DEVELOPING A BUDGET TO PLANT, HARVEST AND TRANSPORT SWITCHGRASS

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DEVELOPING A BUDGET TO PLANT,

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SWITCHGRASS

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CHAPTER I

INTRODUCTION

If there is any hope of moving away from fossil fuels, and towards renewable alternatives, a comprehensive economic analysis of the problem must be performed. This study is the first step in a larger economic analysis. It determines the least-cost method of harvesting and transporting large quantities of switchgrass for a biorefinery by determining the cost of different methods of harvesting and transporting switchgrass.

History

Cellulosic biomass for conversion into fuel has been considered a “best source of fuel” as early as 1921 when Harold Hibbert, a professor at Yale University, warned that the United States would become dependent on foreign sources for oil (Birur, Hertel and Tyner 2007). Unfortunately, this process was always too expensive to compete with petroleum. However, Henry Ford and other early car manufacturers designed cars to run on a variety of fuels including alcohol, gasoline, and even mixtures of the two. After World War I, gasoline emerged as a dominant fuel source and even though leaded gasoline was considered a health hazard in 1921, it was cheap enough to remain the dominant fuel source. During the 1930s, falling corn prices caused a brief interest in corn-based ethanol. Gasoline contained 5%-17.5% ethanol up until the end of World War II when the shortage of petroleum products disappeared. Ethanol remained in the background and unused as a major fuel source until the fuel shortages in the 1970's (e85.whipnet.net 2009).

In the 1970's there were significant disruptions in oil supply from the Middle East, and environmental concerns arose over the use of leaded gas. This, combined with the Arab Oil embargo of 1973, caused long lines at gas stations. In response to fuel shortages, the government passed the Energy Tax Act of 1978, which provided an exemption to the $.04/gallon tax on gasoline blended with 10% ethanol. This tax measure, in combination with two other pieces of legislation, caused ethanol production in the United States to go from 175 million gallons per year to 1.4 billion gallons in 1998 (e85.whipnet.net 2009).

Ethanol remained in the background until 1997, when ethanol production began to increase. Between 1997 and 2005, ethanol production tripled from 1.3 billion to 3.9 billion gallons in the US and has continued to increase since then (KSGrains.com 2008). The reason for this expansion in ethanol production is twofold. First, President Bush stated in his 2006 State of the Union address that the US should produce 35 billion gallons of ethanol by 2017 (Bush 2006). Additionally, the Energy Independence and Security Act of 2007 takes this mandate further and requires 36 billion gallons of renewable fuels to be produced annually by 2022. Second, the government has promised a significant amount of funding for ethanol, including $385 million for five large bio-refineries (MSNBC 2007), $200 million for small scale bio-refineries (Ruggiero 2007) and $30.7 billion from the Department of Energy for a wide variety of renewable energy projects including $800 million for cellulosic biofuels, an unnamed amount for integrated biorefinery operations, and an unnamed amount of for the development of advanced biofuels. (Arizona State University 2009).

Between the increase in fuel prices and the funding for alternative fuels, there is a significant amount of research being conducted to alleviate the United States dependency on foreign oil. In 2006, during his State of the Union Address, President Bush said "We'll also fund additional research in cutting-edge methods of producing ethanol, not just from corn, but from wood chips and stalks, or switch grass. Our goal is to make this new kind of ethanol practical and competitive within six years." (Bush 2006).

This statement caused the creation of the Sun Grant Initiative, a collaboration of land grant universities. The official centers are at Oregon State University, South Dakota State University, Oklahoma State University, the University of Tennessee, and Cornell University. There are also other universities that have contributed to this research. The projects these universities are working on include researching ways to improve lignocellulosic ethanol conversion and pretreatment for cellulosic ethanol. The lignocellulosic ethanol study strives to achieve three goals.

1. Gather residual biomass in a central location for conversion of a primary product.
2. Evaluate the effectiveness of enzymes and compressed water to decrease energy consumption for converting biomass into ethanol.
3. Evaluating the use of ionic liquids and N-methyl morpholine oxide monohydrate (NMMO•H2O) for significantly enhanced enzymatic multiphase solutions instead of solid biomass. (Sun Grant Association 2008).

While the main emphasis has been on the production of ethanol, there are plants considering the use of switchgrass or other lignocelluloses materials to burn with coal in an effort to reduce costs. An example of this is the Chariton Valley coal plant in Iowa.

Studies have started looking at co-firing coal plants with switchgrass to reduce the emissions the coal plants produce. Currently, coal plants produce over half of the electricity used by the United States, and even a minor drop in emissions at all coal plants could significantly reduce total emissions from coal plants. The largest full-scale experiment is the Chariton Valley coal plant in Chillicothe, Iowa. They have done full scale testing at this plant and reported two valuable pieces of information. The first piece of information this study provided was the steps and process modifications required to convert a coal plant to co-fire with biomass. The second piece of information is the raw data collected from the ash and gas analysis. The gas analysis showed a slight reduction in SOx, and a slight increase in NOx. However, it is important to note that the data fluctuated because the switchgrass handling system wasn't perfect and the flow rate of switchgrass into the system varied (Amos 2002).

Another study evaluating co-firing switchgrass with coal evaluates the economic, environmental, and energy aspects of co-firing switchgrass. This study found that switchgrass has a positive energy balance of approximately 90%. This study also found that the green house gas emission during co-firing is 58.1 g of CO2-Eq/kWhr for a 5% co-fire as compared to 90.5 g of CO2-Eq/kWhr for burning switchgrass by itself. These numbers took into account the co-firing ratio, hauling distance, yield, and stand life. According to this study, for switchgrass to become economically competitive under current prices either growing or hauling costs must decrease. Finally, this study found that it will cost $50-

$100/kW to modify a coal only plant to a co-fire plant operating 24 hours/day 300 days per year with an estimated 10 year life and 10% salvage value (Qin, Mohan and El-Halwagi 2006).

Recently, there has been increased use of biomass in electricity generation, which has been helped by the Public Utilities Regulatory Policies Act (PURPA) of 1978. This act guaranteed small electricity producers that utilities would purchase electricity at the same rate they charge their customers. This act is responsible for increasing the connected electricity generation connected to the grid from less than 200 MW to over 7500 MW in the last 30 years. Some of these plants have been able to use waste biomass to supply up to 75% of their electrical needs (Overend 1997).

All of these different projects represent the different ways that have been developed to help the United States reduce its dependency on foreign energy sources. While no single project will solve the problem, hopefully a combination of solutions will be found that can solve the problem.

Biofuels

Biofuels are defined as a solid, liquid, or gas fuel derived from recently dead biological plant material. Currently, switchgrass is one of the most discussed feed stocks for liquid fuel. However, there are different feed stock sources that can be used (Bush 2006). Any type of plant oil, tree, grain, woody material, or cellulose crop can be used to make biofuels such as ethanol, methanol or biodiesel. Biofuels have been used since the late 1800's. However, there are several reasons why switchgrass is being heavily studied as a primary source for biomass. First, it is cheap. When the right species of switchgrass is planted, it takes very little water and fertilizer to produce yields of five to ten tons per acre. Studies show farms should be able to get ten tons of switchgrass per year with the application of 110 lb/acre of nitrogen (Vogel et al. 2002). Additionally, switchgrass is highly resistant to disease and pest infestation which makes switchgrass more attractive than using other crops (Parrish and Fike 2005). However, there is research that is skeptical of the potential for switchgrass. There are six major cost components: land rental, establishment, fertilizer, harvest, storage, and transportation. All of these costs except establishment and fertilizer should be similar across all perennial species. This means finding the species with the lowest establishment and fertilizer cost with respect to yield will be ideal (Aravindhakshan, Epplin and Taliaferro 2008).

Differences between Crops Grown for Biomass and Crops Grown for Food

Farmers have spent thousands of years perfecting methods and machinery for food consumption. However, biomass crops have different needs. Food crops are grown to maximize the consumable yield, while biomass crops need to be grown to maximize lignocellulosic biomass. Bio-refineries see quality as having no outside materials in the product, low price, high concentration of lignocellulosic biomass, and in a form easy to process (Williams 2006).

Currently, one of the biggest challenges that biofuels face is the perception that they are the cause of higher food prices. According to a recent study, this is partially true. The increased production of ethanol has raised food prices between 1.1% and 1.8% which is a much lower number than the actual increase in food prices. There are a variety of other factors that have caused food prices to go up that are not related to biofuels or alternative energy. The price increase due to biofuels translates to approximately $22 billion increase per year, or about $75 per person (Tokgoz et al. 2007).

In May of 2008 USDA Deputy Secretary Chuck Conner; chief economist Joe Glauber; Tom Dorr, Under Secretary for Rural Development; and Dr. Gale Buchanan, the Under Secretary for Research, Education and Economics, had a briefing with reporters to address the concerns that food used for fuels was increasing food prices. In this presentation, the President's Council of Economic Advisors stated that while world food prices have increased more than 40%, only 3% of that increase is due to corn going toward fuel instead of food. To put this in perspective, in 2007, food prices increased 4%, which is 1.5% higher than the average 2.5% increase between 1990 and 2007. They also predicted that the 2008 price levels will increase 5% over the 2007 prices (USDA.gov 2008).

Table I-1 shows the estimated change in output and land usage from 2006 to 2010:

Table I-1. Change in output and land use due to US-EU biofuel expansion: 2006-2009 (Birur, Hertel and Tyner 2007)

Aggregate Land Use Change (%)	USA	Canada	EU	Brazil	All Others
coarse grains	11.2	11.7	0.5	3.7	4.7
other grains	-13.5	-2.4	-12.9	-7.8	0.1
oilseed	-6.2	13.9	21.4	12.4	5.4
sugarcane	-5.8	-3.5	-6.1	1.7	-0.9
livestock	-6.8	-3.8	-6.3	-5	-0.9
forestry	-11.6	-11.1	-16.1	-11.1	-4.3
other agricultural goods	-6.4	-3.7	-7.1	-5.8	-0.9
Change in Output (%)					
coarse grains	13.8	15.6	3.6	6.5	5.8
other grains	-12.5	0.3	-10.8	-6.2	1.3
oilseed	-4.5	18.3	26.4	16.1	8.2
sugarcane	-4.2	-1.2	-3.3	3.7	-0.1
livestock	-5.1	-1.3	-3.2	-2.9	0.4
forestry	-1.5	-0.5	-2.5	-1.3	0.6
other agricultural goods	-4.1	-1	-3.9	-3.8	0.1

Switchgrass

Switchgrass (Panicum virgatum) is a warm season perennial grass native to North America. The two basic types of switchgrass are upland and lowland. The difference between lowland and upland switchgrass is lowland switchgrass develops better in flood regions and requires less nitrogen than the upland varieties. However, there are different subspecies within the major categories. These generalities are sometimes nullified within the various subspecies. For example, one type of upland subspecies may require more water than a different species of lowland switchgrass. After analyzing the different species of switchgrass, Alamo and Kanlow were determined to be the best species of switchgrass to use in Oklahoma (Parrish and Fike 2005).

While there are many different crops that can be used for biomass, switchgrass was chosen for two main reasons. First, and most importantly, switchgrass was specifically mentioned by President Bush in his 2006 State of the Union Address. Second, switchgrass is a hearty crop which can survive with relatively little water and fertilizer. It has been used on Conservation Resources Program Land for this reason to prevent soil erosion.

Purpose

The purpose of this study is to provide more information so a decision can be made as to the viability of switchgrass as a feedstock for ethanol in Oklahoma. There is an increasing demand for liquid fuel to power automobiles that gasoline and diesel cannot keep up with indefinitely. The hope is to find a viable alternative that will last indefinitely, and this study provides another piece of information that will allow a more informed decision to be made.

Problem Statement

The objective of this study is to determine the minimum cost of switchgrass delivered to the door of the refinery by looking at different harvesting and handling processes and currently available baling/compacting machinery.

Objectives

- Determine the lowest cost method to harvest switchgrass
- Determine the lowest cost method to transport switchgrass
- Examine the available storage methods
- Develop an interactive model that will allow ethanol producers and farmers to identify optimal methods for a switchgrass supply chain.

Procedures

A. Review the cost for establishing a 10 year stand of switchgrass

B. Examine how switchgrass is harvested

    a. Determine the different ways switchgrass can be harvested

        i. Mow > Rake > Bale

        ii. Forage

        iii. Forage > Modules

    b. Find the cheapest way to harvest switchgrass

C. Examine how swtichgrass is stored

    a. Determine how switchgrass can be stored

        i. At the plant

        ii. At a storage depot

        iii. In the field

    b. Find the optimal way to store switchgrass

D. Examine how switchgrass can be transported

    a. Examine how switchgrass is transported

        i. Class 7 truck - Day Cab

        ii. Class 5 truck

        iii. Rear Loading Garbage truck

        iv. Shipping containers

    b. Examine the best-fit alternatives for handling and transporting switchgrass

CHAPTER II

LITERATURE REVIEW

An accurate estimation of the cost for getting switchgrass to the processing plant is a critical step if the United State is to move forward with switchgrass as a biofeedstock. Since the scale of ethanol production with switchgrass as a major biofeedstock is significant, even a small error in the estimation of one or more costs could change the profitability potential of switchgrass and cost millions of dollars. This study strives to evaluate the work previous authors have done, and determine a total cost to take switchgrass from a seed to the biorefinery taking into account all of the likely costs. Since this study is not evaluating a specific cost, all of the cost estimates are general estimates, but should give the user the ability to make an informed decision about using switchgrass as a biofeedstock for ethanol production.

The following section shows a synopsis of this research starting with types of switchgrass, their differences, and how to choose the correct type of switchgrass. The next section covers the requirements for switchgrass including enterprise budgets, nitrogen requirements, yield, and land availability. Finally, it finishes with transportation issues, and concludes with similar models.

Switchgrass Budgets

A good example of a region specific budget is the Iowa State University (ISU) Extension budget. This budget assumes a yield of four tons/acre and allocates over $350,000 for the cost of an offsite building to store the switchgrass, which is one alternative for storage. There are other cheaper alternatives such as placing tarps over the bales to prevent weather damage. While this type of budget is helpful, it assumes that there is only one way to harvest, transport, and store switchgrass. Additionally, it only accounts for storage in one place; however, it is more likely that the switchgrass will need to be stored on field, at a storage depot, and at the processing facility. This study only accounts for the storage cost at the storage depot. (Payne 2008).

The budget done by the USDA Natural Resource Conservation Service (NRCS) in Mississippi is another example of a good region specific budget. It takes into account all of the same factors as the ISU budget, but adjusts the costs for the local area. However, there are important differences between the Oklahoma budget and the Mississippi budget. The Mississippi budget uses more herbicide and fertilizer treatments. These costs add up over time and can increase the cost per ton of switchgrass (Wilkes 2007).

The Oak Ridge National Laboratory in Tennessee published a different study in 1995. This study strives to estimate the potential switchgrass yields for 2000, 2005, and 2020 in an effort to determine the energy potential of the United States in the near future. In addition to providing an estimated budget for Tennessee, this study also brings up key points. First, for any significant energy to be produced from switchgrass, land must be converted from something else to switchgrass. This means a corn or wheat farmer must be convinced to stop growing corn or wheat and start growing switchgrass. Second, this study assumes that switchgrass yields will continue to increase by 3.1% per year for the first five years, and 1.7% per year for the following fifteen years. Lastly, this study assumes that research will allow supply costs to go down and the price per ton of switchgrass would have to be near $60/ton to convince corn farmers to grow switchgrass. Unfortunately, while this study does provide a production budget, it does not specify how much fertilizer or herbicide was used (Graham et al. 1995).

Haque et al (2008) provided an itemized switchgrass budget, but also pointed out flaws in the United States energy policy and tries to address issues that potential switchgrass farmers might have. They also described exactly how the perennial grasses were grown. The first issue addressed in this study is the US energy policy. The authors argued that because of the amount of foreign nitrogen used in corn production, it does not provide the US with energy independence. Since approximately two-thirds of the nitrogen used for agricultural use is imported, corn converted into ethanol doesn't count as being independent of foreign sources. Because there are few facilities that use switchgrass as biomass, farmers are concerned about growing switchgrass and not having a local buyer. Since switchgrass is a poor pasture grass, this study also evaluated Bermudagrass, weeping lovegrass, and flaccidgrass. These three grasses are significantly better pasture grasses that could be used to feed cattle if the farmer is unable to sell it to a switchgrass processing facility.

Switchgrass yield potential

Aravindhakshan, Epplin, and Taliaferro (2008) found that test fields in Oklahoma and Texas using 62lbs of nitrogen cut once per year in October had a yield of approximately 5.4 tons/acre on average. If the same amount of fertilizer is used and the field is cut twice per year in July and October, a yield of 4.2 tons/acre is expected. However, if 167lbs of nitrogen is used on a field that is cut twice per year, a yield of 6.26 tons/acre can be achieved. After varying the amount of nitrogen and the number of harvests per year, this study determined that 62lb/acre of nitrogen and cutting once per year produced the cheapest switchgrass per acre.

Before this study, Epplin (1996) used a yield of 6.2 tons per acre which is consistent with the results from the previous study.

Switchgrass yield potential is important to this study for several reasons. First, it directly affects the harvesting cost per acre. Second, it affects the total number of acres required for a biomass plant to operate. Last, it will affect the average distance between the plant and the farm.

Land availability for switchgrass

While it is important to determine the expected price of ethanol derived from switchgrass, it is also important to determine the potential availability of land available for switchgrass. Raneses et al (1998) stated that Oklahoma has the potential to generate up to 174.17 Billion kWh per year using 15.52 million acres with a return to land, capital, and management of $8.82/acre. This study assumed a yield of 7.9 tons/acre at a price of $24/ton with land rental costing $30/acre. According to the National Agriculture

Statistics Service, there are approximately 13 million acres of cropland in Oklahoma in the 2007 census. Currently the land is used for a variety of different crops, only 1,000 acres of which is switchgrass (Jones 2009; USDA - NASS 2009).

Congress mandated the set-aside of 14.7 million ha of erosion-prone croplands for 10 years to curtail erosion of the soil resource base and protect water quality across the nation. The Conservation Reserve Program (CRP) was established in Title XII of the Food Security Act of 1985. Soon after its inception, the very nature of its merit, implementation strategies, benefits, and deficiencies, and its future were extensively debated. The program was reauthorized in 1996, adding environmental benefits to the requirements for new enrollment or renewal of expired contracts. Landowners would have to re-qualify under more stringent environmental benefit criteria or choose alternate land uses for their CRP fields (Daoa et al. 2000).

There are different studies which look at using CRP land to grow switchgrass. Currently in Oklahoma there are approximately one million acres enrolled in CRP (Epplin 1996; Osborn 1995) which is approximately 10% of the cropland in Oklahoma (USDA - NASS 2009).

Claassen and Tegene (1999) published a decision tool that helps the user determine if CRP land should be converted to cropland or pastureland in the Iowa Corn Belt. This model differs from previous models because it uses site-specific data instead of state or county data. While this model was designed to be used with CRP land, this model also has a secondary purpose. It is designed to evaluate how conversion between cropland and pastureland is affected by conversion costs, land quality, and government policy. This study found that higher quality land was best suited for cropland while lower quality land is better suited for pastureland. It also found that once land has been established as cropland, there is a low probability of it being converted into pastureland. The only exception for this is government intervention such as CRP. This includes periods of declining returns for the crop being grown (Claassen and Tegene 1999).

Daoa et al (2000) looked at how to transition idle land in a CRP contract and determine if it should be used as cropland or pastureland, and the best way to transform that land. The authors provided instructions on how to treat CRP land in preparation for cotton, winter wheat, and perennial grasses and show the yields obtained by the various crops on two different test plots.   The study showed the results of a three year test plot to give the reader an idea of yields (Daoa et al. 2000).

These studies are important because they help shed light on some of the different areas which are available for growing switchgrass. The location of switchgrass production will also affect the yield and optimal locations for storage facilities.

Why Square Bales are Used in This Study

Popp and Hogan (2007) looked at planting and harvesting switchgrass. They found that using square bales is more effective than round bales. The round bales used in the study had a tendency to fall apart while the bales were being tested for moisture and density. This study found that the squares bales held together better and were easier to handle, and this study will assume that each of the square bales used weighs 1,000 lbs.

This study also evaluated the cost of harvesting and transporting round bales and modules of switchgrass. Since energy prices have increased in recent history, this study re-evaluates the economics of switchgrass harvesting and transportation based on previous studies. Instead of calculating a cost for transportation, they used the local third party rates.

The only downside with this study is that it assumes there is a local third party transportation service available for transporting switchgrass. While there are different places throughout the country where this service is available, this is not the case in all locations (Popp and Hogan 2007).

Custom Rates

Part of this study will look at the cost of harvesting switchgrass, and one of the primary methods for harvesting is hiring independent contractors to harvest the switchgrass. Custom rate publications were taken from Oklahoma State University, University of Minnesota, Kansas State University, Iowa State University, and the University of Purdue. The Oklahoma State University, University of Purdue, and Iowa State University studies publish the results of custom rate surveys taken in their respective geographical locations. The University of Minnesota study estimates the cost of harvesting by calculating the cost, and Kansas State University has both a calculated and published cost for harvesting (Doye, Sahs, and Kletke 2007; Lazarus 2008; Beaton, Dhuyvetter and Kastens 2003; Iowa State University Extension Office 2008; Dobbins and Matli 2007)

Transportation costs

One of the major costs of using switchgrass as a fuel source is transportation, and the more switchgrass that can be hauled on a truck, the fewer the number of trips that need to be made. Pelt (2002) examined the factors involved in compressing hay for the purpose of transportation and attempted to determine the temperatures and pressures required for this operation.

There are studies looking at the best way to transport hay from one place to another. All of those studies show that the more hay that can be put on a truck, the cheaper the cost per ton of material. There are different methods and types of trucks which can be used to haul hay around, but the common theme is being able to transport hay as cheap as possible (Wilkes 2007; Kumar and Sokhansanj 2006; Thorsell et al. 2004; Epplin 1996).

One question that has been brought up throughout various studies is the value of pre-processing or the use of a storage depot for switchgrass in between the farm and processing facility. According to a progress report from the Oklahoma Bioenergy Center, using a satellite or storage depot between the farm is inefficient because the smaller trucks used to bring the switchgrass to the processing facility are less efficient than the larger trucks that take the switchgrass to the processing plant (Jones 2009). However, in the future, technology may be developed that will allow pre-processing to be profitable.

Similar Harvesting and Transportation Models

Tatsiopoulos and Tolis (2002) developed a mathematical model to estimate the cost of a logistic system for transporting cotton stalks in three different scenarios. The first scenario assumes four major power plants that are attached to existing cotton gin factories. The second scenario assumes one large power plant, and the final scenario assumes one thousand small, decentralized combined-heat-and-power units. A decentralized combined heat and power unit is a small unit that is connected to the power grid and produces both heat and power for its user. The final scenario assumes 250 small power plants. Each of the three scenarios has three sub-options: baling, pallets, and dry storage in a barn. Based on the inputs, this model found that the cheapest method was using the barn to dry the hay in scenario one or two where the farmers participate in the transportation process. However, the system must be large enough to take advantage of economies of scale.

Epplin (1996) focused on the big picture instead of concentrating on the harvesting and transportation. This study looks at land availability, estimating an enterprise budget, harvesting, and transportation. The study found estimated costs for the aforementioned processes, but made assumptions that do not hold. This study assumed that only CRP land would be used, but found that conditions would have to be better than expected to meet the minimum economies of scale for a profitable operation.

Evaluation of the IBSAL model

The integrated biomass supply analysis and logistics model (IBSAL) is a modeling environment used to estimate biomass costs. This program is designed to calculate costs for combining, shredding, baling (large square), transporting and stacking, and storage costs. Different authors have used it as a starting point for estimating biofuel data. This model takes into account current and regional data to estimate biomass costs. The various authors who have used this model are able to tweak the model in different ways to fit the purpose of their individual study (Sokhansanj, Turhollow and Wilkerson 2008).

A 2006 study sponsored by the University of British Columbia and BIOCAP looked at yield, supply area, schedule, harvest and collection, pre-processing, and transportation. Instead of starting from scratch, they used the ISBAL model to crunch the numbers for the project. Unlike other studies, they determined not only a cost to move the switchgrass, but factored in loading and unloading costs, stacking costs, and grinding costs. After looking at the harvesting section of the budget, the harvesting costs ranged from $20/ton to $35/ton. This cost includes everything from mowing until the bales are on the side of the field. It found the total cost to load, transport, unload, stack, and grind switchgrass was between $19 and $26 per ton. This study assumed a variable distance between 20km and 100km. While it does not specify a weight, based on other studies, the bale should weight between 1000 lb and 1700 lbs. While this study looks at all of the important factors of biomass, the authors list the results, not the base numbers used to achieve them making the results impossible to replicate, although the numbers used are still good for benchmarking (Sokhansanj and Fenton 2006).

A 2006 study using the IBSAL model was performed by the Oak Ridge National Laboratory using the cotton gin model for the underlying conceptual framework. This study had similar results to the aforementioned study. The harvesting costs for this study were just over $20/ton while the transportation costs were about $33/ton (Sokhansanj, Kumar and Turhollow 2006).

Hess (2007) looked at the entire process from planting through transportation. It found that 35%-50% of the total production cost of ethanol is the delivered cost of the biofeedstock. The purpose of this study is to determine the actual cost of delivered biofeedstock and how that cost is broken up. This study found the baling and storage costs to be approximately $20/ton. This cost includes baling the biomass in large square bales and the storage cost for biomass. The pre-processing and transportation costs are just under $20/ton. These costs include grinding the biomass in the field and hauling the biomass 76km to a processing facility. The author determined that the best way to reduce costs is to optimize equipment and timing of processes to increase efficiency.

How This Research Differs From Other Studies

This research will differ from the aforementioned studies in two ways. Previous studies only looked at using traditional methods of harvesting, transporting, and storing switchgrass. This study will look at alternative and non-traditional methods to complete these tasks in an effort to lower the costs. Second, this study comes with an easy to use interactive model that lets the user adjust any inputs they desire.

CHAPTER III

METHODS AND PROCEDURES

The model that will be used for this study is a centralized distribution model. The ethanol plant will bring in switchgrass from local producers in a 360° radius, and then convert the switchgrass into ethanol. Once the ethanol has been made, it will in turn be shipped out for consumption. This plant will operate similar to a cotton gin that was running 350 days/year. Cotton gins take in material from different sources, process the material, and ship it out in all directions. The cotton industry has developed methods and procedures over the years that allow them to do this efficiently and much of what they do might be beneficial in a switchgrass conversion facility (Altus Cotton Co-Op 2008).

This model assumes that the ethanol plant will contract with local farmers who live between 15 and 45 miles away from the bio-refinery and operate 350 days per year. This study will assume that the farmers achieve average yields every year, and will not take into account extreme circumstances. However, the ethanol plant should develop a plan of action in the event that the local switchgrass crop is destroyed by circumstances beyond their control. Trucks will make daily runs to pick up the switchgrass. While the plant should have enough switchgrass on hand to last a few days without the deliveries in case of problems such as impassable roads, or holidays, this study does not take into account those factors. Farmers will harvest their crop between October and February, with pickup or delivery dates based on their arrangement with the ethanol plant. The switchgrass will be stored on farm until it is transported to the processing facility or a storage depot. This study will determine the method that will minimize the total cost overall without regard to the party responsible for the equipment. This model will also look at the best place to store switchgrass.

This project will be divided into two parts. The first part will concentrate on finding the costs for traditional methods of harvesting and transporting switchgrass, and the second part will focus on non-traditional methods of planting, harvesting, and transporting switchgrass. All of the results will be placed into a Microsoft® Excel® budget model, and stochastic modeling will be used to identify optimal methods across a wide range of variable.

Break the Project Down Into Three Component Parts

1. Harvesting
2. Storage
3. Transporting

For each of the three parts, determine standard and alternative methods of completing each component part.

Harvesting Switchgrass

Harvesting can be done by either the farmer or contractors that are known as "custom cutters." Each year, the average custom rates are published, and these rates were used to compare against what it would cost a farmer to harvest switchgrass on his own land. The cost for a farmer to harvest his own switchgrass was determined by using a Microsoft®

Excel® powered program called AgMach (Huhnke, Venkateshwaran, and Vikas 2008). There are three different processes which can be used to harvest switchgrass: baling, chopping, and module building.

Baling Switchgrass

There are five basic steps involved in baling switchgrass or any other type of hay. While there are machines that can combine the different steps, each of the steps will be discussed individually.

Step 1 – The farmer makes the first pass in his tractor with a mower attachment on a tractor. This cuts the grass at a predetermined height and leaves it sitting on the ground. Tractors run into the tens of thousands of dollars depending on the brand and power. Mowers usually run between $10,000 and $20,000 depending on the size and are an attachment to the back of a tractor (John Deere 2008).

Step 2 – The second step is called windrowing. This is a process where the loose switchgrass on the ground is stacked up in long rows as shown in figure III-1. The machine that makes the windrows is shown in figure III-2. This allows the switchgrass to dry, reducing the moisture content from about 40% to 12%. This is important because it allows the bales to be more effectively compressed and reduces the energy required in the conversion process. Additionally, it prevents the switchgrass from molding or spontaneously combusting once it has been baled. Attached to the tractor, the windrowing implement is a piece of equipment that usually costs between $10,000 and $20,000 (John Deere 2008). If harvesting takes place after the first frost, this process becomes unnecessary.

Figure III-1. Example of a Windrow (morvik.com/ 3/26/09)

Figure III-2. Example of a Rake (beavervalleysupply.com 3/26/09)

Step 4 – During the fourth step, a machine called a baler goes through the field and picks up the stacks of switchgrass and forms them into bales. The large square bales which will be used for this study measure approximately 4’ x 4’ x 8’. A baler runs into the tens of thousands of dollars and is attached to the back of a tractor.

Form of switchgrass for storage and shipping is also an issue. Currently, in Oklahoma farmers use round bales because they resist moisture better than square bales. Unfortunately, while round bales are more resilient to rain, they are much harder to stack and transport than square bales (Huhnke 1993). This study will be using square bales because they are easier and safer to stack on a truck for transportation.

Step 5 – Lastly, the bales are picked up and moved to the side of the field where they can be stored and easily loaded once the truck arrives for transport. A Stinger is a piece of equipment that is used to pick up bales on the field, load them on a trailer, and move them to the desired location. This study will use a Stinger unit to move bales around the field. Figure III-3 shows a tractor pulling a baler that is picking up hay, baling it, and dropping it off in the field as large square bales.

Baling machines can run in cost from $50,000 and $150,000 (John Deere 2008). Rakes and windrowing attachments each cost between $5,000 and $20,000 (John Deere 2008). These costs were taken from P&K Equipment which is a John Deere dealership in Stillwater, OK (John Deere 2008).

Figure III-3. Example of a Baler (claas.com 3/26/09)

Chopped Switchgrass

Step 1 – The farmer makes the first pass in a piece of equipment call a foraging machine. This machine cuts and chops the grass into pieces as small at one inch in length. Then, the switchgrass will probably need to be raked and left until it dries. Since the optimal harvest time for switchgrass is after frost, it does not need to be raked into windrows to be dried and can be immediately loaded into a forage box for storage. After the switchgrass has been raked into a row, a fan is used to blow the chopped switchgrass into a forage box that is pulled behind the tractor. The foraging machine and the forage box will cost tens of thousands of dollars depending on the specifications and manufacturers. Figure III-4 depicts this process.

Figure III-4. Example of a Foraging Machine (northeastfarmservice.com 3/26/09)

Step 2 – Once the forage box is full, the operation stops until the dump truck is able to drop off its load and return to the tractor. This process repeats until the field has been completely harvested.

Step 3 – The forage box moves the chopped material into a holding area until it is needed. The holding area can range from a pit in the ground to a barn, or even a grain silo. While the barn and silo keep the material from blowing away, there are three concerns that must be addressed. The first is mold. If the grass is stored wet, there is a chance that it will mold and become worthless. The next problem is spontaneous combustion. This can happen anytime switchgrass is stored wet, regardless of what form it is in. Lastly, if the switchgrass is stored wet and left for an extended period of time, it will start to ferment. There is a better chance that the switchgrass will ferment in a pit, while there is a higher chance of combustion in a farm or grain silo.

The cost of a foraging machine was obtained from P&K Equipment in Stillwater, OK. The cost for a typical foraging machine runs between $50,000 and $150,000 (John Deere 2008). The cost for a typical forage box was found on beavervalleysupply.com and runs between $10,000 and $25,000.

While the baling process requires up to five passes over the field, the process creates bales that can be easily stacked and will not blow away. Conversely, the chopping method requires one vehicle to make two passes and two vehicles to make one pass each which should require less energy, and it is more valuable since the ethanol plant will not have to chop up the switchgrass. Also, when switchgrass is chopped up, it can easily be moved with an auger or a fan, while the bales must be moved with a forklift, bale spike, or a front-end loader.

Module Building

Step 1 – The farmer makes the first pass in a piece of equipment call a foraging machine. This machine cuts and chops the grass into pieces less than one inch in length. Then, a fan is used to blow the chopped switchgrass into a module builder that drives beside the tractor. A new module builder can cost between $200,000 and $400,000. Figure III-5 gives an example of a module builder.

Figure III-5. Picture of a Module Builder (k41.pbase.com 7/15/2009)

Step 2 – Once the module builder is full, it will compress the switchgrass into a large brick, which measures 8’x8’x32’.

Step 3 – The modules are left on the field until they can be picked up by a module truck. The module truck is a regular pickup with a custom bed designed to load, unload, and transport modules. While no one has used a module builder for a commercially harvesting switchgrass, there are currently several universities testing module builders for commercial use. Module trucks usually run between one $150,000 and $200,000.

Module building is similar to chopped switchgrass with one important difference. Module building compresses the switchgrass into a large brick instead of leaving it lose on the ground or in a container. The advantage to this is that the switchgrass will not blow away and is easier to transport. The downside to module building is that the plant where the switchgrass is processed must have a machine that will break up the module for processing, and there must be a tarp to cover every module to prevent water damage.

The method for determining the cost of a new module-building machine was to look at the various machines listed on equipmentlocator.com and gain a sense for the high and low cost module building machines (equipmentlocator.com 8/11/2009).

Storing Switchgrass

There are three basic ways to store switchgrass. Each of the three methods will be discussed independently; however, it is likely that all three methods will be used to store switchgrass for a large scale biorefinery. Since ensuring a steady supply of switchgrass is critical to a successful operation, it is important to have both a steady supply of switchgrass in addition to a low cost per ton.

<u>On Farm Storage</u>

The first option is to store the switchgrass on the farm. The farmer is responsible for storing the switchgrass until arrangements are made for the switchgrass to be delivered to the processing facility. The most likely place to store switchgrass on a farm is either on the side of the field, or in a barn. Unfortunately, the farmer must provide the space on his property to store the switchgrass for up to one year.

Bales, shipping containers, and modules can easily be stored on the side of the field or in a barn. Any material that is stored outside needs to have protection from the weather. This can be done with gravel, pallets, or tarps. However, the chopped switchgrass transported in a garbage truck must be stored in a barn to prevent the wind from blowing the loose switchgrass away. Additionally, a blower system must be set up to load the switchgrass into the garbage trucks.

Storage Depot

The second option to store the switchgrass is at a storage depot between the farm and the processing facility. This method usually entails a series of barns, silos, or gravel lots which will hold the switchgrass that the farmers sell to the processing facility and an office to keep all of the records and payment information. Additionally at least one person would be needed to load and unload the trucks and stack the bales for storage. The disadvantage of this method is the cost. It would require two more employees than the on farm option, and would be significantly more expensive. However, it has two main advantages. The first advantage is it divides the transportation between the farmers and the processing plant. Second, it provides a steady flow of switchgrass to the processing facility. A storage depot would make the logistics aspect of transporting the switchgrass easier. Instead of making sure that everyone has their switchgrass transported on the correct day and accounting for weather, there is more leeway in how precisely the plant's feedstock inventory is maintained. One of the major concerns with transporting switchgrass from the farm as opposed to a storage depot is loaded trucks being able to get in and out hard to reach farms connected by poor quality roads.

Storage at the processing plant

The last option is to store the switchgrass at the processing facility. This option would require the processing plant to have a significant amount of adjoining land where the switchgrass would be stored. The advantage to this system is that the switchgrass is right next to the processing facility.

Transporting Switchgrass

There are different methods that can be used to transport switchgrass. Since transportation costs are high for switchgrass, five alternative methods were chosen to see if there was a way to reduce cost. There are a variety of costs that go into transportation and the ones that each of these methods has in common are: insurance, maintenance, fuel, and the cost of a driver.

Semi-Truck with a flat bed trailer

This is the standard method for hauling hay long distances. It consists of using a class 7 or class 8 vehicle to haul a 40' x 8' trailer. The truck can haul up to approximately 40,000lbs of switchgrass depending on the weight of the truck. This size trailer is ideal because it allows the 4' x 4' x 8' bales which are being used for this study to be stacked in a secure manner without having to worry about a bale rolling off the bed of the truck. A Peterbilt model 386 day cab was used for this analysis; however there are other manufacturers that make similar trucks. These trucks should cost around $100,000, and the method for determining the cost of these machines was to call up a Peterbilt dealership and talk to a representative about what a class 7 or class 8 day truck would cost (Peterbilt 2008). The cost of using a Semi-Truck with a flat bed trailer are listed in Table III-1

Table III-1. Sources, Assumptions – Semi Truck Cost for the Ethanol Plant to pick up Switchgrass and haul it to the Plant

Item	Description	Information
Cost of new truck	Peterbilt 2008; high and low values	$110,000 & $100,000
Cost of new trailer	Peterbilt 2008; high and low values	$45,000 & $25,000
Amortized Cost of new truck and trailer	Calculated, 10% over 7 years	Average: $28,757
maintenance cost per mile	Barnes, G. and P. Langworthy. 2003; high and low values	$0.12/mile & $0.10/mile
maintenance costs for 1 year	Barnes, G. and P. Langworthy. 2003; high and low values	$8640 & $7200
insurance per truck for 1 year	http://www.1stguard.com/	$2972 & $2572
Price of diesel/gal	http://www.oklahomagasprices.com; the average price over the last 5 years was used	$2.69; std dev .846
round trip distance	Assumption	30, 60, & 90 miles
fuel efficiency (mpg)	Peterbilt 2008	4.5mpg
driver wage per mile	estimate based on job postings	
hourly driver wage	http://www.bls.gov/oco/ocos246.htm - the upper and lower quartiles were used as the high and low	$21.04 & $13.33
estimated trip time (hrs)	Calculated	distance/average speed (45 to 55 mph) + 30 minutes to load and 15 minutes to unload
trips per day	Calculated based on trip time	Average 6 trips/day
truck life (years)	Assumption	7 years, or 500,000 mile lifetime
cargo weight (tons)	Calculated based on weight of truck, trailer, & maximum legal weight on public roads	20 tons

Assume truck will last for 7 years
Assume the farmer loads the bales
Assume 40 1,000lb 4x4x8 bales per load
Assume average 50 mph + .85 hours to load (30 min) and unload (20 min)
Assume the plant operates 350 days per year
Assume the trucks run when the plant is open
Assume switchgrass can be picked up everyday of the year
Assumes full loads (20 tons)

Pickup truck with a flat bed trailer

Normally, this method is employed by farmers who need to move hay around their land. However, this method would also work for hauling switchgrass to the ethanol plant. The primary disadvantage of this method is that it requires a larger capital investment from the farmers. While an F-550 truck was used to determine the cost of the truck, there are other manufacturers that make similar trucks. These trucks should cost approximately $50,000. The method for determining this cost was to call up the local Ford dealership and talk to a representative about what a class five truck would cost (Ford 2008). The cost of using a pickup truck with a flat bed trailer are listed in Table III-2.

Table III-2. Sources and Assumptions – Pickup Truck

Item	Description	Information
Cost of new Truck	Ford 2008; high and low values	$60,000 & $40,000
Cost of new trailer	http://www.rockanddirt.com/; high and low values	$10,000 & $4,000
Amortized cost of truck and trailer	Calculated, 10% over 7 years	Average: $11,708
truck lifetime in years	Assumption	7 years, or 500,000 mile lifetime
maintenance costs for 1 year	Barnes, G. and P. Langworthy. 2003; high and low values	$1,116 & $558
insurance per truck for 1 year	farmers insurance; high and low values	$1,700 & $1,400
Price of diesel/gal	http://www.oklahomagasprices.com; an average over the past 5 years was used	$2.69/gal; std dev .846
round trip distance to plant (mi)	assumption; evaluated at	30, 60, & 90 miles
fuel efficiency (mpg)	Ford 2008	6.5mpg
tons per acre	Aravindhakshan, S., F. Epplin and C. Taliaferro. 2008	5.23tons/acre
acres	Assumption	500 acres
total tons	Calculated	2615 tons
estimated trip time (hrs)	calculated – distance/average speed (45 to 55 mph) + 30 minutes to load and 15 minutes to unload	2 trips/day
trips per year	Calculated based on trip time and 350 days of operation per year	291 trips/day
miles per year	Calculated based on trips per year	17,433
tons per load	Calculated based on weight of truck, trailer, & capacity of truck	20 tons
driver wage per hour	http://www.bls.gov; mean hourly wage for farm equipment operator	$10.43/hr

Assume 9 4x4x8 bales per load
Assume average 50 mph + 30 minutes to load and 15 minutes to unload
Assume the farmer loads the bales
Assume 500 acres of land
Assume the trailer lasts as long as the truck
Assume full loads (9 bales)

Garbage truck

Currently, there are no common uses for garbage trucks other than to haul garbage. However, it would be possible to use them in the transportation of other material. There are two reasons to consider using a garbage truck to haul switchgrass. First, a garbage truck could haul chopped switchgrass, which would save the ethanol plant from having to grind up the switchgrass. Second, the mechanism that is used to compress trash could also be used to compress switchgrass. While the available area in a garbage truck is less than on a flat bed trailer, the compactor on a garbage truck can compress material down to 725 lbs/cu. yd. A garbage truck should cost around $100,000, and both front and rear load garbage trucks could work depending on the machine loading the switchgrass. The method for determining the cost was to talk to a representative at J & R Equipment to determine the cost of a new chassis and body. Garbage Truck costs are listed in Table III3.

Table III-3. Sources and Assumptions – Garbage Truck

Item	Description	Information
Cost of new Chassis	J&R equipment; high and low values	$125,000 & $95,000
Cost of new Body	J&R equipment; high and low values	$85,000 & $62,000
Amortized Cost of new Chassis & body	Calculated, 10% over 7 years	$37,692
maintenance costs for 1 year	Barnes, G. and P. Langworthy. 2003; high and low values	$8,640 & $7,200
insurance per truck for 1 year	http://www.1stguard.com/; high and low values	$2,972 & $2,572
Price of diesel/gal	http://www.oklahomagasprices.com; an average over the past 5 years was used	$2.69/gal; std dev .846
round trip distance	Assumption	30, 60, & 90 miles
gal per hour of fuel	J&R equipment	5.5gph
fuel cost per trip	Calculated based on trip time and gph	$30.03
hourly driver wage	http://www.bls.gov/oco/ocos246.htm - the upper and lower quartiles were used as the high and low	$21.04 & $13.33
estimated trip time (hrs)	calculated – distance/average speed (45 to 55 mph) + 30 minutes to load and 15 minutes to unload	2 hours
trips per day	Calculated based on trip time	5 trips
truck lifetime (years)	assumption	7 years, or 500,000 mile lifetime

Assume same driver cost as big rig

Assume same maintenance and insurance cost as big rig

Assume all loads are full loads

Semi truck that hauls shipping containers

While companies have been using shipping container to ship goods to all parts of the world, there have not been any cost estimates using shipping containers for switchgrass. While the containers can be expensive to purchase, used containers will last for over a decade and will provide complete protection against the elements, and are easy to transport. Depending on the condition of the shipping container, they range in cost between $1,000 and $4,000 for a used shipping container. The method for determining the cost of a shipping container was to call Michael Cisco who is an independent shipping container dealer. Shipping container costs are listed in Table III-4.

Table III-4. Sources and Assumptions – Shipping Containers

Item	Description	Information
Cost of new truck	Peterbilt 2008; high and low values	$110,000 & $100,000
Cost of new trailer	Peterbilt 2008; high and low values	$45,000 & $25,000
Amortized Cost of new truck and trailer	Calculated, 10% over 7 years	$28,757
maintenance costs for 1 year	Barnes, G. and P. Langworthy. 2003; high and low values	$8,640 & $7,200
insurance per truck for 1 year	http://www.1stguard.com/; high and low values	$2,972 & $2,572
Price of diesel/gal	http://www.oklahomagasprices.com; an average over the past 5 years was used	$2.69/gal; std dev .846
round trip distance	assumption; evaluated	30, 60, & 90 miles
fuel efficiency (mpg)	Peterbilt 2008	4.5 mpg
hourly driver wage	http://www.bls.gov/oco/ocos246.htm - the upper and lower quartiles were used as the high and low	$21.04 & $13.33
estimated trip time (hrs)	calculated – distance/average speed (45 to 55 mph) + 30 minutes to load and 15 minutes to unload	2 hours
trips per day	Calculated based on estimated trip time	5 trips
shipping containers	Michael Cisco - vendor	$2350
Amortized Cost of used shipping container	Calculated, 10% over 10 years	$382
truck lifetime (years)	Assumption	7 years, or 500,000 mile lifetime
cargo weight (tons)	Calculated based on loose density of hay and the internal dimensions of a shipping container	20 tons

Assume expenses will be the same as a big rig
Assume each shipping container is used once each year
Assumes full loads (20 tons)
Assume the plant operates 350 days per year
Assume the trucks run when the plant is open
Assume the truck can load itself
Assume switchgrass can be picked up everyday of the year

Module trucks

Module trucks have been the standard method of transporting cotton for many years. They transport cotton modules that weigh approximately 23,000lbs per bale. While there have not been any experiments to determine if it would be possible to make a module out of chopped switchgrass, they might work just as well for switchgrass as they do for cotton. Module trucks should cost between $150,000 and $200,000. These costs came from John Bates from Bates Brothers, which is the shipping company that hauls all of the cotton for the cotton gin in Altus, OK listed in Table III-5.

Table III-5. Sources and Assumptions – Module Truck

Item	Description	Information
maintenance cost/mile	Harrison, D. and J. Johnson. 2007	$0.43 & $0.04
tax	Harrison, D. and J. Johnson. 2007	$5441 & $215
insurance	Harrison, D. and J. Johnson. 2007	$25,533.00 & $625.00
depreciation	Harrison, D. and J. Johnson. 2007	$14,900.00 & $6,100.00
interest	Harrison, D. and J. Johnson. 2007	$5,600.00 & $4,525.00
Price of diesel/gal	http://www.oklahomagasprices.com; an average over the past 5 years was used	$2.69/gal; std dev .846
round trip distance	assumption	30, 60, & 90 miles
fuel efficiency (mpg)	Bates Brothers	5 mpg
trips per year	Calculated based on average trip time and operating 350 days/year	1050
estimated trip time	calculated – distance/average speed (45 to 55 mph) + 30 minutes to load and 15 minutes to unload	1.37 hours
driver wage per hour	http://www.bls.gov; mean hourly wage for farm equipment operator	$10.43

Assume you can make chopped switchgrass modules
Assume 22,000lb modules
Assume average 50 mph + .85 hours to load (30 min) and unload (20 min)
Assume the plant operates 350 days per year
Assume the trucks run when the plant is open

Determine an Approximate Cost Based on Commercially Available Equipment and Labor Rates.

All of the financial information was put into a Microsoft® Excel® spreadsheet which calculated the cost of the individual component parts and determined the optimal combination of methods which will take into account primarily cost, and additionally simplicity. Once all of the component costs have been determined, they will be put together to determine if using switchgrass for a biomass feedstock is economically feasible.

CHAPTER IV

RESULTS

This section will go through the results starting with planting, then harvesting, transportation, and storage.

Planting

Since different universities have developed their own switchgrass budgets, this study will use the OSU budget (Haque, Francis and Taliaferro 2009); however, three budgets from other schools will be included in the appendix. It is important to note that each location will have its own optimum growing requirements and that the university budgets while good, are only approximants. Currently, the Oklahoma Bioenergy center is the only organization commercially grown switchgrass in Oklahoma. They have a 1000 acre plot where they are commercially growing switchgrass which will be a great tool in the next few years once they have put together some long term data Oklahoma Bioenergy Center 8/11/2009).

Table IV-1 below is the budget that OSU developed which shows the costs involved with growing switchgrass. Unfortunately, this cost can vary widely depending on the amount and price of fertilizer and pesticides that are used.

Table IV-1. OSU's budget for growing Switchgrass (Haque, Epplin, and Taliaferro)

	Price per ha	Cost per acre	Cost for 500 acres
<u>Year 0</u>			
Machinery operations			
Moldboard plow	$30.88	$12.48	$6,237.76
Tandem disk	$43.23	$17.46	$8,732.46
Fertilizer and Chemical application			
Spraying herbicide	$9.88	$3.99	$1,995.76
Applying nitrogen	$9.26	$3.74	$1,870.52
Planting			
Cultipack	$17.29	$6.99	$3,492.58
Grain drill	$24.70	$9.98	$4,989.40
Operational inputs			
Seed	$103.72	$41.90	$20,951.44
Herbicide (2, 4-D)	$7.03	$2.84	$1,420.06
Nitrogen	$25.77	$10.41	$5,205.54
Annual operating capital	$19.02	$7.68	$3,842.04
Land rental	$111.15	$75.00	$37,500.00
Total startup cost	$401.93	$192.48	$96,237.56
<u>Years 1-10</u>			
Nitrogen	$9.26	$3.74	$1,870.52
Annual operating capital	$19.02	$7.68	$3,842.04
Land rental	111.15	$75.00	$37,500.00
Total cost	$139.43	$86.43	$43,212.56
Cost/ton (12% moisture)		$14.55	
Cost/dry ton		$16.53	

The budget above was developed using the standard enterprise budgeting procedure. This budget differs in one major way from other switchgrass budgets. Most of the other budgets account for a significant amount of nitrogen fertilizer to be used on the switchgrass. However, large amounts of fertilizer are not needed if the switchgrass is not harvested until late fall or early winter (Epplin 1996) because the nitrogen and other nutrients translocate back into the soil. Additionally, switchgrass has been show to thrive without herbicides (Epplin 1996) in certain cases. It is important to note that these are generalities, not hard and fast rules. Each area is different and it is important to get the soil tested and determine what is best for a given location.

Harvesting

Harvesting is the difficult part to assess, and the optimal method will likely depend on the way the processing plant wants the switchgrass. There are three basic methods for harvesting switchgrass: baling, foraging, and module building. Both baling and foraging can be done by either the farmer who has his own equipment or by a custom harvester. Table IV-2 shows the cost breakdown for the harvesting machines and Table IV-3 shows the calculated cost for a farmer to bale, forage, and build modules out of switchgrass.

After the switchgrass has been harvested by the foraging machine, it needs to be processed and stored. There are two ways the switchgrass can be processed and stored. First, a bale wagon can follow the foraging machine, collect the hay, and transport it to a barn. Second, the switchgrass can be loaded into a module builder and turned into a module. The bale wagons used in this study will be self-propelled, but the module builder must be moved with a tractor. Once the switchgrass has been harvested, it must be transported to the side of the field. Once on the side of the field, it can be stored in either a barn, under a tarp, or on the ground.

Table IV-2. Harvest Summary – Cost for Farmer to Own Harvesting Equipment (AGMACH - Huhnke, Venkateshwaran, and Vikas 2008)

Machine	Large Square Baler	Wheel Rake	Mower Conditioner	Forage Harvester	Cotton Harvest
Size (ft)	30	10.4	14	15	13.33
Speed (mph)	7	6	5	3.5	3
Beginning Age	NEW	NEW	NEW	NEW	NEW
Purchase Price ($)	$100,000	$5,500	$17,000	$163,000	$280,000
Capacity (Acres/hour)	20.36	6.05	6.79	4.45	3.39
Annual Acres (Acres)	500	500	500	500	500
Fuel Cost ($/gal)	$2.69	$2.69	$2.69	$2.69	$2.69
Labor Cost ($/hr)	$10.43	$10.43	$10.43	$10.43	$10.43
Other	1.00				
Expected Life (years)	10	10	10	10	10
Total Cost per hour ($/hr)	$559.31	$56.03	$76.69	$237.62	$338.07
Total Cost per acre ($/acre)	$27.47	$9.26	$11.30	$53.34	$99.64

While the data calculated in Table IV-3 is reliable for most crops, the yields from switchgrass are higher than most crops. Currently, there is no established data for harvesting a crop that yields over 5 tons/acre. These numbers are a best estimate for the inputs required to harvest switchgrass with a yield of 5 tons/acre.

Table IV-3. Harvest Summary – Cost for Farmer to Bale, Forage, and Build Modules out of switchgrass (AGMACH - Huhnke, Venkateshwaran, and Vikas 2008)

	Harvest Cost		Field Movement Costs			
Total Cost	**$/acre**	**$/1000 lbs (dry ton)**	**Method of Moving**	**Unit**	**Cost to Move 1 unit**	**$/1000 lbs (dry ton)**
Baling*	$48.03	$10.92	Stinger	Bale	$1.84	$12.75
Foraging	$53.34	$12.12	Bale Wagon	forage box	$1.23	$13.35
Module building	$152.98	$34.77	Module Truck	Module	$519.36	$79.08

*It is important to note that the costs generated by the AGMACH program for baling appear to be lower than actual observed baling prices from farmers and custom balers.

Table IV-4 shows the custom rates for large square bales in four different states. The harvesting equipment used for baling switchgrass was a mower conditioner, a wheel rake, a large square baler, and a 150 hp tractor to move the equipment. The default costs used on each of these calculations are $10.43/hr for labor (BLS.gov 8/11/2009), $2.69 per gallon for diesel (transportlink.com. 8/11/2009), 500-acre plot, a yield of 5 tons/acre, and new equipment. The harvesting equipment used for foraging was a forest harvester, and the calculations used the same price for labor, fuel and plot size.

Table IV-4. Harvest Summary – Custom Rates for Baling Large Square Bales

	High	Average	Low
Custom Rates in Oklahoma			
(Doye, Sahs, and Kletke 2007)			
Mowing hay ($/acre)	$13.00	$10.61	$3.00
Raking hay ($/acre)	$12.50	$3.63	$1.00
Baling ($/acre)	$17.00	$14.22	$12.00
Total ($/acre)	$42.50	$156.44	$16.00
Custom Rates from University of Minnesota (Lazarus 2008)			
Mowing Hay		$12.46	
Raking Hay		$8.35	
Baling Hay		$11.33	
Total		$134.11	
Indiana Custom Rates (Dobbins and Matli 2007)			
Mowing Hay	16.02	12.28	$12.28
Raking Hay	8.51	5.91	$3.31
Baling Hay	N/A	N/A	N/A
Mowing and Raking	$24.53	$18.19	$15.59
Iowa Custom Rates (ISU Extension Office 2008)			
Mowing Hay	$15.50	$11.80	$7.00
Raking Hay	$10.00	$5.65	$2.00
Baling Hay	$11.00	$8.95	$7.00
Total	$36.50	$106.95	$16.00
Average Rates			
Mowing Hay		$11.79	
Raking Hay		$5.89	
Baling Hay		$11.50	
Total		$132.67	
Cost per ton (using OK costs)	High	Average	Low
($/ton)	$39.10	$31.29	$24.80

Note: Rates should increase with the price of diesel
Assume bales have a 12% moisture rate, and 5 tons/acre of harvestable material/acre

Table IV-5 shows the custom rates for building cotton modules and foraging switchgrass. It shows the high, average, and low cost for Oklahoma.

Table IV-5. Harvest Summary – Custom Rates for Module Building and Foraging (AGMACH - Huhnke, Venkateshwaran, and Vikas 2008)

	Custom Rate Charge per hour	Custom Rate Charge per acre	Custom Rate Charge per ton	Custom Rate Charge per dry ton
Cotton Modules				
low	$422.59	$124.54	$24.91	$28.30
average	$456.40	$134.51	$26.90	$30.57
high	$490.21	$144.47	$28.89	$32.83
Foraging Machine				
low	$84.21	$27.57	$5.51	$6.27
average	$90.95	$29.77	$5.95	$6.77
high	$97.68	$31.98	$6.40	$7.27

Since this study focuses on Oklahoma, local rates from several local custom cutters were added to help give a better idea of what a farmer would pay per bale. These costs are shown in table IV-6.

Table IV-6. Harvest Summary – Custom Rates from Local Custom Harvesters

Name	Location	Local retail cost to cut, windrow, and bale switchgrass
Matt Crosswaite	Stillwater, OK	$22 - $27 per bale

After evaluating the cost and processes involved in each of the three options, custom cutting is cheaper for both foraging and module building; however, the AgMach results developed for this study contrarily suggest that baling is cheaper if the farmer owns his own equipment. The largest difference between the two costs is baling. Custom cutting costs are approximately $30/ton while the cost for owning your own equipment is approximately $10/ton. The price difference for foraging is approximately $6/ton for custom harvesting and $10/ton for the farmer owing his equipment. Finally, the price difference for module building is $27/ton for custom harvesting and $30/ton for owning the equipment.

While storing bales and modules of switchgrass is not a problem, storing loose chopped switchgrass can cause problems. It has a tendency to blow away and can start to uncontrollably ferment if the weather does not cooperate. If the switchgrass is stored in a barn, there will be a significant startup cost and additional yearly maintenance costs. In addition to a barn, a blower system must be installed to move the switchgrass from the forage box to the barn, then from the barn to the garbage truck. Unless the plant is going to pick up the switchgrass within a few days of being harvested, it will need to be stored inside, or in a pit, which can cause fermentation. When switchgrass is stored in a pit, it has a tendency to either ferment or mold. If the switchgrass begins to ferment, which could possibly make the switchgrass more valuable, it would also make it harder to transport and since the farmer has no way to control the fermentation, reliable results could not be achieved.

Shipping containers and barns were evaluated for the purpose of storing switchgrass. Good quality used shipping containers with a lifespan of ten years cost over $2,000 and would significantly increase the startup capital required for the operation. The estimated cost for a 50’x100’ storage facility is approximately $50,000 (buildingsguide.com. 8/11/2009). Since bales can be stored on the side of the field and do not need to be stored inside, large square bales are the best way to harvest switchgrass using equipment currently available on the market.

Table IV-7 shows the breakdown of the different costs for the storage methods that can be used at a farm, a storage depot, or the processing plant. The quantities shown indicate the cost of storage for a storage depot that has the ability to hold enough switchgrass for a 50 million gallon per year ethanol plant to operate for 4 days. Since it is not possible to completely fill up a storage facility, it is assumed that only 75% of the space is utilized so that man and machinery can work freely.

Table IV-7. Harvest Summary – Storage Cost Summary

Storing switchgrass	Capacity	Quantity	Amortized cost per unit	Total cost per year
Cost of dirt	1 acre	1	$360.00	$360.00
Cost of gravel	1 acre	1	$14,178.00	$14,178.00
Cost of asphalt	1 acre	1	$15,350.00	$15,350.00
Cost of pallets	2 bales	3500	$15.00	$52,500.00
Cost of tarp (bales/modules) (1 year)	1 module or 4 bales	1785	$75.00	$133,875.00
Cost of barn (bales) (10 years) (pre-engineered steel building)	50'x100'x20'=1500 bales x 75% usage = 1125 bales	25	$8,137.00	$203,432.00
Cost of blower to move switchgrass		1	$521.00	$521.00
Administrative building years) (pre-engineered steel building)	20'x40'	1	$2,666.00	$2,666.00
Bar code system		1	$1,920.00	$1,920.00
Forklift	2 ton forklift	1	$8,951.00	$8,951.00
Forklift driver	2,000 hours/yr	1	$10.40/hr	$20,860.00
Administrator	2,000 hours/yr	1	$22.53/hr	$45,060.00

Table IV-7 has the component costs which must be added together to come up with the storage options. Since the quantity of switchgrass going through a given storage depot is unknown, it is impossible to determine an approximate cost per ton. Therefore, the total approximate cost for each piece of the storage depot was listed. The first three methods are just storing bales on dirt, gravel, or asphalt. The next method is using tarps to cover the bales or modules with tarps and the cost is found by adding the cost of the tarp line with the cost of the surface material (dirt, gravel, or asphalt). The fifth method is placing the bales or modules on top of pallets and is found by adding the cost of pallets to the cost of the surface material. The final method can be used for bales, forage, or modules, and is the only practical way to store forage. Total capital investment is found by adding the cost of the barn to the cost of the blower and surface material. Since the barn is the most expensive method and the only way to store forage, it will increase the cost of using forage and a garbage truck. Finally, administrative costs were included at the bottom of the table. These are used for estimating potential administrative costs that may be incurred at a storage depot or the bioprocessing facility.

Transportation

The area that seemed to have the largest number of options was transportation. While it is difficult to predict transportation costs unless all of the locations are known, an accurate estimate can be made. Five different options were evaluated for this part of the study. Each of these options assumes that the truck will back up to where the switchgrass is stored, the farmer will take 30 minutes to load the truck, and once the truck has reached its destination, it will take 20 minutes to unload the truck.

Table IV-8 shows the breakdown of costs for a semi truck carrying large square bales of switchgrass on a flatbed trailer.

Table IV-8. Transportation Summary – Cost for Semi-truck to haul switchgrass Cost for the Ethanol Plant to pick up Switchgrass and haul it to the Plant

	High	Baseline	Low
Cost of new truck	$110,000	$105,000	$100,000
Cost of new trailer	$45,000	$35,000	$25,000
Amortized Cost of new truck and trailer (10%)	$31,838	$28,757	$25,676
Maintenance cost per mile	$0.12	$0.11	$0.10
Maintenance costs for 1 year	$8,640	$7,920	$7,200
insurance per truck for 1 year	$2,972	$2,772	$2,572
Price of diesel/gal	$2.69	$2.69	$2.69
round trip distance (miles)	90	60	30
fuel efficiency (mpg)	4.00	4.50	5.00
driver wage per mile	$0.77	$0.54	$0.30
hourly driver wage	$21.04	$17	$13.33
estimated trip time (hrs)	2.47	2.03	1.50
trips per day	4.46	5.90	7.35
Truck life (years)	7	7	7
cargo weight with 12% moisture (tons)	20	20	20
delivered cargo weight (dry tons)	17.6	17.6	17.6
Cost per load	$140.25	$89.84	$49.87
Cost per ton (12% moisture)	$7.01	$4.49	$2.49
Cost per dry ton	$7.97	$5.10	$2.83

Table IV-9 shows the breakdown of costs for a farmer to haul large square bales of switchgrass on a flatbed trailer behind a heavy-duty pickup such as a Ford F-550 or a Dodge Ram 5500.

Table IV-9. Transportation Summary – Cost for pickup truck to haul switchgrass: Cost for the farmer to haul the bales to the plant

	High	Baseline	Low
Cost of new Truck	$60,000	$50,000	$40,000
Cost of new trailer	$10,000	$7,000	$4,000
Amortized cost of truck and trailer	$14,378	$11,708	$9,038
truck lifetime in years	7	7	7
maintenance costs for 1 year	$1,116	$837	$558
insurance per truck for 1 year	$1,700	$1,550	$1,400
Price of diesel/gal	$2.69	$2.69	$2.69
round trip distance to plant (mi)	90	60	30
fuel efficiency (mpg)	6.50	6.50	6.50
tons per acre	4.20	5.23	6.26
acres	500	500	500
total tons	2,100	2,615	3,130
estimated trip time (hrs)	2.83	2.16	1.50
trips per year	233	291	348
miles per year	21,000	17,433	10,433
cargo weight with 12% moisture (tons)	9	9	9
delivered cargo weight (dry tons)	7.92	7.92	7.92
truck lifetime in miles	200,000	200,000	200,000
driver wage per hour	$10.43	$10.43	$10.43
Cost per load	$110.94	$95.91	$44.03
Cost per ton (12% moisture)	$15.61	$10.66	$6.63
Cost per dry ton	$17.73	$12.11	$7.53

Table IV-10 shows the breakdown of costs for loose switchgrass to be compressed and transported in a garbage truck.

Table IV-10. Transportation Summary – Cost for garbage truck to haul switchgrass: Cost for the Ethanol Plant to pick up switchgrass with a garbage truck

	High	Baseline	Low
Cost of new Chassis	$125,000	$110,000	$95,000
Cost of new Body	$85,000	$73,500	$62,000
Amortized Cost of new Chassis & body	$43,135	$37,692	$32,249
maintenance costs for 1 year	$8,640	$7,920	$7,200
insurance per truck for 1 year	$2,972	$2,772	$2,572
Price of diesel/gal	$2.69	$2.69	$2.69
round trip distance	90	60	30
gal per hour of fuel	6	5.50	5
fuel cost per trip	$39.81	$30.03	$20.13
hourly driver wage	$21.04	$17.19	$13.33
estimated trip time (hrs)	2.47	2.03	1.50
trips per day	4.46	5.42	7.35
truck lifetime (years)	7	7	7
cargo weight with 12% moisture (tons)	15	15	15
delivered cargo weight (dry tons)	13.2	13.2	13.2
Cost per load	$126.77	$90.43	$56.42
Cost per ton (12% moisture)	$8.45	$6.03	$3.76
Cost per ton (dry)	$9.60	$6.85	$4.27

Table IV-11 shows the breakdown of costs for a semi truck to carry loose switchgrass in a 20 foot shipping container.

Table IV-11. Transportation Summary – Cost to haul switchgrass in shipping containers: Cost for the Ethanol Plant to pick up Switchgrass and haul it in shipping containers

	High	**Baseline**	**Low**
Cost of new truck	$110,000	$105,000	$100,000
Cost of new trailer	$45,000	$35,000	$25,000
Amortized Cost of new truck and trailer	$31,838	$28,757	$25,676
maintenance costs for 1 year	$8,640	$7,920.00	$7,200
insurance per truck for 1 year	$2,972	$2,772	$2,572
Price of diesel/gal	$2.69	$2.69	$2.69
Round trip distance	90	60	30
fuel efficiency (mpg)	4	4.50	5
hourly driver wage	$21.04	$17.19	$13.33
estimated trip time (hrs)	2.47	2.03	1.50
Trips per day	4.46	5.90	7.35
shipping containers	2,350	2,350	2,350
Amortized Cost of used shipping container	$382	$338	$309
Truck lifetime (years)	7	7	7
cargo weight with 12% moisture (tons)	20	20	20
delivered cargo weight (dry tons)	17.6	17.6	17.6
Cost per load	$522.70	$427.39	$358.83
Cost per ton (12% moisture)	$26.14	$21.37	$17.94
Cost per ton	$29.70	$24.28	$20.39

Table IV-12 shows the breakdown of costs for a module truck to carry modules of switchgrass in a module truck. The maintenance, tax, insurance, depreciation, and interest costs were taken from Harrison (2007), while the fuel price, and driver wage were taken from DOE (2009) & BLS.gov (2009). The reason for this was to use the ownership costs from the previous study but keep the operating costs consistent with the rest of the transportation methods.

Table IV-12. Transportation Summary – Cost to haul switchgrass in module trucks: Cost for the Ethanol Plant to pick up Switchgrass in module trucks (*Harrison, D. and J. Johnson. 2007)

	High	**Baseline**	**Low**
Maintenance cost/mile*	$28,149	$11,598	$2,901
Tax*	$5,441.00	$1,905.00	$215.00
Insurance*	$25,533.00	$2,961.00	$625.00
Depreciation*	$14,900.00	$11,268.00	$6,100.00
Interest*	$5,600.00	$4,885.00	$4,525.00
Price of diesel/gal	$2.69	$2.69	$2.69
Round trip distance	90	60	30
Fuel efficiency (mpg)	4.00	5.00	6.00
Trips per year	1050	1050	1050
Estimated trip time	1.80	1.37	0.83
Driver wage per hour	$10.43	$10.43	$10.43
Cargo weight with 12% moisture (tons)	11	11	11
Delivered cargo weight (dry tons)	9.68	9.68	9.68
Cost per load	$155.16	$77.22	$35.82
Cost per ton (12% moisture)	$14.11	$7.05	$3.26
Cost per ton	$16.03	$8.02	$3.70

Since the costs used in this study are only estimates, the fuel, driver wage, maintenance, and trailer costs were allowed to vary, using a simulation program call Simetar (Simetar. 2004), which is a Microsoft® Excel® add-on program. A 100 run simulation was performed which varied the trailer cost, maintenance cost, price of diesel, and driver wage. The fuel cost was taken from the Department of Energy from 2000-2009 and varied according to an empirical distribution. The trailer costs were taken from automotive retailers and varied according to a uniform distribution. Last, the driver wage cost which was taken from the Bureau of Labor and Statistics varied according to a GRKS distribution. The GRKS distribution is a variation on a triangle distribution which takes high, average, and low values and creates a distribution where the high and low values are at the 97.5% and 2.5% range. Table IV-13 is a summary of the results of the simulation, with the high, average, and low total cost per ton.

Table IV-13. Transportation Summary – Simulation data for 100 runs (12% moisture) (Simetar. 2004)

Simulation Data	**Max cost per ton**	**Average cost per ton**	**Min cost per ton**
Semi	$5.74	$4.35	$2.74
Pickup	$10.18	$7.53	$5.09
garbage truck	$5.80	$4.38	$2.91
shipping containers	$14.46	$12.79	$11.10
Module truck	$13.45	$8.92	$4.87

To determine the minimum cost possible for transportation, the transportation costs were broken down into component parts instead of using a number published by a private company or statistics company. The costs were broken down into the truck, trailer, maintenance, insurance fuel ($/gal), and driver wage, and assume a moisture rate of 12%. The truck, trailer, and maintenance costs for the semi-truck and garbage truck were determined by calling service representatives from a major manufacturer such as Mack or Peterbilt. The cost of the pickup truck was determined by looking at Ford and Chevy dealerships near Stillwater, OK to determine how much they charge for a new pickup capable of towing at least 11 tons. The maintenance cost for the pickup truck were found through was determined by calling the Ford dealership and talking to a service representative and asking what the recommended maintenance and maintenance cost would be for the truck specified above. These costs were confirmed through an article posted on Automobilemag.com. The module truck ownership costs were obtained from a 2007 study determining the cost of module trucks (Harrison and Johnson 2007). These costs included maintenance, insurance, depreciation, and taxes. The maintenance costs for all of the vehicles were obtained from a 2003 study evaluating the cost of operating a variety of vehicles (Barnes and Langworthy 2003). The fuel costs were calculated using an empirical distribution using the average weekly diesel fuel prices from 2000 through April of 2009. The insurance costs for the big trucks were obtained through 1stGuard.com, and the insurance cost for the pickup was obtained by calling Farmers Insurance. The driver wage information for the semi-truck and garbage truck was taken from the Bureau of Labor Statistics, which provides the hourly wage information for the middle fifty percent of truck drivers. The pickup and module truck calculations assumed that a farm hand was driving the truck, and the average farm vehicle operator wage for Oklahoma was used. While the truck, trailer, insurance, and maintenance costs are significant, they are only a minor portion of the total transportation expense. The fuel and driver costs make up nearly 75% of the cost per ton for the semi-truck. However, it is important to note that all of these costs are only estimates. There are a large number of factors that could affect these numbers one way or another. That is why the simulations were performed, in which two to seven factors were allowed to independently vary.

After evaluating the five different options at a round trip distance of 60 miles, the semi-truck and garbage truck range from $3.19 to $6.09 from the simulations. However, since it is difficult to determine exactly how well switchgrass can be compressed in a garbage truck, the compression ratio could increase or decrease the cost per ton for the garbage truck.

The simulations show that the average cost for the pickup truck, shipping containers, and module truck range from $7.02 to $13.44 per ton, and are not competitive with the other options. The only potential use for these methods would be if the farmer used a pickup truck to deliver his switchgrass to a collection point between his farm and the processing plant.

To gain a better idea of the number of the amount of switchgrass required for a 50 million gallon ethanol plant, a conversion rate of 80 gallons of ethanol per ton of switchgrass will be used (Ethanol Producer Magazine 2009). Published studies have used conversion rates between 70 gallons of ethanol per ton of switchgrass to over 100 gallons of ethanol per ton of switchgrass. However, 80 gallons per ton was chosen because it was an average number with a large amount of sources. Based on this conversion rate, 1,786 tons of ethanol will be required per day. This translates into 90 trips with a semi-truck carrying 20 tons per trip. Since a semi truck can make 5 trips per day, a minimum of 18 trucks will be needed to transport the switchgrass.

To gain a better understanding of how these results compare to other studies, table IV-14 shows a cost breakdown of the results from the studies mentioned earlier in this paper.

Table IV-14. Summary of results from published studies referenced in this paper.

Paper		Cost to move	Cost to harvest
Epplin, F. 1996	1	$15.80/ton	
Duffy, M. and V. Y. Nanhou. 2001	2		$104.21/acre
Payne, J. M. 2008	3	$8.65/ton	$32.33/ton
Kumar, A. and S. Sokhansanj. 2006	4	$21.19/ton	$24.10/ton
Sokhansanj, S., A. Turhollow and E. Wilkerson. 2008	5	$3.54/ton	$24.20/ton
Sokhansanj, S. and J. Fenton. 2006	6	$25.83/ton	$23.72/ton
Sokhansanj, S., A. Kumar and A. F. Turhollow. 2006	7	$32.45/ton	$21.12/ton
Hess, R., C. Wright and K. Kenney. 2007	8	$11.30/ton	$12.80/ton
This study (high costs)		$12.79/ton	9.60/ton
This study (low costs)		$4.35/ton	$33.66/ton

1. This study focuses mainly on establishment costs, but also includes a brief discussion on transportation costs. This study is different because it goes into detail about the harvesting and transportation costs while Epplin, F. (1996) focuses more on the ability to setup a switchgrass to ethanol plant in Oklahoma.
2. This study focuses mainly on developing a budget for establishing and harvesting switchgrass, but also includes some transportation costs. This is different from the current study which focuses on transportation and harvesting.
3. This study gives a brief line item cost estimate of the production, harvest, and transportation costs. This differs from the current study which goes into more detail about each of the line item costs.
4. The main difference between this study and the current one is that this paper goes into detail about how the costs were obtained.

5. The main difference between this study and the current one is that this paper goes into detail about how the costs were obtained. The primary focus of this paper is the IBSAL model and the numbers in the paper are used to validate the model.
6. This paper looks at different harvesting and transportation methods.
7. The main difference between this paper and the current paper are the variables that are allowed to vary. This paper focuses on weather and how it affects yield, while the current paper allows the transportation variables to change.
8. This paper looks at how different scenarios would play out and looks at process mapping while the current paper goes into detail on all of the transportation and harvesting costs.

CHAPTER V

CONCLUSIONS

Although this study attempted to create a model for examining switchgrass harvesting, transporting, and delivery options, the question of a farmer's willingness to grow switchgrass remains unanswered. Since switchgrass is a perennial that takes between two and three years for establishment, participating farmers will not generate significant revenue for three to four years.

Logistics issues involved in harvesting and transporting switchgrass are still unknown, although for this study several assumptions were made. While baling is fairly straightforward, there are still issues with modules and loose switchgrass. There are tests being performed to determine if it is possible to build a module out of switchgrass, but currently using modules for switchgrass is merely a theory. Moving loose switchgrass requires a blower system on the farm, storage depot, and the processing plant. It also requires the vehicles involved to make more trips because the switchgrass is not compressed. After looking at the different options, it appears that the first course of action is still to determine if the farmers are willing to switch their current production acres over to switchgrass.

After looking at all of the options calculated in this study, having a custom cutter harvest the switchgrass in large square bales, then have it transported by a semi-truck to the processing plant is the cheapest way to harvest and transport switchgrass.

Since this simulation is a general model, a sensitivity analysis was performed to determine how the truck & trailer, fuel price, and driver wage. The middle costs for each transportation method were used, and the distributions were replaced with average numbers. The following is a summary of the results from the sensitivity analysis.

Table V-1 shows how changing the price of diesel $0.10 at a time will affect the price per ton with a 12% moisture content.

Table V-1. Sensitivity Analysis – How a change in the fuel price by $0.10 affects the cost per ton with a 12% moisture content

	Fuel Price								
	Baseline	**Change In Price**							
	$2.69	($0.10)	($0.20)	($0.30)	($0.40)	$0.10	0.20	$0.30	$0.40
Semi-truck	$4.49	$4.43	$4.36	$4.29	$4.23	$4.56	$4.63	$4.69	$4.76
Change in baseline	$0.00	($0.0661)	($0.1328)	($0.1995)	($0.2662)	$0.0672	$0.1338	$0.2005	$0.2672
Farm truck	$10.50	$10.3990	$10.29	$10.19	$10.0914	$10.60	$10.71	$10.81	$10.91
Change in baseline	$0.00	($0.1025)	($0.2051)	($0.3077)	($0.4103)	$0.1026	$0.2051	$0.3077	$0.4103
Garbage truck	$6.03	$5.95	$5.88	$5.81	$5.73	$6.10	$6.18	$6.25	$6.33
Change in baseline	$0.00	($0.0744)	($0.1488)	($0.2233)	($0.2977)	$0.0744	$0.1489	$0.2233	$0.2977
Shipping container	$21.46	$21.39	$21.32	$21.26	$21.19	$21.52	$21.59	$21.66	$21.72
Change in baseline	$0.00	($0.0667)	($0.13333)	($0.2000)	($0.2667)	$0.0667	$0.1333	$0.2000	$0.2667
Module truck	$7.02	$6.91	$6.80	$6.69	$6.58	$7.13	$7.24	$7.35	$7.46
Change in baseline	$0.00	($0.1091)	($0.2182)	($0.3273)	($0.4364)	$0.1091	$0.2182	$0.3273	$0.4364

Table V-2 shows how changing the price of the truck and trailer $5,000 at a time will affect the price per ton with a 12% moisture content.

Table V-2. Sensitivity Analysis – How a change in the truck and trailer price by $5,000 affects the cost per ton with a 12% moisture content

	Truck and Trailer Cost								
12% moisture	**baseline** $140,000	($5,000)	($10,000)	($15,000)	($20,000)	$4,000	$10,000	$15,000	$20,000
Semi-Truck (cost/ton)	$4.49	$4.47	$4.44	$4.42	$4.39	$4.51	$4.54	$4.57	$4.59
change in baseline	$0.00	($0.0249)	($0.0497)	($0.0746)	($0.0995)	$0.0199	$0.0497	$0.0746	$0.0995
Farm Truck (cost/ton)	$10.50	$10.11	$9.72	$9.32	$8.93	$10.89	$11.29	$11.68	$12.07
change in baseline	$0.00	($0.3927)	($0.7855)	($1.1782)	($1.5710)	$0.3927	$0.7855	$1.1782	$1.5710
Garbage Truck (cost/ton)	$6.03	$5.99	$5.96	$5.92	$5.88	$6.06	$6.10	$6.14	$6.17
change in baseline	$0.00	($0.0361)	($0.0722)	($0.1083)	($0.1444)	$0.0289	$0.0722	$0.1083	$0.1444
Shipping Container (cost/ton)	$21.46	$21.43	$21.40	$21.37	$21.35	$21.48	$21.51	$21.54	$21.56
change in baseline	$0.00	($0.0271)	($0.0542)	($0.0812)	($0.1083)	$0.0271	$0.0542	$0.0812	$0.1083

The module truck was not included in the sensitivity analysis because the study which was used did not include the cost of the module truck.

Table V-3 shows how changing the price of the truck and trailer $0.50 at a time will affect the price per ton with a 12% moisture content and a baseline wage of $17.19.

Table V-4 shows how changing the price of the truck and trailer $0.50 at a time will affect the price per ton with a 12% moisture content and a baseline wage of $10.43.

Table V-3. Sensitivity Analysis – How a change in the driver wage affects the cost per ton with a 12% moisture content and a baseline wage of $17.19

	Driver Wage								
	baseline	**($0.50)**	**($1.00)**	**($1.50)**	**($2.00)**	**$0.50**	**1.00**	**$1.50**	**$2.00**
	$17.19	$16.69	$16.19	$15.69	$15.19	$17.69	$18.19	$18.69	$19.19
Semi-truck	$4.49	$4.44	$4.39	$4.34	$4.29	$4.54	$4.59	$4.65	$4.70
Change in baseline	$0.00	($0.0508)	($0.1015)	($0.1523)	($0.2030)	$0.0507	$0.1015	$0.1523	$0.2030
Garbage truck	$6.03	$5.96	$5.89	$5.83	$5.76	$6.10	$6.16	$6.23	$6.30
Change in baseline	$0.00	($0.0677)	($0.1353)	($0.2030)	($0.2707)	$0.0677	$0.1353	$0.2030	$0.2707
Shipping container	$21.46	$21.40	$21.35	$21.30	$21.25	$21.51	$21.56	$21.61	$21.66
Change in baseline	$0.00	($0.0507)	($0.1015)	($0.1522)	($0.2030)	$0.0508	$0.1015	$0.1522	$0.2030

Table V-4. Sensitivity Analysis – How a change in the driver wage affects the cost per ton with a 12% moisture content and baseline wage of $10.43

	Driver Wage								
	baseline	**($0.50)**	**($1.00)**	**($1.50)**	**($2.00)**	**$0.50**	**1.00**	**$1.50**	**$2.00**
Farm truck	$10.43	$9.93	$9.43	$8.93	$8.43	$10.93	$11.43	$11.93	$12.43
Change in baseline	$0.00	($0.3927)	($0.7855)	($1.1782)	($1.5710)	$0.3927	$0.7855	$1.1782	$1.5710
Module truck	$7.02	$6.96	$6.90	$6.83	$6.77	$7.08	$7.14	$7.21	$7.27
Change in baseline	$0.00	($0.0621)	($0.1242)	($0.1864)	($0.2485)	$0.0621	$0.1242	$0.1864	$0.2485

Before the economic feasibility of using switchgrass as a biofeedstock for ethanol can be found, a total cost per ton needs to be determined.

- Production - $16.53 per dry ton
- Harvesting - $35.17 per dry ton
- Field Movement - $1.84 per dry ton
- Transportation - $5.10 per dry ton
- Total - $58.64

Table IV-5 shows the lowest cost combination method for each of the methods. Each of the methods uses the same production cost, the lowest cost harvesting method which is stated in parentheses, and the corresponding transportation method listed in the left hand column. The cheapest method for harvesting bales of switchgrass is with a custom harvester, and the cheapest method for harvesting loose switchgrass and building modules is for the farmer to own the equipment. It is important to note that the cost for using forage and a garbage truck appears lower than it actually is. That method requires the forage to be stored in a barn and a silage blower to move the material in and out of the barn where it is stored.

Table V-5. Total cost summary – sum of the lowest cost production, harvest, and transportation cost.

	Semi Truck (custom harvest)	**Pickup Truck (custom harvest)**	**Garbage Truck (AGMACH)**	**Module Truck (AGMACH)**
Production	$16.53	$16.53	$16.53	$16.53
Harvest	$12.75	$12.75	$13.35	$79.08
Transportation	$5.10	$12.11	$6.85	$8.02
Total	$34.38	$41.39	$36.73	$103.63

The price two different studies have used for a feedstock is $40/ton (Kumarappan, S. and R. Ivanic. 2009; Hinman et al 2008), and according to the first study, the feedstock cost accounts for 1/3 of the total cost for cellulosic ethanol. Another study indicated that feedstock cost should account for $0.49/gallon when the total cost per gallon of ethanol is $1.60 (McAloon, A., F. Taylor and W. Yee. 2000). According the estimates in this study, the total cost of production, harvesting, and transportation is over $50/ton of feedstock or $0.63 per gallon at a conversion rate of 80 gallons per ton. Based on these numbers, switchgrass will not be economically feasible until there is either a major rise in the price of ethanol or cheaper methods of feedstock production, harvesting, and transportation are found.

After determining the cost of switchgrass, it is important to compare the calculated costs against what other people have done. The following is a chart which shows the cost some of the other studies.

CHAPTER VI

FURTHER STUDY

There are a few areas that need further study before a optimal switchgrass harvesting and delivery methods can be determined.

1. Determine the compression ratio for compressing switchgrass in a garbage truck.

   If a garbage truck is going to be used, it would be helpful for a study to be performed to determine the exact amount of switchgrass that can be transported in a garbage truck. While the internal dimensions and compression force are known, the amount the switchgrass can be compressed is unknown.

2. Evaluate a collection point between the farms and processing facility.

   While this model evaluates harvesting and transportation of switchgrass in a general sense, the cost estimates for the transportation portion of this model could be significantly improved if the locations of farms, storage depots, and the processing facility were known. Some of the farms will be more than 45 miles away. A plant that produces 50 million gallons of ethanol per year will require approximately 1800 tons of switchgrass per day. If farmers are unwilling to convert their farmland to switchgrass at first, the processing facility would have to travel well over 100 miles each way to find enough switchgrass to keep the processing plant running.

3. Evaluate different equipment or cooperative agreements that could potentially reduce the harvesting, transportation, or storage costs.

   There are currently several industries, such as cotton gins that share equipment to reduce cost and increase profits for the farmers. It would be worthwhile to evaluate these studies before ruling out switchgrass or another biomass as an option for ethanol production.

4. Determine the value of chopped switchgrass versus baled switchgrass.

   Even though determining the cost of chopping switchgrass at the plant should be straight forward, the plants currently in operation have not published that costs. Additionally, it should be determined if the plant is willing to pay extra for chopped switchgrass or require all the farmers to bring in a uniform product.

5. Develop a better estimation of switchgrass yields.

   There are different enterprise budgets and research studies published throughout the nation that estimate the amount of switchgrass produced from an acre of land. While all land will produce a slightly different amount of switchgrass, it would be helpful if a consistent switchgrass yield could be developed. Currently, the estimations range from3 tons/acre to 15 tons/acre. Before an ethanol plant is built, there should be research to determine the yield potential for the surrounding geographic region.

6. Streamline the exact fertilizer and herbicide requirements.

   One of the most expensive parts of growing switchgrass is the fertilizer and herbicide cost. Studies indicate that minimal fertilizer is needed because the nutrients translocate back into the soil, while others claim switchgrass needs upwards of 150lbs of nitrogen per year. It is impossible to accurately estimate the production cost with a wide range of values, so a study should be done on the exact nutritional requirements for switchgrass. This way a soil test will tell the farmer exactly how much of which nutrients need to be used for the optimal switchgrass yield.

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APPENDIX EXCEL MODEL PAGE 1

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General Prices		
Cost of diesel	$2.69	gal

Estimated Yield			region code	region 1	region 2	region 3	region 4	region 5
Land Code (1-5)	2		section of state	panhandle/OK	northwest	southwes	northeas	southeast
estimated yield (tons)	5.0		estimated tons/(acre*ye	0.0	5.0	5.0	6.5	6.0
estimated yield (dry tons)			estimated tons/(acre*ye	0.00	4.40	4.40	5.72	5.28

Production Summary	dry ton	wet ton
OSU budget	$16.53	$14.55
Iowa State University	$25.85	$22.75
NRCS in Mississippi	$25.78	$22.69
Arkansas	$45.07	$39.66

Harvest Summary			AGMACH	
Harvesting method (1, 2, 3, 4, 5 or 6)	1		Baled Switchgrass (4x4:	1
Harvesting cost	$4.80	per bale	Chopped Switchgrass	2
Dry matter harvesting cost	$5.46	per bale	Modules of Switchgrass	
Assumptions:			**Custom Rates**	3
500 acre plot			Baled Switchgrass (4x4x8)	
Cost of diesel	$2.69		Chopped Switchgrass	4
tractor driver wage (hr)	$10.43		Modules of Switchgrass	5
				6

Transportation Summary	default	custom			
type of vehicle (enter value 1 - 5)	5			semi	1
cost of truck	not available	$105,000		pickup	2
cost of trailer	not available	$35,000		garbage truck	3
maintenance per mile	$0.18	$0.11		shipping containers	4
maintenance per year	$4,885	$12,000		module truck	5
insurance per year	$2,961	$2,572			
average trip distance	60	60			
fuel economy	5.00	4.50			
driver wage per mile	$1.37	$0.00			
driver wage per hour	$0.00	$18.00			
estimate trip time	77.22	45	average trip speed		
truck life (years)	7	7			
truck capacity (tons)	10	20			
tons per day	1,800	1,800			
number of trucks needed	34.00	18.00			
total cost per mile	1,050.00	$0.00			
total transportation cost per ton	$7.02	$4.97			
total transportation cost per dry ton	$7.98	$5.64			

Storage Summary

Storing Switchgrass	capacity	quantity	amoratized cost per uni	total cost per year	option	option number
cost of dirt	1 acre	1	$360	$360	bales or modules on dirt	1
cost of gravel	1 acre	1	$14,178	$14,178	bales or modules on gravel	2
cost of asphalt	1 acre	1	$15,350	$15,350	switchgrass on asphalt	3
cost of pallets	1 bales	3500	$15	$52,500	bales or modules on pallets	4
cost of tarp (bales/modules) (1 year)	1 module or 4 bales	1785	$75	$133,875	tarps on bales or modules	5
cost of barn (bales) (10 years) (pre-e	50'x100'x20' x 75%	25	$8,137	$203,432	bales, modules or forage in the bar	6
cost of blower to move switchgrass		1	$521	$521	blower to move switchgrass in and out of the barn	
administrative building (10 years) (s	20'x40'	1	$2,666	$2,666		
bar code system		1	$1,920	$1,920		
forklift	2 ton forklift	1	$8,951	$8,951		
forklift driver	2000	1	10.43	$20,860		
administrator	2000	1	22.53	$45,060		
	option number	option cost				
Farm storage	1	$360				
Storage depot	1	$93,996				
total cost	$94,356					

	default	calculated
Total Cost from establishing to plant per ton	$29.97	$26.98

Simulation Data	Max cost per ton	Average cost per t	Min cost per ton
semi	$6.09	$4.49	$3.30
pickup	$11.59	$9.71	$8.01
garbage truck*	$5.09	$4.07	$3.19
shipping containers	$13.44	$12.42	$11.57
module truck	$9.28	$7.02	$5.78

it is important to note that the garbage truck cost might not be this low. It was assumed that 15 tons can be stored in a garbage truck, however this is only an estimate, and there is no data to support this assumptio
Also, the garbage truck method requires the use of a barn to store the loose switchgrass which is the most expensive storatge method

VITA

Wade Svetgoff

Candidate for the Degree of

Master of Science

Thesis: DEVELOPING A BUDGET TO PLANT, HARVEST, AND TRANSPORT SWITCHGRASS

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Date of Degree: December, 2009

Institution: Oklahoma State University

Location: Stillwater, Oklahoma

Title of Study: DEVELOPING A BUDGET TO PLANT, HARVEST AND TRANSPORT SWITCHGRASS

Pages in Study: 79

Candidate for the Degree of Master of Science

Major Field: Agricultural Economics

Scope and Method of Study: If there is any hope of moving away from fossil fuels, and towards renewable alternatives, a comprehensive economics analysis of the problem must be performed. This study is the first step in a larger economic analysis that must be performed. It evaluates the establishment cost for growing switchgrass in Oklahoma. Then it determines the least cost method of harvesting and transporting large quantities of switchgrass for a biorefinery by determining the cost of several different methods of harvesting and transporting switchgrass.

Findings and Conclusions: This study found that based on current prices and technology, that it is cost prohibitive to use switchgrass as a biofuel feedstock unless there is a major change in one or more of the variables in this study. However, it is likely that in the future the increases in price and advances in technology will make switchgrass a viable method for producing ethanol. Based on the findings in this study, more research needs to be done in the field of biofeedstock for the production of ethanol to further explore this topic.

Advisor's Approval: Dr. Rodney Holcomb