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The economic feasibility of utilizing energy cane in the cellulosic production of ethanol

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THE ECONOMIC FEASIBILITY OF UTILIZING ENERGY CANE IN THE CELLULOSIC PRODUCTION OF ETHANOL

A Thesis

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Agricultural and Mechanical College
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TABLE OF CONTENTS

ACKNOWLEDGEMENTS ii

ABSTRACT iv

CHAPTER 1: INTRODUCTION 1
  1.1 Background 1
  1.2 Problem Statement 4
  1.3 Research Question 6
  1.4 Research Objectives 7
  1.5 Organization of the Study 7

CHAPTER 2: LITERATURE REVIEW 8

CHAPTER 3: GENERAL PROCEDURES 16
  3.1 Conceptual Model 16
  3.2. Variable and Fixed Production Costs 18
  3.3. Energy Cane Yield Data 25
  3.4. Optimal Crop Cycle Lengths 30
  3.5. Transportation Costs 33
  3.6. Total Ethanol Production Costs 34
  3.7. Sensitivity Analysis 35

CHAPTER 4: RESULTS AND DISCUSSION 43
  4.1 Energy Cane Production Cost Estimates 43
  4.2 Energy Cane Yield Estimates for Older Stubble 49
  4.3 Potential Optimal Crop Cycle Lengths 50
  4.4 Transportation Cost Estimates 51
  4.5 Total Cost Estimate for the Cellulosic Production of Ethanol 53

CHAPTER 5: CONCLUSION AND SUMMARY 56

REFERENCES 61

VITA 66

ABSTRACT

With an overall lack of economic information available on energy cane production, the aim of this research has been to provide some insight on the economic feasibility of producing energy cane in Louisiana as a feedstock for cellulosic ethanol production. When dealing with a non-traditional crop such as energy cane, increased uncertainty surrounding potential costs and returns can make the crop seem much less appealing to potential producers. As a high-fiber hybrid of traditionally produced sugarcane, energy cane production costs have been estimated using a standard enterprise budgeting approach developed for sugarcane, along with actual yield and fiber data from energy cane field trials. Monte Carlo simulation was performed in order to estimate energy cane costs and yields under stochastic input prices and yield levels. Breakeven yields for third through sixth stubble were calculated in order to determine the potential optimal crop cycle length that would maximize an energy cane producer's net returns. Delivered feedstock costs to an ethanol producer were estimated along with potential processing costs in order to assess the total cost of producing cellulosic ethanol from energy cane.

Overall, the average variable cost of energy cane production was about $14 per wet ton and the average total cost of producing energy cane was approximately $23 per wet ton. Energy cane yield estimates ranged from 36 to 68 tons per acre and results suggest that the optimal crop cycle length for energy cane is production through sixth stubble, or 8 years. Compared to similar economic studies for other energy crops, the findings of this study indicate that energy cane is capable of producing higher biomass yields at a lower cost. Furthermore, the results suggest that cellulosic ethanol producers utilizing energy cane as a feedstock can attain a minimum ethanol selling price between $2.00 and $2.30 if processing costs remain below $0.90 per gallon and the energy cane supply is sourced from farms within a 40 mile radius of the processing facility.

CHAPTER 1: INTRODUCTION

1.1 Background

Over the past 50 years a number of factors have influenced the expansion of the biofuel industry in the United States. Concerns over oil supply disruptions in the Middle East along with the environmental concern of lead in gasoline both contributed to the rising interest and support for an ethanol industry beginning in the late 1970’s (DiPardo, 2000). The banning of methyl tertiary butyl ether (MTBE) as an oxygen booster in gasoline in the early 2000’s contributed to an increase in the demand for ethanol as an oxygenate alternative (EIA, 2003). In addition, a Renewable Fuels Standard (RFS) was introduced under the Energy Policy Act of 2005 which established the first renewable fuel volume mandate in the U.S., requiring 7.5 billion gallons of renewable fuel to be blended into the nation’s gasoline supply by 2012 (EPA, 2011). In 2007, under the Energy Independence and Security Act, the RFS program was expanded to increase the mandated volume of renewable fuel to be blended into transportation fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022. Along with expanding the mandate requirement, the 2007 Act placed great emphasis on advanced and cellulosic biofuel production, highlighting the growing concern surrounding the use of corn as a biofuel feedstock. For the 2022 target, the legislation placed a cap on corn-ethanol production at 15 billion gallons and mandated that the remaining 21 billion gallons be produced from advanced and cellulosic sources (EPA, 2011).

The push for a shift away from corn-ethanol began around 2006, when the demand for corn increased due to an increase in demand for corn for biofuel. This increase in demand resulted in significant increases in the price of corn. Figure 1 contains historical price data downloaded from the USDA Economic Research Service (ERS, 2012) for corn and ethanol from 2000 to present. In just a year, corn prices rose approximately 51% from $2.00 in January of 2006 to $3.01 in December of 2006. Other agricultural commodity prices also began to increase as farmers of other crops began to shift their acres to corn production in response to the high corn prices. In 2007, the RFS was restructured in order to shift future production of ethanol away from corn-ethanol and towards other forms of ethanol production that have less of a direct effect on food crops.

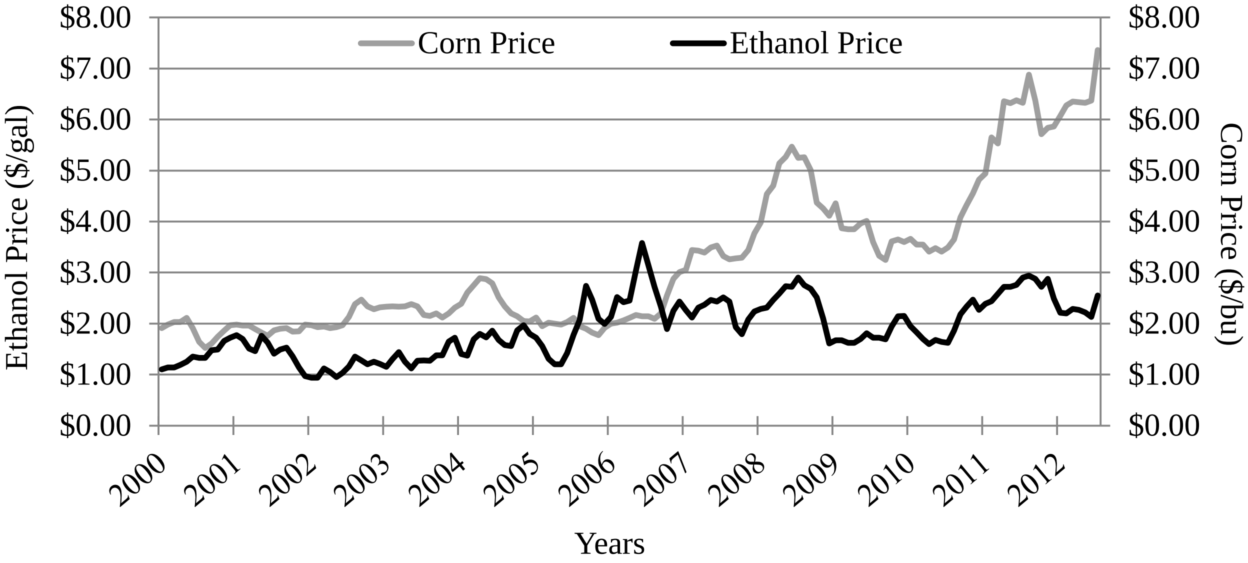

Figure 1. U.S. Historical Prices for Ethanol and Corn, 2000 - 2012

Unlike first generation biofuels which have traditionally been produced from corn and other food crops, feedstocks used in the production of cellulosic ethanol are grown specifically for energy supply leading some to believe that it is likely they will have a less direct impact on the production of food (Coyle, 2010). However, this will only be the case if these energy crops are grown on marginal land that is poorly suited for the production of food crops. Despite the concerns with corn-ethanol, production of ethanol continues to rise and most of the U.S. ethanol supply is still coming from these controversial biofuels. Figure 2 contains historical data on U.S. ethanol production and consumption downloaded from the Energy Information Administration, which provides annual data for the ethanol industry (EIA, 2012). In 2011, total ethanol production in the U.S. was approximately 13.9 billion gallons, while ethanol consumption was about 12.9 billion gallons. In addition, over 150 bio-refineries have been added to the U.S. ethanol industry since 2000 (RFA, 2012).

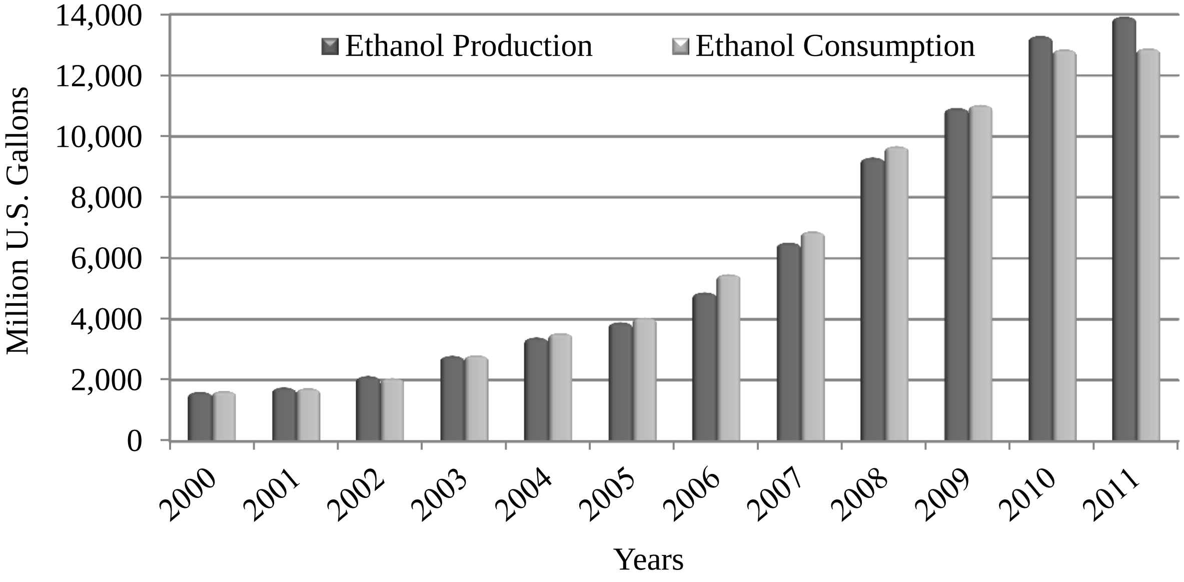

Figure 2. U.S. Ethanol Production and Consumption Data, 2000 - 2011

Meeting the RFS targets for 2022 will require further development of feedstocks for cellulosic ethanol production. Cellulosic ethanol is simply just ethanol that is produced from cellulose, the main component of plant cell walls. One promising feature of cellulose is that it is the most common organic compound on earth, which means that cellulosic ethanol can be produced from a wide variety of feedstock plant materials, including trees, agricultural crops, and grasses, to name a few (RFA, 2012). While the majority of ethanol production is currently concentrated in the Midwest, it is important to note that increasing cellulosic ethanol production to a commercial scale is going to require the participation and resources of states and regions outside of the U.S. Corn Belt. Regional studies will be necessary in order to properly evaluate the location and potential of biomass feedstocks and processing facilities. In order to reduce the costs of these next-generation biofuels and meet the increasing energy demand, low cost feedstocks will need to be identified in each state or region so that each produces the crops for which it has the greatest comparative advantage. One option for Louisiana and other Gulf Coast states featuring subtropical regions is to grow energy cane for the production of cellulosic ethanol. Energy cane varieties are high fiber sugarcane varieties that can be harvested with existing sugarcane equipment. Perhaps the most promising feature of energy cane as a biofuel feedstock is the fact that it has a greater yield potential, in tons of biomass per acre, than that of traditional sugarcane varieties (Mark, Salassi, and Deliberto, 2009).

1.2 Problem Statement

With an ambitious target set for cellulosic ethanol production over the next decade, it is unreasonable to assume that a mandate alone is enough to bring cellulosic ethanol production to a commercial scale. In fact, many obstacles must be overcome before the commercialization of cellulosic ethanol can actually occur. Broadly speaking, developing these next generation biofuels will require careful planning in supply chain design, efficiency enhancements and innovations in production, as well as improved farming techniques. According to the findings of Slade, Bauen, and Shah (2009), supply chain design is imperative to determining the commercial viability of a cellulosic ethanol industry and the importance of feedstock supply assessments highlights the need for location-specific analyses of feedstock availability and price. Furthermore, because energy cane is not a traditionally produced crop, researchers are faced with an additional challenge because data on overall crop performance is limited.

A key challenge to expanding cellulosic ethanol production involves reducing the relatively high production costs throughout nearly every stage of production, specifically, feedstock purchase price, transportation cost, and processing costs. However, because there is currently no market for cellulosic ethanol feedstocks, researchers assessing the economic feasibility of a new production facility are faced with an even greater challenge than would otherwise be the case for a good with an established market. Without a market, determining the price of a feedstock to an ethanol production facility requires complete estimation of cost data involved in growing the biomass feedstock. As a result, a wide range of production costs and feedstock price estimates are provided in the literature. Among these studies, the wide range of biofuel feedstock costs are most often the result of differences in feedstocks, as well as differences in assumptions regarding the items to include in the calculation. Examples of such assumptions are payments to farmers and opportunity costs, yields, distances to conversion facilities, storage needs, and the level at which each of these items is compensated (Carriquiry, Du, and Timilsina, 2011). A location-specific assessment of potential feedstocks will better reflect pertinent data that varies regionally such as infrastructure, product and input markets, labor, as well as state and local policies that are often not accounted for in studies of larger scope. For example, although Louisiana is a major producer of sugarcane in the United States, it would not be reasonable to assume that building an ethanol industry in Louisiana which uses sugarcane as a feedstock would be feasible simply because Brazil has experienced success in doing so. In fact, Brazil's success has been heavily influenced by decades of government support and investment into its sugarcane-ethanol industry and thus has the right combination of policies and infrastructure that has helped it succeed.

One of the greatest factors directly impacting the economic feasibility of biomass production for ethanol or other biofuels is the relative adaptability of various potential feedstock crops to local or regional production areas. Certain potential biofuel feedstock crops are better suited agronomically for production in particular areas over other possible areas of production. Potential feedstock crops such as energy cane, being a subtropical perennial crop, would be expected to have a more limited production area than other feedstock crops such as sweet sorghum, switchgrass or miscanthus which have a greater cold tolerance. In addition, the feasibility of harvesting feedstock crops, both from a mechanical and economical perspective, is another critical issue. Cultivation and harvest technologies are more developed for crops such as energy cane or sweet sorghum. Additional research into feasible harvest technologies would need to be conducted for other, less traditional crops, such as switchgrass or miscanthus.

While reducing feedstock costs will certainly help in securing an economically viable future for cellulosic ethanol, even greater cost reductions will be possible if researchers are able to develop more efficient means of converting cellulose to ethanol. Ethanol is an alcohol that is produced by yeasts from sugars. The popularity of traditional biomass feedstocks such as corn is due to the fact that they contain large amounts of starch that can easily be broken down into simple sugars, or glucose, and fermented into ethanol (Mosier and Ileleji, 2006). Cellulose is a polymer of glucose, meaning that it is a large molecule made up of simpler molecules that are connected in a way that is similar to links in a chain. Producing ethanol from cellulose is more difficult because it is a very long molecule with a rigid structure, unlike simple sugars and starches. As a result, additional steps are required in the conversion process, specifically, a pretreatment step which softens the cellulosic material so that it can be broken down into simple sugar molecules. These additional steps result in additional costs, which is one reason why cellulosic ethanol has not yet become cost competitive with grain ethanol. If cellulosic ethanol is to become a viable fuel option, advances in technology resulting in a more efficient process of converting the raw material into fuel will be needed.

1.3 Research Question

This study explores the economic feasibility of using energy cane as a feedstock to supply a cellulosic ethanol industry in Louisiana. As a major sugarcane producing state, Louisiana has several advantages in producing energy cane. Specifically, Louisiana features a favorable climate in which energy cane production can thrive, as well as farmer expertise and existing equipment and infrastructure. However, because energy cane is not a traditionally produced crop, production costs and potential yields will need to be estimated in order to determine its potential as a biomass feedstock. The minimum market price that energy cane farmers would likely accept from an ethanol producer to cover the total costs of production must also be estimated, as well as transportation and processing costs incurred by the ethanol producer.

1.4 Research Objectives

The general objective of this research project is to evaluate the economic feasibility of utilizing energy cane as a feedstock in the cellulosic production of ethanol. More specifically, this study has estimated the projected feedstock price of energy cane to an ethanol production facility based upon projected feedstock crop production costs and transportation expenses. The specific objectives of this research project are:

(1) To estimate the variable and fixed production costs of energy cane at the farm level,
(2) To project potential energy cane yields and crop stubbling ability,
(3) To project potential optimal crop cycle lengths associated with energy cane production,
(4) To estimate total delivered feedstock cost to an ethanol production facility, and
(5) To estimate total ethanol production costs utilizing assumed cellulosic production technology.

1.5 Organization of the Study

A brief review of the relevant literature is given in Chapter Two, followed by Chapter Three which begins with an introduction of the theoretical model in Section 3.1. The general procedures used in conducting the study are explained throughout the remaining sections of Chapter Three and the results are presented in Chapter Four. Finally, the conclusion and discussion are given in Chapter Five.

CHAPTER 2: LITERATURE REVIEW

For decades there has been a great deal of interest surrounding biofuels which has resulted in an abundance of literature on the subject. Among this literature, many aspects of biofuels have been evaluated and can be categorized as either technical, concerning raw material supply and conversion technologies, economic, or as ecological/political studies, which usually analyze greenhouse gas emissions, efficient land use and reduced dependency on crude oil (Festel, 2008). To remain within the scope of this study, which falls into both the technical and the economic categories, the relevant literature pertaining to the major objectives of this research are reviewed below.

The selection of feedstock for the production of ethanol remains a popular area for research because of its major role in determining the cost competitiveness of the biofuel. According to Balat and Balat (2009), feedstock purchase price represents approximately 60 – 75% of total biofuel production cost, making it an important consideration for financial assessments of feedstock options. Calculating the break-even price of production for potential feedstocks has become a popular method used by economists to analyze potential biomass sources. To compare the alternative costs and yields of various perennial, annual, and intercrops for biomass production, Hallam, Anderson, and Buxton (2001) computed the break-even price for each alternative by dividing cost per hectare by the expected yield per hectare. In estimating the opportunity cost of land for conversion to perennial grass in Illinois, Khanna, Dhungana, and Clifton-Brown (2008) estimated profits per hectare from a corn-soybean rotation. Profits were calculated as the difference between revenues from a corn-soybean crop valued at the loan rates for each county and the cost of production. To obtain site-specific breakeven prices of miscanthus, the authors incorporated spatial yield maps and crop budgets for bioenergy crops and row crops with transportation costs. Focusing on a non-traditionally produced crop, Mark, Darby, and Salassi (2009) conducted their energy cane analysis using relevant data on sugarcane production. In their study, the authors estimated the breakeven price that producers must receive in order to cover energy cane's cost of production. Grower breakeven costs included variable, fixed, overhead, land rental, and transporting costs. The authors assumed a one-sixth land rental agreement and a $3.50 per wet ton (wt) transportation credit to growers for every wet ton delivered to the processor. Results for the grower breakeven analysis found that the combination of averaging 35wt/acre and reaching the sixth stubbling would provide the grower with a price comparable to that of the average price of sugarcane per acre in Louisiana from 2000 to 2007, but only when transportation costs are excluded. In addition, when considering the scenario in which cellulosic ethanol can be produced at 60 gal/dt and have a fifth stubble rotation, cellulosic ethanol costs roughly $1.15 more than corn ethanol when energy cane yields are 35wt/acre. They further estimated that in order to be competitive with corn ethanol when the price of corn is $3.50/bu., the cost of cellulosic ethanol must decrease by $0.90/gal, along with an increase in energy cane yield between 45 and 50wt/acre. A study by Alvarez and Helsel (2011) tested the economic feasibility of growing energy cane on mineral soils in Florida for cellulosic ethanol production. The authors calculated the breakeven price of ethanol for biomass yields ranging from 25 to 40 net tons per acre when cellulosic processing costs were $1.07 and $1.65 and found that energy cane had potential to become a useful bioenergy crop on unmanaged mineral soils in south-central Florida.

A second trend in the economic analyses of biofuel feedstocks is the use of Monte Carlo simulation models to incorporate the uncertainty involved in these production studies. Morris et al. (2008) assessed the economic feasibility of a large scale ethanol firm using sweet sorghum juice in three growing regions of Texas. Monte Carlo simulation models were used to estimate the price ethanol plants would have to pay for sweet sorghum and the uncertain returns for ethanol plants. Bennett and Anex (2009) found that sweet sorghum seasonally processed as a supplemental fermentable carbohydrate and fuel feedstock for existing ethanol production facilities is an economically viable option when compared to corn. The authors used Monte Carlo simulation and sensitivity analysis. Maung and Gustafson (2011) used a stochastic simulation financial model with irrigated sugar beet data from central North Dakota to determine the economic feasibility and risks for producing sugar beets and beet molasses for 10 million gallons per year (MGY) and 20 MGY ethanol plants.

Mathematical programming models are another option for researchers conducting biofuel-related cost analyses. In assessing the economic feasibility of sugarcane as a feedstock for biofuel production on non-prime land in Hawaii, Tran et al. (2011) used both a static and dynamic mathematical optimization model as well as the current conversion rate of cellulosic feedstock to ethanol on both prime and non-prime lands. Egbendewe-Mondzozo et al. (2011) applied a bio-economic model and a regional profit-maximization mathematical programming model to simulate biomass production in a 9-county region of southwest Michigan and identify profitable cropping system choices. To estimate the production costs that would be experienced in a commercial setting, Perrin et al. (2008) used a different method in which they extrapolated data to determine longer term production costs. They collected actual data from ten cooperating farmers growing switchgrass on commercial-scaled fields in North Dakota and Nebraska, and found that applying a 10% discount rate to the data recorded over a 5 year period resulted in an average annualized cost of production of \$65.86 Mg^{-1}, and an average annualized yield of 5.0 $\mathrm{Mg/ha}^{-1}$.

The majority of agronomic research on potential biofuel crops has been conducted on switchgrass. Lemus et al. (2002) evaluated 20 different switchgrass cultivars in Iowa and found substantial differences in potential biomass yields of lowland versus upland switchgrass varieties. In 2008, Lemus et al., found that proper nitrogen application and agronomic management could substantially increase the yield of established switchgrass fields over time without affecting the quality of the feedstock. West and Kincer (2011) evaluated alternative seeding dates and seeding rates for switchgrass and found that higher seeding rates (6.42 mg/ha) and later seeding dates (late May through early June) produced the greatest switchgrass yields. Qualls et al. (2012) evaluated factors affecting the willingness of producers to produce switchgrass in the United States, predicting potential land conversion rates to switchgrass of approximately 56 ha per farm. Zegaga-Lizaraza and Monti (2012) reviewed agricultural practices for sweet sorghum and found that low input requirements, low production costs, drought resistance, versatility, and higher yields gives sweet sorghum a better energy balance compared to other competing energy crops. In 2011, Kim and Day assessed the composition of energy cane, sugarcane, and sweet sorghum suitable for ethanol production in Louisiana and found that energy cane yields were higher than that of sugarcane and sweet sorghum, but also noted that sweet sorghum requires less fertilizer and water than that of energy cane and sugar cane.

Several studies have evaluated the relative feasibility of producing bioenergy feedstock crops. Much of the initial economic research has focused on the use of switchgrass as a biofuel feedstock (Epplin-1996; Lewandowski et al.-2003; Hallam et al.-2001; Turhollow-2000; Ugarte et al.-2003; Duffy and Nanhou-2001). An early study by Epplin (1996) estimated the cost to produce and deliver switchgrass biomass to an ethanol-conversion facility. Cost estimates were in the range of $35 to $40 per metric ton, including crop establishment, land, harvest and transportation costs. A later study by Aravindhaksham et al. (2010) estimated switchgrass production costs to be in the $44 to $52 per metric ton range. A study in Italy by Monti et al.

(2007) determined the dependence on higher yields and market prices required for production of switchgrass to be economically viable.

Miscanthus is another potential biomass feedstock crop which has garnered some attention (Lewandowski et al.-2000; Bullard-1999; 2001; Huisman et al.-1997; Christian and Haase-2001). Khanna et al. (2008) estimated the breakeven farm-gate price of miscanthus produced in Illinois to range between \$42 and \$58 per metric ton. Their results suggested that there is a need for policies to provide production incentives based upon their environmental benefits in addition to their energy content.

Linton et al. (2011) evaluated the economic feasibility of producing sweet sorghum as an ethanol feedstock in the southeastern United States. Using the wholesale ethanol market price as a base for calculating feedstock prices, returns to sweet sorghum production as a feedstock for ethanol were not sufficient to cover estimated production costs. Conclusions from this study indicated that while sweet sorghum may be a viable source of biofuel with ethanol yields comparable to corn, current production incentives lie with other non-feedstock crops for a profit-maximizing producer.

As a perennial crop similar to sugarcane, energy cane is generally grown in a monocrop culture. Therefore, economic viability of energy cane production is much more directly a function of optimal crop production cycle length, rather than rotations with other crops. In Louisiana, a central question is the challenge of developing an economically viable and sustainable biorefinery which would process biofuel feedstocks at existing facilities (Kim and Day, 2011). Nunes (2010) and Salassi (2012) have developed models which can determine the economically optimal crop cycle lengths for sugarcane cultivars in production. Such a model could be revised to accommodate energy cane production with higher yields and longer years of harvest between plantings. Optimal processing facility location is an important issue related to the production of new feedstock crops. Dunnett et al. (2008) developed a mathematical modeling framework which incorporated feedstock production and processing costs as well as processing facility location in a bioethanol supply chain. Mark (2010) developed a mathematical programming modeling framework on a county level basis which optimizes facility location based upon specified feedstock production locations and quantities.

Besides increasing yields and decreasing feedstock costs, another challenge to bringing cellulosic ethanol to market is reducing the relatively high processing costs involved in the production process. With the industry still in its infancy, there is a great deal of research being conducted in order to find the processing technology which will return the greatest ethanol yields at the lowest cost. As the wide variety of cellulose-to-ethanol conversion processes are being developed, a number of techno-economic analyses have been conducted specific to each conversion process, resulting in a relatively wide range of ethanol cost estimates in the literature. These cost estimates vary depending on factors such as the choice of feedstock, conversion process, production capacity, and capital requirements. A study by the United States Department of Agriculture (USDA) in 2007 estimated cellulosic ethanol production costs at \$2.65 per gallon, compared to \$1.65 for corn-ethanol, however in reviewing the estimates, Coyle (2010) explains that capital and conversion costs are expected to decline as new companies increase production and have greater access to low-cost biomass. Many studies have also estimated the minimum ethanol selling price (MESP) which is the price that an ethanol producer would need to receive in order to cover the costs of producing ethanol. Table 1 provides an overview of published cellulosic ethanol processing costs and MESP estimates from various studies.

Table 1. Estimates from the Literature for Alternative Cellulosic Processing Costs and Minimum Ethanol Selling Prices for Biochemical and Thermochemical Conversion Processes

Process/Activity	Estimate ($/gal)	Source
Feedstock (corn stover & switchgrass)	0.67	Rismiller, C.W., and W.E. Tyner (2009) Biochemical Process
Energy	0.10	
Enzymes	0.50	
Variable Costs	0.71	
Total MESP (minimum ethanol selling price)	1.97	
Total Cost without Feedstock	1.30	
Feedstock (corn stover & switchgrass)	0.79	Rismiller, C.W., and W.E. Tyner (2009) Thermochemical Process
Energy	0.05	
Enzymes	0.00	
Variable Costs	0.86	
Total MESP (minimum ethanol selling price)	1.70	
Total Cost without Feedstock	0.91	
Feedstock & Handling (corn stover)	0.74	Humbird, D. et al. (2011) Biochemical Process
Pretreatment/Conditioning	0.29	
Saccharification &Fermentation	0.20	
Cellulase	0.34	
Distillation & Solids Recovery	0.12	
Wastewater Treatment	0.34	
Storage	0.02	
Boiler/Turbogenerator	0.04	
Utilities	0.06	
Total MESP (minimum ethanol selling price)	2.15	
Total Cost without Feedstock	1.41	
Feedstock & Handling (corn stover)	0.53	Tao, L. and A. Aden (2009) Biochemical Process
Pretreatment/Conditioning	0.31	
Hybrid Hydrolysis & Fermentation	0.11	
Cellulase	0.10	
Distillation & Solids Recovery	0.17	
Wastewater Treatment	0.03	
Boiler/Turbogenerator	0.16	
Utilities	0.06	
Storage	0.02	
Total MESP (minimum ethanol selling price)	1.48	
Total Cost without Feedstock	0.95	

Table 1. Continued

Process/Activity	Estimate* ($/gal)	Source
Feedstock (corn stover)	0.57	Tao, L. and A. Aden (2009) Thermochemical Process
Feed Handling & Drying	0.16	
Hybrid Hydrolysis & Fermentation	0.13	
Tar Reforming: Acid Gas & Sulfur Removal	0.38	
Distillation & Solids Recovery	0.10	
Alcohol Synthesis - Other	-0.17	
Alcohol Separation	0.05	
Steam System & Power Generation	0.05	
Cooling Water & Other Utilities	0.04	
Total MESP (minimum ethanol selling price)	1.31	
Total Cost without Feedstock	0.74	
Feedstock (corn stover)	0.74	Dutta et al. (2011) Thermochemical Process
Gasification	0.28	
Reforming and Quench	0.17	
Acid Gas & Sulfur Removal	0.17	
Syngas Compression & Expansion	0.67	
Alcohol Synthesis Reaction	0.03	
Alcohol Separation	0.10	
Steam System & Power Generation	-0.17	
Cooling Water & Other Utilities	0.07	
Total MESP (minimum ethanol selling price)	2.05	
Total Cost without Feedstock	1.31	

*All cost estimates are reported in $2007

CHAPTER 3: GENERAL PROCEDURES

3.1 Conceptual Model

Determining the economic feasibility of utilizing energy cane for the cellulosic production of ethanol refers to the estimation and measurement of costs associated with the complete production process in order to determine whether or not it represents a profitable business for energy cane growers and ethanol producers. To properly address this problem, many factors must be considered. First, the variable and fixed costs associated with the planting and harvesting of energy cane for the optimal farm size must be evaluated. Minimizing costs in the long run for a specific farm size is a common challenge faced by farmers. This involves estimating total farm production costs, which is the sum of variable and fixed costs. The variable costs are those that vary with output, while fixed costs represent those costs that remain constant regardless of the level of output produced. The average cost per ton of biomass is estimated by dividing total costs by total tons of biomass. As biomass tonnage increases, the average cost per ton of biomass decreases. The changes to cost as the production scale increases describes a situation in which a farmer may experience economies of scale, diseconomies of scale, or constant returns to scale. For a farmer with the objective of minimizing costs, achieving efficiency in production, or economies of scale, is very important. Potential energy cane yields and crop cycle lengths are also important components to consider when estimating total farm costs and returns of an agricultural crop.

The total cost of producing cellulosic ethanol from energy cane will be largely determined by the delivered feedstock price that the producer must pay to acquire a supply of biomass plus any processing costs involved in converting cellulose to ethanol. If large scale production of cellulosic ethanol becomes a reality, ethanol producers will also face the challenge of maximizing profits, especially since the industry will be relatively new and operations will not yet be optimized. The ethanol producer’s profit will be equal to total revenue minus total costs, where total revenue is equal to the price of ethanol times the gallons of ethanol sold. For simplicity, the assumption can be made that total cost is a function of feedstock purchase price, transportation costs, and processing costs. It is expected that any increase in the feedstock purchase price, transportation cost, or processing costs will result in an increase in total cellulosic ethanol cost, and if the wholesale price of ethanol remains constant, this will lead to a decrease in net revenue. On the other hand, it is expected that wholesale ethanol price will have the opposite effect on revenue. The intuition behind this is that an increase in the price paid to ethanol producers for the final product will increase their profit margin, assuming all other factors are held constant. This will result in an increase in total revenue, and thus an increase in total profit, but only if total costs remain constant. The profit maximizing level of output for the firm occurs at the level of output where marginal revenue equals marginal cost, where marginal revenue is the additional revenue from producing an additional unit of output, and marginal cost is the additional cost of producing an additional unit of output. Calculating the Minimum Ethanol Selling Price (MESP) is one way to assess the economic feasibility of ethanol production from various feedstocks under various production assumptions. The MESP is calculated as the sum of the delivered feedstock cost plus any processing and operating costs. Economic theory states that a firm will operate in the short run if total revenue covers total variable cost, because as long as operating profit is positive it can be used to offset any fixed costs and reduce any losses. So comparing the estimated minimum selling price per gallon of ethanol to the expected market price per gallon of ethanol is one way that researchers are able to assess the economic potential of producing cellulosic ethanol using various feedstocks and conversion processes.

3.2. Variable and Fixed Production Costs

Part of producing ethanol involves purchasing the biomass feedstock from farmers, which usually represents a significant portion of the ethanol producer's total costs. The grower breakeven price represents the price that the ethanol producer must pay the grower in order to cover the grower's variable, fixed, overhead, and land rent costs. In some cases, the transportation costs may be included as well, however, in this study transportation costs were estimated separate from the biomass breakeven price. Estimating the biomass production costs is not a straightforward process due to the fact that energy cane is not a traditionally produced crop and only limited data on it is available. However, because of the many similarities between sugarcane production and energy cane production, energy cane production costs were estimated using the costs and returns published in the *2012 Sugarcane Production in Louisiana*, which were estimated using a standard enterprise budgeting system (Salassi and Deliberto, 2012). The enterprise budget uses survey data from actual sugarcane producers in order to accurately reflect production practices, equipment, and inputs used in sugarcane production.

While energy cane shares many characteristics with that of commercially produced sugarcane, there are a few distinct features that required adjusting some of the calculations in the budget. First, the gross value of production was adjusted to reflect the value of biomass per ton instead of the raw price of sugar per pound. Also, because energy cane has a longer annual crop cycle than sugarcane, adjustments were made to reflect the added costs associated with an increase in resource requirements and field operations during these additional months. Other necessary changes include changes in harvest costs due to alternative harvest yields and also changes in acreage levels due to alternative seed cane expansion since energy cane has greater stubbling ability than sugarcane.

The crop cycle length refers to the stubbling length of energy cane, which is the number of annual harvests that are possible before replanting is required. Like sugarcane, production of energy cane consists of multiple stages before the first acre of harvestable cane is ready for delivery to the mill. The first step consists of purchasing cultured seed cane which is then planted. Upon harvesting the cultured seed cane it will then be used to expand the energy cane acreage. In the second year, the first harvest for production is made and is referred to as the plant cane crop. In the third year, the second harvest for production is made and is referred to as the first stubble crop, and the third harvest for production in year four is referred to as the second stubble crop. In the years following, a third-, fourth- and perhaps a fifth- or sixth-stubble may be harvested. After harvest of the last stubble crop, farmers then fallow the land for a year before replanting seed cane (Mark, Darby, and Salassi, 2009).

Before discussing the detailed process that was used to estimate energy cane production costs, it is important to first explain how the changes in acreage levels were determined to adjust for alternative seed cane expansion. Energy cane, like sugarcane, is a perennial crop which means that multiple annual harvests can occur before fallowing and replanting operations in a field are necessary. While sugarcane crops are commonly left in production for a total of three or four annual harvests before they are replanted, energy cane crops have the ability to reach a sixth or even a seventh annual harvest before the land is fallowed and new seed cane are replanted. Total farm acres in fallow are generally 25% of total farm acreage for a crop cycle length through a second stubble crop and 20% of total farm acreage for a crop cycle length through harvest of a third stubble crop. The reasoning behind these numbers is this: for a second stubble crop, total farm acreage must be divided four ways among (1) fallow acres, (2) plant cane acres, (3) first stubble acres, and (4) second stubble acres. As crop cycle lengths are increased to produce additional annual harvests, total farm acreage must then be reallocated. Since energy cane has greater stubbling ability than sugarcane, additional changes in acreage levels dedicated to fallow and planting operations must be calculated for each additional year that the crop remains in production. For a crop cycle length through a fourth stubble energy cane crop, total farm acres dedicated to fallow and field operations were determined using the following equations:

$$\mathrm{FLW} = \mathrm{TFA} * 0.167 \qquad \text{(Eq.1)}$$

$$\mathrm{CSCPLT} = \mathrm{FLW}/(1 + (2 * \mathrm{PR1}) + (2 * \mathrm{PR1} * \mathrm{PR2})) \qquad \text{(Eq.2)}$$

$$\mathrm{TAHPLT} = \mathrm{CSCPLT}(1 + 2 * \mathrm{PR1}) \qquad \text{(Eq.3)}$$

$$\mathrm{TAMPLT} = 2 * \mathrm{CSCPLT} * \mathrm{PR1} * \mathrm{PR2} \qquad \text{(Eq.4)}$$

$$\mathrm{TAPLT} = \mathrm{TAHP} + \mathrm{TAMP} \qquad \text{(Eq.5)}$$

where FLW is total farm acres in fallow, TFA is total farm acres, and one sixth of total farm acres are dedicated to fallowing the land for a fourth stubble energy cane crop. The variable CSCPLT is total acres of cultured seed cane planted, where the planting ratio for the first seed cane expansion is given as the variable PR1, and PR2 is the planting ratio for the second seed cane expansion. The planting ratio simply refers to the number of acres that can be replanted from one harvested acre of seed cane and typically varies by cane variety and whether the seed cane is hand planted or mechanically planted. The variables TAHPLT and TAMPLT are total acres hand planted and total acres machine planted, respectively, and TAPLT is total acres planted. Farm acres harvested through a fourth stubble crop cycle are defined as follows:

$$\mathrm{PCHVSD} = \mathrm{CSCPLT}(1 + 2 * \mathrm{PR1}) \qquad \text{(Eq.6)}$$

$$\mathrm{PCHVBM} = 2 * \mathrm{CSCPLT} * \mathrm{PR1} * \mathrm{PR2} \qquad \text{(Eq.7)}$$

$$\mathrm{PCHV} = \mathrm{PCHVSD} + \mathrm{PCHVBM} \qquad \text{(Eq.8)}$$

$$\mathrm{ST1HVSD} = \mathrm{CSCPLT} \qquad \text{(Eq.9)}$$

$$\mathrm{ST1HVBM} = 2((\mathrm{CSCPLT} * \mathrm{PR1}) + (\mathrm{CSCPLT} * \mathrm{PR1} * \mathrm{PR2})) \qquad \text{(Eq.10)}$$

$$\mathrm{ST1HV} = \mathrm{ST1HVSD} + \mathrm{ST1HVBM} \qquad \text{(Eq.11)}$$

$$\mathrm{ST2HVBM} = \mathrm{ST1HVSD} + \mathrm{ST1HVBM} \qquad \text{(Eq.12)}$$

$$\mathrm{ST3HVBM} = \mathrm{ST2HVBM} \qquad \text{(Eq.13)}$$

$$\mathrm{ST4HVBM} = \mathrm{ST3HVBM} \qquad \text{(Eq.14)}$$

$$\mathrm{TFA} = \mathrm{TAPLT} + \mathrm{PCHV} + ST1\mathrm{HV} + \mathrm{ST2HVBM} + \mathrm{ST3HVBM} + ST4\mathrm{HVBM} \qquad \text{(Eq.15)}$$

where PCHVSD is the plant cane acres harvested for seed cane, PSCHVBM is plant cane acres harvested for biomass, PCHV is total plant cane harvested, ST1HVSD is the first stubble acres harvested for seed cane, ST1HVBM is the first stubble acres harvested for biomass, ST1HV is total first stubble acres harvested, ST2HVBM is second stubble acres harvested for biomass, ST3HVBM is third stubble acres harvested for biomass, and ST4HVBM is fourth stubble acres harvested for biomass. Extending the crop cycle length to harvest through a fifth stubble crop requires the following changes to the total farm acreage model:

$$\mathrm{FLW} \ = \ \mathrm{TFA} * 0.143 \qquad \text{(Eq.1a)}$$

$$\mathrm{ST5HVBM} = \mathrm{ST4HVBM} \qquad \text{(Eq.14a)}$$

$$\mathrm{TFA} = \mathrm{TAPLT} + \mathrm{PCHV} + ST1\mathrm{HV} + ST2\mathrm{HVBM} + ST3\mathrm{HVBM} + ST4\mathrm{HVBM} + ST5\mathrm{HVBM} \qquad \text{(Eq.15a)}$$

where ST5HVBM is fifth stubble acres harvested for biomass. Equation (1a) reflects the change to required acreage devoted to seed cane expansion, which is one seventh, or 14.3%, of total farm acreage for a fifth stubble harvest. The model equations can be further adjusted to determine the total farm acres devoted to fallow and planting operations for a crop cycle length through a sixth stubble harvest with the following changes:

$$\mathrm{FLW} \ = \ \mathrm{TFA} * 0.125 \qquad \text{(Eq.1b)}$$

$$\mathrm{ST6HVBM} = \mathrm{ST5HVBM} \qquad \text{(Eq.14b)}$$

$$\mathrm{TFA} = \mathrm{TAPLT} + \mathrm{PCHV} + \mathrm{ST1HV} + \mathrm{ST2HVBM} + \mathrm{ST3HVBM} + \mathrm{ST4HVBM} + \mathrm{ST5HVBM} + \mathrm{ST6HVBM} \qquad \text{(Eq.15b)}$$

where ST6HVBM is sixth stubble acres harvested for biomass. Equation (1b) reflects the change to required acreage devoted to seed cane expansion, which is one eighth, or 12.5%, of total farm acreage for a sixth stubble harvest. Table 2 shows farm acreage allocations for 1,000 acres of total farm area with energy cane production operations for alternative crop cycle lengths of harvest through fourth stubble (6 years), fifth stubble (7 years) and sixth stubble (8 years).

Table 2. Total Farm Acreage Distribution for Harvest through 4th, 5th and 6th Stubble

	Farm Acreage Distribution		
Farm acreage	Harvest through 4th stubble crop	Harvest through 5th stubble crop	Harvest through 6th stubble crop
Cultured seed cane	0.27%	0.23%	0.20%
1st seed cane expansion planted	2.73%	2.34%	2.05%
2nd seed cane expansion planted	13.66%	11.71%	10.25%
Plant cane harvested for seed	3.01%	2.58%	2.25%
Plant cane harvested for biomass	13.66%	11.71%	10.25%
1st stubble harvested for seed	0.27%	0.23%	0.20%
1st stubble harvested for biomass	16.39%	14.05%	12.30%
2nd stubble harvested for biomass	16.67%	14.29%	12.50%
3rd stubble harvested for biomass	16.67%	14.29%	12.50%
4th stubble harvested for biomass	16.67%	14.29%	12.50%
5th stubble harvested for biomass	--	14.29%	12.50%
6th stubble harvested for biomass	--	--	12.50%
Total farm acres	100.00%	100.00%	100.00%

Tables 3, 4, and 5 contain the variable, fixed, and overhead cost estimates from the *2012 Sugarcane Production in Louisiana* publication as well as the acreage allotment for energy cane production through a fourth stubble, fifth stubble, and a sixth stubble, respectively. The variable costs published in the sugarcane enterprise budget were used to build a model that could estimate the production costs of energy cane in two ways. First, energy cane production costs were estimated using the mean energy cane yields at specific 2012 input price values that were also used in the *2012 Sugarcane Production in Louisiana* publication. In particular, variable costs

Table 3. Total Energy Cane Production Cost Estimates through Harvest of 4th Stubble Crop

Item	Dollars per Acre	Number of Acres	Total Dollar Value
Variable costs:			
Fallow field and seedbed preparation	154.92	166.7	25,825
Cultured seed cane	523.62	2.7	1,414
Hand planting seed cane	298.98	2.7	807
Wholestalk seed cane harvest	80.89	32.8	2,652
Mechanical planting	264.68	163.9	43,381
Plant cane field operations	295.97	166.7	49,338
1st stubble field operations	376.88	166.7	62,826
2nd stubble field operations	373.84	166.7	62,319
3rd stubble field operations	373.84	166.7	62,319
4th stubble field operations	373.84	166.7	62,319
Biomass harvest operations	172.91	800.5	138,414
Total variable costs			511,615
Fixed costs	140.00	1,000.0	140,000
Overhead costs	30.00	1,000.0	30,000
Total production costs		1,000.0	681,615

Table 4. Total Energy Cane Production Cost Estimates through Harvest of 5th Stubble Crop

Item	Dollars per Acre	Number of Acres	Total Dollar Value
Variable costs:			
Fallow field and seedbed preparation	154.92	142.9	22,138
Cultured seed cane	523.62	2.3	1,204
Hand planting seed cane	298.98	2.3	688
Wholestalk seed cane harvest	80.89	28.1	2,273
Mechanical planting	264.68	140.5	37,188
Plant cane field operations	295.97	142.9	42,294
1st stubble field operations	376.88	142.9	53,856
2nd stubble field operations	373.84	142.9	53,422
3rd stubble field operations	373.84	142.9	53,422
4th stubble field operations	373.84	142.9	53,422
5th stubble field operations	373.84	142.9	53,422
Biomass harvest operations	172.91	829.0	143,342
Total variable costs			516,670
Fixed costs	140.00	1,000.0	140,000
Overhead costs	30.00	1,000.0	30,000
Total production costs		1,000.0	686,670

Table 5. Total Energy Cane Production Cost Estimates through Harvest of 6th Stubble Crop

Item	Dollars per Acre	Number of Acres	Total Dollar Value
Variable costs:			
Fallow field and seedbed preparation	154.92	125.0	19,365
Cultured seed cane	523.62	2.0	1,047
Hand planting seed cane	298.98	2.0	598
Wholestalk seed cane harvest	80.89	44.6	3,608
Mechanical planting	264.68	123.0	32,556
Plant cane field operations	295.97	125.0	36,996
1st stubble field operations	376.88	125.0	47,110
2nd stubble field operations	373.84	125.0	46,730
3rd stubble field operations	373.84	125.0	46,730
4th stubble field operations	373.84	125.0	46,730
5th stubble field operations	373.84	125.0	46,730
6th stubble field operations	373.84	125.0	46,730
Biomass harvest operations	172.91	850.5	147,060
Total variable costs			521,990
Fixed costs	140.00	1,000.0	140,000
Overhead costs	30.00	1,000.0	30,000
Total production costs		1,000.0	691,990

were calculated under the assumption that the 2012 input prices for diesel fuel, nitrogen, phosphate, and potassium were $3.50, $0.63, $0.70, and $0.51, respectively. Production costs were also estimated under stochastic input prices and yield levels using Monte Carlo Simulation which is discussed in greater detail in Section 3.7.1.

With the exception of a few minor changes to the budget that were explicitly stated earlier in this section, energy cane production costs were calculated in this study under the same assumptions used in the 2012 *Sugarcane Production in Louisiana* report. In particular, the major determinants of total variable planting costs were primary planting expenses for purchased seed cane, as well as fuel, labor, and repair expenses related to field operations. The estimate for fixed cost includes depreciation and interest on equipment, and was allocated per acre on an hourly basis. Specifically, it was assumed that fixed costs were $140 per acre and overhead was $30 per acre. The farm overhead cost includes expenses such as tax services, insurance, and property taxes. Land rent is another cost that must be considered when total farm costs are calculated. A unique feature of sugarcane production is that it is a perennial crop grown in a rotation, therefore the processing, storage, and marketing services are provided by a single entity and payments for these services are often “in kind” (Salassi and Deliberto, 2012). Payments-in-kind are paid in the form of goods or services, rather than cash. For example, the vast majority of sugarcane growers are tenants and land rent is commonly a one-fifth or a one-sixth share of the crop harvested for sugar after the “in kind” mill payment has been made. Since this study is dealing with energy cane produced as a biomass feedstock, rather than sugar, it was assumed that the ethanol producer would pay the grower some feedstock price per ton of biomass instead of receiving any payments-in-kind. Furthermore, land rent was assumed to be 20% of the total biomass production value and was calculated using Equation (16).

$$\mathrm{RENT} = 0.20 * \mathrm{PRICE} * \mathrm{TPROD} \qquad \text{(Eq. 16)}$$

$$\mathrm{PRICE} = (\mathrm{TVCOST} + \mathrm{TFCOST} + \mathrm{TOCOST}) \div (0.80 * \mathrm{TPROD}) \qquad \text{(Eq. 17)}$$

The variable TPROD is total production of biomass harvested and PRICE is the breakeven price of biomass which is calculated using Equation (17). The variable TVCOST is total variable cost for the entire farm, TFCOST is total fixed cost, and TOCOST is total overhead costs.

3.3. Energy Cane Yield Data

Potential energy cane yields were estimated using plant cane, first stubble and second stubble data for yield and fiber content collected from the energy cane field trials that are currently being conducted at the Sugar Research Station in St. Gabriel, Louisiana. The field trial includes five varieties of energy cane, Ho 02-144, Ho 02-147, Ho 06-9001, Ho 06-9002, and Ho CP 72-114, which were first planted in September 2008. Four replications were conducted for each variety, so the yields given in Tables 6, 7, and 8 are actually the mean yields of the four research replications. The cane yield refers to the yield measured in wet tons, and the dry weight is simply the product of cane yield and fiber content. Table 6 shows the energy cane yield and fiber content data collected during the first harvest which took place in mid-December 2009. Table 7 contains the yield and fiber content data collected for the first stubble harvest which took place in December 2010. Table 8 contains the most recent data, the data for second stubble harvest, which was collected in December 2011 and was published in the Sugar Research station's *2011 Annual Research Report* (Gravois et al., 2012). In order to reflect the estimated yields for fourth through sixth stubble in units of dry tons per acre, the average fiber content of plant cane through second stubble was calculated for each variety and is provided in Table 9.

Table 6. Mean Plant Cane Yields from the First Harvest of the Energy Cane Field Trials, St. Gabriel, Louisiana, 2009

Variety	Cane Yield (tons/acre)	Fiber Content (%)	Dry Weight (tons/acre)
Ho 02-144	30.5	20.6	6.27
Ho 02-147	44.2	17.8	7.87
Ho 06-9001	28.9	26.4	7.58
Ho 06-9002	25.5	25.3	6.44
HoCP 72-114	42.8	20.7	8.84

Table 7. Mean 1st Stubble Yields from the Second Harvest of the Energy Cane Field Trials, St. Gabriel, Louisiana, 2010

Variety	Cane Yield (tons/acre)	Fiber Content (%)	Dry Weight (tons/acre)
Ho 02-144	25.0	25.9	6.49
Ho 02-147	47.0	19.5	9.15
Ho 06-9001	26.0	29.7	7.70
Ho 06-9002	24.4	29.6	7.22
HoCP 72-114	35.8	24.0	8.58

Table 8. Mean 2nd Stubble Yields from the Third Harvest of the Energy Cane Field Trials, St. Gabriel, Louisiana, 2011

Variety	Cane Yield (tons/acre)	Fiber Content (%)	Dry Weight (tons/acre)
Ho 02-144	55.3	23.6	12.95
Ho 02-147	72.4	18.4	13.21
Ho 06-9001	57.2	28.7	16.41
Ho 06-9002	50.7	28.3	14.41
HoCP 72-114	57.1	22.6	12.93

Table 9. Average Energy Cane Fiber Contents from the Energy Cane Field Trials, St. Gabriel, Louisiana, 2009 – 2011

	Fiber Content (%)			
Variety	Plant Cane	First Stubble	Second Stubble	Average
Ho 02-144	20.6	25.9	23.6	23
Ho 02-147	17.8	19.5	18.4	19
Ho 06-9001	26.4	29.7	28.7	28
Ho 06-9002	25.3	29.6	28.3	28
HoCP 72-114	20.7	24.0	22.6	22

Due to the great degree of similarities between energy cane and sugarcane, it was assumed that energy cane yields would decline in a pattern very similar to that of sugarcane, once the maximum annual yield was reached. On average, sugarcane varieties have their maximum yield in the first yield of harvest (plant cane crop) and decline in succeeding crops. Given the energy cane yield data available at the time of this study, it was assumed that second stubble yields for energy cane would be the maximum yield level reached and would decline in succeeding crops at a rate similar to sugarcane. More specifically, it was assumed that on average, energy cane third stubble yield would represent about 94% of second stubble yield per acre. It was further assumed that on average, energy cane yields for a fourth-, fifth-, and sixth-stubble would represent 79%, 74%, and 70% of second stubble energy cane yields, respectively. To estimate the yields past a second-stubble for each variety, the complete set of yield and fiber content data was analyzed and the deviations from the mean were calculated for each variety.

Since four research replications were performed for each variety, four yield deviations were calculated for each crop year. The deviations are given in Tables 10, 11, 12, 13 and 14.

Table 10. Mean Energy Cane Yield and Deviations for Variety Ho 02-144

Variety	Rep	Crop[1]	TCA[2]	Mean TCA	TCA Mean Deviation
Ho02-144	1	0	37.4	30.5	6.9
Ho02-144	2	0	25.7		-4.8
Ho02-144	3	0	27.2		-3.3
Ho02-144	4	0	31.8		1.3
Ho02-144	2	1	27.6	25.0	2.5
Ho02-144	3	1	25.0		0.0
Ho02-144	4	1	24.7		-0.4
Ho02-144	1	1	22.9		-2.2
Ho02-144	2	2	69.3	55.3	14.1
Ho02-144	3	2	46.5		-8.8
Ho02-144	4	2	39.2		-16.1
Ho02-144	1	2	66.1		10.8

[1] Crop age – 0 = plant cane, 1 = first stubble, 2 = second stubble
[2] TCA = tons of cane per acre

Table 11. Mean Energy Cane Yields and Deviations for Variety Ho 02-147

Variety	Rep	Crop[1]	TCA[2]	Mean TCA	TCA Mean Deviation
Ho02-147	1	0	42.0	44.2	-2.2
Ho02-147	2	0	46.1		2.0
Ho02-147	3	0	48.4		4.3
Ho02-147	4	0	40.1		-4.1
Ho02-147	1	1	47.2	47.0	0.2
Ho02-147	2	1	43.2		-3.8
Ho02-147	3	1	51.2		4.2
Ho02-147	4	1	46.5		-0.5
Ho02-147	1	2	73.0	72.4	0.5
Ho02-147	2	2	66.8		-5.6
Ho02-147	3	2	87.5		15.1
Ho02-147	4	2	62.4		-10.0

[1] Crop age – 0 = plant cane, 1 = first stubble, 2 = second stubble
[2] TCA = tons of cane per acre

Table 12. Mean Energy Cane Yields and Deviations for Variety Ho 06-9001

Variety	Rep	Crop[1]	TCA[2]	Mean TCA	TCA Mean Deviation
Ho06-9001	1	0	32.1	28.9	3.2
Ho06-9001	2	0	32.1		3.2
Ho06-9001	3	0	19.3		-9.6
Ho06-9001	4	0	32.1		3.2
Ho06-9001	1	1	28.7	26.1	2.6
Ho06-9001	4	1	29.8		3.7
Ho06-9001	2	1	24.0		-2.1
Ho06-9001	3	1	21.8		-4.3
Ho06-9001	1	2	65.7	57.2	8.5
Ho06-9001	4	2	57.7		0.5
Ho06-9001	2	2	55.5		-1.6
Ho06-9001	3	2	49.7		-7.4

[1] Crop age – 0 = plant cane, 1 = first stubble, 2 = second stubble
[2] TCA = tons of cane per acre

Table 13. Mean Energy Cane Yields and Deviations for Variety Ho 06-9002

Variety	Rep	Crop[1]	TCA[2]	Mean TCA	TCA Mean Deviation
Ho06-9002	1	0	26.5	25.5	1.0
Ho06-9002	2	0	20.4		-5.1
Ho06-9002	3	0	28.7		3.2
Ho06-9002	4	0	26.5		1.0
Ho06-9002	1	1	22.1	24.4	-2.3
Ho06-9002	3	1	25.4		1.0
Ho06-9002	2	1	22.1		-2.3
Ho06-9002	4	1	28.0		3.5
Ho06-9002	1	2	48.3	50.7	-2.5
Ho06-9002	3	2	56.6		5.9
Ho06-9002	2	2	43.9		-6.8
Ho06-9002	4	2	54.1		3.4

[1] Crop age – 0 = plant cane, 1 = first stubble, 2 = second stubble
[2] TCA = tons of cane per acre

The deviations were then simulated with an equal probability of occurrence (25%) and for each variety 1,000 random yields were generated for plant cane through sixth stubble. Second stubble yield deviations were used to simulate variable energy cane yields for third through sixth stubble crops for each variety. This process is described in greater detail in Section 3.7.

Table 14. Mean Energy Cane Yields and Deviations for Variety HoCP72-114

Variety	Rep	Crop[1]	TCA[2]	Mean TCA	TCA Mean Deviation
HoCP72-114	1	0	42.4	42.8	-0.4
HoCP72-114	2	0	41.2		-1.6
HoCP72-114	3	0	40.1		-2.7
HoCP72-114	4	0	47.6		4.8
Hocp72-114	1	1	35.2	35.8	-0.5
Hocp72-114	2	1	37.0		1.3
Hocp72-114	3	1	31.6		-4.2
Hocp72-114	4	1	39.2		3.5
Hocp72-114	1	2	53.7	57.1	-3.4
Hocp72-114	2	2	68.2		11.2
Hocp72-114	3	2	49.4		-7.7
Hocp72-114	4	2	57.0		-0.1

[1] Crop age – 0 = plant cane, 1 = first stubble, 2 = second stubble
[2] TCA = tons of cane per acre

3.4. Optimal Crop Cycle Lengths

Another important consideration in evaluating the production costs of growing energy cane as a biomass feedstock is determining the optimal crop cycle length in order to select the optimal number of annual harvests that will maximize net returns over the crop cycle as a whole. The crop cycle length refers to the stubbling length of energy cane, which is the number of annual harvests that are possible before replanting is required. As with other perennial crops, after the first couple of harvests, growers become faced with the tradeoff between declining yields and the costs of replanting seed cane. Since energy cane costs and returns are spread over a number of years, farmers need a way to compare the costs associated with production over various lengths of time. The net present value approach is commonly used in capital budgeting to analyze the profitability of an investment or future project. Net present value is simply the present value of the revenue minus the present value of the costs. It compares the value of a dollar today with that of the same dollar in the future by taking into account inflation and returns, and thereby providing farmers with a way to compare alternative crop cycle lengths so that they can choose the most profitable one. To determine the optimal cycle length for major sugarcane varieties in Louisiana, Nunes (2010) calculated the net present value of the cash flow from one crop cycle starting with initial planting costs in time t=0, through harvest n-1 stubble crops, to represent stubble decisions by evaluating the dollar value associated with different crop cycles. The formula for net present value is given below in Equation 1 which states:

$$\mathrm{NPV_0} = -\mathrm{TPC_0} + \frac{\mathrm{R_1}}{(1+\mathrm{r})^1} + \frac{\mathrm{R_2}}{(1+\mathrm{r})^2} + \cdots + \frac{\mathrm{R_n}}{(1+\mathrm{r})^{\mathrm{n}}} \qquad \text{(Eq.18)}$$

or,

$$\mathrm{NPV_0} = \sum_{\mathrm{t}=1}^{\mathrm{n}} (1+\mathrm{r})^{-\mathrm{t}} \mathrm{R_t} - \mathrm{TPC_0} \qquad \text{(Eq.19)}$$

where $\mathrm{NPV_0}$ measures the net present value of net returns over an entire crop cycle of n harvests, $\mathrm{TPC_0}$ represents initial planting costs in dollars per acre, r is the discount rate, $\mathrm{R_1}$ is the net return from production and harvest of the plant cane crop, $\mathrm{R_2}$ is the net return from production and harvest of the 1st stubble crop, and $\mathrm{R_n}$ is the net return from the production and harvest of the *n-1* stubble crop. Comparing crop cycles of varying lengths requires the annualization of net present value estimates (Salassi and Milligan, 1997).

A common characteristic of sugarcane production is that sugarcane producers generally have the goal of keeping the acreage devoted to major production phases in relatively constant proportions over the years. So once a grower gets in a certain rotation and becomes knowledgeable about expected yields on each stubble crop, he will generally remain in that same rotation, even though yields and returns may vary in some years. Therefore, addressing this problem from the perspective of a profit maximizing producer involves determining what the optimal crop cycle length would be on a year-in-year-out basis, given current market prices, yields, and production costs. Using current sugarcane production costs and energy cane yield data collected from the Sugar Research Station, breakeven levels of a third stubble biomass yield in tons per acre were estimated using a procedure adapted from the one used by Nunes (2010) in order to determine the yield required to return the same net returns above variable costs as the previous stubble. To do so, whole farm net returns above variable costs for a crop cycle through a second stubble harvest ($NRAVC_{Hv2}$) were set equal to the whole farm net returns above variable costs for a harvest of third stubble:

$$\mathrm{NRAVC}_{\mathrm{Hv2}} = \left[\left(\mathrm{Y}_{\mathrm{pc}}\mathrm{AH}_{\mathrm{pc}}\right) + \left(\mathrm{Y}_{\mathrm{1st}}\mathrm{AH}_{\mathrm{1st}}\right) + \left(\mathrm{Y}_{\mathrm{2st}}\mathrm{AH}_{\mathrm{2st}}\right) + \left(\mathrm{Y}_{\mathrm{3st}}\mathrm{AH}_{\mathrm{3st}}\right)\right] * \mathrm{MP}_{\mathrm{bm}} * \mathrm{GS}_{\mathrm{bm}} - \left[\left(\mathrm{A}_{\mathrm{fl}}\mathrm{VC}_{\mathrm{fl}}\right) + \left(\mathrm{A}_{\mathrm{cscp}}\mathrm{VC}_{\mathrm{cscp}}\right) + \left(\mathrm{A}_{\mathrm{hplt}}\mathrm{VC}_{\mathrm{hplt}}\right) + \left(\mathrm{A}_{\mathrm{mplt}}\mathrm{VC}_{\mathrm{mplt}}\right) + \left(\mathrm{A}_{\mathrm{pc}}\mathrm{VC}_{\mathrm{pcfo}}\right) + \left(\mathrm{A}_{\mathrm{1st}}\mathrm{VC}_{\mathrm{1sfo}}\right) + \left(\mathrm{A}_{\mathrm{2st}}\mathrm{VC}_{\mathrm{2sfo}}\right) + \left(\mathrm{A}_{\mathrm{3st}}\mathrm{VC}_{\mathrm{3sfo}}\right) + \left(\mathrm{A}_{\mathrm{hv}}\mathrm{VC}_{\mathrm{hv}}\right)\right] \qquad \text{(Eq.20)}$$

where Y_{pc}, Y_{1st}, Y_{2st}, and Y_{3st} represents biomass yield per harvested acre on production cane sent to the mill (plant cane through third stubble), AH_{pc}, AH_{1st}, AH_{2st}, AH_{3st}, represents the respective acres of cane harvested, MP_{bm} represents the market price for biomass, GS_{bm} represents the grower share to total biomass production, A_{fl}, A_{cscp}, A_{hplt}, A_{mplt}, A_{pc}, A_{1st}, A_{2st}, A_{3st}, and A_{hv} represent the farm acreage that is allocated to fallow, cultured seed cane planting, hand planting, machine planting, plant cane, first stubble, second stubble, third stubble, and harvest, respectively, and VC_{fl}, VC_{cscp}, VC_{hplt}, VC_{mplt}, VC_{pc}, VC_{1st}, VC_{2st}, VC_{3st}, and VC_{hv} represent the variable production costs on those respective acreage tracts. Simplifying the second part of the equation to whole farm variable costs for a third stubble harvest, the breakeven biomass yield per acre for the third stubble crop (Y_{3st}) was calculated as:

$$\mathrm{Y}_{\mathrm{3st}} = \frac{\mathrm{NRAVC}_{\mathrm{Hv2}} - \left(\left(\left(\mathrm{Y}_{\mathrm{pc}}\mathrm{AH}_{\mathrm{pc}}\right) + \left(\mathrm{Y}_{\mathrm{1st}}\mathrm{AH}_{\mathrm{1st}}\right) + \left(\mathrm{Y}_{\mathrm{2st}}\mathrm{AH}_{\mathrm{2st}}\right)\right) * \mathrm{MP}_{\mathrm{bm}}\mathrm{GS}_{\mathrm{bm}}\right) + \mathrm{VC}_{\mathrm{Hv3}}}{\left(\mathrm{MP}_{\mathrm{bm}} * \mathrm{GS}_{\mathrm{bm}} * \mathrm{AH}_{\mathrm{3st}}\right)}. \qquad \text{(Eq.21)}$$

where VC_{HV3} is total variable cost for third stubble. Estimating this biomass yield per acre for the third stubble crop was then used to examine the estimated yields for a third through sixth stubble in order to determine the optimal crop cycle length that will maximize economic returns.

$$Y_{4st} = \frac{NRAVC_{Hv3} - \left(\left(\left(Y_{pc}AH_{pc}\right) + \left(Y_{1st}AH_{1st}\right) + \left(Y_{2st}AH_{2st}\right) + \left(Y_{3st}AH_{3st}\right)\right) * MP_{bm}GS_{bm}\right) + VC_{Hv4}}{\left(MP_{bm} * GS_{bm} * AH_{4st}\right)} \qquad \text{(Eq.22)}$$

$$Y_{5st} = \frac{NRAVC_{Hv4} - \left(\left(\left(Y_{pc}AH_{pc}\right) + \left(Y_{1st}AH_{1st}\right) + \ldots + \left(Y_{4st}AH_{4st}\right)\right) * MP_{bm}GS_{bm}\right) + VC_{Hv5}}{\left(MP_{bm} * GS_{bm} * AH_{5st}\right)}. \qquad \text{(Eq.23)}$$

$$Y_{6st} = \frac{NRAVC_{Hv5} - \left(\left(\left(Y_{pc}AH_{pc}\right) + \left(Y_{1st}AH_{1st}\right) + \ldots + \left(Y_{5st}AH_{5st}\right)\right) * MP_{bm}GS_{bm}\right) + VC_{Hv6}}{\left(MP_{bm} * GS_{bm} * AH_{6st}\right)} \qquad \text{(Eq.24)}$$

Along with Equations (21) – (24), a simple decision rule was used to determine the optimal crop cycle length up to a harvest of sixth stubble. The rule states that the farmer should keep the crop in rotation as long as the estimated yields for crop cycle length *n* are greater than or equal to the break even yield required to generate the same return as crop cycle length *n-1*. In other words, a farmer will leave a crop in production through a sixth stubble as long as the yield projected for sixth stubble is greater than or equal to the yield required to generate the same return as a fifth stubble crop cycle length.

3.5. Transportation Costs

In addition to the feedstock purchase price that the processor must pay to the energy cane farmer, the cost of transporting the biomass must also be determined. In establishing a transportation cost structure to accurately reflect what a cellulosic ethanol industry might face, assumptions had to be made regarding the acceptable transport distances between the farm and the processor, standard hauling rates and fuel prices. For this particular study, the transportation costs, which are often referred to as hauling costs, were estimated for a range of distances under the assumption that an ethanol producer would only obtain feedstocks from farms within a 60 mile radius of the facility. This assumed transportation radius is related to sugarcane transportation and is approximately the point where additional hauling costs need to be closely evaluated relative to profitability per unit processed. Equation (25) gives the general formula that was used to estimate the hauling costs for energy cane to an ethanol processing facility.

$$\mathrm{HC}\ (\$/\mathrm{ton}) = \mathrm{BASE}\ (\$/\mathrm{ton}) + (\mathrm{MRATE}\ (\$/\mathrm{mile})\ \text{ x }\ \mathrm{MILES} \qquad (\text{Eq.25})$$

Here, hauling costs per ton of energy cane is represented by the variable HC, BASE is the base rate per ton of energy cane, MRATE is the rate charged for each mile that the cane is transported and MILES is the total one-way miles hauled. The idea behind charging a base rate is that the processor is likely to favor closer supplies of energy cane and thus the further away the farm is from the mill, the more expensive the hauling costs become. In particular, this study assumes a base rate of \$1.00 per wet ton of energy cane in addition to a rate of \$0.10 per mile transported. By assuming that the maximum distance that the energy cane will be transported is 60 miles, it is predicted that hauling costs are likely to realistically range anywhere from \$3.00 - \$7.00 per wet ton of energy cane.

3.6. Total Ethanol Production Costs

Once a steady supply of biomass has been secured, the viability of a cellulosic ethanol market will ultimately depend on whether or not the ethanol producer can breakeven in the long-run. In addition to the feedstock price and transportation costs, the full costs of cellulosic ethanol production must also include factors such as annual capital requirements, conversion costs, labor, and maintenance. However, without any commercial-scale cellulosic ethanol operations yet in place, estimating the total costs of cellulosic ethanol production was not a straightforward process. Processing cost data from Table 1 was used to develop four scenarios of hypothetical processing costs which ranged from \$0.70 per gallon of ethanol to \$1.50 per gallon of ethanol. These values represent a range of future processing costs that a producer of cellulosic ethanol might experience whether using a biochemical or thermochemical conversion process.

Specifically, the scenario in which processing costs are estimated at $1.50 per gallon of ethanol best describes a situation in which little or no improvements have been made in either the biochemical or thermochemical process and thus processing costs remain relatively high. The scenario in which processing costs are assumed to be $1.20 per gallon of ethanol reflect a situation in which small improvements increasing the efficiency of the pretreatment step have resulted in small decreases in the processing costs. Further increases in the efficiency of the pretreatment and hydrolysis steps that result in relatively large decreases in processing costs are represented by the scenario in which processing costs are assumed to be $0.90 per gallon of ethanol. The final scenario in which processing costs are assumed to be $0.70 per gallon reflect a situation in which very large improvements in the efficiency of the conversion process have been made, resulting in relatively low processing costs. Furthermore, because less is known about thermochemical processing costs, estimates for this process range widely in the literature and thus could fall under any of the four scenarios.

An ethanol yield of 85 gallons per dry ton of biomass was assumed in order to complete the calculations for total ethanol production costs. This was the ethanol yield that was previously used in a 2011 study by the U.S. Department of Energy which measured the national biomass supply for a bioenergy and bio-products industry (U.S. DOE, 2011). Furthermore, 85 gallons per dry ton is also a modest estimate based off of the USDA's goal of achieving ethanol yields of 90 gallons of ethanol per dry ton of biomass by 2012 (Collins, 2007).

3.7. Sensitivity Analysis

Sensitivity analysis of energy cane feedstock production costs and yields estimated as part of this research project were conducted by performing Monte Carlo simulation analysis of projected cost values. Monte Carlo analysis is a stochastic simulation technique which can randomly generate sequences of random values for specified parameters and estimate economic values using those randomly generated values as input (Rardin, 1998). Projected multivariate empirical distributions of production input costs were generated following a procedure developed by Richardson et al. (2000). More specifically, the *Simetar* software package (Richardson et al., 2008) was utilized to generate multivariate input cost distributions.

To address the concerns regarding risk and uncertainty in agricultural crop production, sensitivity analysis was conducted in order to incorporate the stochastic nature of input prices used in energy cane production. Diesel fuel (*FUEL*), nitrogen (*N*), phosphate (*P*), and potassium (*K*) fertilizers were the four inputs for which random prices were simulated using a multivariate empirical distribution. Annual price data ranging from 2002 to 2011 was collected for each of the inputs as well as the price estimates for 2012 that were taken from the *2012 Sugarcane Production in Louisiana* publication. More specifically, 2012 prices for diesel fuel, nitrogen, phosphate, and potassium were assumed to be \$3.50, \$0.63, \$0.70, and \$0.51, respectively and were projected using current quotes obtained from suppliers of agricultural chemicals and services in the area. Using the process outlined in Richardson et al. (2000), parameters for the multivariate empirical distributions were then estimated. These parameters, which included the 2012 projected mean input prices listed above, as well as historical deviations from trend forecasts and the correlation matrix for the deviations from the trend, were then used to generate 1,000 random prices for each of the four inputs. Once the random input prices were generated, variable costs were estimated for harvest of plant cane through fourth, fifth and sixth stubble crops using a simulation model for each of the five energy cane varieties. The equations used to estimate the variable costs per acre of energy cane production were similar to those used in the *2012 Sugarcane Production in Louisiana* publication, minus the portion(s) of the cost attributable to each the four inputs, *FUEL, N, P,* and *K.* The exact equations used in the model to estimate variable energy cane production costs per acre are specified as follows.

$$\mathrm{FLCOST} = \mathrm{FLOVE} + (\mathrm{QTYF}_1 * \mathrm{FUEL}) \tag{Eq.26}$$

$$\mathrm{CSCOST} = \mathrm{CSCOVE} + (\mathrm{QTYF}_2 * \mathrm{FUEL}) \tag{Eq.27}$$

$$\mathrm{HPCOST} = \mathrm{HPOVE} + (\mathrm{QTYF}_3 * \mathrm{FUEL}) + (\mathrm{QTYN}_3 * \mathrm{N}) + (\mathrm{QTYP}_3 * \mathrm{P}) + (\mathrm{QTYK}_3 * \mathrm{K}) \tag{Eq.28}$$

$$\mathrm{WSCOST} = \mathrm{WSCOVE} + (\mathrm{QTYF}_4 * \mathrm{FUEL}) \tag{Eq.29}$$

$$\mathrm{MPCOST} = \mathrm{MPOVE} + (\mathrm{QTYF}_5 * \mathrm{FUEL}) + (\mathrm{QTYN}_5 * \mathrm{N}) + (\mathrm{QTYP}_5 * \mathrm{P}) + (\mathrm{QTYK}_5 * \mathrm{K}) \tag{Eq.30}$$

$$\mathrm{PCCOST} = \mathrm{PCOVE} + (\mathrm{QTYF}_6 * \mathrm{FUEL}) + (\mathrm{QTYN}_6 * \mathrm{N}) + (\mathrm{QTYK}_6 * \mathrm{K}) \tag{Eq.31}$$

$$\mathrm{ST1COST} = \mathrm{ST1OVE} + (\mathrm{QTYF}_7 * \mathrm{FUEL}) + (\mathrm{QTYN}_7 * \mathrm{N}) + (\mathrm{QTYP}_7 * \mathrm{P}) + (\mathrm{QTYK}_7 * \mathrm{K}) \tag{Eq.32}$$

$$\mathrm{ST2COST} = \mathrm{ST2OVE} + (\mathrm{QTYF}_8 * \mathrm{FUEL}) + (\mathrm{QTYN}_8 * \mathrm{N}) + (\mathrm{QTYP}_8 * \mathrm{P}) + (\mathrm{QTYK}_8 * \mathrm{K}) \tag{Eq.33}$$

$$\mathrm{ST3COST} = \mathrm{ST3OVE} + (\mathrm{QTYF}_9 * \mathrm{FUEL}) + (\mathrm{QTYN}_9 * \mathrm{N}) + (\mathrm{QTYP}_9 * \mathrm{P}) + (\mathrm{QTYK}_9 * \mathrm{K}) \tag{Eq.34}$$

$$\mathrm{ST4COST} = \mathrm{ST4OVE} + (\mathrm{QTYF}_{10} * \mathrm{FUEL}) + (\mathrm{QTYN}_{10} * \mathrm{N}) + (\mathrm{QTYP}_{10} * \mathrm{P}) + (\mathrm{QTYK}_{10} * \mathrm{K}) \tag{Eq.35}$$

$$\mathrm{ST5COST} = \mathrm{ST5OVE} + (\mathrm{QTYF}_{11} * \mathrm{FUEL}) + (\mathrm{QTYN}_{11} * \mathrm{N}) + (\mathrm{QTYP}_{11} * \mathrm{P}) + (\mathrm{QTYK}_{11} * \mathrm{K}) \tag{Eq.36}$$

$$\mathrm{ST6COST} = \mathrm{ST6OVE} + (\mathrm{QTYF}_{12} * \mathrm{FUEL}) + (\mathrm{QTYN}_{12} * \mathrm{N}) + (\mathrm{QTYP}_{12} * \mathrm{P}) + (\mathrm{QTYK}_{12} * \mathrm{K}) \tag{Eq.37}$$

$$\mathrm{HVCOST} = \mathrm{HVOVE} + (\mathrm{QTYF}_{13} * \mathrm{FUEL}) \tag{Eq.38}$$

The variable QTYF_i represents the quantity of diesel fuel, measured in gallons of fuel, which is required per acre of each field operation. The variables QTYN_i, QTYP_i, and QTYK_i represent the quantities, measured in pounds of fertilizer, of nitrogen, phosphate, and potassium used per acre of each field operation, respectively. The variables FLOVE, CSCOVE, HPOVE, WSCOVE, MPOVE, PCOVE, ST1OVE, ST2OVE, ST3OVE, ST4OVE, ST5OVE, ST6OVE, and HVOVE are the sum of all other variable expenses for each production phase and do not include expenses for diesel fuel, nitrogen, phosphate, and potassium. Equation (26) and Equation (27) calculate the variable cost per acre for fallow activities and cultured seed cane under stochastic price conditions for diesel fuel. Equation (28) calculates the cost per acre for hand planting under stochastic price conditions for diesel fuel, nitrogen, phosphate, and potassium. Equation (29) is the calculation used to estimate costs per acre associated with wholestalk seed cane harvest under stochastic price conditions for diesel fuel. Equation (30) calculates the cost per acre for mechanical planting under stochastic price conditions for diesel fuel, nitrogen, phosphate, and potassium. The costs per acre of field operations under stochastic price conditions were calculated for plant cane through sixth stubble and are given by Equations (31) through (37). The cost per acre for harvested biomass was estimated under stochastic price conditions for diesel fuel and is calculated by Equation (38).

Variable costs were then estimated for the entire 1,000 acre farm by multiplying the variable costs per acre, estimated by Equations (26) through (38), by the total number of acres devoted to each production phase.

$$\mathrm{TFLCOST} = \mathrm{FA} * \mathrm{FLCOST} \tag{Eq.39}$$

$$\mathrm{TCSCOST} = \mathrm{CSA} * \mathrm{CSCOST} \tag{Eq.40}$$

$$\mathrm{THPCOST} = \mathrm{HPA} * \mathrm{HPCOST} \tag{Eq.41}$$

$$\mathrm{TWSCOST} = \mathrm{WSA} * \mathrm{WSCOST} \tag{Eq.42}$$

$$\mathrm{TMPCOST} = \mathrm{MPA} * \mathrm{MPCOST} \tag{Eq.43}$$

$$\mathrm{TPCCOST} = \mathrm{PCHA} * \mathrm{PCCOST} \tag{Eq.44}$$

$$TST1COST = ST1HA * ST1COST \quad \text{(Eq.45)}$$

$$TST2COST = ST2HA * ST2COST \quad \text{(Eq.46)}$$

$$TST3COST = ST3HA * ST3COST \quad \text{(Eq.47)}$$

$$TST4COST = ST4HA * ST4COST \quad \text{(Eq.48)}$$

$$TST5COST = ST5HA * ST5COST \quad \text{(Eq.49)}$$

$$TST6COST = ST6HA * ST6COST \quad \text{(Eq.50)}$$

$$THVCOST = BMHA * HVCOST \quad \text{(Eq.51)}$$

$$TVCOST = TFLCOST + TCSCOST + THPCOST + TWSCOST + TMPCOST + TPCCOST + TST1COST + TST2COST + TST3COST + TST4COST + TST5COST + TST6COST + THVCOST \quad \text{(Eq.52)}$$

The variables FA, CSA, HPA, WSA, MPA, PCHA, ST1HA, ST2HA, ST3HA, ST4HA, ST5HA, ST6HA, and BMHA are the acres associated with each production phase. Equations (39) through (43) represent the calculations for total variable costs of fallow field, cultured seed cane, hand planting, wholestalk seed cane harvest, and mechanical planting activities on the whole-farm rotational context. Equations (44) through (50) give the calculation for total variable costs associated with plant cane through sixth stubble field operations, and Equation (51) calculates the total variable cost for harvest operations for the entire farm. Total variable cost for the entire farm was estimated by summing the individual variable costs and is given by Equation (52).

The simulation model was also used to estimate energy cane yields under stochastic yield conditions through sixth stubble. In 2012, the only yield data available for the five energy cane varieties consisted of plant cane through second stubble. Under the assumption that energy cane faces yield declines very similar to those seen with traditional sugarcane varieties, although starting at a different stage in the crop cycle, the following equations were used to estimate yields for third through sixth stubble:

$$\text{ST3MEAN} = \text{ST2MEAN} * 0.94 \qquad \text{(Eq.53)}$$

$$\text{ST4MEAN} = \text{ST2MEAN} * 0.79 \qquad \text{(Eq.54)}$$

$$\text{ST5MEAN} = \text{ST2MEAN} * 0.74 \qquad \text{(Eq.55)}$$

$$\text{ST6MEAN} = \text{ST2MEAN} * 0.70 \qquad \text{(Eq.56)}$$

Equation (53) assumes that third stubble mean yield represents 94% of second stubble mean yield. Equation (54) represents the assumption that fourth stubble mean yield represents 79% of second stubble mean yield, and Equations (55) and (56) assume that fifth and sixth stubble mean yields represent 74% and 70% of second stubble mean yield, respectively. Since four research replications were performed for each variety, four yield deviations were calculated for each crop year. Those deviations were then simulated in the model with an equal probability of occurrence (25%) and 1,000 random numbers were generated for plant cane through sixth stubble. The following equations were used to estimate plant cane through sixth stubble total energy cane production for each variety under stochastic yield conditions.

$$\text{PCPROD} = \text{PCYLD}*\text{PCHAB} \qquad \text{(Eq.57)}$$

$$\text{ST1PROD} = \text{ST1YLD}*\text{ST1HAB} \qquad \text{(Eq.58)}$$

$$\text{ST2PROD} = \text{ST2YLD}*\text{ST2HA} \qquad \text{(Eq.59)}$$

$$\text{ST3PROD} = \text{ST3YLD}*\text{ST3HA} \qquad \text{(Eq.60)}$$

$$\text{ST4PROD} = \text{ST4YLD}*\text{ST4HA} \qquad \text{(Eq.61)}$$

$$\text{ST5PROD} = \text{ST5YLD}*\text{ST5HA} \qquad \text{(Eq.62)}$$

$$\text{ST6PROD} = \text{ST6YLD}*\text{ST6HA} \qquad \text{(Eq.63)}$$

$$TPROD = PCPROD + ST1PROD + ST2PROD + ST3PROD + ST4PROD + ST5PROD + ST6PROD \quad \text{(Eq.64)}$$

$$TPRODDRY = TPROD*FIBER \quad \text{(Eq.65)}$$

Equations (57) through (63) measure total biomass produced from plant cane harvest through sixth stubble harvest. The variables PCYLD, ST1YLD, ST2YLD, ST3YLD, ST4YLD, ST5YLD, and ST6YLD represent the estimated biomass yield per acre for plant cane through sixth stubble crops. The variables PCHAB and ST1HAB represent plant cane acres harvested for biomass mill processing and first stubble acres harvested for biomass mill processing. It is important to distinguish these variables from PCHA and ST1HA which represent the total plant cane and first stubble acreage harvested, including the small portion of each that is harvested for seed cane expansion. Equation (64) measures the total biomass produced as the sum of biomass production from plant cane through sixth stubble. The total quantity of biomass produced, in dry tons, is measured by Equation (65), which uses the average fiber content for each variety. Total variable cost per wet ton was then calculated by dividing total variable cost by total biomass produced:

$$TVCWT = TVCOST/TPROD \quad \text{(Eq.66)}$$

Land rent and breakeven biomass prices were calculated using equations (16) and (17) listed in Section 3.2. Once variable costs, fixed costs, overhead, and land rent were estimated, the remaining estimates of total cost, total revenue, and net revenue, were then estimated using the following equations:

$$\mathrm{TVCACRE} = \mathrm{TVCOST} \div \mathrm{TFA} \quad \text{(Eq.67)}$$

$$\mathrm{TVCWT} = \mathrm{TVCOST} \div \mathrm{TPROD} \quad \text{(Eq.68)}$$

$$\mathrm{TVCDT} = \mathrm{TVCOST} \div \mathrm{TPRODDRY} \quad \text{(Eq.69)}$$

$$\mathrm{TOTCOST} = \mathrm{TVCOST} + \mathrm{TFCOST} + \mathrm{TOCOST} + \mathrm{RENT} \quad \text{(Eq.70)}$$

$$\mathrm{TCACRE} = \mathrm{TOTCOST} \div \mathrm{TFA} \tag{Eq.71}$$

$$\mathrm{TCWT} = \mathrm{TOTCOST} \div \mathrm{TPROD} \tag{Eq.72}$$

$$\mathrm{TCDT} = \mathrm{TOTCOST} \div \mathrm{TPRODDRY} \tag{Eq.73}$$

$$\mathrm{TOTREV} = \mathrm{PRICE} * \mathrm{TPROD} \tag{Eq.74}$$

$$\mathrm{TREVPA} = \mathrm{TOTREV} \div \mathrm{TFA} \tag{Eq.75}$$

$$\mathrm{TREVWT} = \mathrm{TOTREV} \div \mathrm{TPROD} \tag{Eq.76}$$

$$\mathrm{NETREV} = \mathrm{TOTREV} - \mathrm{TVCOST} - \mathrm{TFCOST} - \mathrm{TOCOST} - \mathrm{RENT} \tag{Eq.77}$$

$$\mathrm{NETREVPA} = \mathrm{NETREV} \div \mathrm{TFA} \tag{Eq.78}$$

$$\mathrm{NETREVWT} = \mathrm{NETREV} \div \mathrm{TPROD} \tag{Eq.79}$$

The variables TVCACRE, TCACRE, TREVPA, and NETREVPA represent the total variable cost per acre, total cost per acre, total revenue per acre, and net revenue per acre, respectively. The variables TVCWT, TCWT, TREVWT, and NETREVWT represent the total variable cost per wet ton, total cost per wet ton, total revenue per wet ton, and net revenue per wet ton, respectively. The variables TVCDT and TCDT represent the total variable cost per dry ton, and the total cost per dry ton, respectively. Total energy cane production cost is represented by the variable TOTCOST, which is calculated as the sum of total variable cost, total fixed cost, total overhead cost, and land rent. Total revenue is measured by the variable TOTREV and NETREV measures the net revenue or total revenue minus total costs.

CHAPTER 4: RESULTS AND DISCUSSION

With an overall lack of economic information available on energy cane production, the aim of this research has been to provide some insight on the economic feasibility of producing energy cane in Louisiana as a feedstock for cellulosic ethanol production. When dealing with a non-traditional crop such as energy cane, increased uncertainty surrounding potential costs and returns can make the crop seem much less appealing to potential producers. As a high-fiber hybrid of traditionally produced sugarcane, energy cane production costs have been estimated using a standard enterprise budgeting approach developed for sugarcane, along with actual fiber and yield data from energy cane field trials. With the addition of potential transportation and cellulosic processing costs, ethanol production costs were then estimated in order to provide an indication of the potential behind using energy cane to produce cellulosic ethanol in Louisiana.

4.1 Energy Cane Production Cost Estimates

Energy cane production costs were estimated following a standard enterprise budgeting approach developed for sugarcane production in Louisiana. Variable production costs were first calculated for alternative crop cycle lengths using mean yields and 2012 input prices for diesel fuel, nitrogen, phosphate, and potassium, along with other production costs. These results can be found in Table 15. Estimates for variable costs per wet ton ranged from approximately $11 to $17 for production through fourth stubble, and $11to $16 for production through both a fifth and sixth stubble. Results suggest a slight decline in variable costs per wet ton as crop cycle length increases which can be attributed to the small increases in total biomass production that results as crop cycle length is increased. When comparing the yields of the five varieties collected from the energy cane field trials for plant cane through second stubble to the variable costs below, there is an apparent relationship between yield and cost. The variety with the highest yield has returned the lowest cost estimate, while the variety with the lowest yield has returned the highest cost estimate. For example, energy cane variety Ho 02-147 returned the lowest variable cost estimates under all three crop cycle lengths and it produced significantly higher yields than the other varieties during the field trials.

Table 15. Estimated Variable Production Costs per Wet Ton of Energy Cane under Alternative Crop Cycle Lengths

Energy Cane Variety	Through 4th Stubble	Through 5th Stubble	Through 6th Stubble
	($/wet ton)	($/wet ton)	($/wet ton)
Ho 02-144	15.30	14.98	14.86
Ho 02-147	10.96	10.84	10.83
Ho 06-9001	14.94	14.60	14.47
Ho 06-9002	16.73	16.36	16.23
Ho CP72-114	13.57	13.48	13.50
Average	14.30	14.05	13.98

Costs estimated for mean yield levels at specific 2012 input price values.

Variable costs were also estimated on a dry ton basis in order to reflect the actual amount of useable biomass that is converted into ethanol. Using data from the energy cane field trials at the Sugar Research Station in St. Gabriel, Louisiana, the dry weight was determined for each variety by multiplying the quantity of wet tons produced by its average fiber content for plant cane through second stubble. The specific fiber contents used in the calculations are 0.23 for variety Ho 02-144, 0.19 for variety Ho 02-147, 0.28 for variety Ho 06-9001, 0.28 for variety Ho 06-9002, and 0.22 for variety Ho CP72-114. Variable cost per dry ton of biomass for each crop cycle length was calculated by dividing total variable cost by total dry tons of biomass produced for each variety. The results, which are provided in Table 16, reflect the influence of both yield and fiber content on energy cane production costs. While energy cane varieties Ho 06-9001 and Ho 06-9002 have the same fiber content, Ho 06-9001 is a higher-yielding variety and thus has lower variable costs per dry ton under each crop cycle length. Although variable cost estimates per wet ton were lowest for energy cane variety Ho 02-147, these same variable cost estimates measured on a dry ton basis are no longer the lowest since it has the lowest average fiber content. These results provide a great example of why, in addition to potential yields, the fiber content of energy cane is also an important factor when it comes to reducing production costs.

Table 16. Estimated Variable Production Costs per Dry Ton of Biomass under Alternative Crop Cycle Lengths

Energy Cane Variety	Through 4th Stubble	Through 5th Stubble	Through 6th Stubble
	($/dry ton)	($/dry ton)	($/dry ton)
Ho 02-144	66.54	65.12	64.62
Ho 02-147	57.66	57.03	57.00
Ho 06-9001	53.37	52.14	51.68
Ho 06-9002	59.75	58.44	57.97
Ho CP72-114	61.69	61.25	61.38
Average	59.80	58.80	58.53

Costs estimated for mean yield levels at specific 2012 input price values.

Monte Carlo simulation was conducted in order to project energy cane production costs under stochastic input prices and yield levels. The results for variable cost estimates per wet ton of energy cane are given in Table 17 and the results for variable costs per dry ton of biomass can be found in Table 18. Results suggest that variable costs generally decrease as production is increased past fourth stubble, although the changes are not very significant. For production through fourth stubble, energy cane variety Ho 06-9002 returned the highest variable cost when measured on a wet ton basis with 95% of the values ranging from $14.49 to $19.01 per wet ton. However, when measuring variable cost for fourth stubble production on a dry ton basis, Ho 02-144 was estimated to have the highest cost, with 95% of the values ranging from $50.49 to $84.49 per dry ton. Results suggest that 95% of variable cost estimates for energy cane variety Ho 06-9001 will range from $12.86 to $17.14 per wet ton for fourth stubble production, and only slightly decrease for additional stubbles. These estimates for Ho 06-9001 offer some indication of the costs associated with a slightly above average-performing energy cane variety since its yields are higher than the average yields and its fiber content is among the highest when compared to the other four energy cane varieties. With an average fiber content and yields close to the average for all five varieties, Ho CP72-114 is an example of an average-performing energy cane variety when compared to the other four varieties and 95% of the values for fourth stubble variable costs were estimated to range from $11.63 to $15.55 per wet ton and $52.89 to $70.69 per dry ton.

Table 17. Simulated Variable Production Costs per Wet Ton of Energy Cane for Alternative Crop Cycle Lengths

Energy Cane Variety	Through 4th Stubble	Through 5th Stubble	Through 6th Stubble
	($/wet ton)	($/wet ton)	($/wet ton)
Ho 02-144	15.52 (1.96)	15.19 (1.82)	15.05 (1.77)
Ho 02-147	11.01 (0.79)	10.88 (0.78)	10.88 (0.76)
Ho 06-9001	15.00 (1.07)	14.65 (1.01)	14.53 (0.96)
Ho 06-9002	16.75 (1.13)	16.38 (1.08)	16.25 (1.04)
Ho CP72-114	13.59 (0.98)	13.49 (0.95)	13.52 (0.94)

Costs estimated for stochastic yield levels and stochastic input prices at 2012 mean values.
Numbers in parentheses are standard deviations.
Mean ± 1 standard deviation = 68% of values; Mean ± 2 standard deviations = 95% of values.

Table 18. Simulated Variable Production Costs per Dry Ton of Biomass for Alternative Crop Cycle Lengths

Energy Cane Variety	Through 4th Stubble	Through 5th Stubble	Through 6th Stubble
	($/dry ton)	($/dry ton)	($/dry ton)
Ho 02-144	67.49 (8.50)	66.04 (7.92)	65.44 (7.68)
Ho 02-147	57.92 (4.17)	57.26 (4.11)	57.24 (3.98)
Ho 06-9001	53.56 (3.83)	52.32 (3.60)	51.89 (3.43)
Ho 06-9002	59.83 (4.05)	58.51 (3.87)	58.02 (3.71)
Ho CP72-114	61.79 (4.45)	61.34 (4.34)	61.47 (4.26)

Costs estimated for stochastic yield levels and stochastic input prices at 2012 mean values.
Numbers in parentheses are standard deviations.
Mean ± 1 standard deviation = 68% of values; Mean ± 2 standard deviations = 95% of values.

Total production costs were estimated under the assumption that fixed equipment costs were $140 per acre, overhead costs were $30 per acre, and land rent was 20% of the total value of harvested biomass. By dividing total production costs by total tons of biomass produced, the biomass prices required by growers to breakeven were then estimated for each of the five varieties for alternative crop cycle lengths. The results for total production cost per wet ton are given in Table 19. In general, the breakeven prices decline for each additional harvest as costs are spread over additional stubbles and an increase in biomass tonnage is produced. Among the five energy cane varieties, the total cost of producing energy cane biomass ranges from approximately $18 to $28 per wet ton for crops reaching a fourth, fifth, and sixth stubble. The results suggest that on average, the minimum price required to cover a grower's total cost of production is approximately $24 per wet ton of biomass for a fourth, fifth, or sixth stubble crop.

Table 19. Estimated Total Production Costs (Wet Tons) for Energy Cane under Alternative Crop Cycle Lengths

Energy Cane Variety	Through 4th Stubble	Through 5th Stubble	Through 6th Stubble
	($/wet ton)	($/wet ton)	($/wet ton)
Ho 02-144	25.50	24.89	24.71
Ho 02-147	18.27	18.02	18.02
Ho 06-9001	24.89	24.26	24.05
Ho 06-9002	27.83	27.16	26.94
Ho CP72-114	22.57	22.36	22.41
Average cost per wet ton	23.81	23.34	23.23

Costs estimated for mean yield levels at specific 2012 input price values.
Fixed equipment costs=$140/acre, overhead costs=$30/acre, land rent=20% of breakeven price.
Dry ton costs estimated using an average fiber content of 24%.

Results for total production cost per dry ton are provided in Table 20. The estimates for total production cost per dry ton of biomass range from approximately $89 to $111, with an average total cost of $100 per dry ton for production through fourth stubble. For crops reaching fifth stubble, total production costs decrease only slightly, ranging from $87 to $108 per dry ton, with an average total cost of $98 per dry ton. Total production costs for production through sixth stubble are estimated to range between $86 to $107, with an average total cost of $97 per dry ton.

Table 20. Estimated Total Production Costs (Dry Tons) for Energy Cane under Alternative Crop Cycle Lengths

Energy Cane Variety	Through 4th Stubble	Through 5th Stubble	Through 6th Stubble
	($/dry ton)	($/dry ton)	($/dry ton)
Ho 02-144	110.81	108.18	107.15
Ho 02-147	96.02	94.74	94.53
Ho 06-9001	88.87	86.62	85.70
Ho 06-9002	99.51	97.09	96.13
Ho CP72-114	102.74	101.76	101.79
Average cost per dry ton	99.59	97.68	97.06

Costs estimated for mean yield levels at specific 2012 input price values.
Fixed equipment costs=$140/acre, overhead costs=$30/acre, land rent=20% of breakeven price.
Dry ton costs estimated using an average fiber content of 24%.

Total production costs were also estimated under stochastic input prices and stochastic yield levels. Results for total production costs per wet ton are provided in Table 21 and the results for total production costs per dry ton are given in Table 22.

Table 21. Simulated Total Production Costs (Wet Tons) for Energy Cane under Alternative Crop Cycle Lengths

Energy Cane Variety	Through 4th Stubble	Through 5th Stubble	Through 6th Stubble
	($/wet ton)	($/wet ton)	($/wet ton)
Ho 02-144	25.85 (3.17)	25.23 (2.93)	24.96 (2.83)
Ho 02-147	18.33 (1.23)	18.07 (1.20)	18.04 (1.16)
Ho 06-9001	24.98 (1.65)	24.34 (1.52)	24.09 (1.44)
Ho 06-9002	27.90 (1.72)	27.22 (1.63)	26.94 (1.55)
Ho CP72-114	22.64 (1.50)	22.42 (1.45)	22.43 (1.42)

Costs estimated for stochastic yield levels and stochastic input prices at 2012 mean values.
Numbers in parentheses are standard deviations.
Mean ± 1 standard deviation = 68% of values; Mean ± 2 standard deviations = 95% of values.

Table 22. Simulated Total Production Costs (Dry Tons) for Energy Cane under Alternative Crop Cycle Lengths

Energy Cane Variety	Through 4th Stubble	Through 5th Stubble	Through 6th Stubble
	($/wet ton)	($/wet ton)	($/wet ton)
Ho 02-144	112.38 (13.77)	109.70 (12.74)	108.51 (12.33)
Ho 02-147	96.46 (6.46)	95.13 (6.32)	94.93 (6.08)
Ho 06-9001	89.20 (5.88)	86.92 (5.44)	86.04 (5.14)
Ho 06-9002	99.64 (6.14)	97.21 (5.83)	96.21 (5.53)
Ho CP72-114	102.90 (6.81)	101.89 (6.61)	101.93 (6.45)

Costs estimated for stochastic yield levels and stochastic input prices at 2012 mean values.
Numbers in parentheses are standard deviations.
Mean ± 1 standard deviation = 68% of values; Mean ± 2 standard deviations = 95% of values.

For production through fourth stubble, the results suggest that the biomass price required by growers to breakeven is likely to fall somewhere between $18 to $28 per wet ton and $89 to $112 per dry ton of biomass. For production through a fifth stubble, the biomass price required by growers to breakeven is estimated to be somewhere in the range of $18 to $27 per wet ton and $87 to $110 per dry ton. When production is extended through sixth stubble, the biomass price required by growers to breakeven is likely to be in the range of $18 to $27 per wet ton and $86 to $109 per dry ton.

4.2 Energy Cane Yield Estimates for Older Stubble

Since data on energy cane yields from the field trials was only available for plant cane through second stubble, energy cane yields were estimated for each variety for third through sixth stubble under stochastic yield levels using Monte Carlo simulation analysis. Results are presented in Table 23. Estimates for third stubble yields for the five energy cane varieties ranged from 47.7 tons per acre to 68.3 tons per acre, while estimates for fourth stubble yields ranged from 40.1 tons per acre to 57 tons per acre. Fifth and sixth stubble yields were slightly lower than fourth stubble yields, with estimates ranging from 37.6 tons per acre to 53.6 tons per acre for fifth stubble, and 35.6 tons per acre to 50.5 tons per acre for sixth stubble. Results suggest that there is a greater deal of uncertainty surrounding the yield estimates for energy cane varieties Ho 02-144 and Ho 02-147. This is indicated by the relatively high variance corresponding with these two varieties.

Table 23. Simulated Energy Cane Yields through 6th Stubble

Variety	Through 3rd Stubble	Through 4th Stubble	Through 5th Stubble	Through 6th Stubble
	(tons/acre)	(tons/acre)	(tons/acre)	(tons/acre)
Ho 02-144	51.6 (12.77)	44.2 (12.74)	40.6 (12.73)	38.8 (12.71)
Ho 02-147	68.3 (9.52)	57.0 (9.42)	53.7 (9.54)	50.5 (9.54)
Ho 06-9001	53.8 (5.65)	45.1 (5.85)	42.2 (5.64)	39.8 (5.75)
Ho 06-9002	47.7 (5.01)	40.1 (4.89)	37.6 (5.01)	35.6 (4.95)
Ho CP72-114	53.7 (7.08)	45.0 (6.82)	42.3 (7.08)	39.9 (6.91)

Numbers in parentheses are standard deviations.

4.3 Potential Optimal Crop Cycle Lengths

When a sugarcane farmer is faced with the tradeoff between declining yields of older stubble crops and the costs of replanting, the most economically efficient decision that will maximize net returns is often determined using a breakeven method. Given the production cost and yields estimated for third through sixth stubble, potential optimal crop cycle lengths were evaluated for alternative crop cycle lengths up to a maximum of sixth stubble harvest. For each variety, the breakeven yields required for crop cycle lengths past second stubble that would generate the same net return as the previous crop cycle length were estimated. A simple decision rule was used to determine the optimal crop cycle length, which states that the farmer should keep the crop in rotation as long as the estimated yields for crop cycle length *n* are greater than or equal to the break even yield required to generate the same return as crop cycle length *n-1*. After the last harvest of a crop that has reached its optimal crop cycle length, the farmer will then fallow the field for a year before replanting seed cane. The results for breakeven yields are given in Table 24 and the potential optimal crop cycle length for each variety is denoted by the asterisks in each row. For energy cane variety Ho CP72-114, the results suggest that optimal crop cycle length is to produce the crop through a fourth stubble harvest, because the projected breakeven yield for fifth stubble is greater than the actual fifth stubble yield estimate in Table 23. Since the fourth stubble yield estimate in Table 23 for Ho CP72-114 is greater than that of the breakeven yield required for fourth stubble, production through a fourth stubble is considered to be the optimal crop cycle length for this particular variety. Overall, the results suggest that the potential optimal crop cycle length for the other four energy cane varieties, Ho 02-147, Ho 02-144, Ho 06-9001, and Ho 06-9002, is production through a sixth stubble. However, it is important to note that because no data was available for estimating breakeven yields for seventh or eighth stubble, there is still a possibility that production past a sixth stubble could be the optimal decision since the projected sixth stubble yields are actually greater than the breakeven yields.

Table 24. Breakeven Yields Required for Various Energy Cane Crop Cycle Lengths

Variety	3rd Stubble Breakeven Yield (tons/acre)	4th Stubble Breakeven Yield (tons/acre)	5th Stubble Breakeven Yield (tons/acre)	6th Stubble Breakeven Yield (tons/acre)
Ho 02-144	29.52	34.01	38.38	36.37*
Ho 02-147	42.01	47.22	52.50	49.55*
Ho 06-9001	29.91	34.68	39.28	37.26*
Ho 06-9002	27.21	31.31	35.30	33.45*
Ho CP72-114	35.14	38.85*	42.74	40.23

*Denotes the potential economically optimal crop cycle length for each variety

4.4 Transportation Cost Estimates

In addition to the cost of purchasing the biomass feedstock, transportation or hauling costs are incurred when the biomass is transported from the farm to the processing facility and therefore must be included in the total cost of producing the final good. With the assumption that the biomass is not dried before being hauled to the processor, transportation costs were first estimated on a wet ton basis under six hauling distance scenarios. These calculations were made using the assumption that a $1.00 base rate would apply in addition to a rate of $0.10 per mile transported. Table 25 gives the results for estimated hauling costs per wet ton of energy cane that would be charged for distances typically seen in the sugarcane industry, which range from ten to sixty miles.

Table 25. Transportation Cost Estimates per Wet Ton of Energy Cane for Various Transport Distances

Biomass Hauling Cost ($/wt)					
10 Miles	20 Miles	30 Miles	40 Miles	50 Miles	60 Miles
2	3	4	5	6	7

Once the transportation costs were calculated, total delivered cost per ton of biomass was then estimated for each of the five energy cane varieties. Farm gate costs estimated for production through sixth stubble were used since it was found to be the overall optimal crop cycle length. Table 26 gives the results for the total cost per ton of transported biomass. Also, once the biomass is transported to the processor, the cost measurements are then referred to on a dollar per gallon of ethanol basis. Using a conversion factor of 85 gallons of ethanol that can be produced from one dry ton of transported biomass, transported biomass costs were also calculated in dollars per gallon of ethanol. The results suggest that under a scenario in which the farm is located twenty miles from the processor, the average total cost of transported biomass to the processor is estimated at approximately $26 per wet ton or $110 per dry ton of biomass, which factors to approximately $1.29 per gallon of ethanol. However, under another scenario in which the feedstock must be transported forty miles to the processor, the transported biomass will cost the processor an average of $28 per wet ton or $118 per dry ton, which translates to an average of $1.39 per gallon of ethanol produced. When the transport distance is increased to sixty miles, the processor will face an average transported biomass cost of approximately $30 per wet ton or $126 per dry ton, which also averages to $1.49 per gallon of ethanol produced. Overall, these transportation costs show how significant cost savings can be achieved by processors who can secure feedstock supplies within a close distance from the facility. In fact, according to the costs estimated under the assumed scenarios, a processor who can purchase all of its biomass from a source within a twenty mile radius from the facility will save approximately $0.20 per gallon of ethanol, or more, compared to another facility that gets its supply from a farm sixty miles away.

Table 26. Total Costs of Transported Biomass for a 6th Stubble Biomass Crop

Variety	Farm Gate Cost Of Energy Cane	Transport Distance 20 Miles	40 Miles	60 Miles
	($/wet ton)	($/wet ton)	($/wet ton)	($/wet ton)
Ho 02-144	24.71	27.71	29.71	31.71
Ho 02-147	18.02	21.02	23.02	25.02
Ho 06-9001	24.05	27.05	29.05	31.05
Ho 06-9002	26.94	29.94	31.94	33.94
Ho CP72-114	22.41	25.41	27.41	29.41
Average Total Cost per Wet Ton	23.23	26.23	28.23	30.23
Average Total Cost per Dry Ton[1]	($/dry ton) 97.06	($/dry ton) 109.56	($/dry ton) 117.89	($/dry ton) 126.23
Average Total Cost per Gallon of Ethanol[2]	($/gal) 1.14	($/gal) 1.29	($/gal) 1.39	($/gal) 1.49

[1] Average total costs per dry ton of transported biomass calculated using an average fiber content of 24%.

[2] Average total costs per gallon of ethanol calculated using an ethanol yield of 85 gallons per dry ton of biomass.

4.5 Total Cost Estimate for the Cellulosic Production of Ethanol

After estimating the feedstock and transportation costs, cellulosic processing costs were then added to the delivered feedstock price in order to calculate the hypothetical cost of producing cellulosic ethanol from energy cane biomass. A range of processing costs from techno-economic studies on various cellulose-to-ethanol conversion routes were collected and used to develop four processing cost scenarios that a processor may experience for various conversion processes. Specifically, ethanol costs were calculated under four scenarios in which processing costs were assumed to be \$0.70, \$0.90, \$1.20, and \$1.50 per gallon of ethanol. By adding these costs to the previously estimated transported biomass cost, a hypothetical range of minimum ethanol selling prices (MESP) were estimated and the results are given in Table 27.

Table 27. Cellulosic Ethanol Production Costs and Minimum Ethanol Selling Price under Alternative Scenarios for Transportation and Processing Costs

		Minimum Ethanol Selling Price			
Transport Distance Scenario	Average Total Cost of Transported Feedstock	Scenario 1 Processing Costs \$0.70/gal	Scenario 2 Processing Costs \$0.90/gal	Scenario 3 Processing Costs \$1.20/gal	Scenario 4 Processing Costs \$1.50/gal
	(\$/gal)	(\$/gal)	(\$/gal)	(\$/gal)	(\$/gal)
20 Miles	1.29	1.99	2.19	2.49	2.79
40 Miles	1.39	2.09	2.29	2.59	2.89
60 Miles	1.49	2.19	2.39	2.69	2.99
Average	1.39	2.09	2.29	2.59	2.89

Under the highest cost scenario in which the feedstock must be transported 60 miles and processing costs are \$1.50 per gallon, the MESP was estimated at \$2.99 per gallon. That estimate is consistent with a Congressional Report prepared for Congress in 2010 which reported estimates for cellulosic biofuel costs ranging from \$2.50 to slightly over \$3.00 per gallon of ethanol (CRS, 2010). However, if the conversion processes was made more efficient so that processing costs resembled those under the two mid-level cost scenarios (in which processing costs are \$0.90 and \$1.50 per gallon of ethanol) then the average MESP is estimated at \$2.29 and \$2.59 per gallon, respectively. Under the lowest processing cost scenario, the average MESP is estimated at $2.09, approximately $0.90 lower than the average MESP when processing costs are $1.50.

CHAPTER 5: CONCLUSION AND SUMMARY

As a result of the growing national concern regarding the United States' dependence on foreign oil supplies, a wave of legislation has been passed in recent years to aid in the development of renewable energy sources. Under the RFS set by the Energy Independence and Security Act in 2007, 21 billion gallons of ethanol must be produced from advanced and cellulosic ethanol sources by 2022 to displace a portion of the nation's gasoline consumption. In order to meet these ambitious goals, many states and regions have begun identifying the feedstocks for which they have the most comparative advantage. One option for Louisiana is the production of energy cane, a hybrid of sugarcane with higher levels of fiber and lower levels of sugar. Other than feedstock composition, energy cane shares a great deal of similarities with sugarcane, and therefore production practices for the two crops are very similar. As a major sugarcane producing state, Louisiana has several key advantages when it comes to producing energy cane, including existing planting and harvesting equipment, farmer expertise, and a sub-tropical climate in which energy cane crops can thrive. Despite these advantages, there are several obstacles preventing the development of a cellulosic ethanol industry. A key challenge lies in increasing the overall efficiency of the cellulose-to-ethanol conversion process and identifying low cost feedstocks to supply a local cellulosic ethanol industry. Despite the fact that a wide variety of cellulosic conversion processes have been studied, there are still no processes that are fully developed and ready to be used on a commercial scale. As a result, estimating cellulosic conversion costs remains a difficult task because cellulose-to-ethanol conversion technologies are currently only used in laboratories and small-pilot scale plants and so the actual costs associated with these processes are still relatively unavailable to the general public. Determining the energy cane feedstock price to an ethanol producer is also a complicated process because energy cane is not a traditionally produced crop and so no actual market exists for it at this time. With only limited information currently available, determining the price of energy cane biomass to an ethanol producer requires the complete estimation of cost data involved in the production of energy cane.

In order to determine the economic feasibility of using energy cane as a biomass feedstock for cellulosic ethanol production in Louisiana, the feedstock price to ethanol producers was determined by estimating the complete cost of energy cane production on a 1,000 acre farm. Potential energy cane yields were projected and the potential optimal crop cycle length was also determined. Other objectives of the study included estimating the transported feedstock price to an ethanol producer, as well as projecting the potential total cost of producing ethanol from energy cane.

Energy cane yields were estimated using data from the energy cane field trials at the Sugar Research Station in St. Gabriel, Louisiana. Results for energy cane yields estimated for the five energy cane varieties featured in this study ranged from approximately 36 to 51 tons per acre. The yields were estimated under the assumption that energy cane yields would decline in a pattern similar to that of traditional sugarcane. Determining the economically optimal crop cycle length that will maximize net returns over the entire crop cycle length is one of the most important decisions that an energy cane producer is faced with, due to the high costs of purchasing and planting new seed cane. Using projected energy cane costs and yields, production through a sixth stubble was found to be the optimal crop cycle length for four out of the five energy cane varieties. However, since the expected yields were actually greater than the breakeven yields for sixth stubble, it could be the case that production through seventh stubble is actually the optimal cycle, however, this study only estimated yields through sixth stubble.

Ultimately, this finding suggests that energy cane's stubbling ability is much greater than that of traditional sugarcane, which is generally only left in production through second or third stubble.

Using available yield and fiber content data on five energy cane varieties, along with the most current data on sugarcane production costs, estimates of the overall cost of producing energy cane suggest that energy cane has potential to be an economically feasible option to supply an ethanol industry in Louisiana. In particular, results for variable production costs under the optimal crop cycle length ranged from $11 to $16 per wet ton of biomass and total farm gate cost ranged from $18 to $27 per wet ton of biomass. In comparison to production cost estimates from other studies, energy cane is a relatively cheaper option. In fact, according to an early study by Epplin (1996), the cost to produce and deliver switchgrass to an ethanol conversion facility ranged from approximately $35 to $40 per metric ton ($32 to $36 per wet ton). A later study by Aravindhaksham et al. (2010) estimated switchgrass production costs to be in the range of $44 to $52 per metric ton ($40 to $47 per wet ton). In another study, Khanna et al. (2008) estimated the farm-gate price of miscanthus to be in the range of $42 to $58 per metric ton ($38 to $53 per wet ton). In addition to the cost of purchasing energy cane, transportation costs were also found to be a significant portion of total ethanol production costs. For a range of distances from 20 to 60 miles that the biomass would possibly be transported, the delivered cost of biomass to a processing facility was estimated between $21 to $34 per wet ton or an average of $110 to $126 per dry ton delivered. When measured per gallon of ethanol, the transported cost of biomass ranged from $1.29 to $1.49.

In order to provide an idea of what the total cost of producing cellulosic ethanol from energy cane might cost an ethanol producer, hypothetical processing cost scenarios were developed, ranging from $0.70 to $1.50 per gallon of ethanol. By including the cost of transported biomass in each of the hypothetical processing cost scenarios, it was estimated that the minimum ethanol selling price would range from $1.99 to $2.99 per gallon of ethanol. According to data downloaded from the USDA Economic Research Service for the marketing year September 2011 to August 2012, the market price of ethanol has fluctuated between $2.83 per gallon in the first quarter to $2.26 per gallon in the third quarter (ERS, 2012). These prices are fairly consistent with the previous market year, which fluctuated between $2.33/gallon to $2.87/gallon. If future ethanol prices continue to follow the same trend as the previous two years, ethanol producers will need processing costs to stay at or below $0.90 per gallon in order to breakeven.

There were several limitations of this study that are worth noting. First, only three years of actual energy cane yield data were available for use in this study and so the expected yield declines past second stubble were modeled off of typical yield declines seen in traditional sugarcane. As yield data becomes available for additional annual harvests, the actual yield declines of energy cane should be evaluated in future research. Second, since there is currently no actual market for energy cane, transportation costs were also modeled off of the sugarcane industry since it is likely the most representative of an energy cane market. Similarly, because of the lack of historical data available for transportation and processing costs, there was no way of simulating any random variables specific to those particular costs.

Another important area of future energy cane research will be to analyze the competitiveness of energy cane relative to the region's existing crops and determining under what conditions a farmer would chose to grow energy cane over his existing crops. Specifically, assessing producer buy-in will be important because a rational farmer will not produce energy cane if the returns are lower than that of his current crop. Also, in order to actually develop a cellulosic ethanol industry in Louisiana, further research will be required to determine the optimal locations for new ethanol processing facilities in respect to biomass supplies. Capital costs will need to be considered as well. On the other hand, if it is decided that the biofuel is to be seasonally produced at existing sugar mills, location-specific assessments of nearby feedstock supplies will be required to ensure that hauling costs are minimized. In addition, it is important to note that the estimates for cellulosic ethanol production costs are only designed to give a rough idea of what a cellulosic ethanol producer might experience when producing ethanol from energy cane. As a result, these cellulosic ethanol costs should be interpreted as strictly hypothetical. As cellulose-to-ethanol conversion technologies eventually become fully developed, future research using actual processing cost data will be required in order to provide realistic assessments of total cellulosic ethanol costs.

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VITA

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