Cellulosic Ethanol Feasibility Framework

By

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ABSTRACT

The objective was to create a feasibility framework for assessing the feasibility of a cellulosic ethanol refinery. In addition, the research aimed to create a base case scenario based on data from literature and conduct sensitivity analysis to determine significant parameters of a cellulosic ethanol refinery. The base case was found to be not feasible in the financial and economic analysis given the assumptions used.

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1. INTRODUCTION

Problem Statement

Conventional ethanol plants generally produce ethanol as a primary product and dried distillers' grains with solubles (DDGS) as a by-product. Cellulosic ethanol (CE) production, in its development stage, has focused solely on ethanol and waste products have been an afterthought. Currently, CE demonstration plants like Iogen's do not utilize waste products as potential co-products (Iogen, 2010). However, feedstocks used for CE production like wheat straw generally have the ability to offer co-products if the proper technology is used to extract them. Success in this concept can be observed in the multiproduct nature of a petroleum refinery where the feedstock oil is cracked into gasoline and many other high valued co-products.

The expensive startup capital costs including novel technology and large yearly expenses such as enzymes have been a significant hindrance for the business case of a CE refinery in Canada, as well as the U.S. "Cellulosic plants have been regarded as uneconomical in the U.S., especially compared to grain based ethanol...However, assuming technology continues to progress, it is possible that cost will decrease for cellulosic plants; making cellulosic biofuels economically feasible" (Rismiller & Tyner, 2009).

With these two problems of co-product exclusion and high startup costs, the purpose of this research is to create a framework for determining conditions that would lead to a viable multi-product CE biorefinery. This framework will establish which CE co-products are valuable, which feedstocks make sense, where to locate the biorefinery, and with what capacity. With all these important factors addressed in the framework, the primary objective of this research is to develop a model that can predict the viability of a CE business. Modeling a CE business is challenging when technology is constantly changing and improving, and the economic environment ebbing and flowing. Therefore a feasibility framework could be used to assess the sensitivity of assumptions as they change and give entrepreneurs a tool to make decisions.

Another objective of the research is to identify key parameters in the model that affect the profitability of a biorefinery producing primarily CE but also co-products.

Hypothesis

The hypothesis of this research is that cellulosic ethanol as a biorefinery is not a profitable venture at the firm or regional level. Given current availability of robust ethanol production subsidies, and the absence of commercial scale CE plants, the only reasonable explanation for this is that the business model is not profitable yet. This could be evidence that CE production may not be feasible without the co-production of other commercially valuable products (Kaylen, 2000). The majority of ethanol refineries produce ethanol as a primary product and find little value in the co-products and by doing so do not utilize the entire plant biomass.

Chapter Outline

The next chapter will describe the background information needed to understand the main components of this research question. Ethanol is defined and its uses and properties described, as well as the difference between conventional ethanol and cellulosic ethanol. The benefits of ethanol and why it has been supported by government in the past are highlighted. Then the production processes of conventional and cellulosic ethanol are reviewed as well as the concept of a biorefinery. Further on in the chapter the various conversion technologies are described along with the potential co-products which they produce. Then the chapter ends with a brief look at the CE industry status and incentives which are currently in place. Chapter 3 reviews the theory behind the methods used in the feasibility framework. This section will review the theory behind how the players in the CE industry behave, review business plans, and the model used. This theory will provide the framework needed to explore the decision of whether or not to invest in a CE biorefinery. Chapter 4, the methods section, will lay out how the study was conducted and walk through the model in detail. Then the base case scenario used in the model will be presented along with the methodology for the sensitivity analysis. Chapter 5 will present the results in the form of a sensitivity analysis of the findings from the model and discussion of the results will follow with comment on significant parameters in the model. Chapter 6 will present conclusions based on the results and provide recommendations for future research.

2. BACKGROUND

The following section will define what ethanol is and discuss the difference between conventional ethanol and cellulosic ethanol (CE). Then it will go on to review several conversion technologies and the co-products that could be produced alongside ethanol and narrow down which of these has the best chance of being viable. Finally, an overview is done of the ethanol industry and the current role that the government plays.

Ethanol

Ethanol, which is also called ethyl alcohol, is most popular for its use in alcoholic beverages. It is produced by fermenting a variety of feedstocks that contain sugars including potatoes, grapes, barley, and corn. This clear, colourless, and flammable alcohol also has many uses in the chemical industry as an organic solvent and has gained popularity in recent years as a fuel additive, replacing MTBE (Methyl tert-butyl ether**).** Due to MTBE's environmental concerns it has been phased out. Ethanol has taken its place as a gasoline additive to increase the octane level, which prevents engine knocking (Myers, 2007). Furthermore, aside from low level blending of ethanol in gasoline, vehicles that have the designation flex fuel can use E85 fuel - a mixture of 85% ethanol and 15% gasoline. The availability of E85 at retail gas stations is still limited in Canada (Ethanol, 2011).

Conventionally, and most commonly, fuel ethanol is produced on a very large scale from the fermentation of corn grain. However, new technologies have allowed the other parts of the plant, referred to as biomass, to be utilized and produce the same ethanol but called cellulosic ethanol (CE). Even though the ethanol is the same in grain ethanol and cellulosic ethanol, the co-products and waste vary widely depending on the technology used. Conventional ethanol technology is capable of producing ethanol with the animal feed supplement DDGS (dried distillers grains with solubles) as its sole low valued co-product. CE technology on the other hand has many more co-product options lending itself to the biorefinery concept.

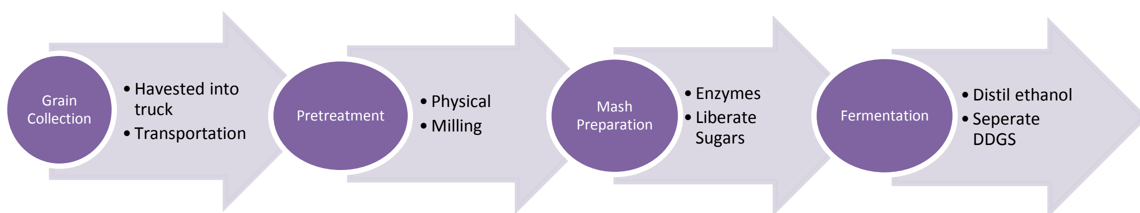
The Canadian government mandated a 5% ethanol blend for all refineries as of September 1, 2010 and this mandated level is even higher in some provinces (Bevill, 2010). The government's interest in renewable biofuels is mainly due to its positive effect on the environment given the greenhouse gas emissions are 86% less for CE than gasoline and 19% less for corn ethanol. In addition, CE requires 90% less fossil fuel inputs to produce an energy equivalent transportation fuel while corn ethanol requires 30% less (USDE, 2010).

Interest in ethanol from another point of view is its renewable nature, which may contribute to national security, rural economic development, and food security (CE). Gasoline supply is limited, which could lead to potential conflicts with other countries or domestically, and there is enough biomass to noticeably increase fuel supply in the country (Mabee & Saddler, 2010). The economic multiplier effect from the construction of new processing plants and the operation of those plants may provide demand for goods and services in rural areas and may create jobs. CE production also has the potential to help relieve the demand for grain in ethanol production by utilizing wasted crop residues, and other non-utilized biomass like woody biomass and municipal solid waste. This relief in demand, as more biorefineries are built, also potentially relieves food prices which rely on corn and wheat as a principal ingredient.

Conventional Ethanol Production

Ethanol is conventionally derived from the grain of corn and wheat, but more specifically it is the sugar in the starch of the grain that is fermented and distilled into alcohol (see Figure 2.1). The process begins with the grain being harvested and delivered by truck or rail, then physically changed or milled to increase its surface area. This better allows added enzymes to break down the starch into glucose when mixed and heated. The glucose is then fermented and distilled into ethanol while the by-product, DDGS, is extracted by centrifuge from the waste (Babcock and Brown Biofuel, 2007).

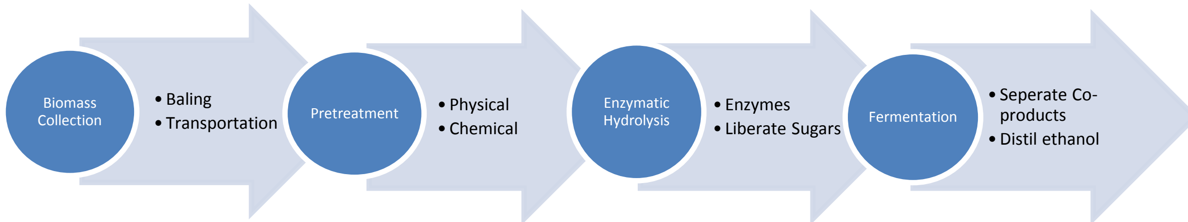
Figure 2.1 Conventional Ethanol Production Process Flow



Cellulosic Ethanol Production

There is also sugar in the other biomass parts of plants, like the stem, which can only be accessed and converted into CE with new technologies. Potential sources of CE are crop residues, wood waste, and dedicated energy crops. Following Figure 2.2 below, the process for CE production from crop residues can be seen in its simplest form. Straw is collected from farmer's fields in the form of bales, and then brought to a biorefinery where they are physically and/or chemically pretreated to breakdown the cell walls of the biomass (Iogen, 2009). Then the product is treated with enzymes to allow access to the sugars, which are then fermented and distilled to yield ethanol and sometimes co-products depending on the technology (Mosier, 2005).

Figure 2.2 Cellulosic Ethanol Production Process Flow



The key difference between the two processes is the pretreatment required in CE production to break down the resilient cell wall which is often very energy intensive and must be done in a manner which does not destroy potential co-products.

Biorefinery Concept

The idea of a biorefinery is similar to a petroleum refinery, in that instead of refining oil to make gasoline and multiple petrochemical co-products it refines biomass to create ethanol and other co-products (Ragauskas, 2006). This is done by utilizing all or some of the potential products from the plant instead of just producing ethanol. Biomass is made of three parts: cellulose, hemicelluloses, and lignin. Cellulose and hemicelluloses are the main source of sugars that yield ethanol, and lignin is the main source of potential co-products. Many of the co-products derived from lignin can be used as petrochemical substitutes and potentially could take market share from oil refineries. The environmentally friendly nature of the co-products compared to petrochemicals could be used as a selling point. Some of the lignin derived co-products considered to be high valued are phenolic precursors, resins, carbon fibre, and adhesives (Lora, 2002). The production of high quality lignin is heavily dependent on the pretreatment technology used. Furthermore, each unique pretreatment technology yields a unique set of potential co-products. Thus the selection of the technology has significant implications on the business model.

Conversion Technology

Conversion technologies which separate the three parts of biomass are called fractionation technology and are more ideal for a biorefinery concept than a technology that focuses solely on ethanol production. There are a variety of fractionation technologies available, some of which are closer to commercialization than others.

Organosolv: This is the most popular fractionation technology and the process employed by Lignol Innovations (Arato, 2005). In this process biomass is cooked for a period of time in water and ethanol, or organic acid like peracetic acid liquor, until chemical reactions occur which fractionate the biomass. The hemicellulose becomes separated into other chemicals which include valuable acetic acid, xylose, and furfural. Lignin is then precipitated and filtered which increases purity and quality. The insoluble cellulose is then recovered and fermented to ethanol.

Alkaline: This method of pretreatment uses bases such as sodium hydroxide, lime, and ammonia to treat biomass at ambient temperatures. For example, a combination of hot water treatment and aqueous ammonia successfully fractionated biomass cellulose, hemicellulose, and lignin (Kim, 2006). The downside of alkaline method is its processing duration is much longer and it produces salts that need to be disposed of.

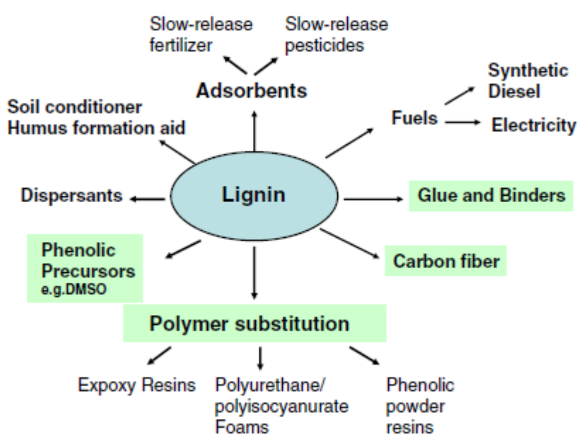
Ionic Fluids: This is a new fractionation technology that has a green aspect to it because the solvent is recyclable and non-flammable in this process and operates under mild conditions. Unfortunately, ionic liquids are very costly and there is much more research that needs to be done to understand their physio-chemical characteristics. Giuseppe Mazza (Mazza, 2010) from the CBioN research network says "at the present time I would not recommend an economic feasibility analysis of biomass pretreatment with ionic liquids…There is not yet sufficient information on these solvents, and presently, they are relatively new and expensive solvents…"

The Organosolv process was used in this financial/economic feasibility model based on recommendations from experts (Pan, Reith), its proven technology demonstrated by Lignol Innovations, and the process' ability to produce a pure high quality lignin among other chemical products using wheat straw as a biomass feedstock. The process is more complex and may cost more than some other popular pretreatments (dilute acid, steam explosion), but to stay in line with the biorefinery concept and have multiple sources of revenue, Organosolv fits best. Given the Organosolv choice, a brief market overview of some co-products produced by that process is presented below.

Co-Products

Lignin – This co-product is derived from the part of the plant that makes up the cell wall and has a variety of chemical uses including resins, foams, dispersants, and flavouring (see Figure 2.3). The flavouring called vanillin from lignin is considered of higher quality than oil derived vanillin, and is increasing in demand because of higher oil prices (MacKay, 2009). The most popular resin application is in oriented strand board (Lora, 2002). High quality and purity lignin, like the kind produced by the organosolv pretreatment, are generally sold in Europe for around €400/ton (Reith, 2010). T There is no fixed price and it is traded in a very thin market (Reith, 2010). There is no clear data yet for lignin in North America, but as demand grows for environmentally friendly chemical feedstocks, the market should develop.

Figure 2.3 Lignin Products



Furfural – Like lignin, furfural is also a base chemical that has many industrial applications. These applications include a solvent in the production of lubricants and nylons, and resin production. Approximately 250,000 tons of furfural are produced in the world annually and it is sold in the range of $1000 and $1750 per ton (MacKay, 2009). Most of the world's furfural is produced in China, while the US and Canada have very limited capacity. Of that production about 10% is consumed in the US. If furfural can be produced as a co-product to ethanol then it will likely be able to compete in the lower end of the price range.

Acetic Acid – This chemical, which is responsible for the bitter taste of vinegar, is a widely purchased commodity and, like the previous two products, has many uses. Its largest application, called VAM, is widely used in paints and coatings. The price of acetic acid was around $57 to $61 per pound in the United States in 2008. The world production capacity is around 7.8 million metric tonnes, 2.9 million of which is produced in North America (MacKay, 2009).

Xylose – Xyiltol, a substitute for sucrose sugar, can be produced from Xylose. It has 60% the sweetness of sucrose but can be used by diabetics without the use of insulin. Xylitol is commonly found in gum, candy, mouthwash, and mints (Arato, 2005). The market price for Xylose is around $5 per kilogram (Murthy, 2005).

Industry Status

The ethanol industry is small in Canada compared to the United States. There are only 15 grain ethanol producers in Canada with a capacity of 1.5 billion litres compared to about 200 in the U.S. with a capacity of 54 billion litres (Ethanol Producer Magazine, 2009). Of Canada's 15 plants, 7 use wheat as a feedstock and 8 use corn. The plants using wheat are located in the prairies, mainly Saskatchewan, and the corn plants are located mostly in Ontario. Although ethanol production is relatively small in Canada, the rate of yearly production increase could accelerate if the CE industry comes online.

The CE industry is in its infancy due to the inability of companies to be profitable. Research is still in progress on many fronts to improve the economics of the biorefinery by way of less expensive enzymes, more efficient conversion technology, feedstock collection logistics, and marketable co-products. Agriculture and Agri-Food Canada invested 20 million dollars into a research network called Canadian Biofuels Network (CBN) which is trying to address all the previously mentioned problems with CE (AAFC). If not for these problems the industry would grow more organically, instead of with great support from government in the form of production subsidies, and capital investment programs.

Key incentive programs that the government uses to encourage ethanol production are the ecoEnergy for Biofuels Program, a 1.5 billion dollar fund that will pay producers based on ethanol sales (Table 2.1) and ecoABC, a 200 million fund that offers producers up to 25 million in repayable loans to invest in biofuels capital projects. Currently there is only 23% of ecoABC allocated and it expired in September 2012. (Canada G. , 2010).

Table 2.1 EcoEnergy Subsidy Timeline

Fiscal Year Incentive	**2008 2009**	**2009 2010**	**2010 2011**	**2011 2012**	**2012 2013**	**2013 2014**	**2014 2015**	**2015 2016**	**2016 2017**
$/L	0.1	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03

Source: (Canada G. , 2010)

Ethanol is also supported on the demand side by mandated blends. Below is a table that summarizes the various ethanol production mandates in Canada at the provincial and federal levels.

Table 2.2 Federal and Provincial Blend Mandates:

Region	Mandate	Announcement/legislation	Regulation approved	Date effective
Bioethanol regulations				
CAN	Average 5% based on gasoline pool by 2010 – ~2.2 billion litres	Bill C-33, July 3, 2008	TBD	2010
BC	Provincial annual average 5.0% renewable content in gasoline pool	Bill 16, April 18, 2008	08/12/2008	2010
SK	Blend average 7.5% ethanol in gasoline pool 11/01/05–01/14/07: 1.0% ethanol 01/15/07 – 12/31/07: 7.5% ethanol 01/01/08 – forward: 7.5% ethanol	Ethanol Fuel Act, July 15, 2002	Updated over the years	01/01/2007
MB	Blend average 8.5% ethanol in gasoline pool [Blend average 5% for first quarter of 2008]	Biofuels Act, December 4, 2003	12/12/2007	01/01/2008
ON	Blend average 5.0% ethanol in gasoline pool	Announcement November 2004	7/10/2005	01/01/2007
QC	Target: average 5.0% ethanol in gasoline pool	Target only, no regulation planned	N/A	2012
AB	5.0% ethanol content in gasoline by 2010	Provincial Energy Strategy, December 11, 2008	TBD	2010
Low carbon fuel standards				
BC	Weighted average of the carbon intensities of fuels supplied in accordance with the regulations	Bill 16, April 18, 2008	TBD	TBD
ON	Reduce the carbon content of transportation fuels by 10%	Part of Ontario's Action Plan On Climate Change, August 2007	TBD	2020

Source: (Mabee & Saddler, 2010)

There are presently no CE companies in Canada that operate at a commercial scale, however there are several lab scale/demonstration facilities operating. Ethanol producer magazine (2010) lists three facilities in the US with capacities of 5.3 (BP), 18.9 (Fiberight), and 37.8 (Range Fuels) million litres. Also, Enerkem in Canada has 5 million litres capacity listed. Enerkem also has an agreement with GreenField Ethanol to build a 36 million litres capacity facility in Edmonton, Alberta. In addition to those listed, Iogen in Ontario has a demonstration plant in operation that is currently producing at a rate of 500,000 litres of ethanol per year from wheat, oat, and barley straw with a capacity of 2 million litres (Iogen, 2010). On April 30th, 2012 Shell cancelled plans with Iogen to build a commercial scale CE refinery in Southern Manitoba.

Previously mentioned CE enterprises are focusing on the sole production of ethanol, but Lignol, another Canadian start-up company operating in British Columbia, is researching the biorefinery concept in an attempt to maximize revenue streams by utilizing more parts of the plant, most specifically the lignin. They do not disclose information on the capacity of their demonstration facility or the ethanol/other product yields but they claim to be making significant breakthroughs in their patented organosolv technology utilizing waste wood from B.C. forests. Lignol is a very unique case in that they are the only company using a fractionation technology with the intent to eventually sell ethanol and multiple high valued co-products (Lignol, 2008).

Summary

This chapter provided the information and context on ethanol production and the industry needed to enable further analysis. Conventional ethanol and CE production were compared in detail then the biorefinery concept was introduced along with all the potential technologies that are appropriate for such an endeavor.   The Organosolv process for making CE was chosen for this study based on its ability to fractionate biomass into components and therefore be in line with the biorefinery concept. The next chapter will lay out the theory which together with this background information will provide a basis to start analysis.

3. THEORY

The previous section explained what Cellulosic Ethanol (CE) is and its potential benefits to society, the various technologies used to fractionate biomass, potential co-products, and the status of the CE industry. This section will proceed by reviewing the theory behind how the players in the CE industry behave, business plan theory, economic vs. financial models, and classification of the model used. This theory together will provide the framework needed to aid the decision of whether or not to invest in a CE biorefinery.

Theory of the firm

The firm, or biorefinery in this case, is assumed to be in a competitive market where one firm does not have more market power than another. This is generally the case in the ethanol industry because the product, ethanol, is a homogeneous commodity and the firm is a taker of input and output prices (Cyert & March, 2005).

It is assumed that the biorefinery has a production function f(x), which is some physical relationship between a vector of inputs (x) like wheat straw and vector of outputs (y) like ethanol. It is also assumed that there is an inverse production function h(y) that will result in a level of input given some level of output, both equations seen below (Just, Hueth and Schmitz, 2004).

$$(1)\ f(x) = y \qquad (2)\ h(y) = x$$

The biorefinery is assumed to maximize profits (π), profits being the difference between total product revenues (py) and the combined fixed costs and variable costs (wx) to produce those products. In a multiproduct firm like an ethanol biorefinery, p represents a vector of all the products prices, and w represents a vector of all the input prices. The maximization of profits is done by choosing the optimal output and input mix expressed in the equation below (Just, Hueth and Schmitz, 2004).

$$\text{(3) } Max_{y,x}\, \pi = py - wx\ ,$$

$$\text{s.t } f(x) = y,$$

$$p \geq 0,\ y \geq 0,\ w \geq 0,\ x \geq 0$$

With first order conditions of profit maximization assuming that x=h(y) exists:

$$\text{(4) } \frac{\partial \pi}{\partial y} = p - w\frac{\partial h(y)}{\partial y} = 0$$

For any particular product, y_i, you would produce it until marginal benefit, pi, equals the marginal costs:

$$\text{(5) } p_i = w\frac{\partial h(\partial y_i)}{\partial y_i}$$

Alternatively, how much of a particular input, x_j, will be used in production of the vector outputs, y, is determined by rewriting the first order condition as:

$$\text{(6) } \frac{\partial \pi}{\partial x} = p\frac{\partial f(x)}{\partial x} - w = 0$$

The amount of x_j to use is found by equating the value of the marginal product in production to the input cost, w_j. This equality is given below:

$$\text{(7) } w_j = p\frac{\partial f(x_j)}{\partial x_j}$$

The input x_j will be used until the value of its marginal product, $p\frac{\partial f(x_j)}{\partial x_j}$, is equal to its price. These equations express a biorefinery's decision in a single static period, but they can also be expressed dynamically over time.

Discrete Dynamic Model

The decision to invest in a biorefinery, or incur costs in the present to receive benefits in the future in the form of positive net cash flows, is described using a discrete dynamic model. The business is dynamic in that throughput changes over time along with loan payments, product prices, and costs, etc. In other words decisions in the present affect states in the future. Modeling a biorefinery enterprise is done with a discrete model because venture capitalists generally assess performance on a yearly basis, and so projections like sales are reported in discrete years.

A biorefinery has a production function at time t, with the current amount of variable input x_t, to produce the corresponding output y_t. The long-run stream of profits Π (8) to the biorefinery, because of the discrete nature of the problem, depend on maximizing profits in each period (9) as displayed below (Just, Hueth and Schmitz, 2004):

(8) $\Pi_T = \sum_{t=1}^{T} \pi_t$

(9) $Max_{y,x}\ \pi_t = p_t y_t - w_t x_t$

Each period with its unique prices that change optimal amounts of input to use and output to produce can be modeled clearly in a business plan from which potential investors can make the decision to invest.

Business Plans

All business plans are different but the basic components of a typical business plan include:

1. Executive Summary
2. Business Concept
3. Marketing Plan
4. Management Plan
5. **Financial Plan**

The purpose of the business plan is to raise capital by presenting it to all types of investors and lenders. If a biorefinery was to have a business plan to attract investors the financial appendix would contain portions of the financial model. The financial appendix must have the pro forma financial statements for the next 3-5 years, which include the sales projections, income statement, cash flow, and balance sheet. The first 12 months need also be mapped out in financial detail. The financial component of the business plan is important for investors because it tells them how much capital is required to start the project and more importantly when they will be paid back that money (i.e., exit strategy). The financial plan must also convey the source of sales and the security of the cash flows, including analysis of the value of investment over different potential scenarios (Canada, Writing your business plan, 2010). The net benefits reveived by the private investor are mapped out in the financial model, but there is much more affected in society by a CE biorefinery.

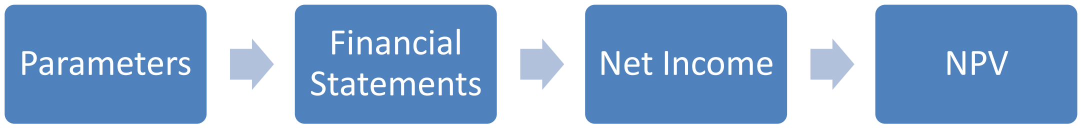
Economic vs. Financial Models

A biorefinery will yield both financial and economic benefits and costs. The financial results are of course easy to conceptualize as either profits or losses to an investor, but the total economic results are harder to comprehend because they are broad welfare effects to society.

Welfare models account for the financial benefits to the investor, but then adjust the benefits or cash flows to not include transfer payments in society that go from one person to another, which may or may not make society better off. Interest payments, subsidies, and taxes fall into this category because they do not create value in society but just transfer wealth. Economic models also include externalities. These are positive or negative consequences unintentionally affecting an economic agent not involved in the business resulting from the use of inputs or production of outputs from the business process (Baumol and Oats, 1988). This would include environmental effects on society from production like air pollution.

Financial models, following the diagram below, simulate the workings of a business using generally accepted accounting principles in pro forma financial statements. These statements accurately project future cash flows from the interactions of assumed parameters. Net income is then analyzed to make a decision of whether the investment is worthwhile based on the value they create or lose.

Figure 3.1 Financial Modeling Process



Both economic and financial models make use of present value (PV) to quantify/analyze the value of an investment. The concept of PV is used in decision making when future costs and benefits need to be accounted for. Due to the time preference of the money, future cash flows do not hold the same value as present day cash flows coming from the biorefinery. Therefore the values are discounted using a discount rate in a net present value (NPV) calculation (10): the value of future net benefits in the present (Just, 2004). NPV uses a discount rate (r) which is usually the prime rate of interest (i.e., cost of borrowing) or a required rate of return. If a project has a positive NPV then it is generating more cash than it costs to finance it (Lusztig, 2001). Alternatively, internal rate of return (IRR)(11) is also used as an investment tool, which is defined as the effective yield from a capital investment solved by equating the net present value to zero (Lusztig, 2001). It should be noted that economists generally avoid using IRR because it can take on different values, one or more being negative because of the polynomial form in equations (10) and (11) (shown below), where Bt represents benefits and Ct represents costs at period t.

(10) $NPV = \sum \frac{B_t - C_t}{(1+r)^t}$ (11) $IRR = \sum \frac{B_t - C_t}{(1+r)^t} = 0$, solving for r

Summary

The theory required to make a framework for making a decision on a potential investment into a biorefinery was described in this chapter. It was assumed that the business will make decisions to maximize profit, and will do so in a competitive environment. Also, financial modeling is often done as a component of a business plan with the purpose to attract funding from investors. The key difference between financial and economic models is economic models value the investment based on its net effects to society and include externalities. Finally, NPV is the tool used to evaluate the costs and benefits for financial and economic models and will be used in a dynamic and discrete model. In the next chapter this theory will provide the basis for the methods used for the model developed.

4. METHODS

Chapter 3 discussed the implications of a multiproduct biorefinery that is profit seeking in a competitive environment. The chapter also clarified the framework for financial assessment in discussing the financial component of the business plan. This assessment, both economic and financial, will provide the foundation for the methods described in this chapter used to model a biorefinery. This chapter will walk through how the model functions in detail by looking at categories of pages that are colour coded in the model. Then the base case scenario used in the model will be presented along with the methodology for the sensitivity analysis.

The Model Framework

The financial model and its economic variant developed here are designed to predict the financial and economic viability of a cellulosic ethanol (CE) biorefinery and to assist decision making for either an investor or government. The model, created in a Microsoft Excel 2007 workbook, contains an assumptions input page and many output pages which ultimately yield a financial and economic NPV from which decisions can be based. Excel was chosen as the modeling software because it is accessible to many potential users of the template. In addition, Excel is commonly used in generating financial statements, which is also in line with the purpose of the project. The model relies on parameters meant to express as accurately as possible the workings of a CE biorefinery. These parameters were taken from recent literature and industry professionals because currently there is no data available from a large scale commercially functioning biorefinery.

To navigate the model more efficiently in the Excel workbook, the workbook tabs are grouped into colours and each are designated in the table below and described in detail in the next section.

Table 4.1 Model Tab Groups

Red	Assumptions
Grey	Sensitivity analysis
Orange	Sales
Green	Cost of goods sold
Yellow	Financial statements
Purple	Financing
Black	Environmental analysis

Red – Assumptions

The assumptions page is the first page and only place that parameters and other data values are entered. This tab allows the user to input their process/biorefinery specific parameters in one place. Specific processing technology will have different yields for ethanol and co-products from a single tonne of biomass, and the biomass itself will yield different amounts of ethanol and co-products depending on its composition of cellulose, hemicelluloses, and lignin. In addition, each location could have a different production environment in terms of utility costs, biomass availability, biomass cost, and incentive programs. The assumptions /input page is colour coded based on certainty of data, which gives the user an idea of how accurate the forecast will be. Red cells indicate rough estimates that are temporary until the correct number is found or estimated based on literature. Green cells are based on recent literature or supported by an industry professional, and white cells are facts like conversion ratios.

Grey – Sensitivity Analysis

Sensitivity analysis was conducted on important economic and production parameters in the model to determine the effect on financial NPV and economic NPV of the investment. When the parameter is varied this results in a change in cash flow for the business whether it be from ethanol price or cost of enzymes for example. The change in cash is also felt in future years as the model keeps the change constant. The future cash flows are discounted by a discount rate to express the time value of money. If the cash flows are positive then the value of money decreases over time. If the cash flows are negative then the value will become less negative over time. In the example below of a financial NPV calculation, the cash flows are determined in each year by the workings of the business (the model), then each year's cash flow is discounted to the present value (PV). Then the PVs are summed which results in the cumulative PV of cash. The final year in the analysis is the NPV. For the economic NPV cash flows from the economic cash flow paged are used instead.

Table 4.1 NPV Calculation Example

Financial NPV	Discount rate	3.25%				
	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Cash Flow	(310,486,000)	8,828,310	20,004,650	33,120,932	29,941,474	29,941,474
PV of cash flow		8,550,421	18,765,098	30,090,705	26,345,893	25,516,604
Cumulative PV of cash flow	(310,486,000)	(301,935,579)	(283,170,481)	(253,079,776)	(226,733,882)	(201,217,279)

PV = Cashflow/1+Discount Rate

The factors analyzed include all product prices, feedstock prices and enzymes prices, ethanol yield, and total subsidy. Product prices and total subsidy were chosen because they will be the key factor in generating cash flow and likely be very dynamic in the real world as markets and governments change. Enzymes and ethanol yield were chosen because they could see improvements as technology improves. And feedstock was chosen because it is the largest contributor to the cost of production. In addition to these parameters the NPV was also calculated for a scenario with no co-product.

Each parameter was varied under 12 different scenarios. Three discount rates were used under four equity investment scenarios to make the 12 cases. Equity investment refers to the portion of the investment financed by the investors own cash rather than loan cash from the bank.

The sensitivity analysis pages are separated into 0, 30, 60, and 100% equity partitions. Within these pages sensitivity is done on the chosen outputs, inputs, and other important factors. Each factor is varied over discount rates of 3.25, 7, and 10%. All of the sensitivity analysis was done using macros, which is a way to program Excel to do tasks using shortcut keys. Each parameter's macro shortcut key is displayed in its heading. The macros are programmed to copy the new assumption into the assumptions page and paste the resulting new NPV back on the sensitivity page. The NPV page, also included in this category, displays the cash flows for a manual calculation (as seen in the example) of financial NPV and economic NPV. The excel formula =NPV(rate,value1,value2...) is also used to double check the NPV of the economic and financial cash flows. The NPV page also includes sensitivity on the discount rate from 0 to 40%. In the example below the feedstock price is varied over a 3.25% discount rate at 60% equity investment, and the base case scenario is highlighted in blue. In this scenario the business is not financially feasible, but has economic value up to $40/tonne.

Table 4.2 Feedstock Price Sensitivity Example

Discount		Feedstock price $/MT	Financial PV	Economic PV
	-50%	25.00	(177,554,043)	131,872,067
		30.00	(198,480,949)	100,424,241
		40.00	(240,361,333)	37,528,587
		50.00	(284,772,908)	(25,367,066)
3.25%		51.18	(290,013,474)	(32,788,753)
		60.00	(329,184,482)	(88,262,719)
		70.00	(373,596,057)	(151,158,372)
		80.00	(418,007,632)	(214,054,026)
		90.00	(462,419,206)	(276,949,679)
	+50%	100.00	(506,830,781)	(339,845,332)

Orange – Sales

The processing volume page feeds the sales page. This model assumes that full production cannot be reached in the first two years because there are learning curves for the technology along with lower productivity while the process is optimized. Therefore, each product’s yearly production is estimated in this sheet using half production in year one and the mean production of full and half production in year 2. The amount of biomass processed will also depend on the chosen capacity of the biorefinery and the ethanol yield of the technology. This sheet is colour coded in green to show the production path from start-up to year 5. To determine future sales, the estimated production is multiplied by the assumed prices of ethanol and co-products, which remain constant over the all years. In addition, there is a provincial subsidy in Saskatchewan and a federal subsidy in Canada given to ethanol producers. Subsidy revenue is calculated by multiplying the litres produced by the combined subsidy rate. Each product’s revenue is calculated then added together with the subsidy revenue to get total sales revenue.

Green – Cost of Goods Sold

Cost of goods sold or COGS are the direct costs associated with the production of a product. There are three sheets that cover COGS in the model; the labour, materials, and utilities sheets. The utilities sheet also breaks down utilities that are used for overhead as opposed to directly making ethanol, which are calculated by multiplying the $/sqft. by the square footage of the facility. The labour cost is calculated by multiplying the wage with the hours worked in a year of all the workers on all shifts. Depending on the process there may be different amounts of shifts, workers per shift, and hours per shift. The materials sheet tracks the inventories of biomass used as well as tracking the additional materials that are used in the process like enzymes and denaturant. The cost of the actual amount of biomass processed, not the cost of inventory, is used in the COGS. The total cost of additional materials is added to the cost of biomass to give the total COGS which is used in the net income statement.

Yellow – Financial Statements

The financial statements include a net income statement, cash flow statements, and balance sheet. The income statement summarizes the earnings resulting from revenues and expenses. The revenues come directly from collections on the sales page and the expenses come from all assumed administrative expenses, as well as COGS. The resulting number is earnings before interest, taxes, depreciation, and amortization (EBITDA). Next, those items are added in by taking depreciation from the capital sheet, calculating the taxes based on the assumed tax rate, adding the interest payments from any loans, and the amortization of start-up expenses. If there are any losses they are carried forward to the next year to reduce the taxable income.

The increase or decrease in cash from the period is fed into the NPV sheets. The financial cash flow statement feeds the cash flows used to calculate financial NPV and an economic cash flow statement feeds an economic NPV. The difference between the two cash flows is subsidy revenue, loan and interest, and taxes are not included in the economic cash flow because they are transfer payments in society. These two statements summarize the increases and decreases in cash from operations, financing activities, and investment activities.

The balance sheet summarizes the assets, liabilities, and equity in the company at a specific point in time. The assets must equal the liabilities plus owners equity for the statement to balance. This model shows the company's financial position at start-up and the projected first 12 months of operations.

Purple – Financing

The financing pages include the capital requirements, the loan, start-up expenses, and administrative expenses pages. The start-up page sums up all the expenses incurred at start-up like office supplies and legal fees. The capital sheet summarizes the fixed assets and the capital requirements to start the biorefinery, which includes the initial equipment, facility, land, initial inventory, start-up expenses, and cash. This compilation is known as the capital requirements, which need to be financed either by loans or equity investment. The facility and equipment depreciate over time so their value must be reduced using a depreciation schedule, found in the capital sheet. This model assumes a life of 25 years for the building and 10 years for the equipment. Using straight line depreciation, the item depreciates by the same amount each year until its value is zero. The purchase price of the fixed assets and other capital requirements are fed into the financing page from the assumptions page and distributed among sources of financing. The portion of financing covered by a loan is shown in detail in the loan page and uses the Excel formula =PMT(rate, nper, pv) to calculate the monthly payment. Then =PPMT(rate, per, nper, pv) is used to calculate the principal portion of the payment, and therefore the interest portion.

Black – Environmental Analysis

There are two pages to determine the environmental net benefits of CE production. One compares the benefits of CE to gasoline and the other CE to grain ethanol. The pages are linked with the financial model, drawing production volumes and assumptions. The final net benefits feed into the economic cash flow, but only from one of the two sheets depending on what the main interest is, gasoline or grain ethanol. One of the direct benefits of using CE is that it displaces gasoline emissions or grain ethanol emissions. To determine the value of this benefit the societal cost of CE emissions are subtracted from the cost of gasoline emissions and grain ethanol emissions. Another benefit of using CE over gasoline as a fuel is the carbon that is sequestered in the above ground biomass and the root system when producing the feedstock. However, in this case of CE, crop residue is not returned to the field it is lost in the combustion of ethanol. To quantify these environmental costs to society, the assumed value of carbon is multiplied by the carbon portion per tonne of wheat straw processed.

The following section will describe all the parameters used and their source. All values are in Canadian dollars and all units are converted to metric.

Base Case Assumptions

The base case assumptions used in the model as a point of reference for comparing different scenarios are grouped as follows and described thereafter.

1. Feedstock analysis
2. Feedstock price
3. Product Prices
4. Product yield
5. Subsidies
6. Man power
7. Utilities
8. Financial parameters
9. Environmental parameters
10. Additional materials

1. Feedstock Analysis

Western Canada has an abundance of biomass that could potentially be a feedstock for a CE biorefinery (Levin, 2007). Before any economic analysis is done it is important to be sure that there is in fact enough biomass in the desired region to support a commercial scale facility. The following section will consider whether the provinces of Alberta, Saskatchewan, or Manitoba can feasibly supply a commercial CE plant with enough biomass feedstock to meet annual requirements. These provinces were chosen for their abundance of agricultural production and because they currently do not have CE plants operating in them. The topics of feedstock selection, commercial size, region selection will be discussed below and sensitivity analysis will follow.

Feedstock Selection - The feedstocks which are available for CE production are crop residues, woody biomass, and dedicated energy crops. There are arguments for and against the use of all three of these sources of biomass. Dedicated energy crops would be the most efficient source of biomass because they would produce the most biomass per hectare (Huang, 2009). But they would also be difficult to convince farmers to grow due to the uncertainty of growing a new crop. Woody biomass is a great source of cellulose, but it does not grow as fast as crops and the pulp and paper industry would compete for it. Crop residues are readily available, but require a large supply radius and remove nutrients from the soil (Huang, 2009). For Western Canada, crop residues are the obvious starting feedstock because cereal crops are so widely grown and the straw is sometimes burnt, polluting the air. For this study wheat straw and alfalfa straw will be considered because of their popularity on the prairies.

The components of biomass feedstocks that produce the most ethanol are cellulose and hemicellulose (holocellulose). The third major component, lignin, can be used for a variety of co-products (Huang, 2009). The holocellulose compositions of wheat straw and alfalfa straw are relatively similar, and therefore yield similar amounts of ethanol (Koegel, 1996). 100 gallons/ton or 416 litres/tonne is a widely used estimate of ethanol yield for most mature conversion technologies (Kanellos, 2008). Tonnes of wheat straw produced are not a statistic that is recorded so it must be estimated based on grain production. To properly predict the straw produced from a hectare of wheat, grain protein and plant height paint a better picture, but those are also not recorded normally (Engel, 2003). A crude estimation can be done by multiplying the amount of grain produced by 1.3 or 1.6 depending on how conservative you want to be (Engel, 2003).

Alfalfa is reported as tonnes of hay not grain so there is no need to make a conversion to straw.

Commercial Size - Conventional corn ethanol plants have grown to capacities of around 378 million litres in the US, and the largest capacity plant is 1,590 million litres (Archer Daniel Midlands) (Ethanol Producer Magazine, 2009). However, in Canada the largest ethanol plants are only 200 million litres because demand is not as high and the amount of feedstock (corn&wheat) supply is more limited (Ethanol Producer Magazine, 2009).

CE biorefineries have not come close to corn ethanol capacities, only producing at pilot scales. The largest in Canada is Iogen's demonstration facility in Ontario producing 581,042 litres in 2009 and with a potential capacity of 2 million litres (Iogen, 2010). In the US, KL Energy's plant in Wyoming has a capacity of 5.6 million litres of CE using wood feedstock (Reuters UK, 2009). What size of ethanol plants would be viable in Canada? This study considers 1,890 million litres (500 million gallons) to be the top capacity and 7.56 million litres (2 million gallons) to be the lowest to be considered viable. The capacities were chosen because 1) Iogen planned on building a CE plant in Saskatchewan with a capacity of 150-200 million litres, 2) they reflect sizes of current conventional US ethanol plants, and 3) plants should be sufficiently large enough to obtain economies of scale from an expensive technology. The table below displays the differing biorefinery capacities which sensitivity will be conducted. The biomass required for each capacity will be compared to the biomass available in each region scenario.

Table 4.3 – Potential Biorefinery Feedstock Requirements

Commercial Capacity				**Biomass Required**
Capacity (l)	Capacity (gal)	Litres/day	Tonnes/day	Annual Tonnes
1,890,000,000.00	500,000,000.00	5,185,495.59	12,465.13	4,549,773.77
756,000,000.00	200,000,000.00	2,074,198.24	4,986.05	1,819,909.51
378,000,000.00	100,000,000.00	1,037,099.12	2,493.03	909,954.75
189,000,000.00	50,000,000.00	518,549.56	1,246.51	454,977.38
7,560,000.00	2,000,000.00	20,741.98	49.86	18,199.10

Region Selection - Looking at each feedstock individually, the province with the highest production would be the logical place to start assessing its feasibility. Saskatchewan, with 12.8 million tonnes of wheat production in 2009 seen in the table below, produces the most in Canada. Therefore it has the most wheat straw available and is the province chosen to study wheat straw feasibility. Alfalfa, on the other hand, is more complicated because even though Alberta has the most production, it is also more valuable. Higher prices were evident when hay listings were compared on both government websites. This is because of the high demand from livestock in the province. This high demand increases the price that farmers would be willing to receive, making it less economic to use for ethanol production. Therefore, Manitoba will be looked at instead of Alberta for the feasibility of alfalfa as a feedstock.

Table 4.4 Alfalfa and Wheat Historical Production

Production		**(000 tonnes)**				
Alfalfa	2005	2006	2007	2008	2009	Avg.
Alberta	8,754.30	8,142.00	9,276.00	9,344.00	5,352.40	8,173.74
Saskatchewan	5,806.00	5,488.50	5,511.10	4,490.60	3,991.60	5,057.56
Manitoba	3,193.29	3,147.93	3,209.62	3,127.34	3,999.70	3,335.58
Wheat	2005	2006	2007	2008	2009	Avg.
Alberta	8,548.30	7,818.10	6,076.10	8,736.20	7,440.70	7,723.88
Saskatchewan	13,450.00	12,482.00	9,058.00	12,437.50	12,805.70	12,046.64
Manitoba	2,441.30	4,084.60	3,211.40	4,280.90	3,356.60	3,474.96

Source: (Statistics Canada, 2009), (Manitoba, 2008), (Saskatchewan, 2010), (Honey, 2009)

The highest production areas in each province can be revealed by looking at the 2006 agricultural census data because each province is subdivided into cropping regions. Alfalfa production is not reported in the census, but tame hay, which is largely made of alfalfa, will be used as a substitute in this study. In Saskatchewan the highest producing areas are in the west, in region 3bn followed by 7a (see Figure 4.1). In Manitoba the highest alfalfa producing areas are in region 12 (Interlake) followed by region 6 (see Figure 4.2). In the analysis these areas will be considered, as well as the closest adjacent areas of the neighbouring province, because biorefineries are not limited to the boundaries of a province.

Figure 4.1 – Selected Regions for Wheat Straw

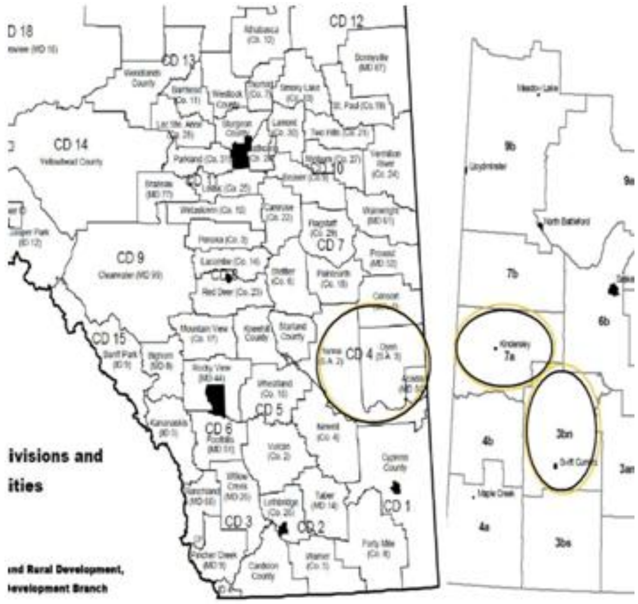
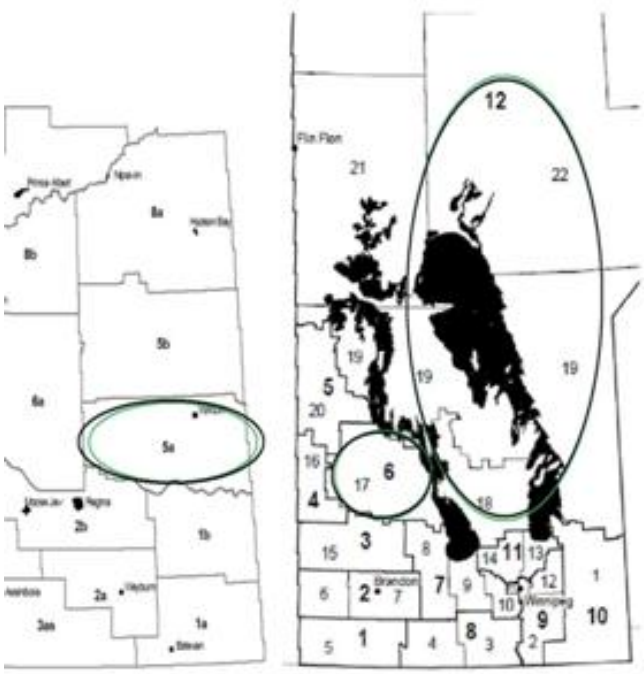


Figure 4.2 – Selected Regions for Alfalfa Straw



Source: (Statistics Canada, 2009)

Feedstock Sensitivity - To determine the feasibility of a region being physically able to supply a biorefinery with a specific feedstock, a sensitivity analysis was done with varying biorefinery capacities (vertically) and the availability of the total produced straw in the region: 100, 50, and 25% (horizontally). The assumptions used to produce the sensitivity analysis are shown in Table 4.5. The analysis was done to the largest producing census districts of the province, the two largest producing districts, and the two largest plus a neighboring province's district (Tables 4.6, 4.7, and 4.8 below). The assumptions are the wheat straw yield of 1.3 tonnes straw per tonne of grain, 1 to 1 yield for alfalfa straw, ethanol conversion yield of 416 litres/tonne straw, and 365 operating days. In the tables below, if the annual biomass requirement can be feasibly supplied to a biorefinery of the given annual capacity, then the cell will say yes.

Table 4.5 - Assumptions	
Wheat Straw Yield (tons/ton grain)	1.3
Alfalfa Straw Yield (tons)	1
Ethanol Yield (gal/ton)	100
Ethanol Yield (l/tonne)	416
Operating Days	365

Table 4.6 - Largest District Supply Analysis						
	Sask. Wheat Straw (tonnes)			Manitoba Alfalfa (tonnes)		
	100%	50%	25%	100%	50%	25%
Capacity (l)	1,483,365.00	741,682.50	370,841.25	555,942.17	277,971.09	138,985.54
1,890,000,000.00	No	no	no	no	no	no
756,000,000.00	No	no	no	no	no	no
378,000,000.00	Yes	no	no	no	no	no
189,000,000.00	yes	yes	no	yes	no	no
7,560,000.00	yes	yes	yes	yes	yes	yes

Table 4.7 - 2 Largest Districts Supply Analysis						
	Sask Wheat Straw (tonnes)			Manitoba Alfalfa (tonnes)		
	100%	50%	25%	100%	50%	25%
Capacity (l)	2,696,302.70	1,348,151.35	674,075.68	968,415.40	484,207.70	242,103.85
1,890,000,000.00	no	no	no	no	no	no
756,000,000.00	yes	no	no	no	no	no
378,000,000.00	yes	yes	no	yes	no	no
189,000,000.00	yes	yes	yes	yes	yes	no
7,560,000.00	yes	yes	yes	yes	yes	yes

Table 4.8 - 1 Adjacent Province District						
	Sask Wheat Straw (tonnes)			Manitoba Alfalfa (tonnes)		
	100%	50%	25%	100%	50%	25%
Capacity (l)	3,120,622.70	1,560,311.35	780,155.68	1,297,804.60	648,902.30	324,451.15
1,890,000,000.00	no	no	no	no	no	no
756,000,000.00	yes	no	no	no	no	no
378,000,000.00	yes	yes	no	yes	no	no
189,000,000.00	yes	yes	yes	yes	yes	no
7,560,000.00	yes	yes	yes	yes	yes	yes

Findings and Recommendation - Of all the above capacity scenarios only the smallest of them is feasible across both feedstocks and straw availabilities. Conversely, the largest capacity scenario is not feasible across both feedstocks and all availabilities. The largest feasible capacity in this analysis was shown to be the 756 million liters wheat straw plant using the largest producing regions in Saskatchewan plus an adjacent province's region. That capacity is four times larger than the largest existing conventional ethanol plants in Canada. An alfalfa biorefinery is less feasible than wheat, and did not improve when an adjacent provinces cropping region was added.

Based on this feedstock analysis, Saskatchewan has a large biomass resource in its wheat straw production to support a biorefinery, and to be conservative in supply estimates a low participation rate of 25% was used. The largest wheat producing area of Saskatchewan can support the straw requirements of a 189 million litre facility. Furthermore, a previously proposed cellulosic ethanol facility by Iogen would produce over 100,000,000 litres/year of ethanol, processing 750 tonnes/day of feedstock (Iogen, 2010). Their proposed supply radius for wheat straw is 160 km. Given that it is a risky venture and that additional revenue will be attained through the sale of co-products, a smaller scale is more feasible. To be conservative, 100 million litres will be used as a capacity in the financial model and will be in line with what other companies are proposing. This is a relatively small size compared to conventional ethanol plants however this will ensure enough feedstock is available, even if participation is low.

For this chosen capacity the base case assumes $150 million for equipment and $150 million for plant. This was based on Lignol's (Lignol, 2008) estimation of $300 million for total capital investment and capital estimates of (Kazi, 2010) of 327MM using a similar pretreatment method. The cost of land is assumed to be $250,000 based on a feasibility report by (Leistritz, 2006).

2. Feedstock Price

The price of wheat straw was determined by building up the price to account for nutrient value, baling cost, return to the farmer, and transportation cost. The nutrient value for wheat straw was estimated based on two sources. The Alberta government has an informative page on the subject and by their methods they come to $29.22/ton nutrient value. Alternatively, $12.27/ton was the value used in a CE biorefinery feasibility report

(Leistritz, 2006). Given these two values $20 was used as the assumed nutrient value of wheat straw. Found in the same report, $12.14 was used as the baling cost while on the Alberta site $9-11.50 was used; therefore $11.50 is an appropriate estimation for the financial model. In addition the return to the farmer was assumed to be $10/tonne and the transportation cost of wheat straw was assumed to be $9.68/tonne. This brings the total cost of a tonne of wheat straw to $51.18.

3. Product Prices

The products used of all the potential co-products from the organosolv/Lignol process in the financial model are ethanol, lignin, and furfural. The ethanol price is easily found on commodity futures markets like the Chicago Board of Trade. Over 2009, the time of the study, ethanol price has hovered around 1.60/gal or just above, so $1.64/gal, or 43 cents per litre was chosen as the base case price of ethanol (Futures Prices - Energies). The co-products lignin and furfural are not traded in organized commodity markets so their prices were estimated based on literature and professional opinion. Lignin, a co-product which has many potential uses, has been utilized more in Europe, so prices there are more accurate. In communication with Hans Reith, who is a researcher at Energy Research Centre of the Netherlands, he was able to quote the price €400/tonne for high quality lignin which is $573 CDN. The price for furfural, the second co-product, was discovered in detailed journal articles (Jong, 2010) (Tin Win, 2005) (Arato, 2005) (MacKay, 2009). Below is a summary table 4.9 of the potential co-products and their assumed market prices.

Table 4.9 – Co-Product Prices

Co-Product	CDN$/Tonne	Sources
Lignin	$570	(Reith, 2010)
Furfural	$1000-$1750	(MacKay,2009), (Yin Win, 2005), (Arato, 2005) (Jong 2010)
Acetic Acid	$800-1400	(MacKay, 2009), (Arato, 2005)
Xylose	$5000	(Murthy, 2005)

4. Product Yield

The ethanol yield was assumed to be similar to the yield from the Lignol process or Organosolv process. The assumed yield was derived from example economics provided by Lignol in a slide show presentation from 2009. In their presentation example they claimed that a 1000t/day plant would produce 107,000,000 litres (Lignol, 2008). Therefore, 107,000,000/365,000 is 293.15 litres ethanol per tonne feedstock. As this is an older report their process has most likely improved significantly so this estimate should be considered very conservative. The yields for lignin and furfural are fixed rates per tonne of straw and were estimated roughly by looking at the portion of revenue that was attributed to each product in the Lignol presentation (Lignol, 2008). Lignin was estimated at .1 tonnes/tonne of straw and furfural at .01 tonnes/tonne of straw. The current yields would be a key secret to a new technology company and such information was not forthcoming from Lignol. The ethanol yield can also be considered a conversion rate that can be changed to produce more ethanol and less co-products depending on the technology.

5. Subsidies

Since cellulosic ethanol cannot compete against low gasoline prices due to its expensive and non-commercial technology, subsidies are in place to increase profitability and bring an alternative to environmentally unfriendly oil based fuel to the market. In Canada there are federal and various provincial incentives. The provincial incentive for Saskatchewan is 15 cents per litre produced (Saskatchewan, 2010). There is also a 10 million dollar loan program called SaskBio to finance projects over 2 million in capacity (Saskatchewan G. o., 2008). The gasoline distributors are also required to blend at least 7.5% ethanol into gasoline. There is also a federal ethanol production incentive of 9 cents per litre that will decline by one cent each year (Canada G. , 2010). Using these provincial and federal incentives, the base case total subsidy used is 24 cents per litre.

6. Man power

The typical ethanol biorefinery needs a management team, administrative staff, lab technicians, maintenance technicians, floor workers, and security personnel. Iogen says their proposed plant will employ around 100 people, but this is not the number of people working at the same time and could include management so it is of no use (Iogen, 2010). It is not hard to define what management and administrative personnel a CE biorefinery needs because the positions will be similar to that of conventional plants, but the real challenge is to find out how many workers are required for a shift given a certain capacity. Cellulosic ethanol plants in construction are still keeping manpower requirements a secret. Lignol was contacted and they could not disclose such information. Another method would be to search literature to get a rough idea of how many a typical facility employs if possible. The ethanol producer magazine does a salary survey of ethanol plants across the United States, displayed in the table below. It was used to determine the types of employees and how much compensation the average type receives, however it does not tell how much of each worker are employed. A rough estimate of 16 employees per shift was used, working 12 hour shifts (Workers Rights, 2011), over two shifts per day. Benefits were determined to be approximately 22% of wages based on Canadian employment standards (Human Resources and Social Development Canada, 2006) and CPP standard contributions (Canada, Canada Pension Plan (CPP), 2010).

Table 4.10 Ethanol Salary Survey

Salary by Job Title

	Less than $40,000	$40,000-$49,999	$50,000-$59,999	$60,000-$74,999	$75,000-$99,999	$100,000-$149,999	More than $150,000
General Manager/CEO/ Corporate Management	0%	0%	0%	10%	0%	48%	38%
Controller/CFC	0%	0%	0%	25%	25%	50%	0%
Plant/Operations Manager	0%	0%	4%	30%	40%	21%	6%
Plant Engineer	0%	0%	33%	22%	22%	22%	0%
Commodities Manager	0%	0%	17%	42%	17%	25%	0%
Maintenance Manager	0%	0%	7%	57%	29%	7%	0%
EH&S Manager	8%	23%	31%	31%	8%	0%	0%
Lab Manager	11%	22%	50%	17%	0%	0%	0%
Lab Technician	80%	20%	0%	0%	0%	0%	0%
Lead Operator/Operator	24%	52%	21%	3%	0%	0%	0%
Administrative	68%	21%	5%	5%	0%	0%	0%
Other - Managerment	6%	22%	11%	28%	22%	11%	0%
Other - Non-Management	53%	0%	20%	27%	0%	0%	0%

Source: (Voegele, 2010)

From this study the positions of general manager, controller, operations manager, plant engineer, lab manager, maintenance manager, and commodities manager were chosen to be relevant to the potential CE biorefinery. The administrative staff that are relevant are administrative assistant, receptionist, quality control, and inventory clerk. These positions and starting salaries are tabled below.

Table 4.11 Management Salaries

Role	Year 1
General Manager/CEO/Corporate Management	$100,000.00
Controller	$ 65,000.00
Operations Manager	$ 75,000.00
Plant Engineer	$ 70,000.00
Lab manager	$ 60,000.00
Maintenance manager	$ 65,000.00
Commodities manager	$ 70,000.00
Total Salaries	**$505,000.00**
Benefits	$110,847.50
Total Management Costs	**$615,847.50**

Table 4.12 Administrative Salaries

Role	Year 1
Admin Assistant	$ 30,000.00
Receptionist	$ 30,000.00
Quality Control	$ 45,000.00
Inventory Clerk	$ 40,000.00
Total Salaries	**$145,000.00**
Benefits	$ 31,827.50
Total Wage Costs	**$176,827.50**

7. Utilities

To accurately represent the cost of utilities, the local Saskatchewan rates for electricity and natural gas are incorporated into the model. SaskPower, the utility provider, has their rates published on their website:

Table 4.13 – SaskPower Electricity Rates

	URBAN	**RURAL**
RATE CODE	E05	E06
Basic Monthly Charge	$33.80	$47.85
Demand Charge		
- First 50 kV.A/mo.	0	0
- Balance $/kV.A	$11.30	$12.25
Energy Charge		
First Block kW.h/mo.	16,750 kWh	15,500 kWh
- First Block (¢/kW.h)	8.764¢	9.160¢
- Balance (¢/kW.h)	5.425¢	4.997¢

Source: (http://www.saskpower.com/services/busrates/sst/doc1.shtml)

Furthermore, SaskEnergy has natural gas rates for industrial users on their website:

Table 4.14 SaskPower Natural Gas Rates

Rate Class:	**Rate Code:**	**Basic Monthly Charge ($/month)**	**Delivery Charge ($/m^3)**		**Commodity Charge**
Industrial:					
First 40,000 m^3/month	G04	216	0.039	$0.1961/m^3	$5.21/GJ
all remaining volumes			0.0333		

Source: (http://www.saskenergy.com/business/comrates_curr.asp)

There are no commercial size cellulosic ethanol plants operating so as a substitute utility consumption of conventional ethanol plants were used. A study by the RFA renewable fuels association found that 25,289 Btu/gal and 0.71 kWh/gal or 18.7 kWh/litre are used in a typical 100 million gallon conventional ethanol producer (Mueller, 2010). Using this parameter, a 100,000,000 litre capacity facility would use 18.7 million kWh of electricity. According to this study the natural gas consumption is 25,289 Btu/gal or 2.7 M^3/litre (Mueller, 2010). From this, the consumption of a 100,000,000 litre plant was found to be 19,000,000 M^3. By using the US plants as a proxy and the rates from SaskPower and SaskEnergy, a good estimate of the power expenses a CE biorefinery were determined. The overhead utility costs were estimated to be $2.25/sqft based on an article written on typical energy consumption of buildings (Quarforth, 2009).

8. Financial Parameters

The financial parameters in the model are discount rate for the calculation of NPV, the loan rate which is assumed to be the same as the discount rate, the loan amount, the loan term, and plant life. The discount rate/loan rate is based on how risky the investment is and the expected return. Risk depends on if you are the government or a private investor because the cost of capital is very different and the risks are very different. A high interest rate of 10% is used to represent a high cost of capital because the risky nature of new technology and a low rate of 3.25% is used to represent the low cost of capital that a government would experience. A rate of 7% is used to represent a situation where there is less risk say with a proven technology or proven business case. A 5 year loan term was chosen because the business is projected to generate large cash flows which could pay back the loan in a short amount of time. The base case scenario either has a 0, 30, 60, or 100% equity financing so the loan amount depends on the required capital. The life of the biorefinery was assumed to be 30 years. There are many studies that use 20 years for the life of the plant, however in this model a more realistic view is taken which assumes the business will last much longer if you take into account repairs, maintenance, and updated technology and many conventional ethanol plants have been operating for over 20 years (Ethanol Producer Magazine, 2009).

9. Environmental Parameters

The environmental assumptions contribute to the environmental analysis and ultimately to economic NPV. They are emissions pollution costs, carbon sequestration costs and environmental benefits from displacing gasoline or corn ethanol production and use. A report done in 2008 by PNAS (Proceeds of the National Academy of Science) describes the environmental costs of biofuels and gasoline (Hilla, 2008). The greenhouse gas emissions cost per litre from CE, gas, and corn ethanol are estimated to be 2, 10, and 10 cents per litre respectively in the report. Also, the costs from particulate matter are 4, 9, 24 cents per litre respectively. Another environmental cost unique to CE is the removal of carbon from the soils when crop residue is removed. Based on the government of Canada's biomass inventory website and a report on carbon sequestration, the portion of wheat straw that is carbon is 40%, the portion of carbon which is sequestered by the soil is 15%, and subsequently the overall portion of the feedstocks carbon sequestered by the soil is 6% (Powlson, 2007). The carbon costs are based on a value of carbon of $120/tonne, also found in the PNAS report.

10. Additional Materials

Depending on the process of making CE there are different additional materials that are required to get the final product or co-products. Therefore, it would be difficult to model this correctly in a financial model. To make the model practical, the term 'chemicals' was used as a catch all term for additional materials for the process. The rough estimate of .10% of feedstock was used at a price of $1000/tonne. Enzymes and denaturant are also common expenses. 13 cents per litre was assumed for enzymes because Novozymes claims that as their cost. And $1.00/litre was used for denaturant because it is essentially gasoline (Lane, 2009), and that was the price at the time of the study.

Sensitivity Analysis

The sensitivity analysis, discussed previously as the grey tab, was done with the purpose of discovering which parameters, if changed, could make a significant impact on the NPV of the business under 12 equity and discount rate scenarios. The ranges of values varied were meant to be realistic in that they could potentially occur, and are justified as follows.

The ethanol price was varied from $.26-$1.32/litre, its historical 10 year range, in 50 cent increments to evaluate potential fluctuations in price. Even though prices only went close to the upper range briefly in 2006, there is a chance demand for ethanol will increase in the future given that there has been increasing government mandates for ethanol production and blending.

Lignin price was varied from $0-$1000 in $100 increments. This range was chosen to account for the possible adoption and creation of new products made from lignin. Furfural was varied from $358-$1326 in 75 euro equivalent increments to account for either an increased supply or decreased supply as it already has an established presence in the market.

The wheat straw price/feedstock price varied based on a 50% increase and a 50% decrease in price in $10 increments. This range was chosen to account for the highly variable nature of wheat production due to drastic weather events like drought and flooding. The other input, enzymes, was varied from $.25 - $.70/gal in 5 cent increments to account for the probable future progress that will be made to reduce their price by private research companies like Novozymes and governments. The ethanol yield was varied from 200-600 litres ethanol/feedstock tonne in 50 litre increments to represent significant upside in the technological process of ethanol conversion technology. Total subsidy was varied from $0-$.51/litre in one cent increments to provide proper analysis to what subsidy would make the investment financially or economically feasible.

Summary

This chapter described the methods used to create a financial and economic analysis tool for the purpose of making CE biorefinery investment decision. An Excel workbook with interconnected input and output pages which utilized macros for sensitivity analysis was chosen as the modeling software. The inner workings of the model were explained in the groupings in which they are ordered in the excel workbook. The assumptions chosen for the base case were described in detail. The different scenarios which the base case was varied over were discussed in the sensitivity analysis section. The next chapter will show and discuss the results from the sensitivity analysis.

5. RESULTS

The previous section outlined the methods used for creating the model, which included the assumptions input page, the output pages, environmental analysis, and the construction of sensitivity analysis. The results from the sensitivity analysis will be shown below and discussion of the results to follow.

Sensitivity Analysis

The results, in the form of sensitivity tables, reveal the points at which the decision to invest would change and with what assumptions the business becomes financially or economically viable. This decision is based on whether the net present value (NPV), financial (FNPV) or economic (ENPV), in the specific scenario has a positive or negative value. The base case scenario is important because it serves as a reference point to compare all other scenarios. The base case was chosen to have conservative, but realistic assumptions according to the research. As discussed in the previous section, the sensitivity analysis was conducted on important economic and production parameters under differing equity investment scenarios and discount rates. The results of the sensitivity analysis will follow in the order of equity investment, starting with 0%, then 30%, 60%, and 100%. Changes in results will only be observed in the financial model from changes in equity investment due to interest payments being transfers in society. In this model the loan interest rate and the discount rate used to calculate NPV are assumed to be the same because the cost of capital is commonly used as a discount rate. The rates used are 3.25%, 7%, and 10%. As equity increases from a financial point of view there is more cash flow from operations that is not eaten by interest payments. The effects on NPV are more significant from some factors than others when they change in different equity scenarios. First the financial results will be explained, then economic results to follow.

As previously demonstrated in the methods, the NPV is calculated in the sensitivity analysis for all the scenarios to follow. As the parameters vary, NPV is determined by the calculation below. The financial and economic models financial cash flow and economic cash flow for each. The cash flow in each year (t) of the business is summed to get the NPV that is seen in the tables.

NPV = $\sum$(Cash Flow$_t$/(1+Discount Rate)) – Initial Cost

Effects of Equity Investment on Financial NPV

0% Equity – In this scenario all the funding requirements for capital investment are covered by a loan. At all discount rates it was found that the base case is not financially feasible. Furthermore when all factors are varied, all cases do not support a financially feasible biorefinery, seen in the table below, keeping in mind the base case is highlighted in blue.

Table 5.1 Ethanol Price Sensitivity at 0% Equity

Discount	$/Litre	FNPV	ENPV
3.25%	0.26	(1,265,737,050)	(334,605,293)
	0.40	(1,114,432,387)	(98,811,121)
	0.43	(1,072,067,081)	(32,788,753)
	0.53	(963,127,724)	136,983,051
	0.66	(820,941,810)	372,777,223
	0.79	(683,744,858)	608,571,395
	0.92	(548,717,502)	844,365,568
	1.06	(415,070,537)	1,080,159,740
	1.19	(281,423,572)	1,315,953,912
	1.32	(147,776,608)	1,551,748,084
	0.26	(1,018,687,544)	(328,982,882)

7%	0.40	(919,164,416)	(178,236,416)
	0.43	(891,297,940)	(136,027,406)
	0.53	(819,641,288)	(27,489,951)
	0.66	(720,118,160)	123,256,515
	0.79	(628,809,916)	274,002,980
	0.92	(540,185,028)	424,749,446
	1.06	(454,610,710)	575,495,912
	1.19	(370,314,871)	726,242,377
	1.32	(286,991,728)	876,988,843
10%	0.26	(902,063,316)	(326,300,778)
	0.40	(826,132,978)	(213,977,220)
	0.43	(804,872,483)	(182,526,624)
	0.53	(750,202,639)	(101,653,662)
	0.66	(674,272,301)	10,669,897
	0.79	(599,179,218)	122,993,455
	0.92	(531,373,583)	235,317,013
	1.06	(464,909,473)	347,640,571
	1.19	(401,949,681)	459,964,129
	1.32	(339,158,846)	572,287,688

When a subsidy of $0.51 is considered, the highest in this study, the financial NPV still remains negative at the lowest discount rate. Furthermore, the magnitude of the loss when the subsidy is removed all together is significant at over a billion dollars, seen in the table below.

Table 5.2 – Subsidy Sensitivity at 0% Equity

Discount	$/Litre	FNPV	ENPV
3.25%	-	(1,346,987,299)	(32,788,753)
	0.03	(1,312,622,272)	(32,788,753)
	0.06	(1,278,257,244)	(32,788,753)
	0.09	(1,243,892,217)	(32,788,753)
	0.12	(1,209,527,190)	(32,788,753)
	0.15	(1,175,162,163)	(32,788,753)
	0.18	(1,140,797,135)	(32,788,753)
	0.21	(1,106,432,108)	(32,788,753)
	0.24	(1,072,067,081)	(32,788,753)
	0.27	(1,037,702,054)	(32,788,753)
	0.30	(1,003,337,027)	(32,788,753)

	0.33	(968,971,999)	(32,788,753)
	0.36	(935,753,037)	(32,788,753)
	0.39	(903,619,422)	(32,788,753)
	0.42	(871,485,807)	(32,788,753)
	0.45	(839,352,192)	(32,788,753)
	0.48	(807,218,576)	(32,788,753)
	0.51	(775,650,633)	(32,788,753)
7%	-	(1,072,131,230)	(136,027,406)
	0.03	(1,049,527,069)	(136,027,406)
	0.06	(1,026,922,908)	(136,027,406)
	0.09	(1,004,318,746)	(136,027,406)
	0.12	(981,714,585)	(136,027,406)
	0.15	(959,110,424)	(136,027,406)
	0.18	(936,506,263)	(136,027,406)
	0.21	(913,902,101)	(136,027,406)
	0.24	(891,297,940)	(136,027,406)
	0.27	(868,693,779)	(136,027,406)
	0.30	(846,089,617)	(136,027,406)
	0.33	(823,485,456)	(136,027,406)
	0.36	(800,881,295)	(136,027,406)
	0.39	(778,277,133)	(136,027,406)
	0.42	(755,672,972)	(136,027,406)
	0.45	(733,068,811)	(136,027,406)
	0.48	(710,708,345)	(136,027,406)
	0.51	(690,109,111)	(136,027,406)
10%	-	(942,837,730)	(182,526,624)
	0.03	(925,592,074)	(182,526,624)
	0.06	(908,346,418)	(182,526,624)
	0.09	(891,100,762)	(182,526,624)
	0.12	(873,855,106)	(182,526,624)
	0.15	(856,609,451)	(182,526,624)
	0.18	(839,363,795)	(182,526,624)
	0.21	(822,118,139)	(182,526,624)
	0.24	(804,872,483)	(182,526,624)
	0.27	(787,626,827)	(182,526,624)
	0.30	(770,381,171)	(182,526,624)
	0.33	(753,135,515)	(182,526,624)
	0.36	(735,889,859)	(182,526,624)
	0.39	(718,644,204)	(182,526,624)
	0.42	(701,398,548)	(182,526,624)
	0.45	(684,152,892)	(182,526,624)
	0.48	(666,907,236)	(182,526,624)

	0.51	(649,661,580)	(182,526,624)

30% Equity – Like the previous equity scenario there is still negative NPVs at all subsidy rates, but at this increased level of investment in the model, financial NPVs begin to increase over all factors due to reduced interest payments. However, the base case scenarios under all three discounts rates remain infeasible. Positive FNPVs begin to appear at high ethanol prices starting at $1.06/litre at the low discount rate and $1.32/litre at the 7% discount rate seen in the table below. Like at 0% equity, a $.51 subsidy would not change investment decisions because the FNPV remains negative.

Table 5.3 – Ethanol Price Sensitivity at 30% Equity

Discount	$/Litre	FNPV	ENPV
3.25%	0.26	(874,710,246)	(334,605,293)
	0.40	(723,405,583)	(98,811,121)
	0.43	(681,040,277)	(32,788,753)
	0.53	(573,841,774)	136,983,051
	0.66	(433,055,185)	372,777,223
	0.79	(297,075,284)	608,571,395
	0.92	(163,148,572)	844,365,568
	1.06	(29,501,607)	1,080,159,740
	1.19	104,145,358	1,315,953,912
	1.32	237,792,323	1,551,748,084
7%	0.26	(740,623,805)	(328,982,882)
	0.40	(641,100,677)	(178,236,416)
	0.43	(613,234,201)	(136,027,406)
	0.53	(541,577,549)	(27,489,951)
	0.66	(446,281,981)	123,256,515
	0.79	(356,426,271)	274,002,980
	0.92	(270,851,953)	424,749,446
	1.06	(186,609,920)	575,495,912
	1.19	(103,286,777)	726,242,377
	1.32	(19,963,633)	876,988,843
10%	0.26	(676,482,520)	(326,300,778)
	0.40	(600,552,181)	(213,977,220)
	0.43	(579,291,686)	(182,526,624)
	0.53	(524,621,843)	(101,653,662)
	0.66	(448,691,504)	10,669,897
	0.79	(380,070,320)	122,993,455
	0.92	(314,080,723)	235,317,013
	1.06	(251,120,930)	347,640,571
	1.19	(189,361,763)	459,964,129
	1.32	(128,591,750)	572,287,688

60% Equity – Again the base case scenario has a negative NPV, though a small increase in ethanol price to $0.79 at 3.25% discount would turn the FNPV positive to $88 million, making the business viable. At the 7% discount level ethanol prices make the business feasible starting at $1.06 and at 10% discount starting at $1.19. A subsidy of $0.51 will make the business nearly financially feasible yielding a FNPV of -$2 million.

Table 5.4 Ethanol Price Sensitivity at 60% Equity

Discount	$/Litre	FNPV	ENPV
3.25%	0.26	(483,683,442)	(334,605,293)
	0.40	(332,378,779)	(98,811,121)
	0.43	(290,013,474)	(32,788,753)
	0.53	(185,261,687)	136,983,051
	0.66	(46,385,611)	372,777,223
	0.79	88,773,393	608,571,395
	0.92	222,420,358	844,365,568
	1.06	356,067,323	1,080,159,740
	1.19	489,714,288	1,315,953,912
	1.32	623,361,253	1,551,748,084
7%	0.26	(462,560,066)	(328,982,882)
	0.40	(363,036,938)	(178,236,416)
	0.43	(335,170,462)	(136,027,406)
	0.53	(263,754,046)	(27,489,951)
	0.66	(173,058,347)	123,256,515
	0.79	(87,093,197)	274,002,980
	0.92	(2,904,968)	424,749,446
	1.06	80,418,175	575,495,912
	1.19	163,741,318	726,242,377
	1.32	247,064,461	876,988,843
10%	0.26	(450,901,723)	(326,300,778)
	0.40	(374,971,384)	(213,977,220)
	0.43	(353,710,890)	(182,526,624)
	0.53	(299,041,046)	(101,653,662)
	0.66	(228,767,056)	10,669,897
	0.79	(163,251,973)	122,993,455
	0.92	(100,334,694)	235,317,013
	1.06	(39,564,680)	347,640,571
	1.19	21,205,333	459,964,129
	1.32	81,975,347	572,287,688

Table 5.5 Subsidy Sensitivity at 60% Equity

Discount	$/Litre	FNPV	ENPV
3.25%	-	(564,933,691)	(32,788,753)
	0.03	(530,568,664)	(32,788,753)
	0.06	(496,203,637)	(32,788,753)
	0.09	(461,838,610)	(32,788,753)
	0.12	(427,473,582)	(32,788,753)
	0.15	(393,108,555)	(32,788,753)
	0.18	(358,743,528)	(32,788,753)
	0.21	(324,378,501)	(32,788,753)
	0.24	(290,013,474)	(32,788,753)
	0.27	(255,648,446)	(32,788,753)
	0.30	(222,860,093)	(32,788,753)
	0.33	(190,726,478)	(32,788,753)
	0.36	(158,592,863)	(32,788,753)
	0.39	(126,459,248)	(32,788,753)
	0.42	(94,964,670)	(32,788,753)
	0.45	(64,080,275)	(32,788,753)
	0.48	(33,195,880)	(32,788,753)
	0.51	(2,311,485)	(32,788,753)
7%	-	(516,003,752)	(136,027,406)
	0.03	(493,399,591)	(136,027,406)
	0.06	(470,795,429)	(136,027,406)
	0.09	(448,191,268)	(136,027,406)
	0.12	(425,587,107)	(136,027,406)
	0.15	(402,982,946)	(136,027,406)
	0.18	(380,378,784)	(136,027,406)
	0.21	(357,774,623)	(136,027,406)
	0.24	(335,170,462)	(136,027,406)
	0.27	(312,566,300)	(136,027,406)
	0.30	(289,962,139)	(136,027,406)
	0.33	(267,357,978)	(136,027,406)
	0.36	(246,658,013)	(136,027,406)
	0.39	(226,058,779)	(136,027,406)
	0.42	(205,459,545)	(136,027,406)
	0.45	(184,860,311)	(136,027,406)
	0.48	(164,367,007)	(136,027,406)
	0.51	(144,930,965)	(136,027,406)
	-	(491,676,136)	(182,526,624)
	0.03	(474,430,481)	(182,526,624)
	0.06	(457,184,825)	(182,526,624)
	0.09	(439,939,169)	(182,526,624)

10%	0.12	(422,693,513)	(182,526,624)
	0.15	(405,447,857)	(182,526,624)
	0.18	(388,202,201)	(182,526,624)
	0.21	(370,956,545)	(182,526,624)
	0.24	(353,710,890)	(182,526,624)
	0.27	(336,465,234)	(182,526,624)
	0.30	(319,219,578)	(182,526,624)
	0.33	(301,973,922)	(182,526,624)
	0.36	(284,728,266)	(182,526,624)
	0.39	(268,391,074)	(182,526,624)
	0.42	(252,990,739)	(182,526,624)
	0.45	(237,590,404)	(182,526,624)
	0.48	(222,190,069)	(182,526,624)
	0.51	(206,789,734)	(182,526,624)

100% Equity – Without the use of debt financing through loans the base case becomes positive with a FNPV $230 million at 3.25% and $35 million at 7% discount rates. At 3.25%, over all factors and their range of values, the business model is feasible, even with feedstock at $100 or no subsidy. Ethanol price can be reduced to below the base case to $0.40/litre and the NPV is positive at 7% discount.

Table 5.6 Ethanol Price at 100% Equity

Discount	$/Litre	FNPV	ENPV
3.25%	0.26	37,685,629	(334,605,293)
	0.40	188,990,292	(98,811,121)
	0.43	230,979,459	(32,788,753)
	0.53	332,845,096	136,983,051
	0.66	469,173,821	372,777,223
	0.79	602,865,299	608,571,395
	0.92	736,512,264	844,365,568
	1.06	870,159,229	1,080,159,740
	1.19	1,003,806,194	1,315,953,912
	1.32	1,137,453,159	1,551,748,084
	0.26	(91,808,413)	(328,982,882)
	0.40	7,714,715	(178,236,416)
	0.43	35,243,229	(136,027,406)

7%	0.53	100,544,132	(27,489,951)
	0.66	186,443,252	123,256,515
	0.79	269,809,348	274,002,980
	0.92	353,132,492	424,749,446
	1.06	436,455,635	575,495,912
	1.19	519,778,778	726,242,377
	1.32	603,101,921	876,988,843
10%	0.26	(150,127,327)	(326,300,778)
	0.40	(74,196,989)	(213,977,220)
	0.43	(53,247,551)	(182,526,624)
	0.53	(4,427,494)	(101,653,662)
	0.66	58,839,625	10,669,897
	0.79	119,651,421	122,993,455
	0.92	180,421,435	235,317,013
	1.06	241,191,449	347,640,571
	1.19	301,961,462	459,964,129
	1.32	362,731,476	572,287,688

Also at that level the price of feedstock can be raised to $70 seen below, and the cost of enzymes can increase to $0.70. If there is a $0.30 subsidy then the business becomes viable with 10% discount.

Table 5.7 Feedstock Sensitivity at 100% Equity

Discount	$/MT	FNPV	ENPV
3.25%	25.00	332,037,057	131,872,067
	30.00	312,736,522	100,424,241
	40.00	274,135,454	37,528,587
	50.00	235,534,385	(25,367,066)
	51.18	230,979,459	(32,788,753)
	60.00	195,071,574	(88,262,719)
	70.00	153,933,224	(151,158,372)
	80.00	112,794,874	(214,054,026)
	90.00	71,656,524	(276,949,679)
	100.00	30,518,174	(339,845,332)
	25.00	101,958,824	(28,868,920)
	30.00	89,217,114	(49,334,636)
	40.00	63,733,693	(90,266,066)
	50.00	38,250,273	(131,197,497)

7%	51.18	35,243,229	(136,027,406)
	60.00	11,094,073	(172,128,928)
	70.00	(16,669,099)	(213,060,359)
	80.00	(44,432,271)	(253,991,790)
	90.00	(72,195,442)	(294,923,220)
	100.00	(99,958,614)	(335,854,651)
10%	25.00	(2,012,678)	(101,346,579)
	30.00	(11,797,795)	(116,850,789)
	40.00	(31,368,029)	(147,859,210)
	50.00	(50,938,263)	(178,867,630)
	51.18	(53,247,551)	(182,526,624)
	60.00	(72,048,112)	(209,876,050)
	70.00	(93,716,613)	(240,884,471)
	80.00	(115,385,115)	(271,892,891)
	90.00	(137,053,616)	(302,901,311)
	100.00	(158,722,117)	(333,909,731)

In all equity scenarios except 100% equity, the base case scenarios are not financially feasible, and when all co-products are removed from the base case so that the refinery only produces ethanol, the business is becomes worse off financially with a FNPV of -$31.7 million at the 3.25% discount and also negative at 7% and 10 % as seen below.

Table 5.8 No Co-Product Scenario at 100% Equity

Discount		**FNPV**	**ENPV**
3.25%	No Co-Products	(31,702,189)	(442,739,721)
7%	No Co-Products	(137,449,391)	(398,114,713)
10%	No Co-Products	(184,948,729)	(377,811,990)

Significant Parameters

When looking at the parameters tested in the sensitivity analysis, the most important factor is ethanol price. This can be seen clearly when looking at the 60% equity scenario. By varying the ethanol price higher the business becomes financially viable quickly and to a large degree, and this is not the case when varying other factors to benefit the business. The rate at which NPV improves is relatively high for lignin price and subsidy rate, but their effects at the upper level of their varied range are not as great as ethanol price.

Surprisingly, increasing the ethanol conversion rate (amount of ethanol produced per tonne of feedstock) decreased the FNPV and ENPV of the investment when intuition says that more ethanol from less feedstock should increase the value of the investment. In fact, the value of the investment decreases due to less feedstock being used, and therefore less feedstock for production of valuable co-products which contribute significant revenue to the business. This is due to the fact that the ethanol capacity of the refinery stays constant .Therefore, there exists an optimal product mix between ethanol and co-products which will depend on the value that the co-products contribute compared to that of ethanol.

Table 5.9 Conversion Rate Sensitivity at 100% Equity

Discount	Litres/MT	FNPV	ENPV
3.25%	200.00	248,479,735	(72,534,818)
	250.00	236,882,970	(48,152,447)
	293.15	230,979,459	(32,788,753)
	300.00	230,156,186	(30,672,358)
	350.00	225,587,941	(17,136,430)
	400.00	222,877,406	(6,065,603)
	450.00	219,893,904	3,361,824

	500.00	216,142,625	11,638,870
	550.00	212,983,853	19,079,276
	600.00	210,291,097	25,892,202
7%	200.00	43,770,192	(163,176,336)
	250.00	37,836,200	(146,693,005)
	293.15	35,243,229	(136,027,406)
	300.00	34,868,052	(134,536,465)
	350.00	33,033,729	(124,852,375)
	400.00	32,365,045	(116,713,568)
	450.00	31,066,101	(109,604,949)
	500.00	28,746,536	(103,217,461)
	550.00	26,786,235	(97,354,432)
	600.00	25,116,259	(91,884,748)
10%	200.00	(48,678,571)	(203,909,730)
	250.00	(52,109,585)	(191,033,490)
	293.15	(53,247,551)	(182,526,624)
	300.00	(53,423,271)	(181,324,173)
	350.00	(54,043,344)	(173,424,526)
	400.00	(53,809,289)	(166,655,924)
	450.00	(54,337,452)	(160,641,351)
	500.00	(55,979,565)	(155,154,598)
	550.00	(57,366,923)	(150,051,714)
	600.00	(58,542,906)	(145,236,733)

Economic Results

The economic results do not change when equity investment changes because the interest payments are transfer payments to society. Seen in table 5.6, the base case is not economically viable at 3.25% discount, however if ethanol prices increase to $0.53, then the business becomes economically viable at 3.25%. And if ethanol price increases to$0.66 then there is viability at 7% and 10%. Also at 3.25%, enzyme price is only economically viable up to $0.16/litre and feedstock viable up to $40/MT seen in table 5.7.

Table 5.10 Enzyme Price Sensitivity at 100% Equity

Discount	$/Litre	FNPV	ENPV
3.25%	0.07	301,840,992	85,108,333
	0.08	287,668,686	61,528,916
	0.09	273,496,379	37,949,499
	0.11	259,324,072	14,370,081
	0.12	245,151,766	(9,209,336)
	0.13	230,979,459	(32,788,753)
	0.15	216,200,830	(56,368,170)
	0.16	201,046,063	(79,947,587)
	0.17	185,891,295	(103,527,005)
	0.18	170,736,527	(127,106,422)
7%	0.07	80,708,327	(60,654,173)
	0.08	71,615,308	(75,728,820)
	0.09	62,522,288	(90,803,466)
	0.11	53,429,269	(105,878,113)
	0.12	44,336,249	(120,952,760)
	0.13	35,243,229	(136,027,406)
	0.15	25,605,428	(151,102,053)
	0.16	15,629,665	(166,176,699)
	0.17	5,653,903	(181,251,346)
	0.18	(4,321,860)	(196,325,992)
10%	0.07	(19,230,683)	(126,364,844)
	0.08	(26,034,056)	(137,597,200)
	0.09	(32,837,430)	(148,829,556)
	0.11	(39,640,804)	(160,061,912)
	0.12	(46,444,177)	(171,294,268)
	0.13	(53,247,551)	(182,526,624)
	0.15	(60,552,338)	(193,758,979)
	0.16	(68,168,182)	(204,991,335)
	0.17	(75,784,026)	(216,223,691)
	0.18	(83,399,870)	(227,456,047)

Summary

This chapter presented notable results from the economic and financial model in the form of sensitivity tables. The base case was used as a reference point as the chosen parameters were varied over multiple equity and interest rate scenarios. The results also included a brief discussion of significant parameters, ethanol price, and conversion rate.

6. CONCLUSION

The last chapter presented the financial and economic results that came from sensitivity analysis over equity investment and discount rates. In addition, significant parameters were pointed out and discussion followed on the entirety of the results. This chapter will now bring this research to a conclusion by summarizing all previous chapters, determining if the objectives of the research were met and finally present major findings and suggest future research.

Summary of thesis

The primary business model used today for cellulosic ethanol (CE) production is a single product firm, producing solely ethanol and the remainder is waste. This research considers that since the feedstock can be made into more valuable products other than ethanol, using a CE biorefinery concept, their could potentially be a profitable business case. The framework used in the study evaluated the business case for a wheat straw CE biorefinery and the economic case, which includes environmental externalities. The framework first involved determining a location in Western Canada for the biorefinery based on the abundance of potential cellulose available for the refinery. Wheat and alfalfa straw where considered as potential feedstocks because of their abundance on the prairies. Next, sensitivity analysis of biorefinery size and feedstock requirements led to the conclusion of using wheat straw from Saskatchewan. Then the co-products to be produced were determined by evaluating the potential co-products available from wheat straw. The result was lignin and furfural were chosen based on market value. Once the base case was assembled, the sensitivity analysis was conducted on the model which produced the results and significant parameters of the biorefinery.

Fulfillment of Objectives

The primary objective of the thesis was to develop a financial and economic feasibility framework for a cellulosic ethanol biorefinery. By creating the framework, potential investment opportunities could be evaluated from a business perspective but also a social perspective. The hypothesis of this research is that cellulosic ethanol as a biorefinery is not a profitable venture financially or economically. It is evident, through the sensitivity analysis of the research that the parameters from which the base cases of the business model are based do not support a profitable biorefinery at most levels of equity investment. In line with the hypothesis the results found the CE biorefinery to be an unprofitable venture. This evidence suggests that the model is predicting with success. This work would be a good starting point for other researchers, and private or public investors to use in the creation of a feasibility model for their own biorefinery project. However, keep in mind that each project is unique and has its own investment environment, feedstock, co-product conversion and markets.

The secondary object of the research was to determine which parameters should be considered significant when looking at investment in a biorefinery. By singling out parameters that have the largest effect on economic and financial profitability recommendations for policy development and future research can be made. The sensitivity analysis identified the parameters that altered the financial and economic net present value significantly.

Major Findings

Through the fulfillment of the primary objective of creating a financial and economic feasibility framework two major findings have been revealed. The results show that biorefinery profitability is tied to financing. The research suggests that a CE business venture not be recommended unless completely financed with equity. However, seeing as there are positive economic returns at a low discount rate and 100% equity, there is a case for supporting such a business to benefit society. Furthermore, the cash flows are quite large when ethanol and co-products are sold together, but are not enough to make the business viable. This is due to the significantly large capital investment at start-up and other costs like enzymes. Based on the model used in this feasibility framework, government policy to subsidize the initial large capital investment could allow the benefits from the large cash flows from operations to contribute to a positive NPV and allow the economic benefits to be received by society. Currently such an incentive exists in the program ecoAgriculture Biofuel Capital Incentive, which provides $25 million loans to agricultural producers. This research makes the case for increasing the incentive, broadening eligible investors, and extending the timeline out from the current September 30th, 2012 construction deadline.

The second major finding that can be drawn from this study is that a biorefinery does much better, though not profitable in the base case, when there are multiple high valued co-products being produced. Since the co-products contribute significantly to the model, the biorefinery does worse when the feedstock conversion ratio is shifted from producing co-products to more ethanol. Therefore the biorefinery concept is recommended as a better business concept over the single product firm when multiple high valued co-products exist. Below is a table that shows a case where ethanol price is varied as was shown in the results. Then it is contrasted with a case where ethanol price is varied when co-products are removed from the model. What we see are drastically higher financial present values when co-products are included.

Table 6.1 Ethanol Prices with Co-Products

	W/ Co-Products				
	Outputs		**Ethanol**	**Financial PV**	**Economic PV**
Discount	/gal		/litre	A	G
3.25%	$	1.00	0.26	37,685,629	(334,605,293)
	$	1.50	0.40	188,990,292	(98,811,121)
		1.64	0.43	230,979,459	(32,788,753)
	$	2.00	0.53	332,845,096	136,983,051
	$	2.50	0.66	469,173,821	372,777,223
	$	3.00	0.79	602,865,299	608,571,395
	$	3.50	0.92	736,512,264	844,365,568
	$	4.00	1.06	870,159,229	1,080,159,740
	$	4.50	1.19	1,003,806,194	1,315,953,912
	$	5.00	1.32	1,137,453,159	1,551,748,084
7%	$	1.00	0.26	(91,808,413)	(328,982,882)
	$	1.50	0.40	7,714,715	(178,236,416)
		1.64	0.43	35,243,229	(136,027,406)
	$	2.00	0.53	100,544,132	(27,489,951)
	$	2.50	0.66	186,443,252	123,256,515
	$	3.00	0.79	269,809,348	274,002,980
	$	3.50	0.92	353,132,492	424,749,446
	$	4.00		436,455,635	575,495,912

			1.06		
	$	4.50	1.19	519,778,778	726,242,377
	$	5.00	1.32	603,101,921	876,988,843
	$	1.00	0.26	(150,127,327)	(326,300,778)
	$	1.50	0.40	(74,196,989)	(213,977,220)
		1.64	0.43	(53,247,551)	(182,526,624)
	$	2.00	0.53	(4,427,494)	(101,653,662)
10%	$	2.50	0.66	58,839,625	10,669,897
	$	3.00	0.79	119,651,421	122,993,455
	$	3.50	0.92	180,421,435	235,317,013
	$	4.00	1.06	241,191,449	347,640,571
	$	4.50	1.19	301,961,462	459,964,129
	$	5.00	1.32	362,731,476	572,287,688

Table 6.2 Ethanol Prices Without Co-Products

	W/O Co-Products				
	Outputs		**Ethanol**	**Financial PV**	**Economic PV**
Discount	/gal		/litre	A	G
	$	1.00	0.26	(225,372,157)	(334,605,293)
	$	1.50	0.40	(74,067,494)	(98,811,121)
		1.64	0.43	(31,702,189)	(32,788,753)
	$	2.00	0.53	77,237,169	136,983,051
3.25%	$	2.50	0.66	228,348,398	372,777,223
	$	3.00	0.79	368,739,515	608,571,395

	$	3.50	0.92	504,154,093	844,365,568
	$	4.00	1.06	637,801,058	1,080,159,740
	$	4.50	1.19	771,448,023	1,315,953,912
	$	5.00	1.32	905,094,988	1,551,748,084
7%	$	1.00	0.26	(264,838,995)	(328,982,882)
	$	1.50	0.40	(165,315,867)	(178,236,416)
		1.64	0.43	(137,449,391)	(136,027,406)
	$	2.00	0.53	(65,792,739)	(27,489,951)
	$	2.50	0.66	33,556,589	123,256,515
	$	3.00	0.79	123,238,343	274,002,980
	$	3.50	0.92	208,267,150	424,749,446
	$	4.00	1.06	291,590,294	575,495,912
	$	4.50	1.19	374,913,437	726,242,377
	$	5.00	1.32	458,236,580	876,988,843
10%	$	1.00	0.26	(282,139,563)	(326,300,778)
	$	1.50	0.40	(206,209,224)	(213,977,220)
		1.64	0.43	(184,948,729)	(182,526,624)
	$	2.00	0.53	(130,278,886)	(101,653,662)
	$	2.50	0.66	(54,508,512)	10,669,897
	$	3.00	0.79	12,337,730	122,993,455
	$	3.50	0.92	74,766,890	235,317,013
	$	4.00	1.06	135,536,904	347,640,571
	$	4.50	1.19	196,306,917	459,964,129
	$	5.00	1.32	257,076,931	572,287,688

Further Research and Industry Suggestions

To further investigate the profitability of a cellulosic ethanol biorefinery a study should be conducted on an actual commercial facility, rather than being reliant on the literature, to more accurately predict the outcome of profitability and which parameters are significant. These parameters will change with the technology, so it is key to that future models be updated as the parameters change.

This research also suggests that CE is not the solution to replacing gasoline at least at the current prices and it should be noted that at best CE could be a bridge to more sustainable fuel alternatives like electric powered cars. Other plentiful fuels like natural gas and biodiesel also offer economic, financial, and environmental benefits and cannot be ignored and could also be used as a bridge.

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APPENDIX

Assumption Input Page

Yields

293.15		Ethanol Yield (l/tonne)
0.1		Lignin Yield (tonnes/tonne straw)
0.01		Furfural Yield (tonnes/tonne straw)

Product Prices

1.64		Ethanol Price per gallon (Futures Market)
$	0.43	Ethanol Price per litre (Futures Market)
$	400.00	Lignin Euro/ton
$	520.00	Lignin CDN$/ton
573.20		Lignin CDN$/tonne (Europe)(high quality)
697.83		Furfural euro/ton
1000.00		Furfural CDN$/tonne
	1.00	Yearly increase

Subsidies

$	0.15	Provincial Production Credit (Sask)
$	0.09	Federal Tax Credit
$	0.24	Total Subsidy

Feedstock

$	20.00	Nutrient value /MT
$	11.50	Baling cost /MT
$	10.00	Return to farmer /MT
$	3.72	Cost per loaded mile
	50.00	Draw radius (miles)
	36.00	Average haul distance
$	9.68	Transportation cost /MT
$	51.18	Price per Tonne
1		MT yield per acre (low)
1.3		MT yield per acre (med)
1.6		MT yield per acre (high)
	1.00	Yearly Increase

Feedstock Mix

38.20%	Cellulose
21.20%	Hemicellulose
23.40%	Lignin
17.20%	Other

Additional Materials

$	1,000.00	Chemicals $/tonne

0.10%		Chemicals used as % of feedstock used
$	0.50	enzyme cost per gallon of ethanol
0.13		enzyme cost per litre of ethanol
$	1.00	Denaturant per litre
5%		Denaturant used as % of ethanol produced
	1.00	Yearly Increase

Overhead

$	2.25	Utility costs (per sqft) non production
200,000		facility size (sq ft)

Direct Utilities

$	0.19	Natural Gas cost per CM
$	0.19	NG used per litre ethanol CM
$	0.07	Electricity cost per kWh
$	0.74	kWh/gallon ethanol produced
$	0.20	kWh/litre ethanol produced
$	1.14	Water cost per CM
$	13.25	Water used per litre of ethanol
$	1.00	Yearly Increase

Sales collected

50%	First Month

Fixed assets

$	150,000,000.00	Equipment cost
10		Years life of equipment
$	250,000.00	Land cost
$	150,000,000.00	Facility
$	25.00	Years life of facility

Financing

$	318,566,000.00	Equity
$	-	Loan
3.25%		Interest Rate/Discount Rate
$	5.00	Years
$	8,000,000.00	Start-up cash

Processing

	100,000,000.00	Litres ethanol per year
	341,122.29	MT feedstock per year
	38.94	MT/Hour
25		MT/Hour (Year 1)
	934.58	MT/Day
365		Operating Days
8640		Hours/year

Year 1

80%	Learning Curve	
90%	Productivity	
16.00	Workers per shift	
22.00	Initial Wage	
12.00	Hours per shift	
2.00	Shifts per day	

Benefits

4.95%	CPP
2%	EI
4%	WC
4%	vacation
2.50%	Group Insurance
5%	RRSP/Pension
22%	Total Benefits

Starting Salaries

$	30,000.00	Admin Assistant
$	30,000.00	Receptionist
$	45,000.00	Quality Control/Assurance
$	40,000.00	Inventory Clerk
$	30,000.00	Security
$	100,000.00	General Manager/CEO/Corporate Management
$	65,000.00	Controller
$	75,000.00	Operations Manager
$	70,000.00	Plant Engineer
$	60,000.00	Lab manager
$	65,000.00	Maintenance manager
$	70,000.00	Commodities manager
$	1.00	Yearly Increase

General start-up costs

$	10,000.00	Legal fees
$	10,000.00	Office computers
$	10,000.00	Office equipment
$	10,000.00	Company cars
$	10,000.00	Forklift for bales
$	10,000.00	Tools
$	10,000.00	Lab Equipment
$	10,000.00	Safety equipment

Administrative Expenses

$	5,000.00	Communications
$	15,000.00	Office Supplies
$	20,000.00	Legal
$	25,000.00	Travel

$	22,000.00	Marketing
$	80,000.00	Insurance
$	55,000.00	Property taxes
$	15,000.00	Security
$	5,000.00	Bank Charges
$	0.01	Disposal cost per litre
$	455,906.88	Waste disposal

Environmental Analysis

$	0.02	Cost of cellulosic ethanol GHG emissions /l
$	0.04	Cost of cellulosic ethanol PM emissions/l
$	0.06	Total cellulosic emissions cost/l
$	0.10	Cost of gasoline GHG emissions/l
$	0.09	Cost of gasoline PM /l
$	0.19	Total gasoline emission cost/l
$	0.10	Cost of corn GHG emissions/l
$	0.24	Cost of corn PM emissions/l
$	0.34	Total corn emissions cost
6%		% of feedstock carbon sequestered by the soil
15%		% of carbon sequestered by the soil from crop residue
40%		% of crop residue which is carbon
$	120.00	Value of carbon