CELLULOSIC BIOFUELS ANALYSIS:
ECONOMIC ANALYSIS OF
ALTERNATIVE TECHNOLOGIES

by

Craig W. Rismiller and Wallace E. Tyner

Working Paper #09-06

June 2009

Department of Agricultural Economics

Purdue University

CELLULOSIC BIOFUELS ANALYSIS:
ECONOMIC ANALYSIS OF ALTERNATIVE TECHNOLOGIES

by
Craig W. Rismiller and Wallace E. Tyner
Dept. of Agricultural Economics, Purdue University
West Lafayette, Indiana 47907-2056
crismill@purdue.edu and wtyner@purdue.edu

Working Paper #09-06
June 2009

Abstract

The passage of U.S. laws mandating and subsidizing advanced cellulosic biofuels may spur the development of a commercial cellulosic biofuels industry. However, a cellulosic industry will only develop if the overall economics including government incentives render investment in the sector attractive to private investors.

This study compares the profitability of three biofuel production types: grain based ethanol, cellulosic biochemical ethanol, and cellulosic thermochemical biofuels. In order to compare the current profitability of each of the production types, the Biofuels Comparison Model (BCM) was developed. The BCM is a spreadsheet model that estimates the net present value (NPV) for each production type given input and output prices, technical, and financial assumptions. The BCM can be updated to reflect the current profitability through embedded web price links.

The study finds that grain, biochemical, and thermochemical production types are all currently unprofitable when subsidies and mandates are ignored. However, the grain based ethanol process is predicted to be the most profitable (lowest loss) compared to the cellulosic biofuels. When the 2008 Farm Bill subsidies are added to the BCM, all three production types are projected to be profitable. With the addition of the different subsidies, the cellulosic biofuels are estimated to have higher NPV's than grain based ethanol.

When compared on an energy equivalent basis, the estimated cost of producing grain ethanol is $114/bbl. crude oil equivalent, biochemical ethanol $141/bbl., and thermochemical gasoline $108/bbl.

Keywords: biofuels, cellulosic biofuels, corn ethanol, biofuel economics

JEL Codes: Z42

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

1. INTRODUCTION

1.1 Overview

Since 2004, ethanol production capacity in the United States (U.S.) has increased drastically; from 3.1 billion gallons per year (BGY) in 2004 to a January 2009 capacity of 10.6 BGY (Renewable Fuels Association, 2009). Currently, almost all of the ethanol produced in the U.S. is produced from corn.

The rapid increase of grain based ethanol production in the U.S. likely resulted from high oil prices, federal mandates and a continued fixed subsidy program (Tyner, 2008). Though these initiatives were successful in increasing ethanol production, many believe they led to higher commodity prices; affecting both livestock producers who rely on corn as a feedstuff and world consumers who purchase grain and meat products. In fact, the previous blending subsidy of 51 cents per denatured gallon was said to increase the price of corn by $1.07 per bushel (Abbott et al, 2008). Because of the negative externalities associated with producing grain based ethanol, there has been political pressure to start producing advanced cellulosic biofuels.

Cellulosic biofuels are gaining attention as a possible solution to decrease our dependency on foreign oil and produce a cleaner burning fuel while not significantly affecting the price of agricultural commodities. The key distinction between grain based ethanol and cellulosic biofuel production is that the cellulosic production can utilize any organic material to produce biofuels; namely wood wastes, corn stover or switchgrass. Two processes, biochemical and thermochemical production, are both advanced cellulosic production methods that likely will be utilized in the United States. Though both of the advanced biofuel production pathways hold promise; there are currently no commercial scale cellulosic plants in the production or construction phases in the U.S.

Cellulosic plants have been regarded as uneconomical in the U.S., especially compared to grain based ethanol. A 2007 study concluded it cost 44% more to produce cellulosic biofuels than grain based ethanol; largely due to the high capital costs associated with building the plants (Wright and Brown, 2007). However, assuming technology continues to progress, it is possible that cost will decrease for cellulosic plants; making cellulosic biofuels economically feasible.

To jumpstart the advanced biofuel industry, the United States Congress passed the “Energy Independence and Security Act of 2007” which mandates the use of advanced biofuels. The Energy Independence and Security Act of 2007 amends the “Renewable Fuels Standard (RFS)” that was signed into law in 2005. An important aspect of this legislation is that 21 billion gallons of the mandated biofuels must derive from advanced biofuels; such as cellulosic ethanol, and 16 of the 21 billion must come from cellulosic feedstocks (U.S. Congress, 2007). In addition to this mandate, the 2008

Farm Bill created subsidy differentiation based on how the ethanol is produced. The 51 cents blending subsidy for all ethanol was reduced to 45 cents per denatured gallon for the grain based platform in January 2009, and the effective subsidy for cellulosic methods was increased to $1.01 per gallon (U.S. Congress, 2008). These increased subsidies and mandates could spur investment in advanced biofuels especially in biomass rich areas such as Indiana, if investors believe they will be upheld throughout the investment life[1].

During the course of this research, a spreadsheet model was developed to compare the profitability of each of the production plant types using current and future technology estimates, current market prices for inputs and outputs, financing assumptions, and assumptions regarding state and federal subsidies. Previous cellulosic economic analysis models are not linked to current price levels, thus making profitability comparisons difficult when markets change. This economic analysis will compare each production type on both a pre and post tax net present value basis (NPV), conduct a sensitivity analysis to the key cost and revenue drivers, and estimate cash flows for each production type.

1.2 Objective and Approach

The key objective of this study is to conduct an economic analysis of cellulosic and grain based biofuels under a range of policy and economic assumptions. This section focuses on defining the research goals and explaining the studies approach.

1.2.1 Cellulosic Economic Analysis Objective and Approach

The objective of the biofuels comparison analysis is to determine the profitability of advanced cellulosic biofuels compared to traditional grain based ethanol. Determining the profitability of the advanced biofuels industry is crucial for both investors and policy makers. The biofuels comparison analysis will focus on comparing the economics of three biofuel production types: grain based ethanol, cellulosic biochemical ethanol, and cellulosic thermochemical biofuels. The underlying objective of this analysis is to determine if cellulosic biofuels are becoming more competitive with traditional grain based ethanol in continually changing markets, in terms of profitability, and establish which inputs are the key drivers of profitability by conducting sensitivity analysis. Of course, since there are no commercial plants, the comparative analysis is somewhat speculative.

The first step in conducting the biofuels profitability analysis is to build an Excel spreadsheet model, the Biofuels Comparison Model (BCM), which compares grain based ethanol to advanced cellulosic biofuels on both a pre and post-tax NPV basis. Part of the spreadsheet model follows a framework similar to Douglas Tiffany's dry mill ethanol spreadsheet that has been cited numerous times in the literature and at major conferences (Tiffany, 2003). The BCM is built in a way that allows the user to

---

[1] Currently the cellulosic subsidy is set to expire in 2012.

easily adjust price, financial and technical assumptions. This flexibility is crucial because no large scale cellulosic plants are currently in the production or construction phases, and it is highly likely that technical and cost estimations for the biochemical and thermochemical processes will change, thus changing the economic outlook of each plant type.

The BCM is built to allow instant updates to key input and output prices through direct web links. The links allow for instant updates on ethanol, diesel, gasoline, oil, corn, liquid propane, electricity and dried distillers grains with solubles (DDGS) prices. This feature allows the user to obtain a ‘snapshot’ of current un-hedged profitability for both the grain based and cellulosic production methods. Alternatively, users can specify their own price inputs.

The second step in conducting the biofuels profitability analysis is to calculate profitability on both a pre and post tax NPV basis using the current profitability outputs from step one. This NPV analysis assumes that all of the revenues and costs will remain fixed throughout the 20 year life of the plants. That is, the subsidies, revenues and expenses of today will be the same throughout the entire plant life. The BCM accounts for inflation by deflating the debt payment over the life of the plant. Other revenues and expenses are not adjusted and are assumed to be constant in real terms. Output from the BCM includes pre-tax NPV, post-tax NPV and a graph indicating the predicted post-tax cash flows.

The third step in this portion of the study is to conduct sensitivity analysis on which input and output prices have the largest impact on profitability for each of the production types. Key costs including feedstuff, energy, enzyme and capital costs were all individually subjected to a 20% price shock. The post tax NPV output from the model was then compared to the base case scenario to establish how changes in key inputs affect the overall profitability for each production type.

1.3 Organization

The paper will study the economics of cellulosic biofuel production compared to the established grain based ethanol industry. In section 2, an extensive review of the literature will be conducted on methodologies for estimating the economics of these alternative investments. Section 3 consists of the economic biofuel analysis and includes a description of the BCM, base case results, sensitivity analysis, and policy implications. Finally, the last section provides conclusions, study limitations, and future research suggestions.

2. LITERATURE REVIEW

2.1 Overview

Chapter 2 will examine the literature related to both the economics of the corn based ethanol and cellulosic biofuel industries. It should be noted that very little literature exists about the specific issues studied, thus much of the literature reviewed is indirectly related to the subject.

2.1.1 Cellulosic Economic Analysis Literature Review

The cellulosic biofuel industry is still in its infant stages, thus the literature that focuses on cellulosic biofuel economics is limited and often contradicting in terms of technical and cost assumptions. With that being said, there have been several publications that exclusively examine the economics of biochemical and thermochemical cellulosic production plants.

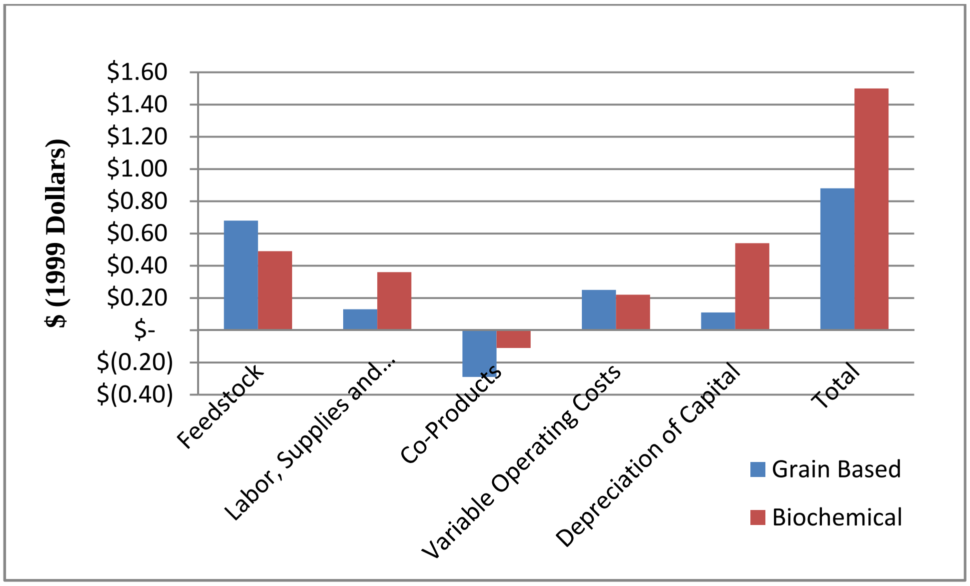
One of the first studies to economically compare advanced biofuel production methods to grain based ethanol production is a publication by Wright & Brown (2007). This publication examined the economics of grain based ethanol, cellulosic ethanol (biochemical process), methanol, hydrogen and Fischer-Tropsch (thermochemical process). The Wright and Brown publication reviewed the literature and then adjusted the literature estimates to reflect 2005 dollars as well as scaling all plants to a 150 million gallon per year gasoline equivalents. Wright and Brown reported that there would be substantial economies of scale with the larger cellulosic plants in terms of both capital and operating costs, and used a capital cost scaling factor of .63 for the biochemical platform and .7 for the thermochemical platform (Wright & Brown, 2007). Wright and Brown concluded that the capital and total costs per gallon of gasoline equivalents would be substantially higher for the advanced cellulosic fuels compared to the grain based ethanol process. Wright and Brown reported in Table 2.1 that the total costs per gallon would be 44% higher for the biochemical cellulosic ethanol process compared to the grain based process and 48% higher for the thermochemical cellulosic biofuel process compared to grain based ethanol production. The total costs per gallon consist of feedstuffs, operation and management, credits and capital charges. In addition, they concluded that it would require approximately 6.8 times as much initial capital dollars to build a biochemical cellulosic ethanol plant compared to a grain based plant that produced the same in terms of gasoline equivalents. Similarly, a thermochemical cellulosic biofuel plant would require approximately 7.7 times as much capital to generate the same amount of gasoline equivalents (Wright & Brown, 2007). This cost data was not used directly in our analysis.

Table 2.1: Capital and Total Cost for 150 MMGPY Plant

Biofuel Type	Total Capital Costs	Capital Cost	Total Cost
	($ millions)	($/gal.)*	
Grain Ethanol	111	$.74	$ 1.22
Cellulosic Ethanol	756	$5.04	$ 1.76
Fischer-Tropsch	854	$5.69	$ 1.80

* Gallons gasoline equivalent
Source: Wright & Brown (2007).

Another publication from the National Renewable Energy Laboratory (NREL) by MaAloon et al. (2000) focused on the technical and cost parameters for the cellulosic biochemical ethanol process. This publication gave cost estimations for biomass, other raw materials, overhead expenses and capital expenses. MaAloon et al. reported that a 25 million gallon per year plant would cost approximately $136 million 1999 dollars. In addition, the report compared the operating cost of a biochemical cellulosic plant to a dry mill grain based ethanol plant. The study concluded that the total cost would be approximately $1.50 per gallon of fuel ethanol compared to 89 cents per gallon of ethanol derived from grain based production. Figure 2.1 shows the break-down of costs for both the grain based ethanol and biochemical cellulosic ethanol process (MaAloon et al., 2000). Clearly, these cost numbers are dated.



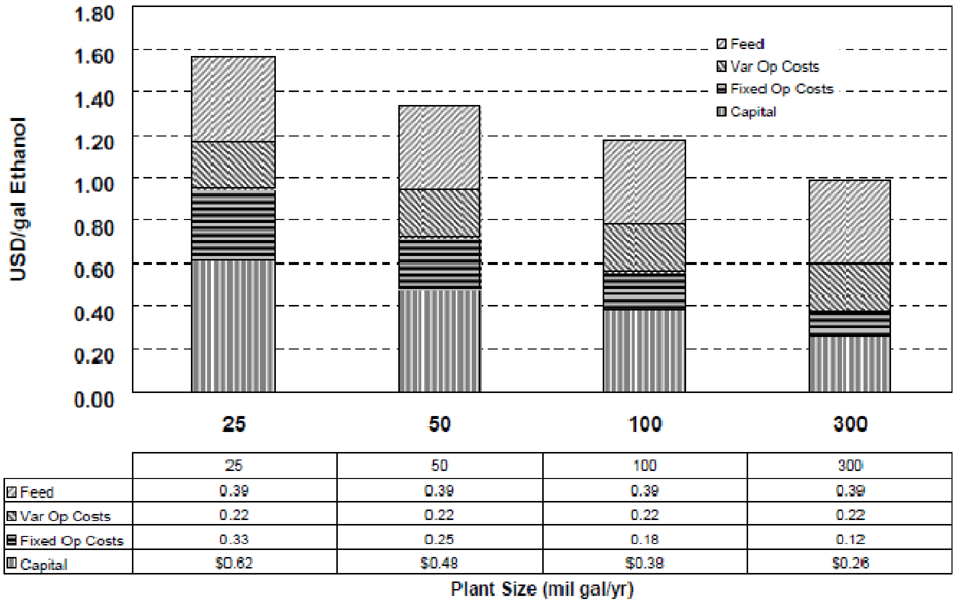
Source: MaAloon et al. (2000).

Figure 2.1: Production Costs in Dollars per Gallon of Fuel Ethanol (1999$)

The literature also gives economic estimations for the thermochemical production process. A 2002 publication by Tijmensen et al. (2002) examined the thermochemical process in technical detail and derived estimations for both capital and operating costs. Tijmensen et al. reported that several types of biofuels could be produced by the thermochemical process depending on the process method and whether hydrocracking is used to further refine the biofuels into products such as diesel and kerosene. In addition, this publication reported that the economies of scale for a thermochemical cellulosic plant diminish greatly once 400 megawatt thermal of energy is produced; which is approximately a plant that produces 50 million gallons per year of biofuels.

The National Renewable Energy Laboratory (NREL) produced an in-depth report on renewable biofuels; which includes cost and technical projections for cellulosic biofuel production. A key estimate in the study is that 89.7 gallons of ethanol can be produced per ton of agricultural residues for the biochemical process compared to 80.1 gallons of ethanol per ton for the thermochemical process. The study also suggests that the thermochemical process can also be configured to produce 94.1 gallons of mixed alcohols per dry ton of feedstuff (Bain, 2007).

The NREL study reported detailed estimates for the biochemical cellulosic conversion processes. The study estimated that a cellulosic plant with a 1,608 ton of biomass conversion per day capacity (~53 million gallons per year), would cost $187.17 million dollars to build based on 2005 dollars (Bain, 2007). In addition, the study estimated the total feedstuff (feed), variable operating costs, fixed operating costs and capital costs on a dollar per gallon of ethanol basis for various sized plants. Figure 2.2 indicates that economies of scale exist for the capital portion of the total cost of production. In addition, the study suggests that the capital costs represent the largest portion of the total cost for facilities that produce 50 million gallons of ethanol per year or less, and feedstuff acquisition represents the largest portion of the cost for larger plants.

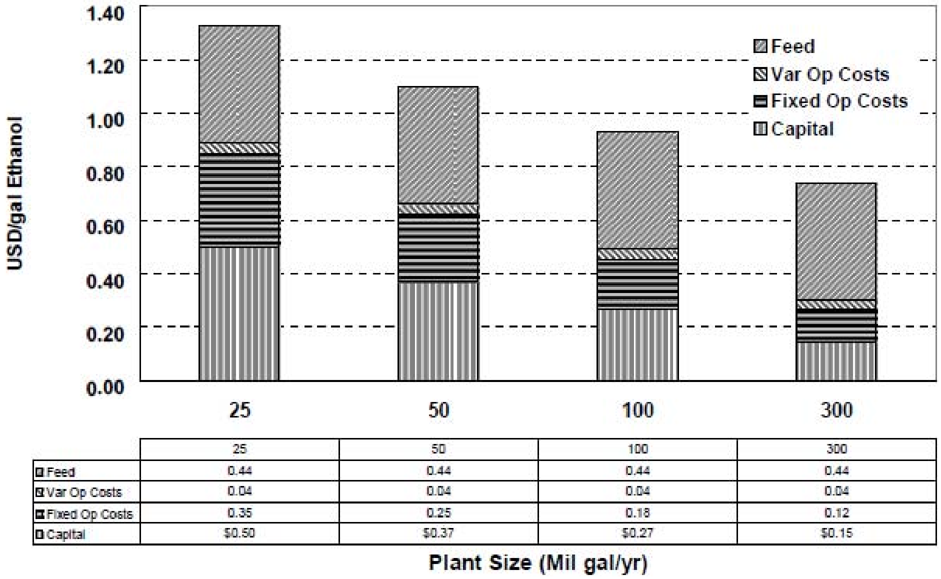


	25	50	100	300
▨ Feed	0.39	0.39	0.39	0.39
▧ Var Op Costs	0.22	0.22	0.22	0.22
▤ Fixed Op Costs	0.33	0.25	0.18	0.12
▥ Capital	$0.62	$0.48	$0.39	$0.26

(Source: Bain, 2007)

Figure 2.2: Comparison of Biochemical Ethanol Costs for Various Plant Sizes

The capital and operating costs were also given for biofuels produced through the thermochemical process. The NREL study predicts that a 1,800 ton per day plant (~53 million gallons per year) would cost approximately 190.34 million 2005 dollars (Bain, 2007). Figure 2.3 shows the estimated total cost for thermochemical biofuel production for various plant sizes. The graph and subsequent table indicate that the cost per gallon for thermochemical biofuel production is less than the cost per gallon for biochemical production when assuming the thermochemical plant is producing the higher yielding mixed alcohols. The lower costs result from lower capital cost per gallon in addition to lower variable costs (Bain, 2007).



	25	50	100	300
▨ Feed	0.44	0.44	0.44	0.44
▧ Var Op Costs	0.04	0.04	0.04	0.04
▤ Fixed Op Costs	0.35	0.25	0.18	0.12
▥ Capital	$0.50	$0.37	$0.27	$0.15

(Bain, 2007)

Figure 2.3: Comparison of Thermochemical Biofuel Costs for Various Plant Sizes

It should be noted that portions of the above literature contain many assumptions surrounding the theoretical and probable capital and operating costs that future cellulosic plants will likely incur. In addition, several of the studies report what costs are likely to be for the nth plant; that is, the cost after several large scale plants have been developed.

3. BIOFUELS ECONOMIC ANALYSIS

3.1 Introduction

The BCM allows the user wide-ranging flexibility in choosing parameters for inputs and outputs to directly compare grain based ethanol to biochemical and thermochemical cellulosic production methods. It is important to note that the technical and cost parameters surrounding this model are the result of an extensive literature review and dialogue with industry experts. Because the commercial cellulosic industry is still in the design phases, most costs and technical projections are uncertain. Thus, this model will serve as the best estimate of today's costs and revenues and will be updated as new technologies and/or costs are developed. In other words, this model provides a consistent framework for analysis that can be easily updated as technical and economic conditions change in the future. In this section we will examine the following topics: the current ethanol industry, current policy, model reasoning, model description, base case analysis, sensitivity analysis and policy options.

3.2 Current Industry

Ethanol has been used as a transport fuel since the development of the first prototype combustion engine in 1826. More recently, ethanol has become the bedrock of several pieces of federal legislation that call for an increased use of renewable fuels. This new demand for ethanol has greatly expanded the US production capacity from 175 million gallons per year in 1980 to an estimated present day production capacity of 10.6 billion gallons per year with 2 billion gallons under construction (Renewable Fuels Association, 2009

The most prevalent ethanol production method in the US is corn based dry-mill fermentation. This process involves completely grinding the whole corn kernel into flour and then converting the starch to ethanol via fermentation. The major co-products are distillers dried grains with solubles (DDGS), an animal feed, and carbon dioxide, which is sometimes marketed but usually vented. An alternative grain-based production method is wet-milling. This process separates the corn kernel into its separate components via a water medium. The components are then transformed to several marketable products including ethanol, high fructose corn syrup, and corn gluten meal and feed.

Current ethanol production is from grain; but advanced biofuels such as cellulosic fuels are gaining momentum. Cellulosic fuels are energy products produced from organic materials such as corn stover, switchgrass or wood waste. Two major cellulosic platforms are being considered for long-term alternative fuel production: biochemical and thermochemical production.

The thermochemical production platform at present appears to be a promising pathway for biofuel production. Organic materials are converted to fuel products through gasification or pyrolysis. The thermochemical platform subjects the biomass to heat which breaks the biomass down in order to convert it to usable fuels. Pyrolysis produces liquid fuels in the almost total absence of oxygen. The pyrolysis oils can be hydro-cracked in the presence of catalysts to produce a range of liquid fuels including gasoline. Gasification produces a syngas (a mixture of H_2 and CO) in the presence of some oxygen. The most common fuels produced during this process are known collectively as FT-liquids (Fischer-Tropsch); or individually diesel, kerosene and naphtha. A key advantage of the thermochemical process is that a wide variety of fuels may be produced. These fuels may be substituted directly for gasoline and diesel. They do not pose the blending and infrastructure problems associated with ethanol biofuels. For simplicity, the BCM assumes at present that gasoline will be the only product produced. By assuming gasoline as the only output, we can more clearly and easily compare the three production processes. To the extent that diesel is produced, the thermochemical process would be more attractive than the numbers we obtain since diesel contains more energy and currently is priced higher.

The second proposed cellulosic production platform is biochemical production. Several small-scale plants are currently in operation including the KL Process Design Group plant in Upton, Wyoming, that produces 1.5 million gallons annually (Renewable Fuels Association, 2009). The biochemical process utilizes an acid pretreatment and enzymatic hydrolysis to break down the organic material into fermentable sugars. These sugars are then converted to fuel grade ethanol as in the grain based process. Though small scale plants are currently producing ethanol, large scale commercial plants that would produce more than 40 million gallons of ethanol per year have yet to be developed.

3.3 Policy

A major driver of the ethanol industry in the United States has been federal and state policy in the forms of subsidies and mandates. The first ethanol subsidy arose from the Energy Tax Act of 1978 in the form of a 40 cent per gallon excise tax exemption. Effective January 2009, the federal blending tax credit is 45 cents per gallon with additional production subsidies in several states. The 2008 Farm Bill changed the blending subsidy for corn and cellulosic based ethanol from 51 cents per gallon to 45 cents per gallon. Cellulose based biofuels receive a total subsidy of $1.01. If the final product is ethanol such that the fuel receives the 45 cent blender credit, then the producer credit is reduced by 45 cents to 56 cents. Note that since this subsidy is volumetric instead of being based on energy content, it is actually much larger for ethanol on an energy basis than for biofuel based gasoline or diesel.

Mandates are also fueling the grain based ethanol industry and the emerging cellulosic industry. The new driver is the “Energy Independence and Security Act of 2007” which mandates 36 billion gallons of renewable fuel by 2022. The “Energy Independence and Security Act of 2007” amends the “Renewable Fuels Standard (RFS)” that was signed into law in 2005. An important aspect of this legislation is that 21 billion of these gallons must be from advanced biofuels; such as cellulosic ethanol (U.S. Congress, 2007), and 16 of the 21 billion must come from cellulosic feedstocks.

3.4 Biofuels Comparison Model Reasoning

Because of the emerging advanced cellulosic industry; it is imperative to analyze the economics of three proposed ethanol production methods: grain-based ethanol, cellulosic biochemical, and cellulosic thermochemical production. The idea of analyzing these three production methods is not a new concept. Wright and Brown conducted an economic analysis in 2007 by comparing each of the production methods on an equal 150 million gallon gasoline equivalent basis (Wright and Brown, 2007). This analysis was based on a literature review of each of the production methods. Though the BCM also relies on current literature for technical parameters, it is designed to allow the user flexibility in choosing input, output, and efficiency values. A limitation of Wright and Brown’s analysis is that all production types were subjected to a scaling factor in order to achieve the 150 MMGPY gasoline equivalents, thus greatly reducing the capital costs. Though it allowed an equal comparison, the ideal plant size and economies of scale are very uncertain. Thus Wright and Brown possibly underestimated the true capital costs for 1st generation advanced plants.

One distinguishing characteristic of the BCM is that the user can insert current market prices for inputs and output products through direct web links to show economic comparisons under specific market conditions as well as varying plant sizes. The spreadsheet format of the BCM follows a framework similar to Douglas Tiffany's dry-mill ethanol spreadsheet (Tiffany, 2003). Limitations of the Tiffany dry-mill model include: manually sourcing price information, inability to change all inputs, and inability to compare production technologies. Because of these limitations in the current literature and drastic changes in market conditions, the BCM was developed.

3.5 <u>Model Description</u>

The BCM utilizes the Microsoft Office 2007 Excel program. Following are key advantages of the BCM*:*

- The user can select historical price predictions, current prices or insert their own value for most input and output prices in the model.

- Input and output prices are directly linked to websites to allow for current price quotes.

- The model shows which production process is the most profitable given the economic and technical parameter values selected by the user.

The model is organized by the following tabs located at the bottom of the work book: (1) Instructions, (2) Assumptions, (3) Grain Based, (4) Biochemical, (5) Thermochemical, (6) Comparison, (7) Asset Based Economic Analysis, and (8) Finance Based Economic Analysis. The model is designed for the user to start at tab (1) and work through the sheets to tab (8). All changes in worksheets (1) through (5) will automatically be updated to evaluation tabs (6) through (8). Each individual worksheet of the model will now be discussed in greater detail.

3.5.1 Instructions

The instructions tab is designed to give the user stand alone instructions to properly utilize the model. Important aspects of this sheet include the "Click to Update Prices to reflect Current Market Conditions" and "Plant Startup" buttons located in the center of the page. Clicking the price button will automatically update input and output prices to reflect current market prices via embedded web links. In order to utilize this tool, the user must be connected to the internet and allow 'macros' upon security system request. The "Plant Startup" buttons give the user a choice between the ethanol plants starting in 2009 or in 2015. Currently this choice only influences the biochemical and thermochemical platforms. Through interaction with Andy McAloon, USDA-ARS-

ERRC biofuels expert, we were able to develop enzyme and capital cost estimates for the years 2009 and 2015 for the biochemical platform. Year 2015 represents the nth year, or in other words, costs after several plants have been built. It also represents a "best guess" of technical progress likely to occur through research and development over the next six years. The BCM also predicts the 2015 thermochemical capital cost by assuming that the same technical and economic advances will be made as for the biochemical platform.

3.5.2 Assumptions

3.5.2.1 Decision Variable Section

The (2) Assumptions tab is where price, production, efficiency and financial decisions are made. Key is the section labeled "Decision Variables," which is outlined in a bold box. This section allows the user to select among multiple options for each of the input/output decisions. The choices for each decision variable are given by a drop down tab in column E under "Choose Values Here." By clicking on the cell, the user will see the following options: "current market price", "adjusted price" and "predicted market price." It should be noted that the "predicted market price" option is not available for every assumption decision. By selecting the "current market price" you are selecting the current market value as reported through the direct web-links. To be consistent, all prices are quoted from recognized exchanges, government agencies or recognized third parties. Where possible, Midwestern or Eastern spot prices are used. The direct web-links and sources are located in columns K and M of the model. By selecting "predicted market price" you are selecting historical regressions determined by the price of oil and corn (Tyner and Taheripour, 2007). In terms of long term accuracy of the model, this option may prove the most valuable as historical regressions may predict future prices more accurately than current market prices. However, in 2009 because of the surplus of ethanol on the market, the historic link between crude oil and corn has weakened substantially, so user caution is advised. The last choice the user can make is selecting "adjusted price." Selecting this option allows the user to insert their own perceived value for inputs/output prices in the yellow cells. This option is useful in accounting for regional differences in prices and for conducting sensitivity analysis. Following is an explanation of the key variables:

- Corn Price: The reported current corn price is based on the nearest futures contract on the Chicago Board of Trade (CBOT). The model does not account for any basis differences that could occur, as they vary substantially by company and region. The user may select "adjusted price" to insert their preferred corn price if it differs from the current futures price.

- Natural Gas Price: The current market price is based on the Henry Hub spot price plus $1.00 per MBtu for transportation expenses.

- Current Ethanol Prices: The current ethanol price can be inserted four different ways (options available through drop down list located in cell E26): 1) Ethanol price pulled from the near futures price on the Web, 2) User input of ethanol price, 3) Calculation of the ethanol price based on the energy equivalence to gasoline, the applicable ethanol subsidy, and the fraction of the subsidy assumed to be passed on from the ethanol blender to the ethanol producer (subsidy pass-through rate), or 4) Calculation of the base ethanol price using a volumetric approach; that is, equal value on a per gallon basis with gasoline instead of per unit of energy, using the nearby gasoline futures, the applicable ethanol subsidy and the subsidy pass-through rate. Using method 3, the current ethanol price is established from the NYMEX nearby gasoline futures using energy equivalents:

  $$DE = 0.98 * G * 0.67 + 0.02 * G \qquad (1)$$

  where DE is the base denatured ethanol price, G is the nearby gasoline futures price, and 0.67 is the ethanol energy fraction of gasoline. This equation reduces to:

  $$DE = 0.6766 * G \qquad (2)$$

  To take into account the subsidy (S) and fraction of the subsidy assumed to be passed on to ethanol producers (F), one gets the result in equation 3 for current denatured ethanol price (CDE) using method 3 above:

  $$CDE = DE + F * S \qquad (3)$$

  The BCM model currently uses the ‘calculation on a volumetric basis’ as the default in the base case when calculating oil price sensitivity. Though an assumption, this option was used because of the recent decoupling between the actual ethanol price and the ethanol price predicted based on energy equivalence. Using option 4), the current ethanol price is established from the NYMEX gasoline futures using equation 4:

  $$DE= G + S * F \qquad (4)$$

  where DE is the base denatured ethanol price, G is the nearby futures price, S is the blending subsidy in the form of a tax credit, and F is the percentage of the blending tax credit that is being passed to ethanol producers. The BCM assumes that S is 45 cents, and F is 100%, thus establishing the base ethanol price by equation 5:

  $$DE= G + \$.45 \qquad (5)$$

  The ethanol price is the price of the denatured product, which is the only product that can be marketed by ethanol plants according to the US Bureau of Alcohol, Tobacco and Firearms regulations. The CDE can differ between technologies if the subsidy level is different or other policy interventions cause the cellulose ethanol price to differ from the corn ethanol price. To avoid problems with different denatured ethanol prices with different production types, the user should select option 3), 'calculation on volumetric basis or 4) 'calculation by energy eqv.'. This option will allow the user to select different subsidy levels for both grain based and cellulosic ethanol. The BCM will then adjust the current denatured ethanol price throughout the model to account for the subsidy difference. If the user chooses to input directly the ethanol price, option 2), the user will be able to enter different prices for corn ethanol and cellulose based ethanol (biochemical) to account for possible differential subsidies.

- Feedstuff Base Cost: The BCM has estimated price and extraction rates for two feedstuffs: corn stover and switchgrass. The predicted base cost for these feedstuffs is based on a 2008 Indiana study (Brechbill, 2008). Brechbill's estimated costs include machinery, labor, material, land (for switchgrass only), transportation and a farmer's premium. Thus, this cost represents the total cost to the ethanol producer. The cost reported on the assumption page is the price per dry ton delivered within five miles of the proposed cellulosic plant. The model automatically calculates the weighted average feedstuff cost based on the size of the plant, and the corresponding radius of feedstuff sourcing to account for transportation expenses. In addition, the user can choose an alternative cellulosic feedstuff by selecting "other" in the drop list located in cell E 33. If this option is chosen, the user must adjust the feedstuff cost in cell G 34.

- Biochemical Conversion Rate: The literature varies greatly on the conversion rate for biochemical production. The conversion rate is the number of anhydrous gallons of ethanol (or other biofuel) produced per dry ton of feedstuff. A 2007 publication by the National Renewable Energy Laboratory estimated that 89.7 gallons of anhydrous ethanol could be produced per dry ton of biomass (Bain, 2007). This differs from Douglas Tiffany's estimate of 69.7 gallons of denatured ethanol per dry ton for corn stover (Tiffany, 2007). To be conservative, the values that are quoted in the model for a 2009 plant startup are based on Tiffany's calculation and are adjusted to accommodate the differences in BTU availability between corn stover and switchgrass. The model assumes that a plant starting production in 2015 will yield 89.7 gallons per ton as reported by NREL (Bain, 2007). Please note that observed literature values in this category range from 55 to 110 gallons per dry ton. There is also confusion in the literature regarding whether the conversion yields are anhydrous or denatured.

- Thermochemical Conversion Rate: The thermochemical base conversion rate of 61.4 gallons per dry ton is based on a study from Wright & Brown and is assumed to be the conversion rate for a plant starting operation in 2009 (Wright & Brown, 2007). The NREL estimate of 94.1 gallons of mixed alcohols per ton

- Ethanol Extracted per bushel: The base rate used in the model is 2.65 anhydrous gallons per bushel of corn with the reported range being 2.5 to 2.8 gallons per bushel (Mosier, 2008). The base rate comes from personal communications with Professor Nate Mosier. Dr. Mosier indicated that the average new corn ethanol plant achieves 2.65 gallons of anhydrous ethanol per bushel of corn. This equates to a denatured ethanol yield of 2.70 gallons per bushel.

- DDGS and CO2 Yields: The literature suggests that the approximate value for both dried distiller's grains with solubles (DDGS) and CO_2 is 18 lbs per bushel of corn (Tyner and Taheripour. Appendix A, 2007).

3.5.2.2 Subsidy, Efficiency, Production and Financial Decisions

The subsidy, efficiency, production, and financial decision section of the BCM uses toggle buttons to allow the user easy adjustment for key decisions. The model is utilized by choosing either the left or right arrow buttons located in column E. The 'Value Used in Model' is your adjusted value. The base values (column G) are set to be the default upon opening the BCM.

- Grain and Cellulosic Subsidy levels: The base values for both grain and cellulosic blending subsidies are derived from the 2008 farm bill. The new farm bill calls for ethanol blending subsidies to drop from .51 cents per gallon to .45 cents per gallon. It is important to note that these are blending credits paid directly to the gasoline blenders in the form of tax credits. The actual amount that the ethanol producer receives is based on the 'subsidy pass-through' rate. In addition to the blending subsidies, the 2008 farm bill also includes provisions for direct production subsidies for advanced biofuels. Biochemical ethanol producers will receive a 56 cent per gallon subsidy and thermochemical producers will receive a $1.01 direct subsidy, but no blender credit. Since these payments are made directly to the producers, the 'subsidy pass-through' has no influence on the revenue received (Capehart, 2008).[2]

- Denatured Blend: The denatured blend is the amount of ethanol that is in each gallon of product shipped from the producer, assumed to be 98% in the grain and biochemical models. The model assumes that only gasoline can be used to denature the ethanol to meet federal requirements. Because thermochemical

---

[2] The 56 cent production subsidy is actually 46 cents plus the 10 cent small producer credit. It is expected that, at least initially, most producers would qualify for the small producer credit. If not, the total production tax credit becomes 46 cents instead of 56.

production does not directly produce ethanol, that process does not require denaturing.

- Debt/Equity Ratio: The base value for the model is a 60/40 debt/equity ratio for financing.

- Annual Interest Rate: The appropriate debt interest rate will need to be selected based on the individual plant and the financing route that is taken. It is likely that financing for cellulosic plants will demand a higher interest rate as the technologies are currently commercially unproven. The default value is 8%.

- Rate of Return on Equity: The base value is the opportunity cost of money that investors could earn in a standard stock market fund. The required rate of return may be higher or lower depending on the individual's personnel preferences and is reported on an after tax basis. The default value is 12%.

- Plant Life: The base value for plant life is 22 years, 2 years for construction and 20 for production. The model assumes that at the end of the 20 year production period there will be no salvage value. The plant life's main influence in the model is in the (7) Asset Based Economic Analysis section where NPV and IRR are calculated. The model already takes into account maintenance/repair costs that will keep the plant operating.

- Loan Life: This variable sets the loan length in years. The loan length will vary with financial institutions but is commonly accepted to be 15 years for similar style plants. The loan amount was amortized into equal payments using the PMT function in Excel.

- Construction Period: The construction period is the number of years that is required to go from ground excavation to production. The model assumes that working capital will be required during the last year of construction and that loan costs will be amortized in the loan payment once production begins. The amount of working capital is determined by the following formula and is reflected in the financial calculations:

  $$\text{Working Capital} = \\ (\text{OC of first year of plant operation} - \text{OC last year of construction}) \text{ x WCF}$$

  where OC is operating cost and WCF is the working capital fraction. The WCF was assumed to be 25% in this model. The working capital was added back into the cash flows in the final year of the plant life to determine the profitability of the project.

- Depreciation Life: The model assumes that the plant will depreciate on a straight line depreciation schedule over 15 years. Depreciation begins in the first year of production.

- Tax Rate: The tax rate should include all state, federal and local income taxes. The model already takes into account wage and property taxes.

- Inflation Rate: The inflation rate adjusts the debt and tax payment in finance based net present value analysis. All other revenues and costs are assumed to be in real terms. The default value is 2 percent.

3.5.3 Grain Based

The grain based portion of the BCM serves as the base to compare the cellulosic production methods. The key technical and cost components are discussed in this section.

- Capital Costs: The plant size for grain based ethanol production is set at 100 million denatured gallons per year. This is primarily due to the fact that these plants are by far the most popular size in terms of new plant construction. Tyner and Taheripour suggest that capital costs are $1.80 per nameplate denatured gallon; which includes all costs associated with bringing a plant online (Tyner and Taheripour. Appendix A, 2007).

- Natural Gas: Natural Gas is a major driver of costs for a dry mill ethanol plant. The BCM utilizes Tiffany's Dry-mill spreadsheet estimate of using natural gas for 98% of the heat energy (Tiffany, 2003).

- Variable Operating Costs: The variable operating costs are based off of the USDA 2002 ethanol production costs survey (Shapouri and Gallagher, 2005). The costs were updated to reflect 2007 dollars by using the GDP deflator found in the assumptions page of the model.

- Labor, Supplies and Overhead: Labor, supplies and overhead expense estimates are based on the National Renewable Energy Laboratory (NREL) estimates and are updated to reflect current dollars (MaAloon et al, 2000). The wage portion of the costs was updated from the 1999 estimates using the National Wage Averages for Petroleum and Coal Products wage index located in the assumptions page of the model. All other variables in this section were updated using the GDP deflator.

3.5.4 Biochemical

One issue with cellulosic economic literature is that the literature reports costs/technologies for the n^{th} year for cellulosic platforms. For this reason there is disconnect between what the current' technology is and what the literature suggests the technology can be. To help clarify this issue, we contacted Andy MaAloon, researcher at USDA-ARS-ERRC, who provided estimates for a plant built today (2009) and a plant built in 2015. The user has the option on the (1) Instructions page to choose either a 2009 or a 2015 plant startup. The following are the key technical components:

- Capital Costs: MaAloon et al provided estimates for the min, mode and the max for both enzyme and capital costs for a plant starting in either 2009 or 2015. A single estimation for each year was then determined using equation (7):

  $$\text{Cost estimation} = (\text{min} + \text{mode} + \text{max})/3 \qquad (7)$$

  Table 3.1 shows the capital cost estimations for both 2009 and 2015 (MaAloon, 2008):

Table 3.1: Biochemical Capital Cost Estimation for 50 MGY Plant

Year	Min	Mode	Max	Average
	$ / denatured gallon of ethanol			
2009	$3.56	$5.58	$11.14	$6.76
2015	$2.67	$4.19	$8.36	$5.07

Source: MaAloon (2008).

The average cost is then set to be the base capital cost for a 50 million denatured gallon per year ethanol plant. Economies of scale were then estimated using published literature by Aden et al (Aden et al, 2002). Aden et al estimated the economies of scale based on plant capacity in terms of metric tons per day. Thus the conversion from metric tons to gallons of denatured ethanol does lead to possible differences in conversion rates and assumptions. None-the-less, Aden's estimates provide a good benchmark for what economies of scale could be. The BCM assumes that a 2,000 metric ton per day plant produces approximately 50 million denatured gallons per year. Thus a 100 million gallon per year plant, approximately 4,000 metric tons per day, would have an estimated nameplate capital cost of $6.68 per denatured gallon, or a savings of 8 cents compared to the base plant. Table 3.2 contains the economies of scale that are embedded in the BCM.

- Energy Usage: The BCM estimates that the waste produced from biochemical ethanol production, lignin, will be able produce the electricity and steam power to run the plant. This assumption may differ as new research is accomplished on the actual energy properties of lignin for different feedstuffs. Currently, the estimate is that there will be 2.26 excess KwH of electricity that will be produced per denatured gallon of ethanol (Aden et al, 2002). The only energy purchased for production purposes will be small amounts of liquid propane.

Table 3.2: Cellulose Plant Economies of Scale

Plant Size Change (metric tonnes)	Savings: $/denatured gal ethanol.
2000 mt to 4000 mt	$0.08
4000 mt to 6000 mt	$0.14
6000 mt to 8000 mt	$0.16

Source: Aden et al. (2002).

- Variable Operating Costs: The variable costs for the model were estimated by NREL (MaAloon et al, 2000). The costs were updated using the GDP deflator from the original estimates in 1999.

- Enzymes: The enzyme cost is one of the major variable costs associated with biochemical production. As with the capital costs, MaAloon estimated both the 2009 and 2015 costs. Table 3.3 shows the estimations for a 50 million gallon per year plant on a per denatured gallon basis (MaAloon, 2008):

Table 3.3: Estimated Cellulose Enzyme Costs for the Biochemical Process

Year	Min	Mode	Max	Average Cost
	$/denatured gallon of ethanol			
2009	$.17	$.33	$.99	$.50
2015	$.14	$.30	$.89	$.44

*estimates were adjusted to reflect a 98/2 denatured blend

Source: MaAloon (2008).

- Labor, Supplies and Overhead: For consistency, NREL estimates were used for the labor, supplies and overhead estimates (MaAloon et al, 2000). The labor costs were updated using the National Wage Averages for Petroleum and Coal Products wage index.

3.5.5 Thermochemical

Many different types of thermochemical biomass conversion are analyzed in the published literature. The BCM assumes efficiency and cost data for the oxygen-blown gasifier of the Institute of Gas Technology (IGT) which also employs hydrocracking as the base plant for the model (Tijmensen et al, 2002). Following are the key technical components of the thermochemical process contained in the model:

- Capital Costs: The 2009 capital costs are based off of Tijmensen's 2002 estimate of a $341 million capital investment for a 35 million gallon/year plant (Tijmensen et al, 2002). These costs were adjusted to 2007 dollars by using the Marshall and Swift Equipment Capital Cost Index found in figure 2 in the assumptions page. The 2015 capital costs were estimated by assuming the same technical progress will be made in the thermochemical platform as in the biochemical platform. According to McAloon's estimates, capital costs could decrease by 25% in the next 6 years. The capital costs for the thermochemical process are drastically higher than the grain based or biochemical platforms with an estimated cost of $10.96 per gallon of nameplate capacity. Assuming the ~25% reduction in capital costs does occur, 2015 capital costs for the thermochemical platform will be $8.23 per nameplate gallon.

- Variable, labor, supplies, capital and overhead: The majority of the costs for the thermochemical platform were estimated from Tijmensen et al. and verified by referencing Wright and Brown. It should be noted that most of Tijmensen's work is based on costs associated with the n^{th} plant. Thus the costs reported in the BCM are most likely understating the true current costs.

3.6 Model Analysis: Base Case

The BCM is designed to show the profitability for the different production types given the underlying market conditions and assumptions. For the base case illustrated here, the following key assumptions were made:

- Production or blending subsidies are not included for any of the production methods

- All prices of inputs and outputs are based on the average monthly price for each commodity from January 2006 to December 31st 2008.

- All inputs and outputs are un-hedged

- Plant sizes are set at what the industry considers likely sizes: Grain based production 100 million denatured gal/year, biochemical production 50 million denatured gallons/year, and thermochemical production ~ 50 million gallons/year

- Profitability and costs are compared on a gallon produced basis: per denatured gallon of ethanol for grain and biochemical production and on per gallon of gasoline produced for thermochemical production

- CO_2 credits are not given for any production method

- Development is set to begin in 2009

3.6.1 Revenues

Using the BCM, gross revenues were calculated for each of the production methods. In the base case, grain ethanol production has the highest level of gross revenues, which results from a higher byproduct credit. Comparing thermochemical bio-gasoline and biochemical ethanol, the BCM shows that the thermochemical platform generates higher levels of gross revenues because of the higher value of gasoline compared to ethanol. The value of ethanol was calculated based on the average 3 year ethanol price minus the 51 cent blending subsidy. The credit for grain based ethanol consist of the sale of distillers dried grains with solubles (DDGS), while the credit for biochemical production consists of the sale of excess electricity. Table 3.4 shows the gross revenues for the base case.

Table 3.4: Gross Revenues for the Three Production Methods ($/gal.)

Conversion Process	Biofuel	Credit	Subsidy	Total Revenue
	$ per saleable gallon			
Grain Based	$1.75	$0.40	$0.00	$2.15
Biochemical	$1.75	$0.23	$0.00	$1.98
Thermochemical	$2.15	$0.00	$0.00	$2.15

Source: Author's Calculations (2009).

3.6.2 Expenses

A key driver of overall profitability is the cost to make a gallon of denatured ethanol (FT gasoline in the case of thermochemical). The BCM suggests that ignoring financing, currently the thermochemical platform is the most cost effective form of biofuels production. The following are key drivers that currently make advanced biofuels less costly to produce compared to traditional grain based ethanol:

- Feedstuff costs are 67 cents per gallon of biochemical ethanol produced. This is very similar to the 79 cents per gallon for FT-gasoline but 2.15 times lower than the $1.45 per denatured gallon costs for grain based ethanol.

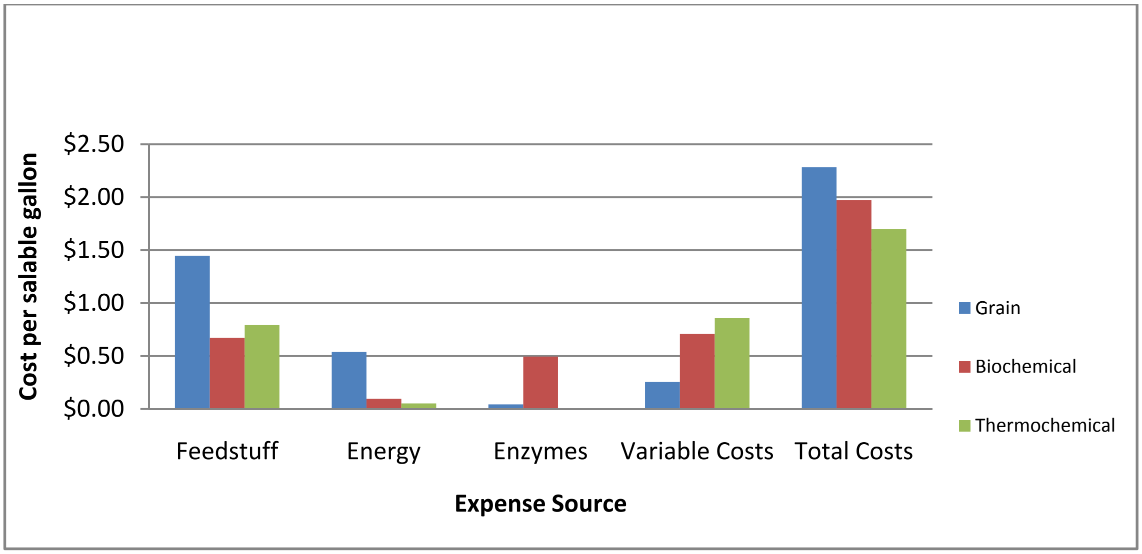
- Grain based ethanol requires large amounts of natural gas, 2008 price increases for this commodity increased the total energy costs for grain based ethanol to $.54 per denatured gallon. 2009 natural gas costs are lower. Biochemical and thermochemical production both have less exposure to energy costs as they utilize the lignin waste product for energy generation.

The thermochemical production method is currently the least expensive form of biofuel production because it is not as exposed to the high energy prices as the grain based platform and the high cost of enzymes for the biochemical platform. Thus, thermochemical fuels are 27 cents per gallon less expensive to produce in the base case compared to biochemical ethanol and 58 cents less compared to grain based ethanol (Figure 3.1 and Table 3.5).

Table 3.5: Expenses for Each Production Technology

Conversion Process	Feedstuff	Energy	Enzymes	Variable Costs	Total Costs
	$ per saleable gallon				
Grain	$1.45	$0.54	$0.04	$0.25	$2.28
Biochemical	$0.67	$0.10	$0.50	$0.71	$1.97
Thermochemical	$0.79	$0.05	$0.00	$0.86	$1.70

*Equity, capital costs and interest are not considered in this comparison
Source: Author's Calculations (2009).



Source: Author's Calculations (2009).
Figure 3.1: Expenses for Each Production Technology

One of the issues pertaining to advanced biofuels made from the biochemical and thermochemical platforms is the high capital costs. These high costs and uncertainty in market conditions may discourage investment. Table 3.6 shows the estimated capital costs per nameplate gallon and capital costs per gallon of denatured ethanol or FT-gasoline produced.

Table 3.6: Capital Costs per Gallon Produced and Per Gallon of Capacity (1000's)

Production Type	Plant Size (denat. gal.)	Total Cost	$/nameplate gal.	Cost per gal. produced.**	Base Year	Source
Grain	100,000	$180,000	$1.80	$0.29	2007	Tyner
Biochemical	50,000	$338,000	$6.76	$1.10	2008	MaAloon
Thermochemical	45,173	$487,666	$10.80	$1.78	2002	Tijmensen*

*costs are were updated from Tijmensens estimates using the Marshall and Swift Installed Equipment Index
**Required return to equity + debt interest + depreciation

3.6.3 Incremental Success/Failure to Meet Required Return

The BCM follows a similar framework as the Tiffany model to determine if each production type is able to meet the required return. The calculations in Table 3.7 determine whether the revenues for each production method can cover all variable costs, fixed costs and required investor return. This simplistic calculation shows that all three production methods currently have negative pre-tax returns in the absence of subsidies.

Table 3.7: Profit or Loss Using Base Case Assumptions

Production Type	Profits/losses in excess of required return to equity ($ per saleable gal.)
Grain	$ (0.43)
Biochemical	$ (1.10)
Thermochemical	$ (1.33)

Source: Author's Calculations (2009).

3.6.4 Asset Based Economic Analysis

To more accurately estimate the profitability of the production alternatives over the life of the plant, an asset based economic analysis was completed on BCM tab 7 with the results also present in the (6) Comparison tab. Note that this economic analysis will update automatically as assumptions are changed throughout the model. It is important to note that costs/revenues are assumed to remain fixed in real terms over the life of the plant; thus, inflation is not a factor. This analysis looks only at the pre-tax profitability of each production method; thus ignoring tax advantages and depreciation. The annual net cash flows for each year were then discounted back to present dollars using the weighted average cost of capital method (WACC) in equation (8):

$$10.3\% = (We * Ke) + (Wd * Kd) \qquad (8)$$

where *We* is long-term proportion of equity, *Ke* is the cost of equity, *Wd* is the long-term proportion of debt, *Kd* is the cost of debt (note all proportions and costs should represent firm level, not project level finances). It should be noted that the pre-tax *Ke* was determined based on an estimation of the effective tax rate, 12.5%, which establishes a pre-tax *Ke* of 13.7% verses the post-tax base of 12%.

The results (Table 3.8) indicate that biochemical based ethanol production and thermochemical production are quite similar on a profitability basis. Grain based ethanol is currently the most profitable in terms of the best NPV. The negative NPV's for all three production types indicate that these plants are generating discounted revenues that are less than required by the WACC. Thus from a pure profitability standpoint, none of the analyzed plants appear to be a good investment without subsidies over the life of the plant.

Table 3.8: Technology Profitability Using Weighted Cost of Capital (pre-tax)

Production Method	NPV ($/gallon of capacity)
Corn	($2.89)
Biochemical	($6.17)
Thermochemical	($6.67)

Source: Author's Calculations (2009).

3.6.5 Finance Based Economic Analysis

The BCM also conducts a finance based analysis on tab (8) to determine after tax and financing annual net cash flows. As with the economic analysis, the financial based analysis assumes that revenues and expenses will remain constant over the life of the plant; thus, they remain in real terms. However, the financed based analysis does deflate the loan payment by using the inflation percentage that is entered on the assumptions page. The after tax and financing annual net cash flows were then discounted back to determine the NPV for each production method using the 12% base cost of equity as the discount rate. The finance based analysis more accurately considers all input decisions compared to the "incremental success/failure to meet required return" calculation conducted in tab (6). The following are assumptions surrounding the finance based analysis:

- Revenues will be non-existent during the construction period
- Working capital will be required during the last year of construction
- Debt payments required during the construction period are amortized for repayment once production begins
- Negative tax burdens will be used elsewhere in the firm

Table 3.9 shows the post tax and financing net present value and internal rate of return for each production method. Again, the results show that each of the production methods fail to meet the required rate of return; resulting in negative NPV for each method. The results also indicate that corn based ethanol is the more profitable compared to the advanced cellulosic methods. IRR values are not reported in these cases because the sum of the cash flows is negative and therefore IRR values are negative and do not have a meaningful interpretation. The finance based NPVs are higher than the asset based analysis because the negative cash flows resulted in negative taxes (assumed to offset positive taxes elsewhere in the company) for each of the production types.

Table 3.9: Technology Profitability Using Financed Based Analysis

Production Method	NPV ($/gal. of capacity)
Corn	($1.91)
Biochemical	($4.00)
Thermochemical	($4.29)

Source: Author's Calculations (2009).

3.7 Sensitivity Analysis

3.7.1 Sensitivity of Input Prices

Any number of sensitivity analyses could be performed on the inputs and technical components found in the BCM. For simplicity, we will examine the after tax and financing NPV effects of a 20% increase in the following key costs: feedstuff, energy, enzyme, and capital costs.

Table 3.10 shows how a price increase in each of the key costs affects the profitability of both grain and cellulosic production methods. The BCM suggests that grain based ethanol is more economically sensitive to increases in feedstuff and energy prices compared to the cellulosic platforms. In fact, a 20% increase in corn price will inversely affect the 20 year NPV by 41% compared to affecting the biochemical platform by 12% and the thermochemical process by 13%. Grain based ethanol production is very sensitive to the corn price because the cost of corn currently represents 58% of the total cost of production compared to less than 27% for both cellulosic methods (utilizing corn stover). Similarly, a 20% change in energy costs will inversely affect the grain based NPV by 21%, while only altering the cellulosic NPVs' by less than 1%. The grain based method has much more exposure to energy prices because of its reliance on natural gas which in 2008 was high by historic comparisons. At the same time, both cellulosic production methods have less exposure to the energy markets because the production processes use lower amounts of natural gas, and the lignin by-product is used to generate most of the electrical and heat energy needed for internal purposes. The increase in corn prices and energy costs are two underlying reasons why cellulosic biofuels have closed the gap in terms of economic feasibility over the last 3 years compared to grain based ethanol.

Table 3.10: Sensitivity Analysis to Cost Increases

	% Change in the After-Tax and Financing NPV after 20% Shock		
Key Costs:	Grain	Biochemical	Thermo.
Feedstuff	-41%	-12%	-13%
Energy	-21%	3%	-1%
Enzymes	-2%	-10%	0%
Capital Costs*	-12%	-19%	-29%

*Interest expense + depreciation + required return to equity
Source: Author's Calculations (2009).

The sensitivity analysis also shows that the cellulosic biochemical process has very high exposure to enzyme costs. According to recent estimates by Andy McAloon, USDA-ARS-ERRC biofuels expert, enzyme costs could range from $.16 to $.96 per denatured gallon in 2009 compared to an estimate of $.04 for the grain based platform (MaAloon, 2008). Thus, a 20% shock in enzyme prices will change the NPV for biochemical ethanol by 10% compared to a 2% adjustment in the grain based NPV.

Currently, capital costs for the grain and biochemical ethanol methods are $.29 and $1.10 per denatured gallon compared to the $1.78 per gallon estimate for the thermochemical platform. After simulating a 20% increase in capital costs, the thermochemical process shows the most sensitivity by inversely affecting the NPV by 29% compared to a 19% reduction in the biochemical NPV. Thus, to drastically improve the economics of cellulosic ethanol, capital cost reduction will need to occur.

3.7.2 Sensitivity of Oil and Ethanol Price

The overall profitability of each of the biofuel production types is extremely sensitive to the value of the biofuel outputs: ethanol and ft-gasoline. In the base case where subsidies were ignored, 80% of the total revenue for the grain based process was generated by the sale of ethanol compared with 20% of the revenue coming from the DDGS sales. The cellulosic methods rely more heavily on the sale of the biofuel products because they only produce electricity as a by-product; most of which is used internally. Thus, 88% of the total revenue in the biochemical process derives from the sale of ethanol while 100% of the revenue from the thermochemical process comes from the sale of ft-gasoline.

In order to simulate what affect oil price has on the profitability of each of the production methods, the relationship between oil, gasoline and ethanol must be established. For this portion of the sensitivity analysis, it is assumed that both the price of gasoline and ethanol are both determined entirely by the price of oil using historical price relationship regressions (Tyner & Taheripour, 2007). This differs from the BCM base case where the price of ethanol and gasoline were based on three year average monthly price levels[3]. We will do this comparison both on a volumetric and energy equivalence basis. The first ethanol price relationship uses the volumetric approach. Equation 9 establishes the relationship between the price of oil and gasoline:

$$G = 0.026 * O + 0.296 \qquad (9)$$

where G is the price of gasoline and O is the price of oil. After determining the price of gasoline, the price of ethanol is predicted on a volumetric basis using equation 10:

$$DE = G + S * F \qquad (10)$$

where DE is the base denatured ethanol price, G is the gasoline price predicted in equation 1, S is the blending subsidy in the form of a tax credit, and F is the percentage of the blending tax credit that is being passed to ethanol producers. The BCM assumes that there is no subsidy in the base case, and F is 100% in the base case, thus establishing the base ethanol price by equation 11:

$$DE = G \qquad (11)$$

---

[3] The gasoline price in the base case was $2.15/gal. and was established based on the average monthly NY nearby gasoline futures price from 2006 to 2008. This analysis utilizes the predicted gasoline price, which was $2.36/gal. for the base case.

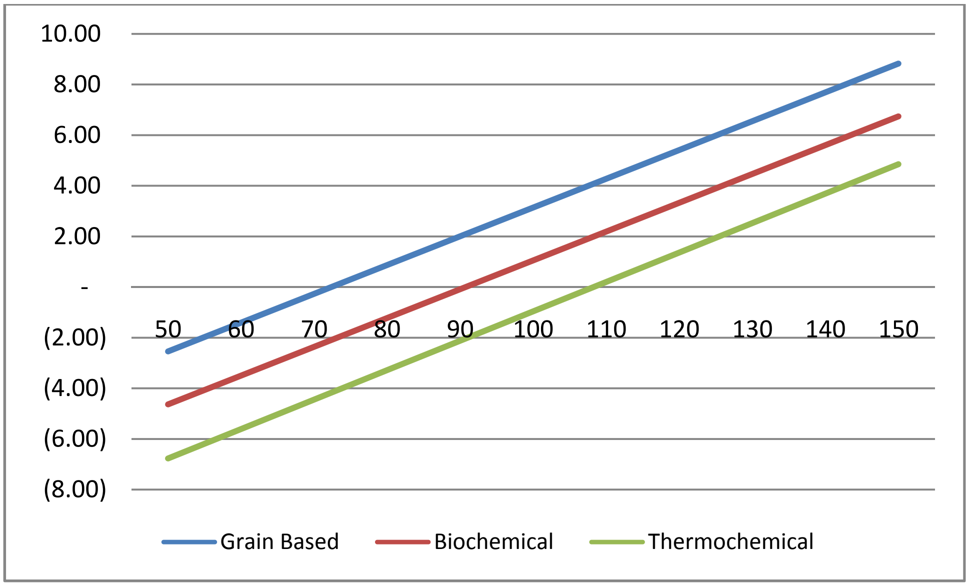
Using the price relationships between oil, gasoline and ethanol as established above, we explored the after-tax profitability on an NPV basis for each production method under various oil prices. It is assumed that changes in oil price will only affect the revenue for each of the production methods. In reality, changes in oil prices will likely alter most expenses, especially the price of natural gas and feedstuffs. Figure 3.2 shows that the oil price must be approximately $72 per barrel for the grain based platform to have a $0 NPV without subsidies. The biochemical would need an oil price of $91 per barrel and thermochemical production would require an oil price of $108 per barrel to generate $0 NPVs – all assuming biofuel priced on a volumetric equivalence to gasoline.

The second method to calculate the break-even oil price is to calculate the ethanol price based on energy equivalents. This method awards the thermochemical process for producing a higher energy value product, ft-gasoline compared to ethanol. The energy equivalent price of ethanol is determined by using equation 12:

$$DE = 0.98 * G * 0.67 + 0.02 * G \qquad (12)$$

where DE is the base denatured ethanol price, G is the predicted gasoline price, and 0.67 is the ethanol energy fraction of gasoline. This equation reduces to:

$$DE = 0.6766 * G \qquad (13)$$



Source: Author's Calculations (2009).

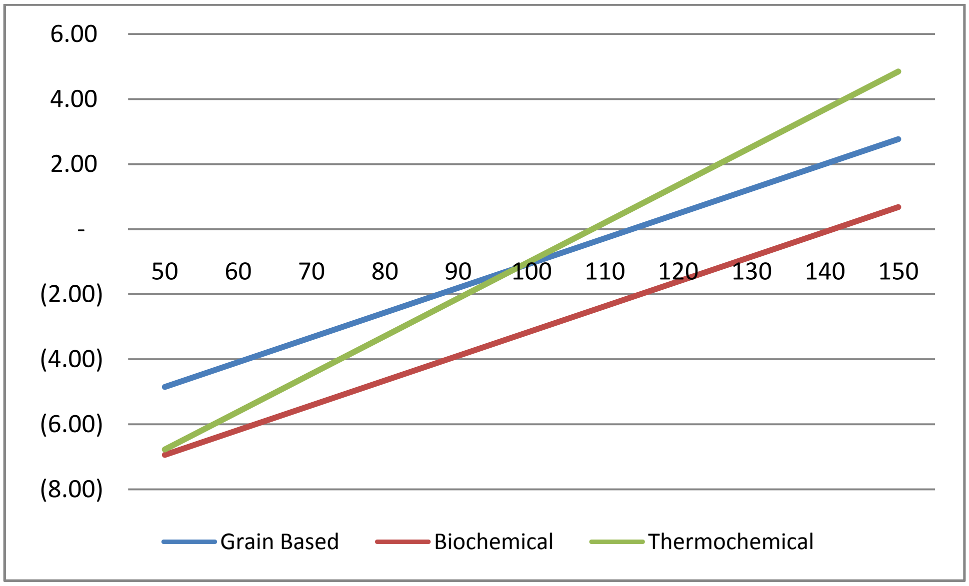
Figure 3.2: Profitability at Various Oil Prices using Volumetric Ethanol Price

Figure 3.3 indicates that the breakeven oil prices for each of the biofuel production methods when calculating the ethanol price on an energy equivalent basis. The results indicate that crude would need to be approximately $108 per barrel for the thermochemical process, $114 per barrel for the grain based process, and $141 per barrel for the biochemical process when subsidies are ignored. This analysis shows that if biofuels are priced based solely on energy content, the thermochemical process is comparable to the grain based process in terms of profitability when oil prices are greater than $108 per barrel.

3.8 Policy Analysis

3.8.1 Sensitivity of Subsidy Levels

A major driver of profitability for ethanol over the past 30 years has been subsidies in the form of tax credits given to blenders. Currently, blenders receive a 45 cent tax credit per denatured gallon of ethanol purchased from ethanol producers. The current subsidy program differentiates between how the ethanol is produced, thus cellulosic ethanol receives a 56 cent per gallon additional subsidy compared to grain based ethanol for a total of $1.01/gal (Tyner, 2007). Biofuels produced through the thermochemical process receive a $1.01/gal. production subsidy, at least through 2012 (U.S. Congress, 2008).



Source: Author's Calculations (2009).
Figure 3.3: Profitability at Various Oil Prices using Energy Equivalent Ethanol Price

Table 3.11 shows the after tax and financing NPV for both grain and cellulosic production methods under the following two subsidy scenarios: no subsidy and the new 2008 Farm Bill subsidy levels. It is important to note that we are assuming that 100% of the subsidies paid to the blenders are passed on to the producers, although the actual subsidy pass-through varies with market conditions and can be adjusted in the BCM.

The projected profitability under each subsidy level shows that all production types fail to meet all required returns without a subsidy in place. However, when the BCM model is adjusted to represent the 2008 Farm Bill subsidy levels, both cellulosic production methods become more profitable compared to grain based ethanol. In fact, the $.51 per gallon NPV for biochemical production method means that under current assumptions, a 50 million gallon per year cellulosic biochemical plant would generate $20.5 million more (20 year plant life) than required by the investors. In addition, the analysis indicates that the thermochemical platform has a $.10 higher NPV per gallon compared to the grain based platform under the current subsidy program. This is the case even though the farm bill subsidy is on a volumetric basis ($/gal.), which penalizes the thermochemical approach because it produces a gasoline or diesel biofuel directly, and these products contain 50% more energy than ethanol.

Table 3.11: After-Tax and Financing NPV Under Different Subsidy Levels

	Grain	Biochemical	Thermochemical
Zero Subsidy ($/gal capacity)	($1.91)	($4.00)	($4.29)
2008 Farm Bill Subsidy ($/gal capacity)	$0.10	$.51	$.20
Breakeven Subsidy ($/saleable gal.)	$0.43	$0.90	$0.96

Source: Author’s Calculations (2009).

Although the BCM suggests that the cellulosic methods will be more profitable than grain based ethanol if the current Farm Bill subsidies are upheld throughout the life of the plant, the cellulosic platfoms require a higher subsidy per gallon. The break-even subsidy shown in Table 3.11 is the subsidy amount that generates a $0 NPV or simply, the subsidy amount per gallon required in addition to revenues to cover all cash, capital and equity expenses. It is important to note that the break-even subsidy does not represent comparing the three production types on an energy equivalence basis; it is simply the subsidy required to create equal profitability based on the average market prices over the last three years. Using the base case assumptions, the grain based subsidy would need to be approximately 43 cents per denatured gallon to create a $0 NPV. The biochemical cellulosic method would require a subsidy of approximately 90 cents per denatured gallon while the thermochemical process would require a subsidy of 96 cents per gallon. Thus, under current assumptions, the cellulosic biochemical production method needs to be subsidized 47 cents/gal. more than grain based ethanol while thermochemical production is projected to need subsidy of 53 cents/gal. more to be economically equivalent to grain based ethanol on an NPV basis.

3.8.2 Production Contract Policy Analysis

Establishing a production contract for biofuels could be one alternative to the current blending and production subsidies in the 2008 Farm Bill. In this analysis it is assumed that the government would be willing to guarantee the purchase of biofuels at a set price for the next 20 years. Biofuel companies would place bids for production contracts and the lowest bids would earn the right to produce and sell at the guaranteed price level. We assume here that companies would place a bid that would generate a post-tax $0 NPV. In other words, companies would compete for the right to have guaranteed prices to the point of eliminating excess profits. However, in reality, the production contract only eliminates fuel price risk, and input costs and technical conversion risks remain. Thus, firms would not actually bid to the point of eliminating all expected profits as we assume here. They would bid something lower, but we have no way of estimating the compensation companies would require for the additional risk. What we produce in table 3.12 is an indication of the relative order of profitability from the three technologies.

Table 3.12: Guaranteed Price Levels for Production Contracts

	Grain Based	Biochemical	Thermochemical
Guaranteed Price ($/saleable gal.)*	$2.18	$2.65	$3.11
Effective Cost/gal. ($/saleable gal.)	$0.43	$0.90	$0.96

*Ethanol for grain and biochemical processes and gasoline for the thermochemical process
Source: Author's Calculations (2009).

Table 3.12 shows that the guaranteed price for grain based ethanol would need to be $2.18/gal or 43 cents/gal higher than the assumed $1.75 to achieve a $0 NPV. Again, the advanced biofuel production methods appear to be quite economically similar, with the biochemical process requiring a 90 cent/gal government price guarantee subsidy compared to the 96 cents/gal for the thermochemical process.

A guaranteed price level production contract policy may reduce the cost to the United States government compared to the 2008 Farm Bill subsidies. The difference between the effective cost/gallon and the proposed blending and production subsidies would be the current savings to the government as shown in Table 3.13. The BCM suggests that the government could save 5 cents/gal. of ft-gasoline produced by the thermochemical process and 11 cents/gal. of ethanol produced by the biochemical process given the assumptions. The aggregate savings to the government for using this policy is unclear because the proportion of production types utilized and the potential amounts produced have yet to be determined.

Table 3.13: Government Costs for Policy Options

	Grain Based	Biochemical	Thermochemical
	$ per saleable gallon		
2008 Farm Bill Subsidy	$0.45	$1.01	$1.01
Price Guarantee	$0.43	$0.90	$0.96
Gov. Savings	$0.02	$0.11	$0.05

Source: Author's Calculations (2009).

In concept, a production contract is similar to a variable subsidy with the subsidy depending on the oil price. The government cost is low (or even profit) if oil prices are high, but the subsidy cost increases as oil price falls.

3.9 Current Economics

The commodity markets have been extremely volatile over the last three years, thus greatly affecting the profitability of the cellulosic and grain based biofuel platforms. The economic analysis conducted thus far assumed that all input and output prices were based on a three year average from January 2006 to December 2008. As of June 19th 2009, energy and grain prices are much lower than the three year average (Appendix B). This section of the chapter will examine the current economics of the three production methods based on June 19th, 2009 commodity prices.

Table 3.14 shows that all three of the production types are expected to generate negative profits without the 2008 Farm Bill subsidies given today's market conditions. The shift to more severe negative profits for the cellulosic platforms is the result of lower output prices for both ethanol and gasoline. The lower ethanol price for grain based ethanol production is offset by the lower corn and energy costs (mainly natural gas), thus making the current NPV for grain ethanol more appealing than the base case. When the 2008 Farm Bill subsidies are added to the BCM, the grain based platform is projected create a positive NPV while the cellulosic platforms are still slightly negative. This analysis underscores that biofuel economic comparisons are highly reliant on both relative input and output prices. Thus, investors and policy makers should look at a variety of price levels in order to judge overall profitability for the three production types.

Table 3.14: June 2009 After-Tax and Financing NPV Profitability

	Grain	Biochemical	Thermochemical
	$/gallon capacity		
Zero Subsidy	($1.51)	($5.66)	($5.21)
2008 Farm Bill Subsidy	$.50	($1.15)	($.70)

Source: Author's Calculations (2009).

3.10 Conclusion

The BCM base case and the subsequent sensitivity analysis conducted in this paper show that grain based ethanol, biochemical cellulosic ethanol, and thermochemical cellulosic gasoline are all economically infeasible without subsidies or other government policies. However, grain based production has a higher level of profitability (lower loss) compared to the cellulosic production methods under the cost and technical assumptions assumed. When the current subsidies are included in the revenue stream, the cellulosic production methods appear to be more profitable compared to the grain based platform. A big underlying assumption in this case is that the cellulosic biorefineries will be able to convert biomass to biofuel under the yield assumed (69.7 gal/ton for biochemical and 61.4 gal/ton for thermochemical) and at the assumed capital costs. The range of reported yields varies from 55 gallons per ton to 110 gallons per ton, thus the actual profits will adjust significantly when a commercial plant actually proves the feasible yield rate.

In addition, this analysis shows that grain based ethanol profitability is much more affected by higher energy and feedstuff costs, whereas cellulosic biofuel production types are more sensitive to capital and enzyme costs. Technical breakthroughs could lower biochemical enzyme and capital costs such that cellulosic biochemical ethanol and thermochemical gasoline could close the gap in terms of profitability.

A quicker solution to spur cellulosic biofuel production would be for the "Energy Independence and Security Act of 2007" mandates and the 2008 Farm Bill subsidies to be upheld or government price guarantee policy used for the life of the plant investments. With the proposed subsidy levels, both cellulosic ethanol and thermochemical gasoline plants are projected to be more profitable than grain based ethanol facilities. However, the government price guarantee policy analyzed could allow the biofuels plants to be profitable, while reducing the costs for the U.S. government. In order for investment to actually occur, investors must believe these subsidies, mandates or other policies will not be drastically altered or eliminated during the life of the plant.

4. CONCLUSION

Based on the average input and input and output prices from 2006 to 2008, and the technical assumptions given in the base case, all forms of ethanol and biofuel production are currently unprofitable without government subsidies. The case indicates that grain based ethanol is the most profitable (least loss) biofuel production type compared to biochemical cellulosic ethanol and thermochemical biofuels. The results show that the after tax and financing NPV for a grain based production facility is $-1.91 per gallon of capacity without subsidies. This is compared to $-4.00 for biochemical cellulosic production and $-4.29 for thermochemical biofuels. The NPV is reported on a per saleable gallon basis with plants being approximately 100 million gallons of ethanol per year for grain based production and 50 million gallons per year for cellulosic production.

Although thermochemical cellulosic production appears to be the most unprofitable on a per saleable gallon basis, the thermochemical process is currently the cheapest form of biofuel energy production compared to the other process' on an energy equivalents basis. Table 4.1 shows the breakeven biofuel price for each of the production types without considering subsidies. The breakeven price is simply the required biofuel price needed to generate an after-tax and financing NPV of zero. Because the thermochemical process can produce products similar in energy value to gasoline, the energy content per salable gallon is roughly 50 percent higher compared to ethanol. Thus, on a crude equivalent basis, thermochemical cellulosic production appears to be as economical as grain based ethanol with an estimated breakeven crude price of $108.27 per barrel compared to $113.64 crude oil for grain based ethanol.

Table 4.1: Energy Equivalents for Production Types for Base Case

	Grain Based	Biochemical	Thermochemical
Gasoline Equivalent ($/gal)	$3.25	$3.97	$3.11
Crude Equivalent ($/barrel)*	$113.64	$141.44	$108.27

*Based on historical gas/oil price relationship (Tyner and Taheripour, 2007)
Source: Author's Calculations (2009).

The cellulosic biofuel industry would most likely develop faster if investors believed the current production and blending subsidies that resulted from the 2008 Farm Bill would be sustained over the 20 year life of the plant investment. The combination of the blending subsidy for grain based ethanol dropping to 45 cents per gallon and the effective subsidy of cellulosic biofuels increasing to $1.01 per gallon, is projected to make cellulosic biofuels more profitable than grain based ethanol given the base case assumptions. This analysis estimates that biochemical cellulosic ethanol would have an after-tax and financing NPV of 51 cents, compared to 20 cents for the thermochemical process and 10 cents for the grain based ethanol process when considering current subsidies. Thus, if investors believe the subsidies will be sustained and that the case assumptions are valid, cellulosic plants may be considered a viable investment. If the subsidy were changed to an energy equivalent basis, thermochemical would become more attractive.

This study also indicates that the cellulosic biofuels industry can become more economically feasible compared to the grain based ethanol industry if any of the following occur:

- Energy prices increase: Advanced biofuels are much less exposed to energy prices compared to grain based ethanol. Grain based ethanol relies heavily on natural gas to convert corn to ethanol whereas the cellulosic production types utilize internal heat for most of the power generation. This study suggest that a 20% increase in energy prices will decrease the NPV for grain ethanol by 21 percent compared to less than 3 percent for both of the cellulosic platforms.

- Biomass Yield: The commercial biomass to biofuel yield is highly unknown in the industry. This case analysis was conservative in estimating the biochemical process would yield 69.7 gallons per ton while the thermochemical process would yield 61.4 gallons per ton. If the actual yields are greater, then the profitability for cellulosic production types will increase drastically, as both the feedstuff cost per gallon and the capital cost per gallon produced would likely decrease.

- Capital Costs: A major concern in the advanced biofuel industry is that the capital costs are too high relative to the grain based ethanol industry. Biochemical cellulosic plants are estimated to cost 276 percent more to build per name-plate gallon of capacity compared to grain based ethanol, and the thermochemical process is estimated to cost 509 percent more per name-plate gallon. If these initial cash outlays were less for the cellulosic platforms, NPV profitability would increase and the large cash barrier of entry would decrease. Andy MaAloon estimates that capital costs for a cellulosic plant starting in 2015 will be approximately 25 percent less, thus if technological progress continues, cellulosic biofuels will become more profitable relative to grain based ethanol (MaAloon, 2008).

To reiterate, comparing profitability between the production types is largely dependent on both current prices and future price projections. The BCM is organized so prices, assumptions and technical parameters can be updated easily. The impact of variations of input prices can be seen when comparing the base case results to the current input and output prices and the subsequent NPV projections. Currently (June 19th, 2009 prices), all production types are projected to be unprofitable even with the assistance of subsidies. Thus, unless ethanol and oil prices rise, the biofuels industry is likely to remain unprofitable without increased government intervention.

4.1 Future Research

As more information surrounding the future cellulosic industry is available, assumptions in this study can be altered and the infrastructure impacts can be predicted more accurately.

The BCM introduced in this thesis serves as a solid framework for future economic comparisons. The model is set-up in a way that will allow future users to adjust technical, financial, and cost assumptions. The BCM and the subsequent economic analysis has flaws as with any other model. The current BCM assumes that input and output prices will remain fixed in real terms over the life of the plants. Future research could include risk and price variation into the BCM. By allowing input and output prices to fluctuate year to year based on historical data, investors would have a better idea of the profits and relative risk of the advanced cellulosic platforms compared to the grain based industry. In addition, adding variation in unknown technical components such as enzyme, biomass to biofuel conversion yield, and capital costs would give investors a range of possible NPV's, thus allowing investors to choose risk parameters such as likelihood of negative profits. Lastly, risk could be added to represent the uncertainty of future subsidy levels. The 2008 Farm Bill subsidies are set to expire in 2012. A range of possible subsidies past that date could be added to the model.

LIST OF REFERENCES

Aden, A. ; Ruth, M. ; Ibsen, K. ; Jechura, J. ; Neeves, K. ; Sheehan, J. ; Wallace, B. ; Montague, L. ; Slayton, A. ; Lukas, J. "Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover." National Renewable Energy Lab., Golden, CO. (US). 2002 Jun 01

Abbott, Philip C.; Hurt, Christopher and Tyner Wallace E. “What's Driving Food Prices?” Farm Foundation. 2008

Bain R.L. World Biofuel Assessment. World Biomass Potential: Technology Characterizations. National Renewable Energy Laboratory. NREL/MP-510-42467. December 2007

Brechbill, S. C and Tyner, W. E. “The Economics of Biomass Collection, Transportation, and Supply to Indiana Cellulosic and Electrical Utility Facilities.” *Working Paper #08-03.* Purdue University, Department of Agricultural Economics. April 2008.

Capehart, Tom and Schnepf, Randy. “Biofuels Provisions in the 2007 Energy Bill and the 2008 Farm Bill: A Side-by-Side Comparison.” CRS Report for Congress. RL34239. June 2008.

Collins, K. “The New World of Biofuels: Implications for Agriculture and Energy.” *EIA Energy Outlook, Modeling, and Data Conference.* 28 March 2007

Dien, B.S., Nichols, N.N., Iten, L.B., Bothast, R.J. 2004. Enhancement of ethanol yield from the corn dry grind process by fermentation of the kernel fiber fraction. In: Nelson, W.M., editor. Agricultural Applications in Green Chemistry. Chap. 6. Washington, DC:American Chemical Society. p. 63-77

Larson, E. D. “Biofuels ProductionTechnologies: Stutu, Prospects and Implications for Trade and Development.” *United Conference on Trade and Development.* 2008

MaAloon, A. Personal Email Correspondence. May 2008.

MaAloon, A., Taylor, F., Yee, W., Ibsen, K., and Wooley, R.. “Determining the cost of producing ethanol from corn starch and lignocellulosic feedstocks.” http://www.nrel.gov/docs/fy01osti/28893.pdf. NREL/TP-580-28893, National Renewable Energy Laboratory, Colorado (2000).

Mosier, N.. Personal Correspondence. Purdue University. May 2008.

Renewable Fuels Association. *Industry Statistics.* May 2009.

Renewable Fuels Association. *Ethanol Biorefinery Locations.* May 2009.

Sheehan J, Aden A, Paustian K, Killian K, Brenner J, Walsh M and Nelson R (2004). Energy and environmental aspects of using corn stover for fuel ethanol. *Journal of Industrial Ecology*, 7(3-4): 117-146

Tiffany, D. G. Dry-Mill Ethanol Spreadsheet. www.agmrc.org/NR/rdonlyres/4C6BD4DE-8DA0-44F6-A9AE-02320DBF99F6/0/ethanolsuccess.xls. University of Minnesota. 23 July 2003.

Tiffany, D. G. "Economic Comparison of Ethanol Production from Corn Stover and Grain." AURI Energy Users Conference. March 13, 2007.

Tijmensen, M.J.A., A.P.C. Faaij, C.N. Hamelinck, and M.R.M. van Hardeveld, Exploration of the possibilities for production of Fischer Tropsch liquids and power via biomass gasification, Biomass & Bioenergy, Vol. 23, 2002, pp. 129-152.

Tyner, W. E. “Ethanol Policy-Possibilities of the Future.” *ID-342-W.* Purdue University, Department of Agricultural Economics. January 2007.

Tyner, W. E. and Taheripour, F. "Ethanol Subsidies, Who Gets the Benefits?." Purdue University, Department of Agricultural Economics. 2007

Tyner, W. E. and Taheripour, F. “Future Biofuels Policy Alternatives.” Purdue University, Department of Agricultural Economics. http://www.agecon.purdue.edu/papers/biofuels/St_Louis_conf_Apr07_Tyner_Taheripour.pdf. Appendix A. April 2007

Tyner, W. E. “The US Ethanol and Biofuels Boom: Its Origins, Current Status, and Future Prospects.” Bioscience. Vol. 58 No.7. 2008. Pp. 646-653.

U.S. Congress (2007). *Energy Independence and Security Act of 2007*. H.R. 6, 110 Congress, 1st session. Available at http://www.whitehouse.gov/news/releases/2007/12/20071219-1.html.

U.S. Congress (2008). *2008 Farm Bill*. H. R. 6124 (P.L. 110–246).

Wright, M. M. and Brown R. C. “Comparative Economics of Biorefineries based on the Biochemical and Thermochemical Platforms.” 17 May 2007.

APPENDICES

Appendix A: Base Case Input Assumptions

Decisions Variables: **CHOOSE VALUES HERE:**

Energy Prices:

	CHOOSE VALUES HERE	Price Used in Model	Adjusted Price
Oil Price:	Adjusted Price	$79.39	$79.39
LP (Propane) Price:	Adjusted Price	$1.21	$1.210
Electric Costs/Credit kwh:	Adjusted Price	$0.10	$0.098
Diesel:	Adjusted Price	$2.33	$2.33
Corn Price:	Adjusted Price	$3.91	$3.91

Energy and DDGS Prices:

		Price Used in Model	Adjusted Price
Natural Gas:	Adjusted Price	$11.85	$11.85
Denaturant Price per Gal. (gasoline):	Adjusted Price	$2.15	$2.15
Current Base Ethanol Price:	Adjusted Price	Insert Values Below	
Current Grain Ethanol Price:	Adj. Grain Ethnal Price	$1.75	$1.75
Current Biochemical Ethanol Price	Adj. Bio Ethnal Price	$1.75	$1.75
DDGS $/ton:	Adjusted Price	$119.60	$119.60

Cellulosic Production choices:

		Price Used in Model	Adjusted Price
Feedstuff chosen for model:	Corn Stover	N/A	N/A
Feedstuff base cost:	Estimated Indiana Price	$41.12	

Cellulosic Extraction Rates (gallons fuel/dry ton):

		Value Used in Model	Adjusted Value
Biochemical extraction rate (anhydrous gal/ton):	Literature Estimate	69.7	
Thermochemical extraction rate:	Literature Estimate	61.4	

Dry Mill Corn Extraction Rates:

		Value Used in Model	Adjusted Value
ethanol extracted (anhydrous gal. per bu.)	Literature Estimate	2.65	
DDGS per Bushel (lb. per bu.)	Literature Estimate	18	
CO2 extracted per Bushel (lb. per Bu.)	Literature Estimate	18	

Appendix B: Current Input Assumptions

Decisions Variables:

CHOOSE VALUES HERE:

Energy Prices:

		Price Used in Model	Adjusted Price
Oil Price:	Current Market Price	$69.60	
LP (Propane) Price:	Current Market Price	$0.93	
Electric Costs/Credit kwh:	Current Market Price	$0.02	
Diesel:	Current Market Price	$1.82	
Corn Price:	Current Market Price	$3.99	

Energy and DDGS Prices:

		Price Used in Model	Adjusted Price
Natural Gas:	Current Market Price	$5.18	
Denaturant Price per Gal. (gasoline):	Current Market Price	$1.93	
Current Base Ethanol Price:	Adjusted Price		
Current Grain Ethanol Price:	Adj. Grain Ethnal Price	$1.53	
Current Biochemical Ethanol Price	Adj. Bio Ethnal Price	$1.53	
DDGS $/ton:	Current Market Price	$119.60	

Cellulosic Production choices:

		Price Used in Model	Adjusted Price
Feedstuff chosen for model:	Corn Stover	N/A	N/A
Feedstuff base cost:	Estimated Indiana Price	$41.12	

Cellulosic Extraction Rates (gallons fuel/dry ton):

		Value Used in Model	Adjusted Value
Biochemical extraction rate (anhydrous gal/ton):	Literature Estimate	69.7	
Thermochemical extraction rate:	Literature Estimate	61.4	

Dry Mill Corn Extraction Rates:

		Value Used in Model	Adjusted Value
ethanol extracted (anhydrous gal. per bu.)	Literature Estimate	2.65	
DDGS per Bushel (lb. per bu.)	Literature Estimate	18	
CO2 extracted per Bushel (lb. per Bu.)	Literature Estimate	18	