ECONOMIC ANALYSIS OF BIOFUEL PRODUCTION FROM

SWITCHGRASS (*Panicum virgatum*) AND SWEET SORGHUM

(*Sorghum bicolor*) IN THE UNITED STATES

A Thesis

by

TRISHA SANWAL

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Approved by:

Chair of Committee: Janaki Alavalapati
Committee Members: Henry Quesada
Bob Smith
Pankaj Lal

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ABSTRACT

Economic Analysis of Biofuel Production from Switchgrass (*Panicum virgatum*) and Sweet Sorghum (*Sorghum bicolor*) in the United States.

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Excessive use of fossil fuels to meet everyday energy demands has led to adverse environmental impacts like global warming and high dependence on foreign oil. Development of cellulosic feedstocks provides energy security and also reduces the burden on food crops like corn and sugarcane used for ethanol production. This thesis uses cost-benefit analysis to ascertain the profitability of producing cellulosic ethanol from Switchgrass and Sweet Sorghum Bagasse. First, breakeven price of producing Switchgrass and Sweet Sorghum is calculated to obtain a raw material (feedstock) cost for ethanol production. Next, net present value (NPV) and minimum ethanol selling price (MESP) for Switchgrass and Sweet sorghum are calculated. Lastly, risk analysis is performed and its impacts on NPV are calculated for two farmer categories. The results show that ethanol production from Switchgrass and Sweet Sorghum is commercially feasible and generates a Net Present Value (NPV) of $39.54 million for Switchgrass and $96.76 million for Sweet Sorghum at an ethanol-selling price of $2.17 per gallon. At NPV zero the MESP for Switchgrass and Sweet Sorghum is estimated to be $2.10 and $1.96 per gallon respectively.
The risk analysis results revealed that there is a 9.5 percent probability that the NPV for a risk-averse Switchgrass farmer will be zero. On the other hand, the probability of the NPV being less than zero for a risk-seeking farmer is 67.4 percent. The overall analysis indicates that ethanol production from Switchgrass and Sweet Sorghum is a promising option. Reduction in feedstock prices, optimization of the conversion process and additional revenues from by-products can make cellulosic ethanol more competitive with current gasoline prices.
To my family
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CHAPTER I

INTRODUCTION

Biofuels are biodegradable, renewable and non-toxic sources of energy and are therefore believed to be a favorable alternative to fossil fuels (Wang et al., 2011). They not only have the potential to reduce greenhouse gas (GHG) emissions, and the dependence on petroleum but can also go a long way in promoting rural development and providing employment to farmers (Wiesenthal et al., 2009).

Biofuels can be divided into first generation biofuels and second generation biofuels based on the type of feedstock they are derived from. First generation biofuels utilize edible feedstock such as corn and sugarcane for biofuel production whereas the second-generation biofuels are extracted using lignocellulosic feedstock such as Switchgrass and Miscanthus. Although first-generation biofuels enjoy low-cost production technologies, they have their limitations. Globally growing food prices, changes in land use pattern, impact on biodiversity and the growing debate over food versus fuel has caused greater emphasis on the production of second-generation biofuels (Carriquiry et al., 2011). Although most feedstocks for second-generation biofuels are available in bulk, they still require conversion technologies to be techno-economically feasible (Eggert et al., 2011).

Biomass is one of the most promising sources of energy in the United States (US) (Rousseau, 2010). It accounts for roughly half of all the renewable energy produced in the US and uses more of it than any other country in the world. According to the billion-ton study (2005), US has the potential of producing 368
million dry tons of sustainable biomass from forestland and about 998 million dry tons of biomass from agricultural lands annually. Such numbers are enough biomass to produce more than 54 billion gallons of ethanol by 2030 (four times as much corn ethanol as the US produced in 2010) or 732 billion kilowatt-hours of electricity (19 percent of total U.S. power consumption in 2010). Figure 1 shows the total biomass resources available in the US.

Figure 1: Total biomass resources of US by county (2009). Source: US Department of Energy.
1.1 Bioenergy: Existing policies and incentives

The US government has taken several measures in the past decade to promote the development and commercialization of bioenergy. The 102nd congress passed the National Energy Policy Act of 1992 (EPACT), which created mandates, set out goals and amended utility laws to increase clean energy use (NRRI 1993). A Biomass Research and Development Board (BRDB) was created under the Biomass Research and Development Act of 2000 for advanced biomass research (BRDB 2008). Title IX of the farm bill of 2002 established new programs and grants for the procurement of bio based products (USDA 2002). The Energy Policy Act of 2005 provided tax credits for businesses investing in renewable energy projects and encouraged small enterprises utilizing forest-based biomass for energy production by providing grants (GPO 2005). The act also created the Renewable Fuel Standard (RFS) program, which mandated 7.5 billion gallons of renewable fuel to be blended with gasoline by 2012 (EPA 2013). The Energy Independence and Security Act of 2007 set a mandatory RFS to use 36 billions gallons or more of biofuel by 2022 (EPA 2013). The food Conservation and Security Act of 2008 allocated $1 billion to renewable energy investments and technology programs (Schnepf 2011).

As a complimentary measure to the RFS, the 110th congress enacted the Biomass Crop Assistance Program (BCAP). BCAP was established in the year 2008 by the Food, Conservation, and Energy Act of 2008. The program assisted farmers and forest landowners in establishing, maintaining and harvesting non-food biomass dedicated to energy production (USDA, 2012). Farm bill 2014 reauthorized
BCAP with an annual mandatory funding of $25 million to establish, harvest and deliver forest and agricultural residues to a qualifying energy facility. BCAP projects have funded 50,000 acres of land in 74 counties in US (USDA 2015).

Apart from the federal tax credit, several states provide tax exemptions and credits for biofuel production and use (Josling et al., 2010). According to Jin and Teahan (2009) 25 of the 50 US states have public funding programs for biofuel producers in some form or the other. These incentives include grants, tax exemptions and deductions, rebates etc. Tax incentive programs for biofuels are categorized into two types; investment incentives and production incentives.

Nebraska provides tax credit for investments made in biodiesel production facilities and South Dakota has a tax refund for contractors excise taxes and sales. Twenty-three US states provide production tax incentives to biofuel producers. While Minnesota and South Dakota offer $0.20 per gallon tax credit to ethanol producers, Nebraska offers $0.18 per gallon (Jin and Teahan, 2009).

1.2 BIOMASS DESCRIPTION

Switchgrass is a warm season, perennial C4 grass found throughout North America. It is drought resistant, has good tolerance towards cold and can survive even in areas with very low soil quality. It is considered to be a productive biofuel crop as it can yield 15 Mg per hectare or more. Switchgrass also has various environmental benefits. Using Switchgrass leads to 95% reduction in soil erosion and 90% reductions in pesticide usage (David and Ragauskas, 2010). The heating
value\(^1\) of Switchgrass is approximately 19 MJ per kg \((David and Ragauskas, 2010)\). The ethanol yield from Switchgrass is also very high. According to Pimentel and Patzek (2005), 1 ton of switch grass has the potential of producing 400 liters of ethanol. Switchgrass has the potential of producing more than 700% of net energy balance \((Schmer et al., 2008)\). Switchgrass, much like other cellulosic feedstocks, is primarily composed of cellulose, hemicellulose and lignin. Cellulose and hemicellulose are carbohydrate components that can be converted onto ethanol by biochemical reactions. Lignin can be utilized either for combustion or gasification to produce electricity or to produce biofuel oil or syngas by a thermochemical conversion process \((Huang et al., 2009)\). Figure 2 pictorially illustrate steps of producing ethanol from Switchgrass. According to Huang et al. \((2009)\), the steps involved in the conversion are as follows:

1. **Switchgrass pre-treatment:** In this step Switchgrass is separated into cellulose, hemicellulose and lignin.

2. **Hydrolysis or saccharification:** In this step cellulose and hemicellulose are converted into sugars by hydrolysis.

3. **Fermentation:** In the last step sugar is fermented to produce ethanol.

---

\(^1\) Heating Value (HV) defined as the amount of heat produced by complete combustion of a fuel and it is measured as a unit of energy per unit mass or volume of substance. According to Jerkins et al. \((1998)\), HV for corn stover ranges between 17.6 – 18.5 MJ/kg and HV for sugarcane bagasse ranges
Sweet Sorghum is similar to grain sorghum (Sorghum bicolor) but can produce both food (grain) and fuel (ethanol from stem and stalk) (Srinivasarao et al., 2009). It originated in East Africa before spreading to other areas of Asia, Europe and US. Sweet sorghum is considered to be one of the most drought resistant crops that can remain in dormant mode even in the most arid climates. The plant usually attains a height of about 120 to 400 cm (Gnansounou et al., 2005). Sweet sorghum can thrive with very less quantities of fertilizers and chemicals, thereby making it a more cost efficient and environmental friendly crop. Sweet sorghum juice can be used for ethanol production and the bagasse can be utilized to generate electricity (Monti and Venturi, 2002). States of Texas, Kansas, and Nebraska are the leading producers of sweet sorghum in US (NASS 2007). Sweet Sorghum is an attractive biofuel crop because of its high yield and easy accessibility to fermentable sugars.

Figure 2: Switchgrass to ethanol conversion process
Sweet Sorghum is primarily composed of sucrose and other reduced sugars and starch. Once harvested, sweet sorghum juice can be extracted and converted into ethanol easily via fermentation and distillation. Both sweet sorghum grains as well as stalks are used for ethanol production (Vermerris et al., 2011). The average stem yield of Sweet Sorghum is about 45 tons per hectare and the total sugar obtained from this is about 5.1 – 10.5 tons per hectare (Gnansounou et al., 2005). Sweet Sorghum plants have high sugar content and hence sugar can be readily extracted to produce ethanol. The residual plant matter, bagasse, can be further utilized either to produce energy for sugar extraction or converted to ethanol utilizing the cellulosic biochemical conversion process discussed in the previous section. Ethanol conversion process for Sweet Sorghum involves three main steps: a. Juice extraction from sweet sorghum stalks, b. Juice conversion to sugar via purification, evaporation, crystallization, and centrifugation, and c. Sugar conversion to ethanol using fermentation and distillation (Gnansounou et al., 2005). Figure 3 pictorially illustrate steps of producing ethanol from Sweet Sorghum.
Recognizing the benefits of biofuels, global leaders around the world support the production and use of alternative renewable energy sources and develop policies and partnerships. US President Barak Obama and Indian Prime Minister Dr. Manmohan Singh launched the US-India Partnership to Advance Clean Energy (PACE)\textsuperscript{2} on November 24, 2009. Among the three priority areas under this
partnership, the Indo-US Consortium for development of sustainable advanced lignocellulosic biofuel systems aims to develop and optimize selected non-food biomass (high yielding biomass varieties of Sorghum, Sweet Sorghum, Pearl Millet, Bamboo and Switchgrass) based advanced biofuels systems the US and India.

1.4 Research Objectives

The primary objectives of this thesis is to conduct an economic feasibility analysis of ethanol production using Switchgrass and Sweet Sorghum and evaluate the risks and uncertainties associated with the process. The specific objectives of the research include;

1. Conduct a benefit cost analysis for Switchgrass and Sweet Sorghum as potential feedstocks for biofuel production in US.
   a. Estimate all costs, benefits, and net returns associated with feedstock production, storage, transportation, and conversion to ethanol for 2205 tons per day feedstock capacity bio-refinery with a life span of 15 years in United States.³

2. Conduct a uni-variate sensitivity analysis to account for uncertainty in the ethanol production process.

3. Evaluate the effect of farmer’s risk attitude on net returns from feedstock production.

³ For this analysis the bio refinery capacity is assumed to be 2205 tons of biomass per day. Most economic analysis for biomass conversion to ethanol have assumed similar values. Humbird et al., 2011 assumed a bio refinery capacity of 2205 tons per in their analysis for process design and economics of corn stover.
CHAPTER II
LITERATURE REVIEW

Carriquiry et al. (2011) reviewed the economics of producing biofuels from crop and wood/forestry residues, jatropha, algae, and other lignocellulosic energy crops. The study concluded that although this feedstock had the potential to replace the first generation biofuels, high costs associated with their conversion to ethanol acted as a major roadblock in commercialization. Depending upon the type of feedstock, the production and conversion costs, the cellulosic ethanol produced was found to be two to three times more expensive than gasoline. The study asserted that even though the total feedstock costs for second generation biofuels was 30-50 percent lower than first generation biofuels, significant cost reductions were needed to make the ethanol production process more economically feasible. It was suggested that policy instruments such as fiscal incentives and consumption mandates be differentiated and policy regimes be revised.

Bell et al. (2010) reviewed the economic costs associated with the implementation of biofuel policy in Thailand. The study evaluated and monetized production, environmental and social costs and benefits for such policy implementation and concluded that domestic biofuel production was $317 million more expensive than importing the same amount of petrol. The net cost for biofuel production was calculated to be $285 million, which included environmental
benefits from green house gas savings, and losses due to increased ozone formation at the ground level. The study concluded that short-term biofuels production in Thailand may be expensive but its long-term benefits cannot be ignored.

*Pimentel and Patzek (2005)* conducted a thorough economic and energy input-output analysis for switchgrass, sunflower, corn, and wood biomass in US. The study concluded that the total energy output form ethanol production from these feedstocks was less than the respective fossil fuel input. This was attributed to the fact that during ethanol production large amount of fossil energy is required to remove 8 percent ethanol from 92 percent water. The same is true for biodiesel production, where two factors contribute to low energy returns. One is the relatively low yield of oil crops and the other being the high energy required for the oil extraction process.

*Wang et al. (2011)* performed a detailed lifecycle assessment of the energy, economic and environmental performance of Jatropha curcas L. (JCL) biodiesel in China. The results of the study showed that although the biodiesel produced from JCL was economically infeasible, it had a positive environmental and energy performance. Three main factors were identified as the cause of the economical infeasibility. They were low seed yield of JCL, low co-product output and high farm energy input.
Hill et al. (2006) evaluated the environmental, economic and energetic costs and benefits of biodiesel and ethanol from soybeans and corn respectively. They concluded that ethanol yields 25% more energy than the output energy invested in it, while biodiesel yielded a net energy balance of 93%. Ethanol production from corn reduced greenhouse gas emissions by 12% whereas biodiesel reduces greenhouse gas emissions by 41%.

Aravindhakshan et al. (2010) conducted a study on Switchgrass and Miscanthus to identify their most economical species for cofiring with coal to generate electricity. The study also focused on determining the harvest frequency and carbon tax required for both switchgrass and miscanthus for this process. The study found that switchgrass produced more biomass and energy than miscanthus. The study also calculated the average cost to produce and deliver switchgrass and miscanthus in a 50 km radius. The estimated cost for switchgrass was found to be $43.9 Mg\textsuperscript{-1} and 51.7 Mg\textsuperscript{-1} for miscanthus. The study also concluded that for switchgrass to be economically competitive, a carbon tax of $7 Mg\textsuperscript{-1} CO\textsubscript{2} would be required. The study suggested government interventions like instituting carbon tax etc. are required to make these two feedstock economically competitive for electricity generation in Oklahoma, United States.

Bansal et al. (2013) conducted a feasibility study for switchgrass and miscanthus as potential bioenergy crops in Tennessee, United States. The study calculated net returns, feedstock production cost per Btu, feedstock cost per gallon
of ethanol, breakeven price of feedstock and breakeven price of ethanol for both switchgrass and miscanthus. All costs were calculated over 25 years keeping in mind the total project period. Results of the study showed that the annual net revenue from ethanol production from switchgrass and miscanthus was $363/acre and 752/acre respectively. The study also conducted a sensitivity analysis which concluded that feedstock cost per gallon of ethanol for switchgrass and miscanthus was from $0.52 – $0.78 and $0.44 – $0.66 per gallon respectively.

Lonsdale and FitzGibbon (2011), DiTomaso et al., (2007), and Rajagopal (2007) studied the various risks and uncertainties surrounding biofuel production. All these studies discussed issues like feedstock shortages, abundance of invasive species and consequences of biomass production on food and land. The studies concluded that net benefits need to be maximized in order to lower the risks in profits.

Wessel and Outlaw (2007) used Monte Carlo simulations to quantify the risk and economic prospects that influence the probability of bio-ethanol production from wheat in the winter rainfall region of South Africa. Economic activity in the area was modeled and simulated for ten tears to obtain the results. Their analysis found that a 103 million liter bio-ethanol plant in the region would not be economically viable and give an average ROI of -8.4 per cent and there would be a 97 percent chance that the NPV for the plant would be negative.
Gill (2002) and Herbst (2003) utilized the Monte Carlo simulation technique to incorporate price and cost risk into their analysis. While Gill analyzed the economic feasibility of ethanol bio refineries in Texas for alternate levels of state subsidies, Herbst estimated the economic potential of ethanol production form corn and sorghum. Both researchers incorporated risk in their analysis and presented results in the form of probability of economic success and probability of positive annual cash flows. Richardson et al., 2007 included risk in his analysis of ethanol production costs in Texas for 50 million gallons per year ethanol plant. He utilized Monte Carlo simulations to define probability distributions for all risk variables and then used these distributions to sample stochastic variables to calculate cash flows. The results of his analysis showed that the probability of economic success will be 9.4 per cent and the probability of a positive return on investment is 9.12 percent.

Not much literature has been dedicated to the risk and uncertainty analysis in biofuel production. Considering the relevance for such studies, this thesis aims to address a research gap pertaining to Switchgrass and Sweet Sorghum based biofuels in US. Uni-variate sensitivity analysis and @Risk addin in Microsoft Excel will be utilized to conduct sensitivity and risk analysis for this study. @Risk will assess the probability of getting a positive NPV for different Risk attitudes of farmers. Limited studies have covered this aspect of risk analysis of ethanol production in US and this study will highlight this aspect and add to the existing literature.
CHAPTER III

METHODOLOGY

The first objective for this research thesis involves economic feasibility analysis for biofuel production from Switchgrass and Sweet Sorghum. For this economic decision making process, a cost benefit analysis technique will be used. This section will discuss the basic concepts and theoretical framework for cost benefit analysis and risk and sensitivity analysis.

3.1 Benefit cost analysis

Benefit cost analysis (CBA) is a systematic stepwise process to identify all strengths and weaknesses associated with an investment or project. It is a technique that is used to determine the options that provide the best approach for the adoption and practice of benefits in time, labor, and cost savings (Boardman et al., 2011). Benefits and costs associated with any investment program can be seen as the positive and negative impacts the project will have. A comprehensive CBA framework includes all direct and indirect, social and private, market and non-market, tangible and intangible costs and benefits associated with the project. All these costs and benefits are assessed to calculate the net benefits of the project. Such tools give the decision maker the option to evaluate and compare different projects and choose the one, which maximizes net benefits. The main objective of conducting a cost benefit analysis is to efficiently allocate the limited resources
available to the society. A project should be undertaken relative to other alternatives, only if it is able to demonstrate superior efficiency (Boardman et al., 2011).

There are three types of cost benefit analysis (Boardman et al., 2011). *Ex ante* CBA, *Ex post* CBA, and *in medias res*. *Ex ante* CBA is conducted before the implementation of any project or policy and assists in making a decision of whether or not resources should be allocated or not. *Ex post* CBA on the other hand is a decision making tool that is carried out at the end of a project. Its main purpose is to evaluate if particular classes of projects are worth implementing or not. *In medias res*. CBA is performed during the course of the project and is conducted to decide whether or not the project under analysis should be continued or not (Boardman et al., 2011).

Boardman et al., 2011 has broken down CBA into nine different steps:

1. Identify and list a set of alternative projects.
2. Decide whose benefits and costs count.
3. List benefits and costs separately and select a measurement indicator.
4. Quantitatively predict the impacts over the life cycle of the project.
5. Attach dollar values to all costs and benefits.
6. Calculate present values for all costs and benefits of the project by discounting.
7. Calculate net present values of all alternatives.
8. Conduct sensitivity analysis.

9. Compare net present values of all alternatives and make a decision.

Step 6 and step 7 of the cost benefit analysis require the calculation of present values of costs and benefits of the project. Present Value (PV) is calculated using the formula;

\[ PV = \sum_{t} \frac{E_t}{(1 + r)^t} \]  

(1)

where;

\( E_t \) is the annual costs or benefits
\( t \) is the year in which costs or benefits are occurring
\( r \) is the discount rate

Since we are conducting an economic analysis for a project spread over a timeline of 15 years, there are costs and benefits happening in different time frames. To bring all costs and benefits to the current year or the base year (Year 1) it becomes vital to calculate present values of all costs and benefits as shown in the formula above and thereby calculate the Net Present Value (NPV). BCA utilizes the concept of calculating present values because of two reasons: 1. All resources being utilized in a project has some opportunity cost or the other and 2. Most people prefer to consume now rather than later (Boardman et al., 2011).
3.1.1 Deterministic Model

To assess the economic feasibility of producing ethanol from Switchgrass and Sweet Sorghum, we will perform an Ex ante CBA to decide whether or not the limited resources available today in our society should be allocated to such a project. Financial feasibility will be calculated using net present value of the final products, which is given by:

\[ N = P_e Q_e - C_e Q_e \]  \hspace{1cm} (2)

Where

*NR is the Net returns*

*\( P_e \) is the unit price ethanol produced*

*\( Q_e \) is the quantity of ethanol produced*

*\( C_e \) is the unit cost of producing ethanol*

Since the CBA will be conducted over a period of 15 years, costs and benefits can be easily understood by calculating Net Present Value (NPV);

\[ NPV = \sum_{n=1}^{N} \frac{P_n Q_n + C_n}{(1 + r)^n} + (-C_0) \]  \hspace{1cm} (3)

Where

*NPV is the Net present value*

*\( P_n \) is the price of ethanol produced in the nth year*

*\( Q_n \) is the quantity of ethanol produced in the nth year*
\( C_n \) is the total operating cost incurred to produce the ethanol in the \( n \)th year

\( C_0 \) is the total capital investment in year zero (establishment year)

\( r \) is the discount rate

The cost function \( C_n \) for producing ethanol is a complex function in this process of calculating the net returns. It can be broadly divided into three main categories for our ease.

a. Cost of producing the feedstock (biomass from Switchgrass and Sweet Sorghum): This includes the cost of biomass storage and transportation to bio-refinery

b. Cost of converting biomass to ethanol: This includes total capital investment for 2205 tons per day feedstock capacity bio-refinery and total operating cost to produce ethanol.

The cost function \( C_n \) is calculated as follows:

\[
C_n = P_f F + L + A + E + U + FD \quad (4)
\]

Where

\( P_f \) is the unit cost producing feedstock

\( F \) is the quantity of the feedstock used per year

\( L \) is the total cost of labor per year

\( A \) is the total cost of chemicals used per year

\( E \) is the total cost of enzymes used per year
For the project to be economically feasible the total benefits should be more than the total costs incurred. In this case, for the project to be economically viable;

\[ P_e Q_e \geq C_e Q_e \quad \text{(5)} \]

\[ NR \geq 0 \quad \text{(6)} \]

Apart from calculating the net returns and the net present value, Minimum Ethanol Selling Price (MESP) is also calculated. MESP is defined as that price of ethanol at which the NPV will be zero (Humbird et al., 2011).

### 3.2 Sensitivity Analysis

As mentioned in the previous section, we will be performing an ex ante CBA for conducting our economic analysis in this study. Since an ex ante analysis is conducted before the start of the project, it requires the decision maker to predict the future returns. This incorporates several uncertainties and risks in the project causing certain variability in net returns (Boardman et al., 2011). Net returns from ethanol production using Switchgrass and Sweet sorghum can vary depending on the various costs incurred during the entire ethanol production process.
Sensitivity analysis is conducted to ascertain how sensitive the predicted net returns are to changes in the assumptions made in CBA. If the sign of net benefits does not change when the range of reasonable assumptions is considered, then our results are robust and more reliable (Boardman et al., 2011). There are three types of sensitivity analysis: Partial sensitivity analysis (Univariate sensitivity analysis), Worst-and best-case analysis and Monte Carlo sensitivity analysis. Univariate sensitivity analysis is the simplest form of sensitivity analysis wherein only one parameter is varied at a time keeping all other parameters constant (Andronis et al., 2009). In worst-and best-case sensitivity analysis the main objective is to analyze and study the results under the most optimistic or pessimistic combination of parameters (Andronis et al., 2009). Finally, Monte Carlo simulation technique evaluates runs a large number of simulations for each parameter based on defined distributions and aims at constructing a probability distribution for the results (Andronis et al., 2009). For the purpose of our thesis we will be using the univariate sensitivity analysis since we want to observe the effect of each parameter individually on the NPV. This will give the decision maker a better perspective of which variables impact the NPV more and how varying one parameter at a time will change the net returns.

3.3 Farmer’s risk attitude

Agricultural production is a risk bound environment where farmers make decisions based on production, market, price, and financial uncertainties. Farmers
manage these risks based on their willingness to take risk or their risk attitude 
(Brad and Barry, 2001). Risk can be measured by computing variance of the 
distribution of net returns;

\[ \sigma^2 = Var(NR) = [Var(P_e Q_e) - Var(C_e Q_e)]^2 \]  

(7)

Where

\( \sigma \) is Variance of net returns

\( P_e \) is the unit price of ethanol produced

\( Q_e \) is the quantity of ethanol produced

\( C_e \) is the unit cost of producing ethanol

Equation 6 explains the basic concept behind risk and variance. Different 
levels of net returns have different levels of risks associated with it. Higher risk is 
associated with higher variance in net returns.
Figure 4 above illustrates the various tradeoffs between different levels of net returns and the risks associated with them. Point A on the frontier reflects very low risk and low profits. In order to achieve high returns a farmer will have to move to points B or C which demonstrate high profits but also high risks. Since the curve has an increasing slope, more net returns will be accompanied by higher risks. Point D reflects returns that are impossible to achieve under the current available resources, whereas point E reflects inefficient operations that may achieve greater returns else where with the same level of risk.
Webster and Hillson (2008) describes risk attitudes of individuals in the following way:

a. **Risk Averse:** A risk averse individual is uncomfortable with uncertainty and exploits every opportunity to remove uncertainty. Such a person will likely be comfortable with low outcome, as there is minimum risk involved and would lie on point A of the risk frontier.

b. **Risk Seeking:** A risk-seeking individual is comfortable with uncertainty and is usually satisfied with an uncertain outcome. Such an individual would lie on point C of the risk frontier.
CHAPTER IV
DESCRIPTION OF DATA

As mentioned in chapter one, Switchgrass and Sweet Sorghum were selected as potential biofuel feedstocks for conducting benefit-cost analysis for the purpose of this thesis. This section presents a detailed description of the data sources, data type and all related assumptions. Both primary and secondary data were used to conduct benefit cost analysis and to develop various scenarios for sensitivity and risk analysis. The sources for secondary data included journal research articles, university extension websites, energy yearbooks and commodity price databases. Analysis for Switchgrass was done taking cost and benefit data from three mid-western states namely Illinois, Iowa, and Missouri. Study area for Sweet Sorghum was Florida, Oklahoma, and Texas. Feedstock to ethanol conversion data for Switchgrass and Sweet Sorghum came from the Stan Mayfield Bio-refinery pilot plant located at Florida.

All estimates were adjusted to inflation rates of 2015 using the Gross Domestic Product (GDP) deflator\(^4\). Consumer Price Index (CPI) can also be used adjusting inflation but this thesis utilized GDP deflator, as it is a broader measure of economy-wide inflation as compared to CPI because it includes the prices of all

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\(^4\) The GDP deflator also known as the GDP implicit price deflator is an economic metric that accounts for inflation. It shows how much change in base year’s GDP depends upon changes in price level (Investopedia). Accessed at http://www.investopedia.com/terms/g/gdppricedeflator.asp?layout=infini&v=58&orig=1&adtest=5B
goods and services in the economy (Baumol and Blinder 2009). Prices in 2015 U.S. dollars were calculated using the following formula (Humbird et al., 2011).

\[
\text{Value in 2015} = (\text{Value in year } t) \times \left( \frac{\text{GDP deflator in 2015}}{\text{GDP deflator in period } t} \right)
\] (8)

Data for DGP deflator was taken from the World Bank data Site\(^5\).

**4.1 Feedstock Production: SWITCHGRASS**

Producing Ethanol from Switchgrass requires two main cost components: A. Cost of producing Switchgrass and B. Cost of converting Switchgrass to ethanol. The cost of producing Switchgrass depends on (i) land rent cost (ii) input costs such as fertilizers, chemicals, and seeds, (iii) equipment cost, and (iv) storage and transportation costs. For the purpose of this thesis the per acre costs for overheads (farm insurance and utilities), farmer’s labor, and building repair and depreciation have not been included in the unit cost analysis since it is assumed that these expenses will be same for all perennial and row crops respectively and hence will not affect the relative profitability (Khanna et al. 2008).

Switchgrass is a perennial crop and is can adapt to varied soil and climatic conditions. Its stands typically have a lifespan of 10 years and it takes it up to three years to completely establish itself after which it reaches its full yield potential.

---

Switchgrass yields may vary depending upon the type of soil, cultivar type, climatic conditions, and agronomic practices (Willschleger et al. 2010). Yields in the first three years are 30 percent of the full potential yield (Garland 2008). In some cases the yields in the first few years may be 50 percent of the full potential (Hoque et al. 2015). For our analysis, we assume that yield in year one will be fifty percent less than the full potential yield. The Switchgrass will start producing at full potential from year two onwards.

As mentioned above, Switchgrass stands in US show considerable variation in per acre yields. Garland (2008) reported two different yields for Switchgrass stands in his study. He estimated a yield of 6 to 8 tons per acre for commercial stands and a yield of 10 tons per acre for test plots. Willschleger et al. (2010) conducted a study at several US locations for different Switchgrass ecotypes and varieties. The study found that while upland ecotype of Switchgrass had a mean biomass yield of 8.7 ± 4.2 Mg per hectare, the lowland ecotype had a yield of 12.9 ± 5.9 Mg per hectare. The study also reported a biomass yield between 6.49 and 9.90 Mg per hectare for high quality Cave-in-Rock variety and a yield of 7.13 to 8.58 Mg per hectare for the marginal quality cropland. Finally, Hoque et al. (2015) assumed a Switchgrass yield of six dry tons per acre for his analysis in Iowa. For our research, we assume a Switchgrass yield of 6 tons per acre.

Costs in the establishment year (year 0) are different from the succeeding years as it includes only land preparation costs. Switchgrass crop requires reseeding
in year 2 to achieve high yields. Various studies in the United States have used different reseeding rates for Switchgrass. Turhollow (2000) used a reseeding rate of 15 percent, while Duffy and Nanhou (2001) used a reseeding rate of 25-50% for Switchgrass production. Other researchers like Haque et al. (2015) and Dolginow and Massey (2013) used a reseeding rate of 10 and 30 percent respectively. For our analysis, we have assumed a reseeding rate of 15 percent in the second year. Year 3 onwards per acre costs of production remain same for the Switchgrass stands.

Since costs and yields of Switchgrass are spread over a time frame of ten years, we estimate the discounted value of costs and yields using discounted cash flows. Such analysis of long-term investments is sensitive to the choice of the discount rate (Feldstein, 1964). In the year 2016 there was an interest rate of 2.375 percent on direct farm operating loans (USDA 2016). Hoque et al. (2015) in his study conducted on Liberty Switchgrass in US assumed an interest rate of 8 percent on production costs and an interest rate of 5 percent on operating expenses. Other researchers like Perrin et al. (2008) determined the costs of producing Switchgrass in Nebraska and South Dakota using a discount rate of 10 percent. For our analysis, we estimate the discounted values of costs and yields by using a discount rate of 8 percent. The breakeven Price (BP) of Switchgrass is the price per ton of dry matter produced to cover all costs of production incurred over the life span of 10 years divided by the discounted value of Switchgrass yield (Khanna et al., 2008).

\[
BP = \frac{\sum_{t=0}^{T} \frac{c_t}{(1+d)^t}}{\sum_{t=0}^{T} \frac{Y_t}{(1+d)^t}}
\]  

(10)
Here, \( T \) is the life span of Switchgrass stands i.e. ten years, \( C_t \) is the production cost per acre in time period \( t \), \( Y_t \) is the Switchgrass yield in time period \( t \), and \( d \) is the discount rate (8 percent).

**Land rent:** Switchgrass can be grown on varied soil types and does not require much irrigation or soil nutrients for its growth. It can be grown on land currently utilized for crop production, land under the Conservation Reserve program (CPR) and pastures (Walsh et al., 2003). Various studies conducted in the United States have utilized different land rents for Switchgrass production cost estimates. Perrin et al. (2008) assumed a land rent of $59.67/acre for a farm-scale production study conducted for Switchgrass in North Dakota and Southern Nebraska. While Hoque et al. (2015) assumed a land rent of $77.0/acre, Duffy (2008) used a land rent of $80/acre for his production estimates in Iowa. Current estimates of land rent costs obtained from a farmer in Missouri revealed a per acre land rent of $90. This information was obtained from Mr. Danuser via email on February 11th, 2016. For our current analysis, we assume a land rent of $77 per acre.

**Input Requirements (Fertilizers, Chemicals, and Seeds):** As mentioned above, our current analysis of Switchgrass production focuses on three Midwestern states namely Iowa, Illinois and Missouri. Nitrogen (N), Phosphorous (P) and Potassium (K) is applied to Switchgrass fields at the rate of 60, 2, and 14 pounds per acre respectively. Lime is added in the establishment year for field preparation at
the rate of 1 pound per acre. Herbicides like Atrazine, Acetochlor and 2,4-D, are added at the rate of 1 gallon per acre (Dolginonow and Massey 2013) in year one and year 2 to protect the Switchgrass stands from weed damage (Khanna et al. 2008). We use 5 pounds per acre of pure live seed for Switchgrass establishment in year 1 and 15 percent reseeding is done in year 2 (Hoque et al. 2014). Cost of fertilizers, chemicals and seeds in 2015 prices are: 0.58 $ per lbs for N, 0.51 $ per lbs for P, 0.49 $ per lbs. for K, 19.47 $ per lbs. for Lime, 8.05 $ per gallon for Atrazine, 18,45$ per gallon for Acetochlor, 18.89 $ per gallon for 2, 4-D and 15 $ per lbs. for seeds (Dolginonow and Massey 2013; Hoque et al. 2014). Interest on operating inputs is assumed to be 5 per cent for six months (Haque et al. 2014).

Machinery: The machinery used in establishing Switchgrass in the Midwestern United States consists of a tandem disk, a harrow, airflow planter (to spread fertilizers), and self-propelled sprayer for spraying herbicides (Brummer et al., 2000). Costs of these operations are obtained from Khanna et al. (2008) and converted to 2015 dollars. Seeds are planted using a seed drill at the rate of 16.36 $ per acre (Hoque et al., 2015). Harvesting of Switchgrass can be divided into four main operations. (i) Mowing, (ii) Raking, (iii) Bailing and (iv) Staging and Loading. The first three operations can be performed using conventional grass harvesters and bailers (Duffy and Nanhou 2001). Switchgrass is bailed in square bales for the ease of storage and transportation (Teel et al., 2003). Mowing and raking costs are assumed to be 12.19 and 6.01 $ per ton (Duffy 2008). The cost for making square bales is considered to be 19.64 $ per ton. Once the bales are ready, they are stored
in a storage area one mile away from the Switchgrass field. The cost of staging, loading and transporting the Switchgrass to the storage area is assumed to be $9.34 per ton (Khanna et al., 2008).

**Storage and Transportation:** There are various ways to store Switchgrass after harvesting but for our analysis, we will consider the one, which is the most cost efficient. Switchgrass is stored outside in the open over crushed rocks covered only with a reusable tarp. This type of storage results in a 7% loss in yield. The cost for this method is assumed to be 4.10 $ per ton (Khanna et al., 2008). Transportation costs for Switchgrass vary depending upon the assumptions made. For our analysis, we assume transportation cost to include the cost of transporting Switchgrass bales from the storage facility to a bio-refinery 30 miles away. The semi-tractor used for this purpose is assumed to carry 20 tons of Switchgrass in one load. The total cost of transportation for a bio-refinery situated 30 miles away is considered to be $9.63 per ton (Duffy 2008). Table 1 enlists all the production costs incurred for producing Switchgrass over a period of 10 years. All costs are based on the assumptions made above.
## Table 1: Switchgrass Production cost per acre in 2015 US$

<table>
<thead>
<tr>
<th>Cost Items</th>
<th>Year 0</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Rent</td>
<td>77.00</td>
<td>77.00</td>
<td>77.00</td>
<td>77.00</td>
</tr>
<tr>
<td><strong>Operating Inputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed</td>
<td>0.00</td>
<td>88.67</td>
<td>13.30</td>
<td>0.00</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.00</td>
<td>34.64</td>
<td>34.64</td>
<td>34.64</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>0.00</td>
<td>1.03</td>
<td>1.03</td>
<td>1.03</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.00</td>
<td>7.20</td>
<td>7.20</td>
<td>7.20</td>
</tr>
<tr>
<td>Lime</td>
<td>0.00</td>
<td>19.47</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Atrazine</td>
<td>0.00</td>
<td>8.45</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Acetochlor</td>
<td>0.00</td>
<td>18.89</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2,4-D</td>
<td>0.00</td>
<td>18.89</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>0.00</td>
<td>197.25</td>
<td>56.17</td>
<td>42.87</td>
</tr>
<tr>
<td><strong>Interest on operating inputs</strong></td>
<td>0.00</td>
<td>4.93</td>
<td>1.40</td>
<td>1.07</td>
</tr>
<tr>
<td><strong>Pre-harvest machinery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disking</td>
<td>10.71</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Harrowing</td>
<td>7.09</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Seed Drilling</td>
<td>0.00</td>
<td>16.36</td>
<td>16.36</td>
<td>0.00</td>
</tr>
<tr>
<td>Fertilizer Application</td>
<td>0.00</td>
<td>10.19</td>
<td>5.10</td>
<td>5.10</td>
</tr>
<tr>
<td>Chemical Application</td>
<td>0.00</td>
<td>15.39</td>
<td>7.70</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>17.80</td>
<td>41.94</td>
<td>29.15</td>
<td>5.10</td>
</tr>
<tr>
<td><strong>Harvesting</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mowing</td>
<td>0.00</td>
<td>12.19</td>
<td>12.19</td>
<td>12.19</td>
</tr>
<tr>
<td>Raking</td>
<td>0.00</td>
<td>6.01</td>
<td>6.01</td>
<td>6.01</td>
</tr>
<tr>
<td>Bailing</td>
<td>0.00</td>
<td>58.91</td>
<td>117.82</td>
<td>117.82</td>
</tr>
<tr>
<td>Staging and Loading</td>
<td>0.00</td>
<td>28.02</td>
<td>56.04</td>
<td>56.04</td>
</tr>
<tr>
<td>Storage</td>
<td>0.00</td>
<td>12.29</td>
<td>24.59</td>
<td>24.59</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>0.00</td>
<td>117.42</td>
<td>216.65</td>
<td>216.64</td>
</tr>
<tr>
<td><strong>Transportation</strong></td>
<td>0.00</td>
<td>24.39</td>
<td>48.78</td>
<td>48.78</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td>94.80</td>
<td>462.94</td>
<td>429.15</td>
<td>391.46</td>
</tr>
<tr>
<td><strong>Yield per acre in tons</strong></td>
<td>0.00</td>
<td>3.00</td>
<td>6.00</td>
<td>6.00</td>
</tr>
</tbody>
</table>
4.2 Feedstock Production: SWEET SORGHUM

As discussed in section 4.1 above, producing ethanol from Sweet Sorghum also consists of two primary costs: A. Cost of producing Sweet Sorghum and B. Cost of converting Sweet Sorghum to Ethanol. This section gives details of all expenses incurred during Sweet Sorghum production. The main cost components involved in producing sweet sorghum can be classified as (i) land rent cost (ii) input costs such as fertilizers, chemicals, and seeds, (iii) equipment cost, and (iv) storage and transportation costs. In this analysis as well, the per acre costs for overheads (farm insurance and utilities), farmer’s labor, and building repair and depreciation have not been included.

Sweet Sorghum is an annual drought resistant crop known for its high photosynthetic efficiency and high adaptability to temperate regions (Worley et al., 1992; Gnansounou et al., 2005; Martini et al., 2006). Sweet Sorghum yields can vary considerably depending upon factors like soil type, crop variety, climatic conditions and irrigation used. Worley et al. (1992) found that Sweet Sorghum stalks could grow over ten ft. tall and produce a dry matter yield of more than 10 tons per acre. While Veal et al. (2013) estimated a dry matter yield of 11 tons per care per year, Amosson et al. (2011) assumed a dry yield yields of 8.34 tons per acre for irrigated Sweet Sorghum and 3.25 tons per care for dry land Sweet Sorghum. They also estimated a total wet yield of 28.75 tons per acre for irrigated Sweet Sorghum and 11.20 wet tons per acre for dry land Sweet Sorghum. For the purpose of this thesis, we assume a total wet yield of 22 tons per acre and bagasse yield at 7 tons per acre.
Sweet Sorghum being an annual crop, costs and benefits happen in the same year, and hence this analysis does not require discounted cash flows. For our analysis, we estimate the breakeven price (BP) of Sweet Sorghum. BP of Sweet Sorghum is determined using the same formula as used in section 4.1 for Switchgrass.

\[
BP = \frac{\sum_{t=0}^{T} \frac{c_t}{(1+d)^t} \cdot \frac{Y_t}{\sum_{t=0}^{T} \frac{1}{(1+d)^t}}}{\sum_{t=0}^{T} \frac{Y_t}{(1+d)^t}}
\]

Here T is the life span of the Sweet Sorghum crop (T=1), C_t is the production cost per acre in time period t (t=1), Y_t is the Sweet Sorghum yield per acre in time period t (t=1) and d is the discount rate (d=0).

**Land rent:** Sweet Sorghum crop is drought resistant and requires less water and fertilizer inputs as compared to sugarcane (Bradford, 2008; Vecchiet, 2010). It can be grown on any land type but gives best yields on loamy and sandy loam soils (Bioenergy, 2012). Helsel and Alvarez (2013) assumed a land charge of $75 per acre to calculate the economic potential of Sweet Sorghum in South Florida. For our analysis, we assume a land rent of $77 per acre keeping it constant with the land rate used for our Switchgrass analysis.

**Input Requirements (Fertilizers, Chemicals, and Seeds):** As mentioned previously, Sweet Sorghum establishes easily in most conditions, but it prefers warm soils. The appropriate planting period for establishment lies between late April to early May (Veal et al., 2014). A seed rate of 5 lbs per acre is assumed to
achieve desired yields. Nitrogen (N) and Phosphorus (P) fertilizers are assumed to be added at the rate of 60 lbs per acre to increase biomass yield (Veal et al., 2014). Lime is added to Sweet Sorghum fields to reduce counter acidic soils at the rate of 2 tons per acre (Helsel and Alvarez, 2013). Two different herbicides are added to control weeds in Sweet Sorghum. For this study, we assume a rate of 1.50 pt per acre for herbicide 1 and two qt per acre for herbicide 2 (Helsel and Alvarez, 2013; Amosson et al., 2012). Cost of fertilizers, chemicals and seeds in 2015 prices are: 0.58 $ per lbs for N, 0.51 $ per lbs for P, 0.49 $ per lbs. for K, 19.47 $ per lbs. for Lime, 8.05 $ per gallon for Atrazine, 18$ per gallon for Acetochlor, 18 $ per gallon for 2, 4-D and 15 $ per lbs. for seeds (Helsel and Alvarez, 2013; Amosson et al., 2012). Interest on operating inputs is assumed to be 5 per cent for six months.

**Machinery:** Sweet Sorghum crop requires minimum to no-tillage practices as it is planted in fully prepared seedbeds (Viator et al., 2014). Seeds can be planted using grain drills or row crop planters (Veal et al., 2014). Here we assume that seeds are planted once using a plant drill at the rate of $13.20 per acre (Amosson et al., 2012). Harvesting Sweet Sorghum is a difficult process, and it has traditionally been harvested manually using machetes. The cost of such manual labor costs approximately $540 per acre (Veal et al., 2014). For this analysis, Sweet Sorghum was assumed to be de-headed before harvesting. This was done to increase sugar yields. After de-heading, Sweet Sorghum crop was harvested using a corn silage harvester (Helsel and Alvarez, 2013).
**Storage and Transportation:** In spite of its high biomass yield and high concentration of fermentable sugars, Sweet Sorghum has found limited use as a feedstock for ethanol production. This can be attributed to the fact that it has poor post-harvest storage characteristics and very short harvest window (Bennett and Anex 2008). Conversion should be initiated soon after harvest to avoid spoilage of the feedstock. Delayed fermentation may lead to sugar reduction due to the production of organic acids, thereby reducing ethanol yield (Cundiff and Parrish, 1983). For this analysis, we assume that Sweet Sorghum stalks were crushed on the farm to extract Sweet Sorghum juice immediately after harvesting and then sold off at the rate of $28.80 per ton (Gnansounou et al., 2005). The bagasse obtained from this juice extraction can further be utilized for lignocellulosic ethanol production. The transportation cost for this bagasse is assumed to be $0.30 per ton per mile. The biorefinery should be within a 50-mile radius from the place feedstock production, or the cost of transportation would be too high (Chang, 2013). Here we assume that the bio-refinery is located 30 miles away, same as considered in the case of Switchgrass analysis. Table 2 enlists all the production costs incurred for producing Sweet Sorghum yearly. All costs are based on the assumptions made above.
Table 2: Sweet Sorghum Production Costs in 2015 US$

<table>
<thead>
<tr>
<th>Cost Items per</th>
<th>Year 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Rent</td>
<td>77.00</td>
</tr>
<tr>
<td><strong>Operating Inputs</strong></td>
<td></td>
</tr>
<tr>
<td>Seed</td>
<td>28.40</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>34.80</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>30.60</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.00</td>
</tr>
<tr>
<td>Lime</td>
<td>38.94</td>
</tr>
<tr>
<td>Herbicide 1</td>
<td>3.60</td>
</tr>
<tr>
<td>Herbicide 2</td>
<td>3.27</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>139.61</td>
</tr>
<tr>
<td>Interest on operating inputs</td>
<td>3.49</td>
</tr>
<tr>
<td><strong>Pre-harvest machinery</strong></td>
<td></td>
</tr>
<tr>
<td>Disking</td>
<td>12.82</td>
</tr>
<tr>
<td>Plant Drill</td>
<td>14.10</td>
</tr>
<tr>
<td>Fertilizer Application</td>
<td>5.10</td>
</tr>
<tr>
<td>Chemical Application</td>
<td>7.70</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>39.72</td>
</tr>
<tr>
<td><strong>Harvesting</strong></td>
<td></td>
</tr>
<tr>
<td>Deheading</td>
<td>17.45</td>
</tr>
<tr>
<td>Harvesting</td>
<td>215.94</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>233.39</td>
</tr>
<tr>
<td>Transportation</td>
<td>64.21</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td>557.42</td>
</tr>
<tr>
<td>Wet Yield per acre in tons</td>
<td>22.00</td>
</tr>
<tr>
<td>Dry yield per acre in tons</td>
<td>7.00</td>
</tr>
</tbody>
</table>
4.3 Feedstock conversion to ethanol: Switchgrass and Sweet Sorghum

The University of Florida operates a pilot-scale bio-refinery, located in Perry, Florida. The bio-refinery has a capacity of 100,000 gallons per year and uses the process called liquefaction with simultaneous saccharification and co-fermentation (L+SSCF). This process includes a phosphoric acid-catalyzed pretreatment, followed by enzymatic liquefaction and fermentation using engineered E.coli. (Gubicaza et al., 2016). Primary data generated from this bio-refinery was utilized to perform a cost-benefit analysis for a commercial bio-refinery with 2205 dry tons of feedstock capacity per day. Design, economic and scaling up process data was obtained from SuperPro Designer software. The pilot scale refinery utilized Sugarcane bagasse for ethanol production and the scaled up data thus obtained from SuperPro Software was also for Sugarcane bagasse. Extensive conversations with Dr. Leonnie Inngram and his team during the bio-refinery visit on November 12th, 2015, revealed that the costs involved for Conversion of Switchgrass and Sweet Sorghum bagasse to ethanol would primarily remain the same and hence the Sugarcane bagasse data can be utilized for the unit cost analysis for both Switchgrass and Sweet Sorghum. Costs being the same, ethanol yield per ton of feedstock and the byproducts would differ, thereby impacting the net returns. The data for ethanol yield for each feedstock and their respective by-products was obtained from the existing literature.
**Ethanol Yield (Switchgrass and Sweet Sorghum):** The overall process design and economics of ethanol production is based on the type and composition of feedstock used for such analysis. Feedstock composition plays a vital role in the analysis as it affects the ethanol yield (Humbird et al. 2011). Switchgrass is composed of 37.5 percent Glucan, 21.7 percent Xylan, 2.7 percent Arabinan, 1.6 percent Galactan, 0.6 percent Mannan and 18.5 percent Lignin (Lee et al., 2007). Sweet Sorghum has 13 percent fiber while sugarcane contains 13 percent fiber (Kim and Day, 2011). Sweet Sorghum is composed of 33 percent Cellulose, 27 percent hemicellulose, and 19 percent lignin (Aragon et al. 2013). Ethanol yield of feedstocks determines the net benefits obtained from ethanol production. Different studies have assumed varying levels of ethanol yield for lingo-cellulosic biomass. Humbird et al. (2011) considered an ethanol yield of 79.0 gal/dry ton of Corn Stover. Department of Energy (DOE) estimated an ethanol yield of 97.7 gal/dry ton for Switchgrass and 113.0 gal/dry ton for Corn Stover (DOE, 2016). Laser et al. (2009) found in his comparative efficiency analysis study on mature biomass refining scenarios that ethanol yield of Switchgrass can range from 97-105 gal/dry ton. While Amosson et al. (2011) used an ethanol yield of 80 gallons per ton of Sweet Sorghum Bagasse, DOE (2016) estimated an ethanol yield 111.5 gallons per ton of bagasse. For the estimates of this study, we assume an ethanol yield of 100 gal/dry ton for Switchgrass and 82 gallons per ton for Sweet Sorghum Bagasse.

Cost estimates in table 3 and table 4 are based on a medium capital bio refinery located in Florida (Rijn et al., 2015). The cost of the equipment purchased for the bio refinery is based on the SuperPro Designer database. Total capital
investment consists of the direct fixed capital cost, working capital and startup costs. The direct fixed capital costs are calculated by using cost factors as listed in Appendix C (Rijn et al. 2015). Working capital is assumed to cover 30 days of operation and the startup costs are assumed to be 5 percent of the direct fixed capital costs. These assumptions are based on the standard values that are set in the SuperPro Designer software (Rijn et al. 2015). Table 4 enlists the total capital investment cost for a 2205 tons feedstock capacity per day bio refinery in Florida (Rijn et al. 2015). The total operating costs listed in table 4 consists of raw material costs, labor, utilities and facility dependent costs. Facility depend costs include maintenance, depreciation, and miscellaneous costs. The life of the bio-refinery is assumed to be 15 years, and it is assumed to be functional for 333 days a year. The discount rate for the NPV calculation is set to 11%. The discount rate used here for NPV calculations is similar to discount rates used in such analysis (Humbird et al., 2011).
Table 3: Total capital investment for 2205 tons feedstock per day capacity ethanol plant. All figures are in 2015 Million U.S.$

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Million US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment purchase cost</td>
<td>34.20</td>
</tr>
<tr>
<td>Installation</td>
<td>18.90</td>
</tr>
<tr>
<td>Process Piping</td>
<td>10.30</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>10.30</td>
</tr>
<tr>
<td>Insulation</td>
<td>1.00</td>
</tr>
<tr>
<td>Electrical</td>
<td>1.70</td>
</tr>
<tr>
<td>Buildings</td>
<td>13.70</td>
</tr>
<tr>
<td>Yard Improvement</td>
<td>3.40</td>
</tr>
<tr>
<td>Auxiliary Facilities</td>
<td>10.30</td>
</tr>
<tr>
<td><strong>Total Plant Direct Cost:</strong></td>
<td><strong>103.80</strong></td>
</tr>
<tr>
<td>Engineering</td>
<td>20.80</td>
</tr>
<tr>
<td>Construction</td>
<td>31.10</td>
</tr>
<tr>
<td><strong>Total Plant Indirect Cost</strong></td>
<td><strong>51.90</strong></td>
</tr>
<tr>
<td><strong>Total Plant Cost</strong></td>
<td><strong>155.70</strong></td>
</tr>
<tr>
<td>Contractors fee</td>
<td>6.20</td>
</tr>
<tr>
<td>Contingency</td>
<td>12.50</td>
</tr>
<tr>
<td><strong>Direct Fixed Capital Cost</strong></td>
<td><strong>174.40</strong></td>
</tr>
<tr>
<td>Working Capital</td>
<td>6.70</td>
</tr>
<tr>
<td>Start-up Cost</td>
<td>8.70</td>
</tr>
<tr>
<td><strong>Total Capital Investment</strong></td>
<td><strong>189.80</strong></td>
</tr>
</tbody>
</table>
Table 4: Total operating costs per year for Switchgrass and Sweet Sorghum. All figures are in 2015 Million US$.

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Switchgrass</th>
<th>Sweet Sorghum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor (^a)</td>
<td>3.6</td>
<td>3.60</td>
</tr>
<tr>
<td>Facility Dependent (^b)</td>
<td>27.7</td>
<td>27.70</td>
</tr>
<tr>
<td>Utility (^c)</td>
<td>14.1</td>
<td>14.10</td>
</tr>
<tr>
<td>Feedstock (^d)</td>
<td>58.33</td>
<td>18.60</td>
</tr>
<tr>
<td>Enzymes (^e)</td>
<td>8.3</td>
<td>8.30</td>
</tr>
<tr>
<td>Chemicals (^f)</td>
<td>18.5</td>
<td>18.50</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>130.53</strong></td>
<td><strong>90.80</strong></td>
</tr>
<tr>
<td><strong>Ethanol Produced (Gallons)</strong></td>
<td><strong>73.43</strong></td>
<td><strong>59.84</strong></td>
</tr>
</tbody>
</table>

\(^a\) 60 FTE/year @ $60,000 average salary  
\(^b\) Facility dependent cost = maintenance (10% of equipment cost) + depreciation (using straight-line method) + miscellaneous (insurance 1%, local taxes 2%, factory expenses 5% of direct fixed costs)  
\(^c\) Water @ $0.22/MT  
\(^d\) Breakeven price ($/ton) for Switchgrass and Sweet Sorghum calculated in this study  
\(^e\) 2.5% (w/w) on dry matter basis @ $1/kg  
\(^f\) Phosphoric acid 0.8% (w/w), ammonia 1% and 2% (w/w) on dry matter basis. Cost of phosphoric acid and ammonia was assumed to be $0.80/kg and 0.68/kg respectively.

### 4.4 Sensitivity analysis

As discussed in section 3, cost-benefit analysis of biofuels is a complex process using many uncertain variables. For the appropriate handling of such uncertainty, sensitivity analysis is conducted. This section details the data used for sensitivity analysis for Switchgrass and Sweet Sorghum.
Table 5: Scenarios for Switchgrass sensitivity analysis

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Base case</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Varying Switchgrass Yield</td>
<td>6 tons per acre</td>
<td>20% increase in yield 20% decrease in yield</td>
</tr>
<tr>
<td>2: Varying Land Rent</td>
<td>$77 per acre</td>
<td>20% increase in land rent 20% decrease in land rent</td>
</tr>
<tr>
<td>3: Varying ethanol yield from Switchgrass bagasse</td>
<td>100 gallons per dry ton of Switchgrass</td>
<td>5% increase in ethanol yield 5% decrease in ethanol yield</td>
</tr>
<tr>
<td>4: Discount rate</td>
<td>11%</td>
<td>Using discount rates 5%, 7%, 9%, and 14%</td>
</tr>
<tr>
<td>5: By-products</td>
<td>None</td>
<td>Liquid fertilizer – covers half the cost of chemicals used in ethanol production</td>
</tr>
</tbody>
</table>

Note: Sensitivity analysis range for each parameter listed in the above table is based on existing literature. The highest and lowest ranges mentioned come from the highest and lowest values of the parameters recorded in the existing literature. Section 4.1 and 4.2 discuss the ranges for each parameter in detail.

The sensitivity of Net Present Value (NPV) is examined by investigating the impact of changes in project variables on the base case scenario. For this purpose, five scenarios were analyzed. The range of different scenarios builds on the assumptions made in this section for different variables like Feedstock yield, Feedstock production land rent, ethanol yield per gallon of feedstock, discount rates, and by-products obtained. Table 5 and 6 enlist the different scenario assumptions for Switchgrass and Sweet Sorghum.
### Table 6: Scenarios for Sweet Sorghum sensitivity analysis

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Base case</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1: Varying Sweet Sorghum yield</td>
<td>22 tons wet yield per acre</td>
<td>20% increase in yield 20% decrease in yield</td>
</tr>
<tr>
<td>Scenario 2: Varying land rent</td>
<td>$77 per acre</td>
<td>20% increase in land rent 20% decrease in land rent</td>
</tr>
<tr>
<td>Scenario 3: Varying ethanol yield from Sweet Sorghum bagasse</td>
<td>82 gallons per ton of Sweet Sorghum bagasse</td>
<td>5% increase in ethanol yield 5% decrease in ethanol yield</td>
</tr>
<tr>
<td>Scenario 4: Discount rate</td>
<td>11%</td>
<td>Using discount rates 5%, 7%, 9%, and 14%</td>
</tr>
<tr>
<td>Scenario 5: By-products</td>
<td>None</td>
<td>Liquid fertilizer – covers half the cost of chemicals used in ethanol production</td>
</tr>
</tbody>
</table>

Note: Sensitivity analysis range for each parameter listed in the above table is based on existing literature. The highest and lowest ranges mentioned come from the highest and lowest values of the parameters recorded in the existing literature. Section 4.1 and 4.2 discuss the ranges for each parameter in detail.
4.6 Farmer risk attitude

The last objective of the study was achieved by analyzing the effect of farmer’s risk attitude on the net returns from Switchgrass. @Risk software was utilized to define probability distributions for two different farmer categories (Risk averse and Risk taker). Feedstock yield was selected as the parameter against which the net returns for Switchgrass were varied. Triangular\(^6\) distribution was selected for both risk seeker and risk averse farmer, but the feedstock yield was varied differently for different risk attitudes. Results were calculated by running 1000 iterations using @Risk add-in in Excel. Table 6 describes the feedstock yield range for Switchgrass for different risk attitudes.

Table 7: feedstock yield range for Switchgrass for different risk attitudes

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Most Likely</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Risk Averse</strong></td>
<td>6.5</td>
<td>6</td>
<td>5.7</td>
</tr>
<tr>
<td><strong>Risk Seeker</strong></td>
<td>8</td>
<td>6</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Note: Since a risk averse farmer is not comfortable with uncertainty and is satisfied with lower returns to counter risk his feedstock yield range is very narrow. On the other hand a risk seeker farmer is comfortable with uncertainty and hence has a wider range for his feedstock yields.

\(^6\) Triangular probability distribution is one of the many probability distributions found in @risk. It is a continuous distribution that allows the data to take up any value between upper and lower limits (Rees 2009).
CHAPTER V

RESULTS

This section presents the results obtained from data analysis using the methodology discussed in chapter 3. Results of unit cost analysis of Switchgrass and Sweet Sorghum along with the sensitivity and risk analysis have been presented in this section with the help of tables and graphs. Since the objective of this study was to analyze the economic viability of Switchgrass and Sweet Sorghum as potential feedstocks for ethanol production, this section accounts for the costs, benefits, net returns and Net Present Value (NPV) for both feedstocks. Results from sensitivity analysis and risk analysis are presented to understand the economics better and help the stakeholders make better investment decisions.

5.1 Unit Cost Analysis: Switchgrass and Sweet Sorghum (Base Scenario)

Using the data and assumptions from chapter 4, total costs, benefits, net returns, and NPV for ethanol production from Switchgrass and Sweet Sorghum were simulated. At an ethanol price of $2.17 per gallon, both Switchgrass and Sweet Sorghum give positive net returns. Per gallon net returns from Sweet Sorghum are three times more than Switchgrass. This can be attributed to high feedstock costs incurred in the case of Switchgrass.

The NPV at 11% discount rate for Switchgrass and Sweet Sorghum was estimated to be 39.54 and 96.76 respectively in the base case scenario. A positive
NPV for both feedstocks shows that total revenues are more than total costs. Since benefits exceed costs, ethanol production from Switchgrass and Sweet Sorghum is feasible. Results from the base case scenario are summarized in Table 8.

Table 8: Unit cost analysis results (base Scenario). All values are in 2015 U.S.$

|                                | Switchgrass | Sweet Sorghum |
|                                |             |               |
| Breakeven Price per ton (Feedstock Production) | 75.24       | 25.34         |
| Total Costs per gallon         | 2.10        | 1.94          |
| Total Benefits per gallon      | 2.17        | 2.17          |
| Net Returns per gallon         | 0.07        | 0.22          |
| NPV (Million U.S.$)            | 39.54       | 96.76         |
| MESP per gallon                | 2.10        | 1.94          |

5.2 Sensitivity Analysis: Switchgrass and Sweet Sorghum

The sensitivity of the NPV was examined in five different scenarios using one-way sensitivity analysis in excels. The assumptions made for sensitivity analysis have been discussed in chapter 4. This section presents the results obtained from the sensitivity analysis for both feedstocks.
**Sensitivity to By-products**

In the base case scenario, it is assumed that there are no by-products and all energy produced is utilized in the bio-refinery itself for ethanol production for both feedstocks. However, liquid fertilizer obtained at the end of the process can be sold as a by-product. The NPV for Switchgrass increased from 39.54 to 106.05. Similarly, the NPV for Sweet Sorghum also rose from 96.76 to 228.82 when the revenues from liquid fertilizer were added to the analysis. NPV for both feedstocks is highly sensitive to addition revenues from by-products.

**Sensitivity to changes in biomass yield**

A 20 percent increase in Switchgrass yield increases the NPV to 93.66 while a 20 percent decrease results in an NPV of -34.85, making the investment infeasible. Decreasing Switchgrass yield by 20 percent results in lower net benefits and thereby makes the investment unprofitable. On the other hand, a 20 percent increase in Sweet Sorghum yield increases the NPV to 110.42 and a 20 percent decrease results in an NPV of 76.27. There is a considerable change in NPV taking it closer to zero but the investment remains profitable. NPV for Switchgrass is highly sensitive to Switchgrass yield as even a 10 percent change from the base scenario results in a negative NPV. Figure 6 illustrates changes in NPV for Switchgrass and Sweet Sorghum with percentage changes in their respective yields.
Figure 5: NPV sensitivity to percentage change in feedstock yield (Switchgrass)

Figure 6: NPV sensitivity to percentage change in feedstock yield (Sweet Sorghum)
Sensitivity to changes in land rent

A 20 percent increase in land rent decreases the NPV to 24.98 while a 20 percent reduction results in a higher NPV of 54.09. Varying land rent charges over the assumptions made in Chapter 4 does not result in a negative NPV. Doubling the land rent would result in a negative NPV for Switchgrass but such a scenario is unlikely as the maximum land rent observed in our study area is $90. Meanwhile, a 20 percent increase in Sweet Sorghum land rent decreases the NPV to 93.07, and a 20 percent reduction results in a higher NPV 100.46. Figure 7 illustrates changes in NPV for Switchgrass and Sweet Sorghum with percentage changes land rent charges.

![NPV sensitivity to percentage change in land rent (Switchgrass)](image)

Figure 7: NPV sensitivity to percentage change in land rent (Switchgrass)
Sensitivity to changes in ethanol yield

A 5 percent increase in Switchgrass ethanol yield increases the NPV from 39.54 to 96.83 while a 5 percent decrease results in an NPV of -17.75, making the investment infeasible. Decreasing Switchgrass ethanol yield by 5 percent results in lower net benefits and thereby makes the investment unprofitable. On the other hand, a 5 percent increase in Sweet Sorghum yield increases the NPV to 143.74 and a 5 percent decrease results in an NPV of 49.49. There is a considerable change in NPV taking it closer to zero but the investment remains profitable. NPV for Switchgrass is highly sensitive to Switchgrass ethanol yield as even a 5 percent change from the base scenario results in a negative NPV. Figure 8 illustrates changes
in NPV for Switchgrass and Sweet Sorghum with percentage changes in their respective yields.

Figure 9: NPV sensitivity to percentage change in ethanol yield (Switchgrass)

Figure 10: NPV sensitivity to percentage change in ethanol yield (Sweet Sorghum)
Sensitivity to changes in discount rate

A 20 percent increase in land rent decreases the NPV to 24.98 while a 20 percent reduction results in a higher NPV of 54.09. Varying land rent charges over the assumptions made in Chapter 4 does not result in a negative NPV. Doubling the land rent would result in a negative NPV for Switchgrass but such a scenario is unlikely as the maximum land rent observed in our study area is $90. Meanwhile, a 20 percent increase in Sweet Sorghum land rent decreases the NPV to 93.07, and a 20 percent reduction results in a higher NPV 100.46. Figure 9 illustrates changes in NPV for Switchgrass and Sweet Sorghum with percentage changes land rent charges.

![Switchgrass NPV sensitivity to percentage discount rate](image)

Figure 11: NPV sensitivity to percentage discount rate (Switchgrass)
5.3 Effect of risk attitude on net returns: Switchgrass production

Defining probability distributions for risk averse and risk seeking farmers and running thousand iterations in @risk gives us an estimate of the variance in net returns for these two farmer categories. The results show the probabilities of getting different NPV’s for varying Switchgrass yields based on the risk attitude of the farmers. For a risk-averse farmer, there is only a 9.5 percent probability that the NPV will be less than zero. There is an 85.5 percent probability that the NPV will be between 0 and 76.8, while there is just 5 percent probability that it will be higher than 78.8. These results clearly indicate that while a risk-averse farmer might not achieve very high net returns but he/she will definitely have a very low probability of facing losses. The maximum and minimum NPV that can be achieved by a risk-
averse farmer is 122.56 and -38.06 respectively. The mean NPV was estimated to be 33.65 with a standard deviation of just 26.04. In the case of risk seeking farmer the mean NPV was estimated to be 72.51 with a standard deviation of 148.66. While the probability of a risk-seeking farmer having a NPV of less than zero was estimated to be 67.4 percent, probability of a positive NPV was only 32.6 percent. There is only a 5 percent probability that the NPV would be over 168. The maximum and minimum NPV observed in the case of a risk seeking farmer lie between 353.74 and -495.11. These results clearly reinforce the idea that a risk-seeking farmer is comfortable with high variance in net returns and is willing to take higher risks even for a lower probability of achieving higher net returns. Figure 10 and 11 show the probability distribution of NPV for risk-averse and risk-seeking farmers.

Figure 13: Probability distribution of NPV for risk-averse farmer
Figure 14: Probability distribution of NPV for risk-seeking farmer
CHAPTER VI

CONCLUSION AND DISCUSSION

The NPV for both Switchgrass and Sweet Sorghum at 11% discount rate and ethanol price of $2.17 is positive. Thus it can be inferred that at an ethanol price of $2.17, ethanol production from Switchgrass and Sweet sorghum is commercially competitive. The MESP for Switchgrass and Sweet Sorghum were estimated to be $2.10 and $1.94 per gallon. The national renewable energy laboratory (NREL) estimated an MESP of $2.15 per gallon while Sarica et al. (2009) reported a price of $2.04 - $2.20 per gallon (NREL, 2011). The current gasoline price in the United States is $2.24 (EPA 2016). Blending gasoline and the ethanol produced from Switchgrass to obtain E85 gives a price of $2.12. Similarly, E85 obtained from blending gasoline and ethanol from Sweet Sorghum gives a price of $.1.99 Also, E85 contains 17 percent less energy than gasoline. Adjusting for these lower energy content, results in a price of $2.90 per gallon gasoline equivalent for Switchgrass and $2.73 per gallon gasoline equivalent for Sweet Sorghum. To be competitive with the current gasoline price in the United States, MESP for Switchgrass and Sweet Sorghum needs to be $1.53 per gallon. This is 47 percent less in the case of Switchgrass and 44 percent less in the case of Sweet Sorghum. Although the results indicate that the MESP for ethanol for both Switchgrass and Sweet Sorghum is not competitive with the current price of gasoline in the US, it will be naïve to compare just the dollar values and not take into account the green house gas emission reductions associated with using ethanol. This huge difference can be attributed to
historically low gasoline prices in the United States. Reducing high feedstock prices in case of Switchgrass by utilizing more efficient production technologies can bridge this gap. Also, the process of lignocellulosic ethanol production needs to be optimized further to achieve such a target.

Wu et al. (2006) analyzed the benefits of utilizing biofuels produced from cellulosic biomass as a transpiration fuel in US. Their results found that using E85, bio-DME (Dimethyl ether), and bio-FTD (Fischer-Tropsch Diesel) as transportation fuel reduced the use of gasoline by 66 to 93 percent and fossil energy use by 65 to 88 percent per mile. This reduction in the fossil fuel usage also results in an 82 to 87 percent reduction in green house gas emissions (Wu et al., 2006).

The MESP for Switchgrass and Sweet Sorghum obtained from this analysis is in line with other techno-economic analysis conducted for lignocellulosic feedstocks (Humbird et al., 2011, Degrauwe et al. 2013, Nesbit et. al 2011, Hill et al. 2006, Perrin et al. 2008). Sensitivity analysis of net returns in all five scenarios resulted in understanding the most sensitive parameter in this cost-benefit analysis. Net returns of Switchgrass were found to be very sensitive to ethanol yield, and hence measures need to be taken to sustain and eventually further optimize the conversion process. Additional revenues from by-products increased the net returns of both feedstocks. On the feedstock production end, Sweet Sorghum production costs estimated in this analysis were relatively low compared to other lignocellulosic feedstocks. Further research on the use and market price of the liquid fertilizer obtained at the end of the ethanol conversion process will further reduce MESP for lignocellulosic feedstocks making it economically competitive with
gasoline. This was due to the exclusion of Sweet Sorghum juice extraction costs. Risk analysis conducted to estimate variance in net returns of Switchgrass farmer based on his risk attitude reconfirmed that higher net returns are associated with higher risks.

Although the results obtained provide a thorough insight into the questions and objectives of this study, they are limited by some data constraints. The biofuels production data for Switchgrass and Sweet Sorghum utilized in this analysis came from existing literature and utilizing primary data from actual production sites would further strengthen the analysis. The inclusion of primary conversion data for Switchgrass and Sweet Sorghum from the Perry bio-refinery would also further enhance the results of this analysis. Another factor not included in the results includes the costs associated with the distribution and marketing of the ethanol produced at the bio refinery. The MESP obtained in the analysis is the price at the bio refinery gate and including costs associated with its distribution to ethanol pumps will further increase the MESP. Also, to obtain an unbiased economic viability report, inclusion of factors other than just production and conversion costs should also be taken into account. Impact of government subsidies, tax rebates and incentives should also be incorporated in the economic feasibility analysis. Another notable limitation of this study lies in not incorporating the non-market values associated with the development of Switchgrass and Sweet Sorghum as biofuel crops. The study is also limited in its scope, as it does not account for the energy and environmental impacts associated with the ethanol production process. Incorporating impacts of land use change, non-market values and broader economic
impacts on the economy would provide a new perspective on the economic viability of these biofuels. Overall this study concludes that production of Ethanol from Switchgrass and Sweet Sorghum is a profitable investment in the United States. While it reduces the burden on food crops like corn for ethanol production, it also contributes to making the world less dependent on non-renewable fuels. While the study was successful in satisfying the objectives outlined, considerable amount of work needs to be done in this research area to enhance the productivity of existing biofuels.
APPENDIX A

BIOMASS PRODUCTION AND CONVERSION AREA IN THE UNITED STATES USED FOR THIS STUDY

SWITCHGRASS PRODUCTION STUDY AREA

SWEET SORGHUM PRODUCTION STUDY AREA
APPENDIX B

SCHEMATIC REPRESENTATION OF ETHANOL PRODUCTION PROCESS AT STAN MAYFIELD BIOREFINERY (Rijn et al., 2015)
APPENDIX C

COST FACTORS USED TO CALCULATE DIRECT, INDIRECT, AND OTHER COSTS INVOLVED IN ETHNOL PRODUCTION PROCESS

The table below shows the cost factors associated with the calculation of direct, indirect, and other costs associated with a high, medium, and low capital bio refinery. Peters et al. (1968) developed this approach of calculating low, medium, and high capital projects. The costs are calculated based on land factors. The lang factor associated with a high capital investment facility producing fine chemicals is taken as 6.3. This is the SuperPro Designer default value for any high capital fine chemicals producing facility (Rijn et al., 2015). While the lang factor for a medium capital biomass-based bio refinery is 5.1, for a low capital investment it is 3.2. A lang factor of 3.2 is considered the lowest possible value for a facility that produces ethanol using a process used in a pilot scale bio refinery (Rijn et al., 2015).
<table>
<thead>
<tr>
<th>Cost Factors</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>1.00 x PC</td>
<td>1.00 x PC</td>
<td>1.00 x PC</td>
</tr>
<tr>
<td>Installation</td>
<td>0.53 x PC</td>
<td>0.53 x PC</td>
<td>0.42 x PC</td>
</tr>
<tr>
<td>Piping</td>
<td>0.35 x PC</td>
<td>0.30 x PC</td>
<td>0.10 x PC</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>0.40 x PC</td>
<td>0.30 x PC</td>
<td>0.10 x PC</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.03 x PC</td>
<td>0.03 x PC</td>
<td>0.03 x PC</td>
</tr>
<tr>
<td>Electrical facilities</td>
<td>0.10 x PC</td>
<td>0.05 x PC</td>
<td>0.05 x PC</td>
</tr>
<tr>
<td>Buildings</td>
<td>0.45 x PC</td>
<td>0.40 x PC</td>
<td>0.15 x PC</td>
</tr>
<tr>
<td>Yard Improvement</td>
<td>0.15 x PC</td>
<td>0.10 x PC</td>
<td>0.05 x PC</td>
</tr>
<tr>
<td>Auxiliary Facilities</td>
<td>0.40 x PC</td>
<td>0.30 x PC</td>
<td>0.15 x PC</td>
</tr>
<tr>
<td>Direct Cost (DC)</td>
<td>3.41 x PC</td>
<td>3.01 x PC</td>
<td>2.05 x PC</td>
</tr>
<tr>
<td>Engineering</td>
<td>0.25 x DC</td>
<td>0.20 x DC</td>
<td>0.15 x DC</td>
</tr>
<tr>
<td>Construction</td>
<td>0.35 x DC</td>
<td>0.30 x DC</td>
<td>0.25 x DC</td>
</tr>
<tr>
<td>Indirect Cost (IC)</td>
<td>0.60 x DC</td>
<td>0.50 x DC</td>
<td>0.40 x DC</td>
</tr>
<tr>
<td>Contractor’s Fee</td>
<td>0.05 x (DC + IC)</td>
<td>0.04 x (DC + IC)</td>
<td>0.04 x (DC + IC)</td>
</tr>
<tr>
<td>Contingency</td>
<td>0.10 x (DC + IC)</td>
<td>0.08 x (DC + IC)</td>
<td>0.08 x (DC + IC)</td>
</tr>
<tr>
<td>Other Cost</td>
<td>0.15 x (DC + IC)</td>
<td>0.12 x (DC + IC)</td>
<td>0.12 x (DC + IC)</td>
</tr>
<tr>
<td>Direct Fixed Capital</td>
<td>6.3 x PC</td>
<td>5.1 x PC</td>
<td>3.2 x PC</td>
</tr>
</tbody>
</table>

PC: Equipment purchase cost, DC: Direct Cost, IC: Indirect Cost
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