolPlug.com: http://www.ethanolplug.com/PlugNews/WebExclusive25ofEthanolPlantstogoUnder/tabid/144/Default.aspx

Layzell, P. R. (2006). An Inventory of the Bioenergy Potential of British Columbia. *BioCap Canada* , 2.

Mabee, W. (2008). *Biorefining technologies to process mountain pine beetle-killed wood.* Vancouver: University of British Columbia.

Mabee, W. (2006). *Economic, Environmental and Social Benefits of 2nd-Generation Biofuels in Canada.* Vancouver, BC: BIOCAP Research Integration Program .

Mathis, J. Z. (2008). *Human Resources Management* . Toronto: Nelson, a dividson of Thomas Canada Limited.

Ministry of Finance . (2008). *British Coumbia Carbon Tax.* Vitoria: BC Ministry of Small Business and Revenue .

Ministry of Forests and Range. (2009). *Budget 2009 Service Plan.* Victoria: Ministry of Forests and Range.

Mountian Pine Beetle . (2008, 02 01). Retrieved 02 18, 2009, from Ministry of Forests and Range: http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/faq.htm#6

Mountian Pine Beetle- Trend Analysis. (n.d.). Retrieved 01 25, 2009, from Natural resources Canada: http://canadaforests.nrcan.gc.ca/articletrend/215

News Room. (2007, 09 12). Retrieved 01 06, 2009, from Sustainable Development Technology Canada: http://www.sdtc.ca/en/news/media_releases/media_12092007.htm

Northwind Ethanol. (2008). *Northwind Ethanol Prince George Business plan.* Victoria: Northwind Ethanol.

Office of Energy Efficiency. (2008, 12 09). *Ethanol The Road to a Greener Future*. Retrieved 12 21, 2008, from Natural Resources Canada: http://oee.nrcan.gc.ca/publications/infosource/pub/vehiclefuels/ethanol/M92_257_2003.cfm

Pedersen, L. (2003, 10 30). How Serious is the Mountain Pine Beetle Problem? Kelowna, BC, Canada: BC Forest Service.

Schwietzke, S.M. L. (2008). *Analysis and identification of Gaps in research for the production of second-generation liquid transportation biofuels.* IEA BIOENERGY.

Sims, R. T. (2008). *From 1st to 2nd Generation biofuel technologies.* Paris : OECD/IEA.

(S&T)2 Consultants Inc. (2006). *Second generation biofuels A review from the market barrier perspective* . Delta BC: (S&T)2 Consultants Inc.

Stennes, B., & McBeath, A. (2006). *Bioenergy options for woody feedstock:are trees killed by mountain pine beetle in British Columbia a viable bioenergy resource?* Victoria, British Columbia: Natural Resources Canada Canadian Forest Service Pacific Forestry Centre.

Summary Table energy consumption and disposition . (2008, 07 30). Retrieved 12 20, 2008, from Statistics Canada: http://www40.statcan.gc.ca/l01/cst01/trade37c-eng.htm

The BC Energy Plan. (2007, 02 27). Retrieved 01 15, 2009, from BC governement: http://www.energyplan.gov.bc.ca/default.htm

Timmenga & Associates, Zbeetnoff Agro-Environmental Consulting. (2005, 02). Retrieved 03 02, 2009, from BC Bioproducts Association: http://www.bcbioproducts.ca/documents/timminga2.pdf

Tokgoz, A. E. (2006). *Removal of US Ethanol Domentic and Trade Distortions: Impact on US and Bazilian Ethanol Markets.* Ames, Iowa : Center for Agriculture and Rural Development, Iowa State University .

UN Energy . (2007). *UN Energy* . Retrieved 03 01, 2009, from United Nations: http://esa.un.org/un-energy/pdf/susdev.Biofuels.FAO.pdf

UN-Energy. (2007). Sustainable Bioenergy: A Framework for Decision Makers. Vienna: UN-Energy .

US Department of Energy. (2008, 12). *Annual Energy Outlook 2009 Early Release.* Retrieved 02 24, 2009, from Energy Information Administration: http://www.eia.doe.gov/

Walburger, D. A., Roy, D. D., Kaushik, D. K., & Klein, D. K. (2006). *Policies to stimulate Biofuel production in Canada: Lesson from Eurpe and United States.* BioCap Canada.

Wingren, A., Galbe, M., Roslander, C., Rudolf, A., & Zacchi, G. (2005). Effect of reduction in yeast and enzyme concentrations in a simultaneous saccharification-and-fermaentation-based bioethanol process: Technincal and economic evalution. *Applied Biochem Biotechnology* , 121-124:485-499.

Wyman, K. R. (2006). *Comparative data for enzymatic digestion of corn stover and poplar wood after pretreatment by leading technologies.* San Franciso, California: AIChE Annual Meeting.

10. APPENDICES

Potential co-products from biorefinery

	Description/Primary use	Alternate uses
Xylose	Five carbon sugar suitable for diabetics to consume without insulin	Marketed as Xylitol in products such as sugarless chewing gums, mints, mouth wash and candy
Cellulose	Specialty and Dissolving Cellulose and other cellulose grades	
Lignin	Agricultural Chemicals, Battery expanders, Bypass protein, Carbon black, Cement, Ceramics, Fertilizers, Gypsum board, Humic Acid, Industrial Binders, Micronutrients	One way to supplement organic matter in low humus soils is to add commercial humic acid preparations.
Fine Chemicals	Aminoalcohols, Hydroquinone, Cathecol, Vanillin and derivatives	Intermediate for agro chemicals, pharmaceuticals, aroma chemicals. Catechol is also as a polymerisation inhibitor and stabiliser.
Food Ingredients	Vanillin, Denomega, Nutritional Oils, Yeast products	Premium Omega-3 for Foods and Dietary Supplements
Ethanol		
Energy		
Basic Chemicals	Sodium Hydroxide, Sodium hypochlorite, Hydeochloric Acid	
Trading products	Acetic Acid, Acidifier, SoftAcid	Vinyl acetate, for manufacture of latex paint and paper.

Table 3. Potential co-products from biorefinery (Arato *et al.*, 2005; Borregaard, 2008)

Commercial lignocellulosic ethanol production in Interior BC		[Challenge]		[Opportunity]	
		Short term 2009-2020	**Long term** 2020+	**Short term** 2009-2020	**Long term** 2020+
1	Ethanol demand/export	No	Yes	Yes	Uncertain
2	Fibre supply/costs/pricing	No	Yes	Yes	Uncertain
3	Technology /Infrastructure	Yes	Uncertain	Yes	Uncertain
	Financing	Yes	No	Yes	Uncertain
4	Process integration/synergies	Yes	Uncertain	Yes	Yes
	Economic driver for BC	Yes	Uncertain	Yes	Yes
5	Government support/Legislation	Yes	Uncertain	Yes	Uncertain

Key:	(orange)	Orange shaded area indicates a **problem issue/risk** that needs to be addressed
	(green)	Green shaded area indicates **favourable conditions/opportunity** to be maximized
	(grey)	Clear area indicates **uncertainty** that require more research

Table 4. Simplified view of key challenges and opportunities over short and long term.