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Evaluation of Capital Investment and Cash Flows for Alternative Switchgrass Feedstock Supply Chain Configurations

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To the Graduate Council:

I am submitting herewith a thesis written by Jie Chen entitled "Evaluation of Capital Investment and Cash Flows for Alternative Switchgrass Feedstock Supply Chain Configurations." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

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Evaluation of Capital Investment and Cash Flows for Alternative Switchgrass Feedstock Supply Chain Configurations

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Abstract

Biofuels have been widely recognized as a potential renewable energy source, and the United States' government has been interested in producing ethanol from lignocellulosic biomass such as switchgrass. To evaluate whether lignocellulosic biomass based biofuels production is economically feasible, this paper estimated the capital investment outlays, operation costs, and net present value for investment in alternative switchgrass feedstock supply chain configurations in East Tennessee a 25 million gallon per year ethanol biorefinery. Two scenarios are analyzed in the study. The conventional hay harvest scenario includes the production, harvest, storage and transportation of biomass feedstocks from the fields to the biorefinery. The preprocessing scenario added preprocessing facilities into the biomass supply chain. According to various harvest, storage, preprocessing, and harvest equipment options, analysis and comparisons were made among different systems. The capital budgeting model developed in this study generated the optimal feedstock supply chain configurations to determine the largest net present value of cash flow from investment. Results of this study shown that with the Biomass Crop Assistance Program (BCAP) incentives, a round bale system using feedstock stored without tarp on pallets using custom hired equipment had the largest positive net present value. By comparison, if all the harvest equipment is purchased rather than custom hired, the stretch wrap baler preprocessing systems, using switchgrass harvested by a chopper with rotary cutter-header, was found to have a cost advantage over conventional hay harvest logistic systems (large round bale and large square bale systems) and pellet preprocessing systems. Assuming most likely values for switchgrass price and production costs, none of the feed stock supply chain configurations evaluated in this study produced a positive net present value when BCAP subsidies were

assumed to not be available. However, without the BCAP incentives and based on combination of optimistic assumption, the round bale system using feedstock stored without tarp on pallets using custom hired equipment still has the largest positive net present value. Without the BCAP incentives, no feedstock supply chain configuration using purchased rather than custom hired equipment generated a positive net present value.

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Chapter 1: Introduction

1.1 Description of the Problem

Ethanol is a potential substitute for petroleum in the production of transportation fuels. Ethanol has been primarily produced from corn in the United States (Lynd 2004; Sheehan et al. 2004). However, the cost of ethanol as a transportation fuel is high relative to petroleum if produced using corn grain (Farrell et al. 2006; Mapemba and Epplin 2004). Producing ethanol in a way that is cost competitive with petroleum-based fuels is crucial if ethanol and other biobased fuels are to be a sustainable and renewable source of transportation fuels in the United States. The most efficient way to make ethanol cost-competitive is to decrease costs within the feedstock supply-chain by using feedstocks other than corn starch to produce ethanol (Farrell et al. 2006). Perennial switchgrass has been suggested as an alternative feedstock for ethanol production and may have the advantage of being a sustainable, low input source of biomass feedstock that may be cheaper than corn (Wright et al. 2006). Switchgrass has high biomass yields, low input requirements, and can be grown on marginal agricultural soils not suited to other crop production because of problems with soil erosion. Thus, switchgrass production has the potential to help conserve soils through decreased erosion and can also improve climate regulation through carbon sequestration in agricultural soils (Wang 2009).Tennessee may have a comparative advantage in the production of switchgrass for ethanol and other biofuels because of the large amount of marginal agricultural land in the state that could be used for switchgrass production and abundant rainfall and sunshine that facilitate the production of large amounts of biomass (Tiller 2008). In addition, Tennessee has a large number of small and mid-sized farmers (Table 1). Nearly 97% of the farms in Tennessee are classified as small using the United States Department of Agriculture's (USDA) definition based on the value of sales and 95%

are less than 500 acres (Table 1). Such small farms may be suited to the production of bioenergy crops because they have reduced economic viability when engaged in traditional farm enterprises and because they have land quality that may be more conducive to the production of switchgrass than other traditional crops such as corn, soybeans and winter wheat. Thus, bioenergy crop production may be advantageous for many Tennessee farmers due to the decrease in economic viability of small and mid-sized farms in recent years and the heightened degree of environmental sensitivity in Tennessee.

However, many issues related to the logistics of feedstock production using switchgrass need to be overcome for switchgrass to be a cost effective alternative to corn. One issue with switchgrass production is that the bulkiness of the feedstock increases the costs of biomass harvest, transportation and storage (Egg et al. 1993). High harvest and handling costs and high dry matter losses during storage with conventional hay harvest methods are significant barriers to the development of a sustainable switchgrass feedstock supply chain in the Southeastern United States (Biomass Research and Development Technical Advisory Committee 2007). Another issue is the small size of farms in Tennessee and throughput the southeast which may result in higher transaction costs associated with the need to contract with a large number of small farmers. There are also potential market power issues for farmers in dealing with a single biorefinery (Carolan, Joshi, and Dale 2007). Coltrain, Barton, and Boland (2001) state that one way for small and midsize farms to remain viable businesses is to pool their limited resources through cooperative development by participating in profitable value-added processing and market activities. Carolan, Joshi, and Dale (2007) propose developing a network of Regional Biomass Preprocessing Centers (RBPC) that form an extended biomass supply chain feeding into a biorefinery. They evaluated the technical and financial feasibility of such centers in a feedstock supply-chain.

They believe that RBPCs can lower the cost of producing ethanol and other biofuels, ameliorate the potential market power of biorefineries, and reduce transaction costs for the biorefinery.

Another significant problem for a potential cellulosic-based biofuels industry is the need for a reliable feedstock supply chain system. Ample feedstock needs to be available to biorefineries at the appropriate time and at competitive prices with petroleum-based fuels, while assuring reasonable, steady profits to the biomass suppliers (Carolan, Joshi and Dale 2007). Eksioglu et al. (2009) state that supply-chain design decisions for biorefineries will be influenced by transportation costs and biomass availability. In a potential supply chain for switchgrass, it is desirable to build up a feedstock procurement network aggregating feedstock in such a way that would make the entire supply chain operate smoothly and efficiently. When harvested, switchgrass is low in density. Preprocessing is designed to improve biomass handling, transport, and storability, and also potentially add value by making biomass more fit for final conversion to fuels. Potential preprocessing functions include cleaning, separating and sorting, chopping, grinding, mixing/blending, moisture control, and feedstock densification (Carolan, Joshi and Dale 2007). Sokhansanj and Fenton (2006) also indicate the need for intermediaries between the field and the biorefinery that would secure and preprocess the feedstock into a form that satisfies the quality and quantity requirements of biorefineries. They also suggest that such an intermediary entity would have the responsibility of assessing biomass availability; organizing contractual agreements; coordinating collection, storage, and preprocessing activities; and ensuring time-efficient delivery to a biorefinery. Wright et al. (2006) also mentioned that such a feedstock assembly system would influence critical cost and quality barriers associated with bulk handling, transportation, and biomass variability, quality, and constancy. A biomass feedstock procurement entity would supply preprocessed biomass to the biorefineries for the production of biofuels and other co-products. Thus, preprocessing could improve biomass handling, transport, and storage characteristics of the feedstock. There is also the potential to pretreat biomass to facilitate the conversion process at RBPCs. Possible pretreatment technologies include: dilute acid, hot water, ammonia fiber expansion (AFEX), ammonia recycle percolation (ARP), or lime processes (Carolan, Joshi and Dale 2007). Thus, preprocessing could add value given that these steps could make biomass more fit for energy conversion in biorefineries (Carolan, Joshi and Dale 2007).

In addition, the delivered cost of feedstock to a biorefinery is a crucial factor in determining the economic feasibility of a switchgrass-based feedstock supply chain. The delivered costs of biomass are influenced by various logistic options, such as harvest and collection methods, preprocessing methods, storage duration, transportation methods, capacity of preprocessing facilities, and size of biorefinery (Kumar and Sokhansanj 2007). The logistics of switchgrass production, harvest, storage, and transport are challenged by the bulky nature of switchgrass (Hess, Wright and Kenney 2007). There are several potential kinds of feedstock harvesting systems, including conventional hay technologies, e.g., large round or large rectangular bales, and systems where the feedstock is chopped and densified in some manner, e.g., chopped feedstock that is processed into pellets (Bransby et al. 2005). There are also a number of different methods of transportation including trucking, rail, and pipeline delivery of feedstocks to the plant (Sokhansanj and Fenton 2006). For example, Kumar and Sokhansanj (2007) compared costs for two conventional hay harvesting methods within a feedstock supply chain system. They found that the harvest cost for large round bales was $22.62/dry ton (dt) and $24.10/dt for large rectangular bales. In another study evaluating conventional hay harvest systems, Cundiff and Marsh (1996) compared harvest and on-farm storage costs for large round bales and large rectangular bales. Net-wrapped round bales can be stored outside on crushed rock. They estimated harvest costs to be $16.71/dt and storage costs to be $3.20/dt. For the large rectangular bales that must be stored in covered storage, they estimated harvest cost to be $12.64/dt and storage costs to be $14.16/dt. The main factor that influences the cost differences is the dry matter losses. They found that the difference in costs becomes less significant when the yield is above 3.64 dt/acre and when storage loss for round bales stored outside increases above 5%. A key assumption of their analysis was that rectangular bales were stored indoors and did not sustain storage dry matter losses. Thorsell et al. (2004) estimated the costs to harvest lignocellulosic biomass as large rectangular bales for use as feedstock for biofuels, and the potential economic size of feedstock supply chain operations that might result from a coordinated harvest equipment compliment. In an enterprise cost budgeting analysis, Larson et al. (2010) found that a switchgrass feedstock supply chain that incorporated preprocessing to densify feedstock and package it in a form that minimized storage losses reduced the costs of feedstock delivered to the biorefinery by up to 32% when compared with conventional hay methods. The aforementioned analyses suggest that cash flows including capital outlays, revenues, operating expenses and taxes will vary depending on the configuration of the switchgrass feedstock supply chain. Thus, how the feedstock supply chain is configured will have an important impact on costs of feedstock delivered to the biorefinery and profits for farmers and intermediaries within a potential feedstock supply chain.

In Tennessee, most farms are small and most farmers do not have experience with switchgrass production. As shown in Table 1, average farm size and sales per farm in Tennessee are lower than at the national level (U.S. Department of Commerce, 2004). Many of these small farms do not have the resources necessary to invest in preprocessing methods to densify biomass and prepare it for storage to minimize storage losses and transportation costs. Thus, the development of a feedstock procurement entity by farmers may allow them to pool resources together and to participate in a large portion of the switchgrass value chain. The emerging switchgrass industry may need a business entity such as a feedstock cooperative to interrelate feedstock producers, bio-refineries, and auxiliary service providers, such as transportation and storage, and help them bear or share costs and risks. In the United States, most new agricultural cooperatives have followed the new generation cooperatives model. New generation cooperatives can vertically integrate and provide producers larger earnings by selling processed products instead of raw products (Nilsson 1997). It focuses on value-added products. The key organizational feature of new generation cooperatives is the linking of producer capital contributions and product delivery rights (Harris, Stefanson and Fulton 1996). Biomass feedstock procurement can be organized as a new generation cooperative. Members (farmers) contract with the cooperative to deliver a specific amount of commodities for value-added processing activities, which ensures a steady supply of the feedstock required for biorefinery operations.

Switchgrass is a relatively new bioenergy crop for farmers. Farmers are likely to be reluctant to grow perennial switchgrass as a dedicated energy crop due to the uncertain revenue stream from selling biomass to a biorefinery (Larson 2008). Perennial switchgrass does not reach its full yield potential until the third year. Thus, incentives may need to be provided to facilitate the adoption of switchgrass as an enterprise alternative. The Bioenergy Crop Assistance Program (BCAP) in the 2008 Food, Conservation and Energy Act (U.S. Congress, House of Representatives 2008) is an example of an incentive program designed to facilitate the development of feedstock supply chains using dedicated energy crops for the production of biofuels. Dedicated energy crops such as switchgrass, miscanthus, and other perennial grasses, as well at short rotation woody crops are eligible for the BCAP. Farmers sign the contract with the BCAP program and are required to contract with a biomass-to-energy conversion facility to receive payments.

1.2 Need for the Study

Past research has analyzed the feasibility of RBPCs (Carolan, Joshi and Dale 2007). Such independent consolidators could potentially handle the logistics of biomass more efficiently than individual farmers, resulting in a lower cost for feedstock for the biorefinery. The potential development of a switchgrass feedstock procurement business entity, as an intermediary between farmers and biorefineries, may potentially be beneficial for the switchgrass industry. It potentially will be a bridge between producers and biorefineries, allowing for a more efficient production industry. An intermediary between farmers and the biorefinery exploits scale economies and provides a balance of market power between many small producers and the biorefineries. The procurement entity could create value for the entire chain, and reduce transaction costs (Carolan, Joshi and Dale 2007). However, there is little research comparing alternative biomass feedstock supply chain configurations, cash flows, and the net present values of net cash flows of different feedstock supply chain arrangements (Tembo, Epplin and Huhnke 2003). According to early research results for switchgrass production in Tennessee, preprocessed biomass may reduce delivered cost to the biorefinery and promote efficiency within the supply chain based on budgeted costs (Larson et al. 2010). However, no research has been conducted for switchgrass production in Tennessee to evaluate alternative switchgrass feedstock supply chain configurations, and how these alternative configurations influence cash flows and net present value.

1.3 Objectives of the Study

The objectives of this research are: 1) to determine the capital investment outlays for alternative switchgrass feedstock supply chain configurations between the field and the biorefinery, 2) to analyze cash inflows and outflows for alternative switchgrass feedstock supply chain configurations, and 3) to evaluate the net present value of net cash flows from investment in alternative switchgrass feedstock supply chain configurations and government policies.

1.4 Methods for the Study

The methods used to achieve the objectives of this study are through the development of capital budget models using discounted cash flows to evaluate alternative structures. For different supply chain structures, cash inflows and outflows are simulated and evaluated using net present value (Soldatos and Lychnaras 2003). Sensitivity analysis is used to evaluate how factors in the capital budgeting model would affect the cash flows and net present value for alternative feedstock supply chains.

1.5 Organization of the Thesis

This thesis has six chapters. Chapter I is an introduction to the study. A review of literature on prior research on biomass and switchgrass feedstock supply chain logistics is presented in Chapter II. The conceptual framework of the study is developed in Chapter III. Chapter IV describes the cash inflow and cash outflow methods, net present value methods and the data for the study. Results and discussion are presented in Chapter V. Chapter VI concludes and summaries the key finding of the study.

Chapter 2: Literature Review

2.1 Biomass Logistics Research

The potential for biomass crops for feedstock in energy production has become a prominent issue throughout the world. The worldwide debate about dependence on fossil fuels that are becoming increasingly expensive and the environmental issues associated with petroleum products have stimulated the exploration for a sufficient and cleaner energy source. Biofuels produced from cellulosic biomass have been widely recognized as a renewable substitute for petroleum (Wright et al. 2006). In determining cost effectiveness, there is a significant price disparity between starch-based feedstocks such as corn and potentially more plentiful cellulosic-based feedstocks from agricultural and forestry residues and dedicated energy crops (Perlack and Turhollow 2003, Eksioglu et al. 2009). In addition, dedicated energy field crops could used for producing ethanol from biomass, such as sugar cane, corn, sorghum, oilseeds, and perennial switchgrass. A major issue in the production of cellulosic feedstock is harvest, storage, and transportation logistics between the field and the biorefinery (Biomass Research and Development Technical Advisory Committee 2007). Thus, important issue that must be resolved to develop sustainable feedstock supply chains for energy production is to determine the optimal logistics system which would provide the largest financial return under specific climatic and geographic conditions.

The most evaluated fuel source supply chains are for corn stover and wood feedstocks. Petrolia (2008) estimated costs for harvesting, storing, and delivering corn stover for a 100 million gallon ethanol facility in the Midwestern United States. In the analysis, there are three erosion-control options times six different collection technologies that resulted in 18 different stover quantities, and six different per-ton harvest costs that were estimated for each county in the feedstock draw area for the biorefinery. A linear- programming model was developed in GAMS to determine the most cost efficient allocation of available corn stover for a given number and location of conversion facilities, under alternative soil erosion constraints using conventional tillage, no-tillage and unconstrained between conventional and no tillage practices scenarios. The results showed that the marginal cost curve of feedstock collection shifts downward as collection efficiency increases with a decreasing rate.

Perlack and Turhollow (2003) calculated the costs incurred in collecting, handling, and hauling corn stover for large round and large rectangular baling systems at varying levels of feedstock demand or conversion facility sizes. They examined key logistical issues and tradeoffs between the size of conversion facilities and transportation costs. According to their study, moving large round bales directly from the field to storage is less costly than moving rectangular bales. Also, stover resource availability, the field-level and landscape level factors greatly affect delivered costs and offset scale economies in conversion processes.

Atchison and Hettenhaus (2003) developed a feedstock logistics model to calculate costs and net income to find the optimal methods for corn stover collection, handling, storage and transportation by minimizing cost. They found that modifications to existing combines, forage and ear corn harvesters are necessary in an attempt to achieve a one pass harvest of grain and stover. Collection risk and cost is less for wet processes as stover is collected when grain is ready and no drying or densification is required.

In another logistics study for corn stover, Ileleji and Wan (2006) used discrete event simulation software and GIS tools to model the transportation logistics from on-farm storage to the ethanol plant. Their study demonstrates that reduction in the unloading station capacity at the biorefinery will increase the requirement for semi-trailers to haul biomass and increase the average waiting time for semi-trailers. Through observation, they found that the use of a delivery schedule reduces the average waiting time, as well as the utilization of alternative pathways and different capacities.

For forest energy research Johansson et al. (2006) suggested using bundling of wood feedstock to handle and transport logging residues and other small size wood, which has advantages such as creating a compressed and uniform handling unit. In the study, they discussed the economics and other advantages and disadvantages of handling and transporting logging residue bundles. They found that bundles, especially if dry, are cheaper to transport than wood chips in road transport bins.

2.2 Switchgrass Feedstock Supply Chain Research

2.2.1 Government Policies and Programs

Switchgrass is bulky, so it is expensive to harvest, store and transport (Cundiff 1996). The production of ethanol is heavily dependent on subsidies, specifically federal and state excise tax exemptions, in order for it to be priced competitively with gasoline (Perlack and Turhollow 2003). Several states and the federal government have created various incentive programs to develop a local bioenergy industry. For example, the Iowa Switchgrass Project has been working to develop markets for switchgrass as an alternative energy crop in southern Iowa since 1996 (Duffy and Nanhou 2002). In Tennessee, the Tennessee Biofuels Initiative (TBI) was designed to develop an appropriate farm-to-fuel business plan for biorefineries in Tennessee (Office of Bioenergy Programs 2007). The TBI switchgrass farmer incentive program pays enrolled farmers to grow switchgrass for a three-year term, and assists the farmers with technical support and supply of high quality switchgrass seed (Wilson 2008). Title IX of the Food, Conservation and Energy Act of 2008 authorized funds to expand the production of lignocellulosic biomass (LCB) as biofuels feedstock, support biofuel plants, and enhance energy production in rural America (U.S Congress 2008). The

BCAP provides guidelines for feedstock eligibility to participate in the program, and how to work with different feedstock crops. Perennial crops and short rotation woody crops are eligible for payments for establishment and the collection, storage, transportation, and logistics of feedstocks. Feedstocks produced from agricultural and forest residues are only eligible for collection, storage, transportation, and logistics payments. With the BCAP, farmers could contract with the USDA to receive biomass crop payments of up to 75% of establishment costs during the first year. In addition, the BCAP provides for cost-share payments up to $45 per dry ton for the harvest, storage, and transportation of biomass crops to a biorefinery during the first two years of the operation (USDA/FAS 2009).

2.2.2 Switchgrass Conventional Hay Harvest Logistics Research

Switchgrass has been identified as a promising energy crop for the Southern United States (Epplin 1996). Some studies have focused on switchgrass production and ethanol conversion in biorefineries. According to early research results, production costs will vary under different on-farm harvest and storage methods and allocation of farm resources, constraints and weather conditions (Hwang and Epplin 2007). Several studies have been conducted to estimate the costs of producing switchgrass as a feedstock for ethanol production. Methods used for research on the logistics of switchgrass harvest can be classified into several categories: traditional enterprise budgeting analysis (Bransby et al. 2005, Epplin 1996, Larson et al. 2010), mathematical programming optimization (Eksioglu et al. 2009, and Tembo, Epplin and Huhnke 2003), simulation analysis (Cundiff and Marsh 1996, Herbst et al. 2003, Carolan, Joshi and Dale 2007, Sokhansanj and Fenton 2006), capital budgeting analysis (Kumar and Sokhansanj 2007), and cash flow simulation (Perkis, Tyner, and Dale 2008).

Bransby et al. (2005) developed an enterprise budget for switchgrass in a spreadsheet model. They developed alternative combinations of labor and equipment to determine the delivered costs of feedstock to a biorefinery. The results demonstrated that the estimated cost for feedstock handled as bales and pellets is higher than for feedstock that is chopped and compacted into modules using a cotton module builder. Delivered cost increased linearly with hauling distance, and decreased as truck capacity increased. However, the cost of handling and processing feedstock more significantly influenced total costs. Epplin (1996) also conducted a study to determine the costs of producing and transporting switchgrass biomass to a biorefinery using enterprise budgeting. The system modeled in the analysis was assumed to be a vertically integrated feedstock supply chain run by the biorefinery. Three possible arrangements for the supply chain are suggested in the study: 1) the processing firm engages in production contracts with individual farmers; and 2) the biorefinery leases a sufficient quantity of land to fulfill plant requirements; and 3) forming a processing cooperative for producers. The machinery and equipment for harvest, establishment, transportation, preprocess and maintenance would be owned by the plant, the cooperative, or the specialized firms. Two budgets were built in the study: 1) the estimate of the cost of establishment, and 2) the estimate of the cost of maintaining and harvesting an established stand. Epplin (1996) varied the key parameters in the model using sensitivity analysis, which included varying switchgrass yields, land rental rates, harvesting costs and transportation costs to evaluate delivered cost to the biorefinery. The delivered cost to a conversion facility is estimated to be $37.08/dt. Larson et al. (2010) applied enterprise budgeting and geographical information system (GIS) software to analyze the delivered cost for large round bales, large rectangular bales and stretch wrap bale systems from farm to the biorefinery.

Their results suggested that the preprocessing system outperformed the conventional bale harvest methods in the delivered costs of switchgrass at the biorefinery plant gate.

Eksioglu et al. (2009) developed a mathematical model to study the logistical challenges of supplying corn stover and woody biomass to a biorefinery. The objective function was to minimize the annual costs of harvesting, storing, transporting and processing biomass, storing and transporting ethanol, and locating and operating biorefineries. In the Eksioglu et al. (2009) study, it was assumed that there was a farm cooperative handling feedstock logistics between farms and the ethanol biorefinery. The feedstock supply chain network consisted of the potential feedstock draw area, potential locations for collection facilities, potential locations for biorefineries, and potential locations for blending facilities. The delivered cost of cellulosic ethanol that was calculated includeed all costs incurred from the commencement of biomass collection, to the final delivery of cellulosic ethanol to a blending facility. Eksioglu et al. (2009) pointed out that smaller size biorefineries are economical when biomass availability is low and transportation costs are high. High biomass availability would decrease transportation costs and increase the production capacity of the biorefinery. Other factors that strongly influence the delivered cost are initial investment costs, improvements in the technology of converting biomass feedstock to ethanol, and planting and harvesting costs.

Carolan, Joshi and Dale (2007) estimated the capital costs, operating parameters, and process input costs using an agent-based simulation model of the U.S. economy (ASPEN). They evaluated the technical and financial feasibility of a simple preprocessing facility that used an ammonia fiber explosion (AFEX) pretreatment process. Herbst et al. (2003) utilized a Monte Carlo simulation and a capital budgeting model to evaluate an ethanol production facility. They found that labor, administration and maintenance costs are the primary factors that influence plant total costs.

Kumar and Sokhansanj (2007) used the IBSAL (Integrated Biomass Supply Analysis & Logistics) model to evaluate switchgrass delivery systems where feedstock was packaged using conventional hay baling technology or as chopped material packaged in loafs or in loose, ensiled piles and calculated the costs by capital budget analysis. They simulated the collection, storage, and transportation of feedstocks under given harvest schedules, yields, harvest moisture contents, biorefinery capacities, and capital and operating costs. In this study, the delivered cost of switchgrass includes collection and transportation costs only, and does not include pre-harvest production costs. They found that collection cost would not vary with the plant size; however, the transportation cost increases or decreases directly with the plant size. They also estimated field and storage losses, because dry matter loss is a significant parameter in switchgrass collection, storage and transportation.

The cash flows of an investment in a given year is a function of variables such as selling prices, tax rates, operating costs, fixed costs, and salvage values of assets (Parker 1997), and sensitivity analysis is used to analyze the effects of making changes in estimated parameter values. Perkis, Tyner, and Dale (2008) used a financial model to determine the financial impact of process changes for the ethanol industry. The process changes included adding recycling and pretreatment in the supply chain. They found that the net present value (NPV) for the overall operation is expected a 32% increase when applying the process modifications to a 100 million gallon ethanol plant, and an enzyme cost of $0.20 per ethanol gallon produced. The revenue would increase from higher ethanol yields outpacing the sum of all additional costs, which include higher capital costs, increased operating costs, larger loan payments, and decrease in dried distillers' grains.

Some researchers have evaluated switchgrass production using methods other than those described above. For example, Mapemba and Epplin (2004) examined how the accounting method used for the harvest costs changes the estimated costs in the production of ethanol. Mapemba et al. (2007) studied the influence of policies on switchgrass production. Under the Farm Security and Rural Investment Act of 2002 (U.S. Department of Agriculture 2002), Conservation Reserve Program (U.S. Department of Agriculture 2004) harvest the grassland acres for biorefinery feedstock use. Mapemba et al. (2007) determined the cost to procure, harvest, store, and transport a flow of lignocellulosic biomass feedstock produced on CRP grasslands to an optimally located biorefinery and to determine how policies that restrict harvest frequency and harvest days influence cost. They found that it would be prudent for policy makers to enable an expanded harvest period for biomass for biorefinery processing. Finally, Thorsell et al. (2004) developed an agricultural machinery complement computer program for biomass feedstock logistics to find which specific type of machines complements can minimize the delivered biomass costs at intensive levels of use. Thorsell et al. used a machinery complement estimator to design a coordinated set of machines, which includes ten laborers, nine tractors, three mowers, three rakes, three large rectangular balers, and one bale transporter, and estimate costs for owning and operating the machines. Their research determined the cost to harvest lignocellulosic biomass (LCB), and the potential economics of scale that would result from a coordinated structure.

2.2.3 Biomass Feedstock Preprocessing Research

Biomass preprocessing is potentially the first operation after harvest in the feedstock assembly system at the front-end of a biorefinery production process (Wright et al. 2006). Preprocessing may include one or a combination of several processes of size reduction, fractionation, sorting and densification (Sokhansanj and Fenton 2006). Chopping, grinding, or otherwise formatting the biomass into a suitable feedstock is used for conversion to ethanol and other bio-products (Wright et al. 2006). In addition, Cox (1996) found that feedstock procurement can be managed to reduce transaction costs and improve the quality and value of feedstock. Laffont and Tirole (1990) evaluated renegotiation in contracts for procurement, and characterized the equilibrium of a two-period procurement model. Carolan, Joshi and Dale (2007) pointed out that the potential preprocessing steps include cleaning, separating, sorting, chopping, grinding, mixing/blending, controlling moisture, and densification of the feedstock. Distributed preprocessing produces a material that has bulk flowable properties and fractionation benefits that can improve the ease of transporting, handling and conveying the material to the biorefinery and improve the biochemical and thermochemical conversion processes (Wright et al. 2006). Distributed preprocessing can be accomplished at the side of the field or at a satellite preprocessing facility. As indicated above, feedstock procurement can involve both physical transformation of feedstock and mechanical and chemical pre-treatment processing of feedstock. Thus, Carolan, Joshi and Dale (2007) state that these satellite preprocessing facilities could have two main processing functions for feedstock after the harvest operation: 1) the feedstock handling and processing steps described above, and 2) pretreatment processes such as ammonia fiber expansion (AFEX).

Wright et al. (2006) determined that these preprocessing functions have the potential to produce significant cost savings by providing value added to feedstock with improved handling, transporting, equipment efficiencies, improved compositional quality, and improved merchandising potential by putting the feedstock in a standardized form that is easy to handle and transport. By doing so, the biochemical and thermochemical conversion processes at the biorefinery using the preprocessed feedstock would be improved. Eriksson and Bjorheden (1989) suggested that a preprocessing facility they called a fuel terminal be used to collect raw materials to process into fuel chips at the facility and deliver the fuel to heating plants. Activities at the fuel terminal include processing wood feedstock into chips, transporting feedstock to and from the facility, and storage. They concluded that optimizing forest-fuel production is essentially minimizing transportation costs, and preprocessing operations at the terminal.

Sokhansanj and Fenton (2006) used a dynamic model to simulate the collection, storage, transport, and preprocess operations for supplying agricultural biomass to biorefineries and calculate the costs of collecting and transport costs. They used the IBSAL (Integrated Biomass Supply Analysis & Logistics) model, developed at the Oak Ridge National Laboratory. In the study, the base scenario is a baling system where biomass is harvested using round bale technology and transported to a biorefinery. The alternative harvest system is to chop the biomass and transport to the biorefinery. The preprocessing scenario involves pelletizing switchgrass, which is a densification process. The comparisons of the two scenarios are shown in Figure 1. They found the important factors influencing the delivered cost are the bulk density of the biomass, the moisture content, and the distance of transportation. The delivered cost varies from a minimum of $46/ton to more than $78/ton. However, the costs do not include payment to the farmer, which they assumed might be an additional $10/ton.

Through contracting with existing pellet mills to have switchgrass pelleted, Bransby et al. (2005) determined substantial cost reduction compared with conventional hay harvest logistics system. An intermediate market step would evolve as systems of independent entrepreneurs, cooperatives, or processing companies choose to follow the trend towards vertical integration, and this should improve overall cost efficiency. Eggeman and Elander

(2005) found that in contrast to the cases void of pretreatment, all of the pretreatment cases have higher yield and lower capital requirements per annual gallon of capacity.

2.3 Need for Further Feedstock Logistics Research

Weather affects not only switchgrass yield before harvest, but also dry matter quantity and quality losses after harvest (English, Larson and Moony 2008). Wang et al. (2009) reported that storage loss from a harvest and storage experiment ranged from 11.8% to 57.3% for 200 days in storage under different harvest and storage methods in Tennessee. Precipitation and weathering may affect the quality and dry matter losses of switchgrass bales delivered to the plant and the yield of ethanol from a ton of switchgrass (Wiselogel et al. 1996). Thus, the dry matter losses influence the quantities produced and the required production area of switchgrass, as well as storage and transportation costs. Only a few of the studies took dry matter losses into consideration, and thus may underestimate the costs of production for switchgrass. In addition, the costs of production might dramatically differ among the alternative harvest and storage methods that could be used for switchgrass production in Tennessee.

In addition, because of the large storage requirement for feedstock, a substantial portion of that feedstock may be stored away from the plant, either at a satellite area or on the farm (Larson 2008). A feedstock procurement entity as a preprocessing facility in the supply chain may decrease the total production cost. Previous studies mostly focused on the delivered cost for alternative harvest configuration. But a few studies researched the different switchgrass preprocessing operations, compared alternative switchgrass feedstock supply chain configurations, and evaluated the cash flows (both revenue and costs are considered) and the net present value for alternative switchgrass feedstock supply chain configurations. Additionally, there are several incentive subsidy programs for switchgrass, but only a few studies evaluated those influences for the net present value for investment. Furthermore, many studies only focus on annual costs rather than looking at the issue as an investment for a longer period of time. Since these important factors have not been thoroughly researched, it is important to further consider and study them.

Chapter 3: Conceptual Framework

The capital budgeting technique is used in this study to evaluate different switchgrass feedstock supply chain configurations between the farm field and the biorefinery. Capital budgeting is defined as the process of determining the profitability of a capital investment, using cash inflows and outflows coming from the investment (Carter, Macdonald, and Cheng 1997). The capital budgeting method used in this study is the discounted cash flow (DCF) valuation to find the net present value (NPV) of cash inflows and outflows from an investment. Each potential switchgrass feedstock supply chain configuration is valued using the cash inflows and cash outflows during each year of the investment such as:

$$NPV_{jt} = \sum \frac{CF_{jt}}{(1+r)^t}, \quad (1)$$

where r is the discount rate (the rate of return that could be earned on an investment with similar risk); CF is the net cash flow (cash inflows minus cash outflows) at the end of year t for switchgrass feedstock supply chain configuration j.

Following Wang (2009), the costs of producing and delivering switchgrass feedstock to a biorefinery for a planning horizon of T years include the expenses to establish the stand ($ESTABLISH_0$, \$/acre) at the beginning of the first year of production (t=0), and the recurring annual costs, which include the opportunity cost of land planted in perennial switchgrass, nutrient management, pest control, harvest, preprocessing, storage, and transportation of biomass to the biorefinery ($SGAC$, \$/acre) in years t=1,…,T. The recurring switchgrass annual costs ($SGAC$, \$/acre) can be calculated by:

$$\begin{aligned} SGAC_t = {} & RENT_t + MAINTENANCE_t + HARVEST(SGY)_t^i + PREPROCESS_t \\ & + STORE(SGY)_t^i + TRANSPORT(SGY)_t^i \end{aligned}, \quad (2)$$

where *RENT* is the annual rental rate on land ($/acre) paid in years *t*=1,2,3,..,*T*; *MAINTENANCE* is the annual production expenses for nutrients and pest control in years *t*=2,3,…,*T* after the stand is established ($/acre); *HARVEST* is the annual expenses for harvesting (eg., mowing, raking, baling or chopping) and moving switchgrass from the field to storage or a preprocessing facility ($/acre) in years *t*=1,2,3,..,*T*; *PREPROCESS* is the annual expenses to densify and package switchgrass feedstock before storage; *STORE* is the annual expenses of storing switchgrass ($/acre) in years *t*=1,2,3,..,*T*; and *TRANSPORT* is the annual expenses of transporting the switchgrass from storage to the biorefinery ($/acre) in years *t*=1,2,3,..,*T*.

Harvest, storage and transportation costs are modeled as a function of switchgrass yields (*SGY*) adjusted for dry matter losses (dry tons/acre) for each production activity *i* in production year *t*. Dry matter losses can influence the delivered cost for feedstock to the biorefinery by influencing how much switchgrass collect it from the field to the biorefinery (Sanderson, Egg, and Wiselogel, 1997). Thus, switchgrass yields are adjusted for dry matter losses at each stage of logistics process between the field and the biorefinery. Thus, switchgrass yields (*SGY*) (dt/acre) in year *i* adjusted for dry matter losses (DML^i) (dt/acre) are defined as:

$$SGY_t^{Biorefinery} = SGY_t^{Field} \times (1 - DML^{Harvest}) \times (1 - DML^{Store}) \times (1 - DML^{Transport}) \qquad (3)$$

Incentive programs by government to encourage establishment of biomass feedstock supply chains for perennial crops such as switchgrass are often designed to reduce the cost of establishment and collection costs during the start up phase. Yields for switchgrass are low until the crop reaches full maturity in year three after establishment (Parrish and Fike 2005). The Bioenergy Crop Assistance Program (BACP) as authorized in Title IX of the Food, Conservation and Energy Act of 2008 (U.S Congress 2008) is an example of a subsidy scheme that can be used to encourage establishment of a feedstock supply chain for a biorefinery. The BCAP establishment and harvest payment scheme is used in this analysis to evaluate the impact of this incentive on the NPV of alternative feedstock supply chain configurations. The BCAP incentive payment for planting at t=0 (*ESTPMT*, \$/acre) can be modeled using:

$$ESTPMT_0 = 0.75 \times ESTABLISH_0 \tag{4}$$

and harvest payment in year t ($HARVPMT_t$) can be defined as:

$$HARVPMT_t = \$45 \times SGY_t^{Biorefinery} \leq [HARVEST(SGY)_t^i + STORE(SGY)_t^i + TRANSPORT(SGY)_t^i] \tag{5}$$

where $SGY_t^{Biorefinery}$ is switchgrass yield (dry tons per acre) delivered to the biorefinery.

All maintenance, land, rent, and harvesting costs incurred over the estimated lifespan of the switchgrass stand are discounted to their establishment year dollar value using a standard net present value (NPV) formula. Including BCAP, to determine cost of production per dry ton in current dollars (Perrin et al., 2008), the net present value of production costs (*SGCNPV*, \$/acre) was calculated using:

$$SGCNPV = ESTABLISH_0 - ESTPMT_0 + \sum_{t=1}^{T} \frac{SGAC_t - HARVPMT_t}{(1+r)^t} \tag{6}$$

where r is the discount rate accounting for the time value of money and the risk of producing switchgrass. Establishment cost and the BCAP planting payment were assumed to be respectively incurred and received at t=0. The annual maintenance, harvest, storage, and transportation costs of production and BCAP harvest payments were assumed to be respectively incurred and received at the end of each year of production t=1,…,T where T is the expected life of the switchgrass stand or the life of the contract to produce switchgrass.

The net present value of total capital investment cost (*SGTCICNPV*) of switchgrass was calculated using:

$$SGTCICNPV = \sum_{t=1}^{T} \frac{CAPITAL_{jt}}{(1+r)^t} \quad (7)$$

where *CAPITAL* is the cost for each capital investment *j*, *r* is the discount rate, *t* is year of operation, and the *T* is the expected life of the switchgrass stand or the life of the contract to produce switchgrass. Thus, the net present value of total cost (*SGTCNPV*) of switchgrass production as a biofuel feedstock is:

$$SGTCNPV = SGCNPV \times ACRES + SGTCICNPV \quad (8)$$

The net present value of total revenue (*SGTRNPV*) of switchgrass was calculated using:

$$SGTRNPV = \sum_{t=1}^{T} \frac{P \times SGY_t^{Biorefinery} + SALVAGE_{tj}}{(1+r)^t} \quad (9)$$

where *P* is the switchgrass sale price constant over the planning horizon, *SALVAGE* is the salvage value of equipment *j* used for switchgrass production, *r* is the discount rate accounting for the time value of money and the risk of producing switchgrass, *t* is year of operation, and the *T* is the expected life of the switchgrass stand or the life of the contract to produce switchgrass. Thus, the net present value of total cash flows for the *T* years (*SGCFNPV*) of the switchgrass stand is:

$$SGCFNPV = SGTRNPV - SGTCNPV \quad (10)$$

In switchgrass production and harvest logistics, the ownership of harvest equipment influences the cash flows significantly. Compared to an entity that uses custom hired equipment, an entity that owns equipment would have a large expenditure on purchasing the equipment. The purchase costs for harvest equipment that happened in year zero is the largest proportion of cash outflows.

Chapter 4: Data and Methods

4.1 Overview

For this study, feedstock supply chain configurations using conventional hay harvest systems and those using preprocessing methods to densify and package feedstock before storage and transport to the biorefinery are analyzed using annual net cash flows and the net present value criterion. It is assumed that the planning horizon of the project is a ten-year period which corresponds with the expected life-span of a stand of perennial switchgrass (Walsh 2007). The assumed feedstock draw area for the biorefinery is located in East Tennessee. The assumed size of the biorefinery is 25 million gallons of ethanol processed per year (Larson et al. 2010). The annual production capacity was based on Larson et al.'s discussions with decision makers with Genera Energy LLC and DuPont Danisco Cellulosic Ethanol LLC regarding the potential capacity of a first-generation commercial cellulosic ethanol biorefinery in East Tennessee. Based on an assumed ethanol conversion rate at 76 gallons per dry ton (Wang et al. 1999), the plant operating about 360 days per year would require about 329,000 dry tons of switchgrass feedstock per year. In this study, the assumed feedstock draw area for the biorefinery is diamond shaped, representing an east-west, north-south grid road system (English et al. 1981). The maximum shipping distance within the feedstock draw area is assumed to be 50 miles (Epplin 1996).

4.1.1 Harvest Season and Yield Assumptions

The assumed harvest time for switchgrass is once a year after senesce in the fall (Rinehart 2006). Plant nutrients move into the root system after senesce. Thus, harvesting late in the fall or winter would minimize the removal of nutrients and maximize available switchgrass for conversion to ethanol. The once-a-year, late-season harvest may be critical towards switchgrass production being a sustainable low-input system. Thus, the assumed harvest period for switchgrass is from November 1 up to March 1 (Larson et al. 2010). Another important activity in the feedstock supply chain that is related to the once-a-year harvest will be the storage of switchgrass before processing. The biorefinery will need a steady supply of feedstock throughout the year and not just during the November 1 to March 1 harvest period.

Based on historical weather for East Tennessee, a total of 53 days would be suitable for harvest operations during the four-month period with six hours available for harvest operations per suitable harvest day and a total of 325 hours per year available for harvest operations (Table 2) (Larson et al. 2010). Switchgrass yields were simulated using the Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) model (Kiniry et al. 1996), and daily weather data for Knoxville, TN. The location of the weather station, soil types and nitrogen rates were the most important determinants for switchgrass yields. Production practices and input application rates assumed in the simulation came from the switchgrass production budget from the University of Tennessee Extension (Gerloff 2008). The representative soil type simulated in this study is a Dandridge soil, a common soil used for pasture, hay, and crop activities in East Tennessee. Switchgrass yields were simulated for a 10 year planning horizon using the daily weather data. The simulation was repeated 10 times using different weather data for each of the 10 replications. Simulated annual yields are shown in Table 3 and Figure 2. As indicated in Figure 2, switchgrass yields typically reach full maturity by the third year of production (Parrish and Fike 2005). The mean yields for the 10 replications for each year of the 10 years growth and development cycle of switchgrass were used in the simulation of cash flows and net present value.

4.1.2 Switchgrass Feedstock Supply Chain Configurations Simulated

For the switchgrass feedstock supply chain configurations that use conventional hay harvesting equipment, the switchgrass is harvested, stored at the edge of the farm field and transported to the biorefinery as needed. Three alternative conventional hay harvest systems will be evaluated: 1) large rectangular bales, 2) large round bales, and 3) a mixed-bale system. With the mixed-bale system, one-third of feedstock is baled into rectangular bales transported directly to the biorefinery during harvest season and two-thirds of the feedstock is baled into round bales and transported to the biorefinery after storage during off harvest season. For the mixed-bale system, round bales were harvested in year one through three and placed into storage until transport to the biorefinery. The logistics schedule for ten years is shown in Table 4.

For the switchgrass feedstock supply chain configuration that includes preprocessing to densify and prepare feedstock for storage and transportation to the biorefinery, satellite preprocessing facilities in between the farm fields and the biorefinery are used in the preprocessing scenarios. Switchgrass is chopped in the field and transported by truck to the preprocessing facility where it is processed using one of the densification and packaging technologies modeled in this study, stored on site at the satellite facility, and then transported to the biorefinery as needed. Two preprocessed methods are considered in this analysis: 1) a stretch wrap bale technology and 2) a pellet mill technology.

The varied capital investment costs in alternative feedstock supply chain configurations and the cost of producing switchgrass are influenced by switchgrass yields, the lifespan of the switchgrass stand and harvest period for switchgrass. Therefore, the related costs and the cash flows were simulated for alternative feedstock supply chain configurations. All costs related to cash flows are calculated using the American Society of Agricultural and

Biological Engineers standards (ASABE 2009) and American Agricultural Economics Association budgeting guidelines (AAEA 2000). All simulated cash flows were made over an expected 10 year period following the establishment of the stand in year zero of the simulation. At the end of the 10 year lifespan of the switchgrass stand, production is assumed to cease, with total liquidation of all assets following standard capital budgeting practices (Ross, Westerfield, and Jaffe 2008).

Another assumption of the cash flow simulation is that the sales of biomass feedstock to the biorefinery and the processing of switchgrass feedstock into ethanol by the biorefinery were not assumed to occur until the beginning of the fourth year of switchgrass production. Planting switchgrass three years in advance of the plant opening would allow the switchgrass stand in the feedstock draw area to reach full production and build an inventory of biomass feedstocks to ensure a steady supply for the biorefinery. This was especially useful due to the nature of the expected switchgrass yields, which are dramatically lower over the first few years of production. So from years four to ten, one-third of harvested switchgrass is transported to the biorefinery directly during the harvest season, and the two-thirds of switchgrass is stored for off- harvest season delivery to the biorefinery (Table 4). The total switchgrass harvested during the expected lifespan period is assumed to satisfy the biorefinery demand of 329,000 dt/year from years 4 through 10 and are assumed to be completely used by the end of the planning time frame of 10 years, i.e., feedstock inventory was zero at the end of year 10 in the simulation.

Simulation was used to estimate the net present value of the net cash flows for each switchgrass feedstock supply chain configuration for the 10 year time frame. Scenario I, as a base scenario, included only the conventional hay harvest, storage and transportation system. The cash flow of the biorefinery was influenced by alternative ownership arrangements for equipment used for harvest. For scenario II, cash flow was simulated for a procurement process that used a preprocessing function after harvest to densify and package the feedstock for storage and transportation. The cash flow simulation model included all the cash transactions for every year. Depending on the scenario, the total revenue included the BCAP subsidy, the sale revenue of switchgrass that was sold to the biorefinery, and equipment salvage value. The total cost included capital investment outlays and operating costs. The following assumptions were made when creating the cash flow model for both scenarios: 1) improvements in technologies for harvesting and transportation were constant, 2) the switchgrass sale price is $75 per dry ton (Garland 2008), and 3) annual cash flows were discounted to present value using a 10% discount rate (Perrin et al. 2008).

The formula for annual net cash flow is as follows:

$$\begin{aligned} \text{Net Cash Flow}_{tj} &= \text{Cash Inflow}_{tj} - \text{Cash Outflow}_{tj} \\ &= \text{BCAP Subsidy}_{tj} + \text{Sales Revenue}_{tj} + \text{Salvage Value}_{tj} - \text{Operating Costs}_{tj} - \text{Investment Cost}_{tj} - \text{Labor Cost}_{tj} - \text{Management Costs}_{tj} - \text{Rent Cost}_{tj} \end{aligned} \quad (15)$$

where t is year of simulation, j is feedstock supply chain configuration. Cash flow costs included switchgrass establishment, maintenance, harvest, preprocessing if conducted, storage, and transportation to the biorefinery plant gate.

Feedstock draw area acreage for each feedstock supply chain configuration was determined using an assumed constant demand of 329,000 dry tons per year in years four through ten, a zero feedstock inventory balance at the end of year ten, the real annual yield during the ten years, and weighted average dry matter losses during storage for each bale harvest and storage method. The Solver function in Excel was used to determine the acreage that results in a zero ending feedstock inventory at the end of year ten of the simulation. The stored feedstock every year needs to ensure that ample switchgrass is delivered to the biorefinery every year after accounting for the dry matter losses. At the end of year ten, the switchgrass already stored in the inventory from the previous years and the tenth year, with an adjusted yield accounting for dry matter loss, will just satisfy the biorefinery's tenth year feedstock demand.

4.2 Storage Dry Matter Losses

Dry matter losses during handling and storage affect the total switchgrass tonnage delivered to the biorefinery (Cundiff and Grisso 2008). From a study by Robles-Martinez and Gourden (2000), which used the same stretch wrap bale technology, it was found that garbage with a high organic matter content incurred negligible dry matter losses once the bales were protected by the air-tight mesh and film wrapping. Thus, dry matter losses were assumed to be negligible for the technology. For the pellet technology, since the pellets are stored in water proof storage, the dry matter losses were also assumed to be negligible. Only the conventional hay harvest scenarios included dry matter losses. Values for dry matter loss during storage differed among the alternative harvest configurations. Bale storage treatments included covering or not covering the round bales and rectangular bales with a tarp on a gravel surface or a wooden pallet.

For the 100% round bales system, the four storage treatments were:

(1) uncovered on gravel;

(2) uncovered on wooden pallets;

(3) covered on gravel; and

(4) covered on wooden pallets.

For the 100% rectangular bales system, the two storage treatments were:

(1) covered on gravel; and

(2) covered on wooden pallets.

For the mixed-bale system, the rectangular bales were delivered to the biorefinery directly during the harvest season from year four, and only round bales needed storage. The two storage treatments for round bales were:

(1) covered on gravel; and

(2) covered on wooden pallets.

Storage dry matter loss equations from Larson et al. (2010), estimated from storage dry matter loss data from a study at the Milan Research and Education Center in Milan, Tennessee (English et al. 2008), were used to predict storage dry matter losses for each storage option for the conventional hay harvest systems. For the first and the second years of production, all switchgrass needs to be stored, and were assumed to stored an average of 2.5 years (913 days), and 1.5 years (548 days), respectively. Biomass yields were adjusted for storage dry matter losses using 17% for round covered bales stored ≥1.5 years, for round uncovered bales using 14%, and for rectangular covered bales using 32%; which were the plateau values from the Mitscherlich-Baule functional form estimated by Larson et al. (2010). The Mitscherlich-Baule functional form assumed that dry matter losses increase at a decreasing rate with respect to days in storage as affected by precipitation and weathering up to some maximum level as organic matter is exhausted. Starting in year 3, the weighted-average dry matter loss was used to determine dry matter losses for each storage treatment, due to the multiple storage treatments implemented for harvested switchgrass and transportation schedule. Switchgrass stored during the off harvest season is used to supply the biorefinery with feedstock from March through October (Table 5).

4.3 Capital Budgeting Procedures

Capital budget analysis is used to predict cash flows. The operations schedule and the labor, materials, machinery operating, and machinery ownership expenses for the establishment, maintenance, harvest, storage and transportation activities were estimated using parameters produced by The University of Tennessee Department of Agricultural and Resource Economics (Gerloff 2008, English et al. 2008, Larson et al. 2010a, Larson et al. 2010b, Mooney et al. 2009, McKinley and Gerloff 2010). Equipment operating and ownership costs were based on the ASABE (2009) and AAEA (2000). Several assumptions were utilized over the entire life of the entity. The first of these was an opportunity cost on land for switchgrass production of $22.00 per acre (USDA 2009). All land, buildings, equipment, and materials were assumed to be used only for switchgrass production. The labor time was assumed to be 1.25 times the corresponding machine time and a wage rate of $9.75 per hour was used (McKinley and Gerloff 2010). Diesel fuel for all equipment operations was expensed at a rate of $2.75 per gallon (Gerloff 2010).

4.3.1 Pre-harvest Cost

Switchgrass establishment typically includes land preparation, seed, pest control, and fertilizer. The switchgrass stand is established in May at the beginning of year 0 of the simulation. The operations include two herbicide spray applications as a burn-down treatment before planting, sowing the switchgrass using a no-tillage drill, spreading fertilizer, three post-emergence sprays to control weeds, and a pass with a rotary mower to clip weeds taller than the fledgling switchgrass stand. It was assumed that P_2O_5 and K_2O were applied as fertilizers at the University of Tennessee Extension's recommended rates of 40 and 80 lbs per acre, respectively. It was assumed that equipment and labor were custom hired to carry out the tasks associated with establishment. As was done for all contract work, a 10% premium above estimated budgeted equipment and labor costs was included in the estimated per-acre cost of these services. Furthermore, a 20% replanting rate was assumed during this year. The details for establishment cost calculation are shown in Table 14.

Annual switchgrass maintenance included primarily fertilizing and weed control. Two spray operations to control weeds were assumed in year 1 after establishment. P_2O_5 and K_2O were assumed to be applied every 4 years after the establishment year. Nitrogen was applied at 60 lb/acre at $0.48/lb (Gerloff 2010) each year of the simulation. In addition, two spray operations to control weeds were only conducted in year 1. The cost represents the cost of the required fertilizers and herbicides, along with the costs of the required equipment on a per acre basis, and a 10% premium. The details for maintenance cost are shown in Table 15.

4.3.2 Harvest Cost

The operations schedule for harvest in each year of the simulation included mowing, raking, and baling of switchgrass; movement of the bales from the field to the storage location; and placement of bales into storage. The equipment assumed for the round bale harvest included a 5 ft× 4 ft large round baler, mower, rake, loader and tractor. For the rectangular bale harvest, a 4 ft× 8 ft rectangular baler is used instead of the round baler. It was assumed that dry matter losses are the same for both bale harvest methods, regardless of the harvest period, and only happen in storage and transportation. Machine and labor time and twine for the baling and handling operations were assumed to be a function of switchgrass yield (Mooney et al. 2009). It was also assumed that throughput is 12 dry tons per hour for the large rectangular baler, and 5.5 dry tons per hour for the large round baler. The total harvest cost per acre is the sum of the per acre costs of mowing, raking, baling and loading.

For the preprocessing scenario, there were two different harvest options. The first option was chopped with the windrow pickup option, where the harvest equipment included a self-propelled forage chopper, a tandem-axle truck, a mower, a rake, and a tractor. The second option was chopped with the rotary cutter-header option, where the mower and the rake would not be used during harvest. The harvest cost included the tandem-axle truck transportation cost from farms to the storage area at the preprocessing facility. The machine time of the chopper was based on an assumption of a 20 dt/hour throughput capacity (Hanna 2002).

4.3.3 Preprocessing Costs

For the preprocessing scenario, the steps between the farm field and the biorefinery are assumed to be the following: 1) a multiple pass harvest using mow, rake, and chopping operations or a single pass using a chopper with a rotary cutter-header; 2) transportation to a satellite facility or biorefinery using a tandem-axle truck; 3) densification and preparation of feedstock for storage; 4) storage of preprocessed feedstock at the satellite facility; and 5) transportation of preprocessed feedstock to the biorefinery. Each preprocessing facility consisted of a building to preprocess feedstock, covered storage for a two-day supply of chopped switchgrass before preprocessing, and land for on-site storage of preprocessed bales.

After densification and packaging in the preprocessing facility, the densified feedstock was assumed to be placed in on-site storage at the facility before transportation to the biorefinery. In order to effectively process the entire yearly harvest of switchgrass in the four month harvest season, the number of preprocessing facilities was determined by the switchgrass annual yields and the throughput capacity of the equipment. For the stretch wrap bales systems, the throughput capacity of a stretch wrap baler is 45 tons/hour, processing 63,360 tons per year (16 hours per day for 88 days per year). For one pellet preprocessing facility, there are three pellet mills, and the throughput capacity of one pellet mill is 14 tons/hour, processing about 60,000 tons per year (16 hours per day for 88 days per year). Thus, for both preprocessing methods, it was determined that two preprocessing facilities are required in year one, three in year two, and four preprocessing facilities would be required from year four. The preprocess system required that the diamond shaped feedstock draw area be divided as indicated in Figure 3 into five shipping zones. The five zones have one center zone that serves the biorefinery during the harvest season and four equal-size zones, each having one preprocess facility. For years one to three, all chopped switchgrass is assumed to be delivered to the preprocessing facilities for densification and packaging, and stored until year four, when the biorefinery starts to process biomass feedstock. Due to the low yields of the first three years, the four preprocessing facilities are gradually erected as yields increase and the amount of feedstock processed increases. As a result, for year one, only two preprocessing facilities were built, and the whole feedstock draw area was split into two equal sizes zones for delivery of chopped switchgrass for preprocessing. For year two, an additional preprocessing facility was built, and the feedstock draw area was divided into three equal harvest zones. For year three, one more preprocessing facility was built, and the feedstock draw area was separated into a total of four zones each having a preprocessing facility. From year four and beyond, the central harvest zone delivered chopped material directly to the centralized biorefinery location during the harvest season. The four equal-size zones have all harvested feedstock delivered to a preprocessing facility during the harvest season, and then delivered to the center biorefinery during the off-harvest season. The average distance between each preprocessing facility and the biorefinery was assumed to be 40 miles (Table 6, Figure 3).

Deviating from conventional biomass harvest methods, such as in-field baling using round and rectangular balers, the preprocessing scenario has a dramatically different harvest process. For harvest, switchgrass is chopped with a windrow pickup after mowing and raking operations or chopped with a rotary cutter-header was assumed for both preprocessing scenarios. The tandem-axle truck will then deliver chopped feedstock to the preprocessing facility. After preprocessing, the pre-processed switchgrass is assumed to be delivered to the plant by semi-trucks during the off-harvest season.

There are two preprocess systems considered. One is stretch wrap bale technology marketed by TLA Bale Tech LLC that was originally developed to compact and store garbage in Europe (Larson et al. 2010). The facility would use a shrink-wrap baler that would form dense 3000 pound 6 foot by 5 foot round bales (about 2 times more dense than a conventional round bale of a similar size), wrap the bales with mesh and a multi-layered plastic film that shrinks around the bale to provide an air-tight storage environment, and store it until delivery can occur. Another preprocessing option was processing feedstock through a pellet mill. As with the stretch wrap bale technology, the chopped switchgrass is assumed to be delivered to the preprocessing facilities for processing. The main production process at the satellite facility include: 1) feedstock drying, 2) fine grinding, 3) pelleting, 4) cooling, and 5) screening (Grbovic 2010). After preprocessing, the pellets are assumed to be stored until delivery to the biorefinery.

4.3.3.1 Stretch Wrap Baler

The preprocessing cost included charges for land, buildings, labor, machinery ownership and operating expense, and labor and management (Larson et al. 2010). Building costs include a pole shed structure to house the baler and provide for two-days of loose storage of chopped feedstock. The building area for storage is assumed to be 85,714 sq ft, and the area for compactor baler is assumed to be 5175 sq ft. The building cost is $596,942. The land area is assumed to be 15 acres. The post-storage cost included the cost of the preprocessed bale also stored in the preprocessing facility before transport to the biorefinery. The cost of materials for each preprocessed bale (film and net wrap) that was processed through the facility was assumed to be $15 dt bale (Falconi 2010).The stretch wrap baler with supporting conveyor equipment was estimated to have a purchase price of $1.4 million, a useful life of 36,000 hours, and a throughput capacity of 45 dt/h (Falconi 2010).. Three loaders per compactor baler are needed during the preprocessing operation. The baler is assumed to work over a four- month season (88 days), which could be able to process 63,360 dt (16 hour/day for 22 days/month). All energy consumption parameters and stretch wrap baler related parameters were provided by TLA BaleTech LLC (2009). Table 7 summarizes the estimated cost for one stretch wrap baler preprocessing facility.

4.3.3.2 Pellet Mill

The preprocessing cost for the pellet mill included the electricity costs, drying costs, labor costs, service and maintenance costs, the wheel loaders' operating costs, and other variable costs. For the pellet preprocess line, the throughput is 14 tons/hour. It was assumed that the preprocessing line ran 24 hours/day and 88 days/year, and there are three pellet-mills per preprocessing facility. The description and usage for each type of equipment in the preprocessing facilities are listed in Table 8. For the pellet scenario, calculating the costs is difficult because there are no engineering companies or contractors with already created templates or design packages for pellet plants. The main assumptions for pellet preprocessing facilities were based on Grbovic (2010). The preprocessing facility used 1.5 BTU/lb of evaporated water and assumed natural gas as the source of fuel for the drying process. In Grbovic's study, the pellet plants run 7,143 hours per year, and after a ten-year period, the salvage value is zero. The same pellet plant assumptions were used in budgeting, but only run four months per year. As a result, it was assumed there would be a 66% average value left after the ten-year period.

4.3.4 Storage Costs for the Conventional Hay Harvest Systems and Preprocessing Systems

In years one to three the biorefinery does not operate and 100% of the harvested switchgrass is assumed to be stored until the biorefinery opens at the beginning of year four. Starting in year four, two-thirds of harvested switchgrass is assumed to be stored for delivery during off-harvest season, and one-third of switchgrass is assumed to be delivered to the biorefinery directly during the harvest season. Bales are assumed to be stored outdoors at the edge of the field. The estimated costs for related storage materials were obtained from an informal survey of suppliers located in Tennessee (Wang 2009). The costs included materials costs, which constitute plastic tarps, gravel, wooden pallets, and equipment and labor required to create the storage site and bale stack (Wang 2009). The storage cost was determined by tonnage and the cost per dry ton for each storage option. Collins et al. (2008) found that the 3-2-1 pyramid design with three bales on the bottom, two in the middle, and one on top is the most effective way to store in the southeastern region of the USA. Thus, covered round bales were assumed to be stored in the stack using this configuration. Uncovered round bales were assumed to be stored individually at the edge of the field. The rectangular bales were assumed to be stored in a 2-2-1 configuration. The compactor bales produced at the preprocessing facility were assumed to be stored in 3-2-1 pyramids on site until transport to the biorefinery. The pellets are assumed to be stored in a water proof container at the preprocessing facility before transport to the biorefinery.

4.3.5 Transportation Costs for the Conventional Hay Harvest Systems and Preprocessing Systems

The transportation costs included the machinery ownership and operating costs for semi-trucks with flat bed trailers, driver labor costs and tractors with loaders. For the conventional hay harvest scenarios, the semi-truck is assumed to deliver the bales from the farm to the biorefinery. For the preprocessing scenario, the transportation cost was calculated from the farms to the biorefinery during the harvest season using tandem-axle trucks, and from the preprocessing facility to the biorefinery during the off-harvest season using the semi-tractor with flat bed trailers. Dry matter loss during transportation was assumed to be 2% for the traditional scenario (Kumar and Sokhansanj 2007). The average distance traveled for the round and rectangular bale was assumed to be 37.5 miles, and for the preprocessing scenario the distances are shown in Table 5. The average travel speed of the semi-tractor truck and trailer was assumed to be 50 miles/hour (Brechbill et al. 2008) and if could operate 10 hours per day. The number of bales that the truck is assumed to haul on a single trip is 36 large round bales, 24 rectangular bales, or 16 preprocessed bales. The time per round trip to the plant was assumed to be 1.4 hours for the round and rectangular bale, and 1.15 hours for the stretch wrap bales. Thus, the number of truck loads per workday to supply the biorefinery is assumed to be ten, eight, seven and five trucks per day respectively, for the round, rectangular, stretch wrap bales and pelletized bales.

4.3.6 Management Costs

The feedstock supply chain will likely need managers to oversee contracting, production, harvest, storage, and transportation activities within the feedstock supply chain. Management costs were included as a constant cash outflow in each year of the simulation. For the conventional hay harvest scenarios, management costs include one manager for the entire supply chain. For the preprocessing scenarios, management included an operations supervisor for each preprocessing facility (for a total of four) and one general manager for the entire operation. These managers are assumed to be full time employees while the labors handling harvest and trucks equipment are assumed to be seasonal employees. According to occupational employment statistics for TN provided by the Bureau of Labor Statistics, the supervisors' salaries began at around $48,800 per year for each preprocessing facility, and the manager's salary began at $79,100 per year, each with a 3% growth rate each year (Bureau of Labor Statistics 2010).

4.4 Harvest Equipment Ownership Scenarios

There were two ownership options evaluated for the harvest equipment: 1) to be owned and operated by a feedstock logistic entity or 2) custom hiring of equipment operation. For the equipment ownership scenario, all harvest equipment was assumed to be dedicated to switchgrass production and was used 325 hours per year for the harvest operation during the November 1 to March 1 harvest period. In addition, purchase of harvest equipment was treated as a cash outflow in year zero and replaced at the end of its useful life if shorter than the planning horizon. Equipment was assumed to be disposed of at current salvage value at the end of the planning horizon. For the custom hiring options, rather than purchasing the machinery, the possibility of custom hiring existing tractors, mowers, rakes, and forage choppers in the East Tennessee area was explored. This may reduce cash outlays for equipment acquisition and decrease per acre harvest costs. Three additional assumptions were described in the custom hiring option: 1) capital recovery was factored into the per acre price of equipment rather than as a cash outflow in year zero, 2) a 10% premium would be paid to the owners of the leased equipment and 3) annual usage of equipment was set greater than

325 hours using UT Extension assumptions about farm size and annual equipment usage for calculation of equipment costs (Johnson 1991) (Table 9).

4.5 Operation Equipment

4.5.1 Equipment Numbers

Production equipment included equipment for harvest, preprocessing, and transportation. Numbers of machines were calculated based on the throughput capacity of the machinery, switchgrass yields, the amount of switchgrass required by the biorefinery, and the speed and distance to the destination. The harvest equipment that was required, which includes mowers, rakes, loaders, tractors, and balers, were determined based on 325 hours of available harvest time considering weather between November 1 and March 1. In order to calculate how many machines will be needed to harvest the necessary tons of switchgrass during the four month harvest period, the number of acres that can be harvested in one hour must be determined first. Then, the number of acres that one piece of equipment will harvest during each month is found by multiplying the number of acres per hour by the amount of working hours monthly. The amount in tons that one machine could process during the harvest season is calculated given the average yield per acre (6 dt/acre). About 329,000 dt of switchgrass is needed based on 76 gallons/dt, which was used in the conversion of 25 million gallons of ethanol (Wang et al. 1999). The Dandridge soil switchgrass yield over a ten year period has a mean yield of 6.14 dt/acre. When calculating the amount of equipment necessary for harvest, stage, storage and transportation, it is assumed that the yield is 6 dt/acre. For the transportation equipment, the semi-truck was used for both the conventional hay harvest and preprocessing scenarios, while the tandem-axle truck was only used for the preprocessing scenario.

Additionally, for the preprocessing scenario, forage choppers and tandem-axle trucks were used to harvest switchgrass and deliver it to the preprocessing facility. Due to the yields of first three years being lower than 6 dt/acre, annual yields were used when calculating the number of choppers and tandem-axle trucks.

4.5.2 Salvage Value and Depreciation

It is assumed that each piece of equipment experiences depreciation annually and the salvage price would be accounted for at the end of the project lifespan regardless of whether or not the equipment has reached the end of its lifetime. If the equipment lifespan is less than the project lifespan (10 years), the salvage value calculation also needs to determine the specific year in which its lifetime is finished. When the equipment useful life is reached, the salvage value is determined by the salvage factor. If the equipment still can be used at the end of year 10, the salvage value is determined by the proportion of the list price based on hours of useful life.

4.6 Sensitivity Analysis

In order to evaluate the effects of the variability and uncertainty of input parameters on the net present value of the net cash flow for each switchgrass feedstock supply chain configuration, one-way sensitivity analysis was used in the study (Soldatos and Lychnaras 2003). The most influential factors for the net present value included: 1) government policies, 2) switchgrass sale price, 3) discount rate, 4) fuel price, 5) wage rate, and 6) the stretch wrap baler throughput. Only one factor at a time was changed while leaving the other parameters at their base values to evaluate how the net present value of net cash flow changed. These variables were defined by three categories: 1) optimistic, 2) base and 3) pessimistic. Unless otherwise stated for a variable, each variable was changed 20% above and 20% below the base value (Table 10).

4.6.1 BCAP

Government policies and subsidies are often an important factor to be considered in an investment project. The Bioenergy Crop Assistance Program (BACP) was assumed as the subsidy program in the study (U.S Congress 2008). With or without BACP determines whether the farmers receive financial support from the government. It is assumed that farmers are responsible for the service fee for the collection, harvest, storage and transportation of switchgrass to facilities, and maintain ownership until the switchgrass is transported to the biorefinery. All supply chain configurations were assumed to be eligible to receive the BCAP subsidy for the analysis. The BACP includes the establishment subsidy paid in year zero, which is 75% of the cost of establishment cost; and harvest subsidy in year four and year five of up to $45 per ton for harvest and transportation activities.

4.6.2 Break-even Switchgrass Sales Price

The switchgrass sale price is one of the most significant factors influencing net present value of net cash flow. The break-even switchgrass price is the sales price to the biorefinery when the net present value of the net cash flow is zero, which is found using the Solver function in Excel. It demonstrates the minimum switchgrass price needed when sold to the biorefinery to ensure that the net present value of net cash flows for the feedstock supply chain is positive. The break-even price is evaluated for the systems with BCAP and without BCAP. For the systems with BCAP incentives, the break-even price is determined based on the 10% discount rate, the fuel price of $2.75/gallon, the wage price of $9.75/hour, and throughput capacity of the stretch wrap baler of 45 dt/hour. This is the base value data in the simulation. For the systems without the BCAP incentives, the break-even price is determined based on the discount rate of 8%, the fuel price of $2.2/gallon, the wage price of $7.8/hour, and the throughput capacity of stretch wrap baler at 54 dt/hour. These values are the optimistic value for each factor. The break-even price is the sale price to the biorefinery when the net present value is zero.

One-way sensitivity analysis is also used for evaluating the sale price. The base value of the switchgrass sale price was $75/dt, and the optimistic and pessimistic was 120% and 80% of the base value, with the price at $90/dt and $60/dt, respectively.

4.6.3 Discount Rate

Discount rate is the most influential variable in the present value function. It determines present value of future cash flows. Discount rate influences every cash flow, which constitutes costs and revenue. The base value of discount rate was 10%, as assumed in the simulation model (Perrin et al. 2008). The optimistic and pessimistic values were 12% and 8%.

4.6.4 Fuel Price

Most machinery costs include the cost of fuel. By determining the fuel price, the net present value of net cash flow fluctuates and significantly impacts the equipment cost variable as a parameter in present value. The base value of the fuel price was $2.75/gallon in the simulation model. The pessimistic and optimistic values $3.30/gallon and $2.20/gallon were chosen by varying price from −20% to +20% of the base price.

4.6.5 Wage Rate

Labor cost is one of the other factors which is always considered for net cash flow of an investment analysis. Wage rate was a parameter for most machinery operations costs. The value in the simulation model as the base value was assumed to be $9.75/hour, and for sensitivity analysis, the pessimistic and optimistic values were $11.70/hour and $7.80/hour, which were ranging from −20% to +20% of the base value.

4.6.6 Stretch Wrap Baler Throughput Capacity

The stretch wrap baler throughput capacity parameter determines the preprocessing efficiency, which affects preprocessing cost. The base throughput was 45 dt/hour (TLA BaleTech LLC 2009), and 36 dt/hour and 54 dt/hour were collected to perform the sensitivity analysis.

Chapter 5: Results and Discussion

5.1 Conventional Hay Harvest Baseline Scenario

5.1.1 Feedstock Draw Area and Tonnage Delivered

For the conventional hay harvest scenario, the harvest acres needed to result in 329,000 dt of switchgrass to be delivered to the biorefinery annually in years four to ten is based on the following: 1) switchgrass yields in each year, 2) dry matter losses assumed in each year, and 3) the assumption of a zero ending balance for feedstocks in year ten. Switchgrass is assumed to not be delivered to the biorefinery until year four as production is ramped up to supply the biorefinery during years four through ten. The quantity of switchgrass delivered to the biorefinery is determined by the dry matter losses during storage and transportation and the original total harvest amount. Dry matter losses at the harvest and handling stages before placement into storage are assumed to be the same for each alternative. For each system, the storage dry matter losses for years one and two used the plateau values for dry matter losses from the Mitscherlich-Baule functional form estimated by Larson et al. (2010). For years three to ten, where switchgrass was assumed stored less than 1.5 years, the weighted average dry matter losses were predicted using the Mitscherlich-Baule function by Larson et al. (2010) used for estimating net present value of cash flows. The weighted average dry matter losses are assumed to be 5%, 10%, and 23% for round bales with tarp, round bales without tarp and rectangular bales with tarp, respectively (Table 5). In addition, dry matter losses during transportation of feedstock to the biorefinery for all systems are assumed to be 2%. As a result, the acreage harvested for each feedstock supply chain configuration varied due to the dry matter losses incurred during storage. The biorefinery requires 329,000 dt per year, and the total switchgrass required for the biorefinery running from year four to year ten is 2,302,632 dt. So the total switchgrass required to harvest during the ten years is 2,551,124 dt, 2,473,662 dt, 2,866,398 dt, and 2,473,662 dt for the round bales without tarp systems, round bales with tarp systems, rectangular bale with tarp systems, and the mix bale systems, respectively (Table 11).

5.1.2 Capital Investment Outlays

The equipment required for production and logistics to provide 329,000 dt of feedstock to the biorefinery is reported in Table 12.

In the category of harvest equipment, the conventional bale technologies require the largest capital investment. Assuming a 325 hour harvest season and throughput capacities of 5.5 dt/hour and 12 dt/hour respectively for round and rectangular baler, it is estimated that 140 round balers are required for the round bale without tarp system; 136 round balers are required for the round bale with tarp system; 72 rectangular balers are needed for the rectangular bale system; and, 91 round balers and 21 rectangular balers are required for the mixed-bale system. For the round bale without tarp system, 49 mowers and 32 rakes are required for harvest based on a 325 hour harvest season. For the round bale with tarp and mixed-bale systems, 48 mowers and 31 rakes are needed. For the rectangular bale, 55 mowers and 36 rakes are needed. Given that harvest equipment reached the end of its useful life before the end of the 10 years simulation, it was assumed that equipment was repurchased at the end of their useful lives. And thus, mowers were purchased in year zero and year six; rakes were purchased in year zero and seven. Rectangular balers were purchased in year zero and year nine; and round balers need to be purchased in year zero, year four, and year eight. For the mixed system, the rectangular balers were purchased once in year three.

In the category of vehicles, the number of tractors required for harvest logistics for each system is determined based on mowing and raking time and the throughput of the round baler and the rectangular baler to complete harvest in a 325 hour period. It is estimated that

344, 302, and 312 tractors were needed for the round bale, rectangular bale, and mixed-bale systems, respectively. The semi-trucks used to transport the switchgrass from the farms to the biorefinery account for the smallest part of the total capital investment outlays. It is estimated that 10, 8, and 8 semi-trucks were needed for the round bale, rectangular bale, and mixed-bale systems, respectively.

For the custom hired equipment scenario, the equipment needed to harvest for each conventional hay harvest system is based on a 325 hour harvest period and the throughput capacity of equipment. Overall investment in equipment in year zero and for some equipment whose life-time is shorter than the project life-span, new equipment must be purchased respectively in subsequent years. The estimated net investment for all equipment purchased over the 10 year period in present value dollars is reported in Table 13. These numbers are determined by the purchase price minus the salvage value, both in year zero present value dollars. The net investment for equipment is presented as a negative number, because the cash outflows are bigger than the cash inflows. For all systems, the switchgrass is assumed to be sold to the biorefienry starting in year four. From year one to year three, the cash inflow from sales is zero. The mixed-bale system has the smallest net investment for equipment, which is −$34.5 million. The mixed-bale system only purchases the rectangular balers in year three, because round balers are used before them and does not need to be replaced during the ten year period. But with the round bale and rectangular systems, the balers need to be purchased in year zero, the round balers need to be replaced in year four and year eight, and the rectangular balers need to be replaced in year nine. Thus, the round and rectangular bale systems have higher net investment cost for equipment.

If the machinery utilized for harvesting operations is custom hired, only truck investment costs are calculated and the harvest equipment investment costs are zero. The result is significant cuts to the capital investment cost. The total cash outflows would decrease by a minimum of $30 million no matter which conventional hay harvest system is utilized.

5.1.3 Operation Cost of Switchgrass Production

The operation cost of switchgrass production includes the pre-harvest cost, harvest cost, storage cost and transportation cost. The establishment cost is incurred in year zero $425.85 per acre and includes a 10% custom work premium and a 20% replanting rate cost (Table 14). The annual maintenance cost in years two through ten years, including a 10% custom work premium, is $62.20 per acre for all harvested area (Table 15). Table 16 summarizes the estimated costs of switchgrass by harvest and storage methods. Because the harvest cost varies by yield in each year, the average harvest tractor and mower, rake, and loader costs over the ten years are shown in Table 16. For each system, the average harvest tractor and mower, rake, and loader costs are consistent at $33.37/acre, $20.29/acre, and $88.66/acre respectively. The baler cost varies by different baler. The rectangular baler cost per acre is higher than the round baler. Thus the harvest costs for the rectangular systems are the most expensive, which average $324.79/acre/year over the 10 year planning period, and the round systems and the mixed-bale systems are $287.67/acre/year, and $300.05/acre/year, respectively.

Dry matter losses have been considered when determining the storage cost. For the mixed-bale system, the storage costs are the same as for the round bale system, because the same amount and type is stored under both systems. Among the two harvest and four storage methods, the weighted-average storage cost of the round bales stored under tarp on gravel is the most expensive at $18.68/dt. The most inexpensive weighted-average storage cost is for the round bales stored without a tarp on pallets at $4.52/dt. The transportation costs occurred between years four and ten in the simulations, and varying with respect to the harvest method. The average transportation costs for the round bale, rectangular bale, and the mixed-bale systems are $21.68/dt, $17.37/dt, and $20.40/dt, respectively. For all harvest and storage methods, the annual amount of switchgrass required to be transported per year starting in year four is 335,661 dt given an assumed 2% dry matter loss during transportation to the biorefinery.

Table 17 shows operation cost of production for each system from year zero to year ten. Storage cost per year is the largest difference among varied conventional hay harvest systems compared with establishment, maintenance, harvest, and transportation costs. The round bale with a tarp on gravel system has the largest accumulation storage costs over the ten years, which is $1147.86/acre. The round bale without a tarp on pallet system has the lowest total storage costs over the ten years, which is $277.99/acre. The largest accumulation operation cost over the ten years is the mixed-bale system with a tarp on gravel, which is $6377/acre; and the lowest is $5429/acre for the round bale without a tarp on pallet system. Production costs are significantly affected by harvest method and storage methods which influence dry matter losses during storage. Due to different dry matter losses with each logistics method, the acres of switchgrass in the draw area required to meet the feedstock needs and the yields vary. As a result, the different harvest and storage methods that affected the total operation cost in each year of the simulation.

5.1.4 Net Present Value and Sensitivity Analysis

Two options for harvest equipment were evaluated in the analysis: 1) purchased equipment dedicated to switchgrass harvest, and 2) custom hiring of equipment and labor to complete harvest and storage logistics. For the conventional hay harvest scenario, there are 16 systems compared in the net present value analysis (two harvest equipment options and eight different harvest and storage options). The net present value of cash flows for the 10 year life-span of the project is determined by land lease payments, management costs, capital investment outlays, operating costs, revenue and the discount rate. The land lease payments vary based on the harvested acreage among different harvest and storage systems. The management costs for all traditional systems are the same every year, which comprises a small proportion of the total annual cost.

Based on the switchgrass sale price of $75/dt, 10% discount rate, $2.75/gallon fuel price, $9.75/hour wage rate, and having the BCAP subsidy, all of the conventional hay harvest custom hiring systems produced positive net present values, and all of the conventional hay harvest purchasing systems produced negative net present values (Table 18). The custom hire harvest equipment scenario has much less capital investment costs than the purchased harvest equipment for each system. The conventional hay harvest system that had the largest net present value of net cash flows was round bales stored on pallets without a tarp following harvest using custom hired equipment, which equals a net present value of $22 million. The least profitable system is rectangular bale stored on gravel with a tarp following harvest using purchased equipment, and the net present value of cash flow is −$27 million. The large negative number is due to non-existent sales revenue during the first three years, and all equipment is purchased in year zero. The biorefinery does not start operating until the beginning of year four, which has a significant influence on net present value. Among the custom hiring harvest equipment systems, the lowest net present value system is the rectangular bales system where bales are stored on gravel with a tarp, and the net present value of cash flow is $7 million. On the other hand, among the purchased harvest equipment systems, the system with the smallest loss is the mixed-bale stored on pallet with a tarp system, with a net present value of −$12 million. For all of the feedstock supply configuration with negative net present values, the corresponding break-even switchgrass sale price is higher than $75/ton. In order to receive a zero net present value (ie, a compound rate of return of 10%), the break-even price for the conventional hay harvest using purchased equipment scenario was $97.54/dt. The break-even price is needed to ensure the net present value of cash flow is not negative. For the positive net present value systems, the break-even sale price is less than $75/dt (Table 18).

The base system net present value is determined based on having the BCAP subsidy, the switchgrass price is $75/dt, the discount rate is 10%, the fuel price is $2.75/gallon, and the wage rate is $9.75/hour. For different harvest and storage systems in the traditional scenario, the results of sensitivity analysis for the BCAP subsidy, switchgrass sale price, discount rate, fuel price, and wage rate are shown in Table 19. Without the BCAP establishment subsidy in year zero and harvest subsidy in year four and five, the net present value of cash flow were negative for all feedstock supply chain configurations evaluated in the analysis. Without the BCAP subsidy, the NPV of all the conventional hay harvest systems with custom hired equipment become negative (Figure 4.1). In addition, the switchgrass sale price influences the net present value by impacting revenue from sales to the biorefinery starting in year 4. When the sale price is higher, cash inflows are higher and begin to offset the considerable cash outflows in the first few years as the switchgrass stands are established and feedstocks are built up (Figure 4.2). When the purchased harvest equipment system is used, the $90/dt sale price results in a positive net present value if switchgrass is harvested by round baler and stored on pallets with or without a tarp, or when the mixed-bale system is used and switchgrass stored on pallets with a tarp. If the sale price is $60/dt, the custom hired equipment systems yielded a negative net present value, except for the round bale stored on pallets systems and the mixed-bale stored on pallets with a tarp system. The discount rate is also an important factor that influenced the net present value of alternative traditional bale systems. Compared to the custom hiring systems, the purchasing equipment systems are much more influenced by the discount rate (Figure 4.3). Among different harvest and storage systems, the fuel price has the strongest influential in the rectangular bale stored on the gravel with a tarp system (Figure 4.4). Wage rate has little influence on net present value compared with other factors (Figure 4.5). In the sensitivity analysis, BCAP and switchgrass sale price are the two most important factors influencing net present value given the assumption that sales would not start until year 4. If the switchgrass sale price is $90/ton, the round bale system stored on pallets with a tarp after harvest and using custom hired equipment had the highest net present value of $39 million. When calculated without the BCAP subsidy, the rectangular bale system stored on gravel with a tarp after harvest by purchased equipment resulted in the lowest net present value with a dollar value of −$62 million.

5.2 Preprocessing scenario

5.2.1 Feedstock Draw Area and Tonnage Delivered

For the preprocessing scenario, the storage dry matter losses are negligible when compared with traditional hay system with outdoor storage, and the dry matter loss during transportation to the satellite facility is 2%. So for all the preprocessing systems, the acres required to harvest every year is 38,249 acres to meet 329,000 dt per year (2,302,632 dt for seven years) of the biorefinery demand.

5.2.2 Capital Investment Outlays

Required equipment is estimated based on the same assumptions as the conventional hay harvest scenario. The only difference between the compactor bale system and the pellet mill system is the preprocessing throughput performance for biomass that is densified and packaged by the facility. Thus, the number and the type of harvest and transportation equipment is the same for both the stretch wrap baler system and the pellet mill system.

In the category of harvest equipment, for the chopper with the windrow pickup requires 45 mowers and 30 rakes. For the chopper with rotary cutter- header, no mowers and rakes are needed. The total number of choppers required to complete the harvest in 325 hours on the 38,249 acres of switchgrass in the feedstock draw area is 45. The chopper with windrow pickup and the chopper with rotary cutter- header have different purchase prices of $266,000 and $333,112, respectively.

In the category of vehicles, there are three types of vehicles that are considered. The systems using choppers with rotary cutter- headers do not need tractors for mowing and raking operations. For the chopper with windrow pickup system, 75 tractors are needed for mowing and raking operations for both the stretch wrap baler system and the pellet mill systems. It is estimated that seven semi-trucks are required for the stretch wrap bale and five semi-trucks for the pellet mill systems to move feedstock from the satellite preprocessing facilities to the biorefinery.

For the preprocessing scenario, the two harvest systems (chopper with windrow pickup and chopper with rotary cutter- header) need different harvest equipment. The number of each type of equipment is shown in Table 20. For the most efficient investment in equipment, the choppers were assumed to be purchased in increments as switchgrass production increased in years one to three, 14 in year one, 9 more in year two, and 22 more in year three. For the tandem-axle trucks, 66 are assumed to be purchased in year one, but 22 should be re-sold in year four as less trucks are needed to haul when field to satellite facility travel distance becomes shorter. In the preprocess operation, the compactor bale system requires four stretch wrap balers at four satellite facilities and 12 tractors with loaders to handle bales. For the pellet mill system, the preprocessing equipment required and the costs are shown in Table 21.

The estimated net investment for all equipment purchased over the 10 year period in present value dollars is reported in Table 22 and Table 23. Net investment includes investment in equipment in year zero and for replacement equipment whose life-time is shorter than the project life-span, new equipment must be purchased in subsequent years. As with the conventional hay harvest scenarios, the net investment number for equipment includes the purchase price and the salvage value both in year zero present value dollars. For the stretch wrap baler systems, the chopper with the windrow pickup system has a net investment for equipment of −$28.2 million and chopper with the rotary cutter-header system is −$23.5 million. The pellet mill preprocessing system have a net investment for equipment of about −$76.3 million and −$71.6 million total investment costs for harvest by chopper with the windrow pickup and chopper with the rotary cutter-header, harvest option respectively. As a result, the investment cost for the equipment is the largest portion of cash outflows.

Compared with the conventional hay harvest scenario, the preprocessing scenario has substantial investment in preprocessing equipment for densification and purchasing of feedstock for storage and transportation. For the stretch wrap baler systems, the net capital investment cost for preprocessing facilities is about $6.6 million for four preprocessing facilities within the feedstock draw area. For the pellet mill system, the capital investment cost for preprocessing facilities is much higher at $55.9 million. Though some equipment can be sold at the end of the assumed 10 year life-span, the capital investment cost for pellet mill preprocessing facilities had the largest capital outlays among all of the feedstock supply chain configurations evaluated in this study.

If the machinery utilized for harvesting operations is custom hired for the preprocessing option, semi-truck and tandem axle truck investment costs are calculated and the harvest equipment investment costs are zero. The result is a significant reduction in the capital investment cost.

5.2.3 Operation Cost of Switchgrass Production

Table 24 summarizes estimated operation costs of switchgrass by harvest and preprocessing methods. As with the conventional hay harvest scenario, the preprocessing scenario has the same establishment costs and the same maintenance costs every year. The harvest costs in Table 24 are also average costs over the ten years given that the harvest cost varying by yield in each year. The harvest tractor and mower, rake, and chopper costs are consistent for the chopper with windrow pickup systems, which are $20.29/acre, $33.37/acre, and $65.13/acre, respectively. For the chopper with rotary cutter- header system, the harvest cost only includes the chopper costs, which is $72.14/acre. The preprocessing system cost is different for the two methods. The pellet preprocessing system costs are much higher than for the stretch wrap bale preprocessing system, which are $86/ton and $20.15/ton, respectively. The transportation costs include tandem-axle truck hauling cost, which happens from year one, and semi-truck hauling cost, which happens starting in year four. From year one to year three, all of the switchgrass is transported to the preprocessing facilities by tandem-axle trucks. From year four, one-third of switchgrass is assumed to be transported as chopped material directly to the biorefinery during harvest by tandem-axle trucks, and two-thirds of the switchgrass will be transported by semi-trucks as densified and packaged feedstock to the biorefinery. Due to various transportation distances, the tandem-axle transportation cost for chopped switchgrass is $31.42/dt in year one, $30.44/dt in year two, $23.49/dt in year three, and $22.94/ton for year four through ten based on the average miles traveled. The semi-trucks are responsible for the transportation of the switchgrass from the preprocessing facilities to the biorefinery. Thus, for the stretch wrap bale system, the semi-truck cost is $12.64/dt and for the pellets system, the semi-truck cost is $6.28/dt. The average transportation distances for the preprocessing scenario are shown in Table 5. The semi-trucks need to deliver 335,661 tons per year to the biorefinery from year three.

Table 25 shows operation cost of production for each system from year one to year ten. Preprocessing cost per year is the largest difference among varied preprocessing systems compared with establishment, maintenance, harvest, and transportation cost. The pellet mill systems have much larger preprocessing costs over the ten years, which is $5311.84/acre, than the stretch wrap baler systems. The largest total operation cost over the ten years is pellet mill with the chopper with the windrow pickup system, which is $8868.85/acre; and the lowest is the $4600.04/acre, which is stretch wrap baler with the chopper with rotary cutter-header system.

5.2.4 Net Present Value and Sensitivity Analysis

The net present value of cash flows for the 10 year life-span of the project is determined by land lease payments, management costs, capital investment outlays, operating costs, revenue and discount rate. The cropland lease payments are the same every year for different preprocess systems, which is $824,644.22 annually. The management costs are higher than conventional hay harvest systems because there is one more operations supervisor for each preprocessing facility (for a total of four). The net present value and break-even prices for each preprocessing with the BCAP system are shown in Table 26. Based on a switchgrass sale price of $75/dt, the present values of cash flows are determined. The system with the highest net present value in the preprocessing scenario is the stretch wrap baler system for feedstock harvested by the chopper with rotary cutter- header using custom hired equipment, which results in a positive present value of $15.6 million. The lowest net present value system is the pellet mill system in which biomass is harvested using the chopper with a windrow pickup using purchased equipment. The net present value is - $64.7 million. The large negative net present value is due to the substantial initial capital cost and the operation cost of the pellet mill. Custom hiring harvest equipment is much less expensive than owning the harvest equipment for each system. Among the custom hired harvest equipment systems, the most unprofitable system is the pellet mill preprocessing option using switchgrass harvested by the chopper with windrow pickup, and the net present value is a −$47 million. Among the owned harvest equipment systems, the highest net present value system is stretch wrap baler system using feedstock harvested by choppers with rotary cutter- headers. The net present value of cash flow is $756,669. For the stretch wrap baler system, the break-even prices range from $62.04/dt to $81.84/dt. By comparison, the break-even prices for the pellet mill system are much higher and range from $110.47/dt to $128.74/dt.

The sensitivity analysis results are shown in Table 27. In the sensitivity analysis, BCAP incentives and switchgrass sales price are still the two most important factors influencing the net present value of net cash flows. If the switchgrass sale price is $90/dt, the stretch wrap bale system using switchgrass harvested by the chopper with rotary cutter-header that is custom hired increased the net present value of net cash flow to $33.6 million. Without the BCAP subsidy, the pellet mill system using switchgrass harvested with the chopper with the windrow pickup system had the largest negative net present value of $96.2 million. The sensitivity of net present value to the BCAP incentive is shown in Figure 5.1. Compared to the harvest equipment system using purchased equipment, the BCAP incentive program has a much larger influence on net cash flow and net present value for the custom hiring harvest equipment system. The switchgrass sale price influences the net present value of cash inflows from sales of feedstock to the biorefinery in years four to ten. When the sale price is higher, the cash inflows increase accordingly (Figure 5.2). When the switchgrass sale price increases from $75/dt to $90/dt, the net present value changed from −$8.2 million to $9.9 million for the stretch wrap baler system using switchgrass harvested by the chopper with the windrow pickup that is purchased by the feedstock supply entity for harvesting switchgrass.

When the discount rate was increased from 10% to 12%, the net present value for all systems decreased. On the other hand, the net present value for all systems increased when the discount rate was reduced to 8% (Figure 5.3). Among the different preprocessing systems, diesel fuel price has the strongest influence on the net present value of the stretch wrap baler systems (Figure 5.4). Wage rate has little influence when compared to other factors (Figure 5.5). Stretch wrap baler throughput capacity per hour of operation is another parameter influencing net present value for this logistics system in the sensitivity analysis. Table 27 shows that a stretch wrap baler system using feedstock harvested by choppers with rotary cutter- headers still has a positive net present value when throughput capacity was decreased from 54 dt/hour to 36 dt/hour.

5.3 Without BCAP Analysis

BCAP is an important factor influencing the net present value of the investment. Based on the base values of the sensitivity analysis factors, all of the feedstock supply chain configurations evaluated in this analysis did not have a positive net present value without BCAP subsidy. Combination of optimistic values of discount rate, fuel price, wage rate and throughput capacity of stretch warp baler, the net present and break-even price for conventional hay harvest and preprocessing without BCAP systems are shown in Table 29 and Table 30, respectively. Without the BCAP incentives, based on the optimistic assumptions, which are $90/dt switchgrass sale price, 8% discount rate, $2.2/gallon fuel price, $7.8/hour wage rate and 54dt/hour throughput capacity of stretch warp baler, the round bale system using feedstock stored without a tarp on pallets using custom hired equipment had the largest positive net present value of $12.9 million among the conventional hay harvest and preprocessing systems. The breakeven switchgrass sales prise given the other optimistic assumption about costs was $80.51/dt. For the preprocessing systems, only the stretch wrap baler custom hired harvest equipment generated a positive NPV under the optimistic assumption combination without the BCAP incentives. No equipment purchased systems can generate a positive NPV under the optimistic assumption combination without BCAP.

5.4 Scenario Analysis

Baseline scenario and preprocessing scenario comparison analysis is shown in this section. The baseline scenario using traditional hay harvest system has a greater number of acres needed to harvest because of higher dry matter losses during the storage. Among all of the conventional harvest systems, rectangular bales stored with a tarp required the most acres of switchgrass at 46,661 acres. However, the preprocessing systems only required 40,268 acres of switchgrass (Table 11). The land lease cost, the establishment cost and maintenance cost per acre for every year are the same but overall costs for these cost items vary by system. So the total land lease cost and establishment and maintenance costs for the feedstock supply chain are a function of the switchgrass acres required to deliver 329,000 dt to the biorefinery.

In the previous capital investment outlays section, the net capital investment analysis for systems considers both purchase price and salvage value for each type of equipment. Among all systems, the pellet mill preprocessing systems had the highest equipment investment cost due to the large preprocessing facilities cost relative to the stretch wrap baler system. For the operating costs, the most expensive operating cost is for the pellet mill system, and the least expensive operating cost is for the stretch wrap baler system.

The optimal net present value of net cash flows among all of the evaluated systems with the BCAP incentives, is the round bale system using feedstock stored without a tarp on pallets using custom hired equipment. The net present value of the cash flow is $21.7 million, and the break-even price is $56.94/dt (Table 18). This is due to the system not having the tarp storage material cost, which can decrease the cash outflows. But if the equipment can only be purchased, the stretch wrap baler system using feedstock harvested by the chopper with the rotary cutter-header is optimal. This system is the only system that has a positive net present value in the purchased equipment scenario. The net present value for this system is $756,660, and the break-even price is $74.37/dt (Table 26).

The sensitivity analysis results indicate that BCAP subsidy and switchgrass sale price are two of the most important factors that influence the net present value among other factors. Based on the combination of base values of the parameters and without the BCAP subsidy, all of the systems evaluated in the study generated a negative net present value. The optimal systems for the conventional hay scenario and the preprocessing scenario are same for both BCAP incentive scenarios.

Based on the combination of optimistic values of factors in sensitivity analysis, none of the systems had a positive net present value without the BCAP incentives if the sale price is $75/dt. However, when the sale price is $90/dt and the other cost factors in the model are still optimistic values, some systems can generate positive net present value even without BCAP. The 100% round bale system using feedstock stored without a tarp on pallets using custom hired equipment can generate the largest net present value of $12.9 million (Table 29). Thus, without the BCAP incentives, net present value can be positive for some of the systems evaluated in the analysis based on the combination of optimistic values of the parameters (Table 29 and Table 30).

Chapter 6: Conclusions and Recommendations

The objective of the research was to simulate the cash flows for alternative switchgrass feedstock supply chain configurations between the field and the biorefinery, and identify the optimal feedstock supply chain configuration by determining the total costs and revenues of producing and moving switchgrass from the field to the biorefinery under various logistic systems. The logistic systems evaluated include both conventional hay technology and preprocessing technology to package and store biomass before delivery to the biorefinery. As indicated in Table 18 and Table 26 for the 25 mg/year biorefinery, the highest net present value of net cash flows among all of the evaluated systems assuming BCAP incentives are available, is the round bale system using feedstock stored without a tarp on pallets and custom hired equipment. The net present value of cash flows is $21.7 million, and the break-even price is $56.94/dt. However, if the harvest equipment is purchased rather than custom hired, the stretch wrap baler using feedstock harvested by the chopper with the rotary cutter-header and assuming BCAP incentives are available generated the greatest net present value. This preprocessing system is the only system when combined with BCAP incentives that can always generates positive net present value regardless of whether the equipment is purchased or custom hired. The stretch wrap baler system using feedstock harvested by the chopper with the rotary cutter-header yields a net present value of $756,660 if equipment is purchased and a net present value of $15.6 million if the equipment is custom hired. However, if production of feedstock is under taken without BCAP incentives, the round bale system using feedstock stored without a tarp on pallets using custom hired equipment system still can generate the highest net present value ($12.9 million) based on the following combination of optimistic assumptions: 1) $90/dt sale price, 2) 8% discount rate, 3) $2.2/gallon fuel price and 4) $7.8/hour wage rate.

The analysis indicates that government policies and equipment ownership are the key factors influencing the net present value of switchgrass supply chain cash flows. Results indicate that the BCAP subsidy program and harvest equipment ownership assumptions had a strong influence on net present value for all feedstock supply chain configurations in the analysis. Table 31 indicates the optimal system under alternative assumptions for the BCAP incentives and harvest equipment ownership. If harvest equipment was custom hired rather than owned by a feedstock supply entity, the round bale system using feedstock stored without a tarp on pallets equipment provided the highest net present value among the alternatives considered in the analysis.

However, if harvest equipment was purchased by a feedstock entity rather than custom hired, then the stretch wrap baler preprocessing system using switchgrass harvested by choppers with rotary cutter- headers generated the largest positive net present value assuming BCAP incentives were in place. Without the BCAP incentives, none of the feedstock supply chain configurations produced a positive net present value if harvest equipment was assumed to be owned rather than custom hired by the feedstock supply entity. On the other hand, with the BCAP incentives, the stretch wrap baler preprocessing system using switchgrass harvested by choppers with rotary cutter- headers outperformed conventional large round baler and large square baler systems and other preprocessing systems by producing the largest net present value of cash flow based on the biorefinery annual capacity of 25 million gallons. This system provided a positive net present value no matter which equipment ownership options are assumed. Thus, results suggest that the stretch wrap baler preprocessing system can outperform conventional hay methods under East Tennessee conditions with the BCAP subsidy and harvest equipment is purchased rather than custom hired. The conventional large round bale system have low storage dry matter losses, is widely used in East Tennessee; and the large square bales are cost efficient in harvest and transportation but not in storage because of large dry matter losses. However, the savings in harvest and transportation costs and dry matter losses for the stretch wrap baler system offset the additional capital cost in preprocessing facilities and lowered net investment in harvest equipment relative to the conventional hay systems. The results of this study suggest that incorporating the industrial stretch wrap baler preprocessing facility into the switchgrass supply chain could be economically feasible and save considerable logistic costs. A stretch wrap baler preprocessing facilities added into the supply chain may decrease the delivered cost at the biorefinery plant gate, and increase the quality of switchgrass feedstock. A procurement entity using the technology may exist as a feedstock cooperative that provides preprocessing, arranges harvest, storage, equipment rental and other services, and schedules transportation that may allow the whole supply chain to run smoothly and allow farmers to participate in a greater proportion of the feedstock value chain. Although pellet processing is also a preprocessing operation, its substantial capital investment and operation costs lead to an unprofitable result in the analysis and do not appear to be a feasible.

There are several limitations in the analysis. First of all, the analysis only considers a biorefinery with a size of 25 million gallons per year. With different biorefinery sizes, the tradeoffs among plant scale economies, operation costs and capital investment costs could lead to a different optimal system. Different biorefinery sizes need to be considered in any future study. Another limitation of the analysis is that it only considers one transportation method for moving switchgrass to the biorefinery. Trains are also another option that the analysis did not consider. For some locations of preprocessing facilities and biorefineries, trucks interfacing with trains at preprocessing facilities may be a feasible transportation solution to reduce the transaction cost and further improve the switchgrass logistics. In addition, there is only limited information and research related to the pellet preprocessing treatment. So, its estimated capital investment costs and operation cost are not as accurate as they are for the stretch wrap baler. A study on the benefits and costs of pellet preprocessing treatment is needed to obtain more information and calculate the costs more accurately. Another limitation is that the analysis considered the start up period and not a mature industry. Decision makers may be more interested in a mature industry. More studies need to focus on a longer expected life-span and what needs to be done after the initial ten-year period considered in this study.

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Appendix

Table 1. Farm Size Distribution and Selected Characteristic

Farm Size Distribution and Selected Characteristics		
Item	U.S.	Tennessee
Number of Farms	2,128,982	87,595
Average Farm Size (acres)	441	133
Average Sales per Farm ($)	942,445	25,113
Principal Occupation (%):		
Farming	57.5	50.35
Other	42.5	49.65
Average Farm Age (years)	54.3	55.4
Farms by Value of Sales (%)		
Small (Up to $250K)	90.58	97.33
Medium ($250K−$500K)	4.53	1.39
Large (Above $500K)	4.89	1.28
Farms by Land Area (%):		
1 to 9 acres	8.42	6.93
10 to 49 acres	26.48	36.66
50 to 179 acres	30.94	39.13
180 to 499 acres	18.25	12.97
500 to 999 acres	7.59	2.79
> 1000	8.31	1.53

Source: 2002 Census of Agriculture (U.S. Department of Commerce, 2004)

Table 2. Estimated Available Harvest Time for Switchgrass in East Tennessee

	Month				
Item	November	December	January	February	Total
Avg days precip>0.01 inches[a]	10	11	12	11	44
Total days	30	31	31	28	120
Avg dry days	20	20	19	17	76
Available dry days	14	14	13	12	53
Proportion availible	0.47	0.45	0.42	0.43	0.44
Avg Daylight Hours	10.28	9.76	10.05	10.91	10.25
Avg Effective Hours	6.17	5.85	6.03	6.55	6.15
Avg Hours Total	86	82	78	79	325

a.Estimated harvest days assuming that 70% of the days per month when precipitation was less than 0.01 inches were available for harvest operations (Knoxville, TN, precipitation data).

Available harvest hours assume an average 60% of daylight hours of harvest time per available harvest day (Knoxville TN).

Sources: Dry days, NOAA, US Department of Commerce, Daylight hours, US Naval Observatory; Hanna, 2002; Mooney et al. 2009.

Adapted from Larson et al. 2010a.

Table 3. Dandridge Soil 10 Year Stand Life Switchgrass Yields

	Replication												
Year	1	2	3	4	5	6	7	8	9	10	Mean	Std Dev	CV
	Dry tons per acre												
1	3.32	2.44	1.95	3.51	2.17	1.48	2.40	2.28	2.42	2.33	2.43	0.60	24.53
2	5.90	4.53	3.73	4.00	3.19	3.66	0.26	4.50	4.25	5.65	3.97	1.55	39.18
3	5.82	5.90	6.84	3.90	5.53	6.12	5.33	7.52	4.75	5.38	5.71	1.01	17.78
4	3.73	4.84	6.54	6.03	6.19	5.43	5.79	6.67	7.30	6.88	5.94	1.06	17.78
5	8.26	6.38	8.65	8.63	5.14	7.58	6.06	4.78	8.85	7.67	7.20	1.51	20.94
6	7.60	6.28	8.37	6.95	7.00	4.80	2.63	6.14	6.10	6.79	6.26	1.60	25.47
7	5.63	7.57	11.43	8.01	6.39	5.88	8.30	7.47	8.94	7.35	7.70	1.68	21.85
8	4.13	6.96	10.47	7.12	7.64	5.62	6.76	6.34	8.05	7.94	7.10	1.67	23.44
9	7.62	7.81	9.63	9.58	7.32	3.86	8.51	7.95	6.96	5.28	7.45	1.79	23.95
10	5.68	8.75	10.17	6.33	8.17	6.03	8.44	6.41	9.67	7.09	7.67	1.59	20.68

Table 4. Logistics Schedule for Traditional Harvest and Preprocessing Scenario

	Traditional Harvest Scenarios				Preprocessing Scenarios			
			Mixed-bale		Stretch Wrap Baler		Pellet Mill	
	100% Round	100% Rectangular	1/3 Rectangular	2/3 Round	Chopped	Stretch wrap baler	Chopped	Pellet
Year 1-3	all store	all store	round, store		-	store	-	store
Year 4-10								
Nov-Feb	1/3 deliver, 2/3 store	1/3 deliver, 2/3 store	deliver	store	deliver	store	deliver	store
Mar-Oct	deliver	deliver	-	deliver	-	deliver	-	deliver

Table 5. Storage Dry Matter Losses for the Different Harvest and Storage Systems

	Conventional Hay Harvest Scenarios				Pre-processing Scenarios	
	100% Round	100% Rectangular	Mix 1/3 Rectangular	Mix 2/3 Round	Stretch Wrap Bale	Pellet mill
Year1-2						
Cover	17%	32%	-	17%	0	0
Uncover	14%	-	-	-	0	0
Year 3						
Cover	5%	23%	-	5%	0	0
Uncover	10%	-	-	-	0	0
Year4-10						
Cover	5%	23%	0	5%	0	0
Uncover	10%	-	-	-	0	0

Table 6. Transportation Distances for the Preprocessing Scenario

	Tandem-axle (Miles)	Semi-truck (Miles)
Year 1	30.3	-
Year 2	26.9	-
Year 3	20.665	-
Year 4-10	19.986	40

Table 7. Selected Equipment Budget Stretch for the Stretch Warp Bales System

Item	Unit	Chopper with windrow pick up	Chopper with rotary cutter-header	Baler	Buildings
Cost calculation parameters					
Purchase price (PP)	$	266,000	333,112	1,400,000	596,942
Useful life	hours	4,000	4,000	36,000	36,000
Annual use	h/year	325	325	1,218	1,218
Repair factor	% of PP	48	48	100	59
Salvage value	% of PP	25	25	10	-
Throuphput performance	dt/h	20	20	45	-
Electricity use (in operation)	kw/h	-	-	2,010	-
Electricity use (stand by)	kw/h	-	-	60	-
Land cost	$	-	-	-	300,000
Ownship costs					
Depreciation and interest	$/h	64	81	2	1
Taxes, insurance, and housing	$/h	16	20	14	6
Annualized land cost	$/h	-	-	-	20
Tractor ownership costs	$/h	-	-	-	-
Operating costs					
Repairs and maintenance	$/h	38	47	39	10
Equipment operatior	$/h	12	12	12	12
Fuel and oil	$/h	46	46	-	-
Electricity	$/h	-		11	-
Property taxes	$/h	-			7
Tractor operating costs	$/h	-			-
Total cost	$/h	174	204	76	56

Table 8. Main Preprocessing Operations for the Pellet Mill Preprocessing System

Main Equipment	Operation	Description
Grinder	breaking and grinding	It is used to break bales and chop forage fibres to a length suitable for drying (2.5-10 cm).
Dryer	drying	A dryer is normally used to reduce feedstock moisture to levels suitable for pelleting.
Hammer mill	fine grinding	A hammer mill is used to reduce the size of feedstock particles in preparation for pelleting.
Pellete Mill	pelleting	Chopped feedstock is fed into a pelleting chamber where rollers force the ground feedstock through holes on the inside face of a die.
Cooler	cooling	Pellets exit from the pelleter at high temperature and are cooled with forced air to prevent "sweating".
Screener	screening	A screening process is used to separate fines from the finished pellets before bagging.

Table 9. Annually Usage Hour for Custom Hired Equipment and Purchased Equipment

Equipment	Purchased hour	Custom hired hour
Rake	325	365
Tractor	325	925
Mower	325	385
Round baler	325	395
Rectangular baler	325	395
Chopper	325	392
Loader	325	425

Table 10. Parameters in the Sensitivity Analysis

Parameter	Unit	Base Value	Alternative Values	
BCAP	$	With	without	
Switchgrass Price	$/ton	75	60	90
Discount Rate	%	10	8	12
Fuel Price	$	2.75	2.2	3.3
Wage Rate	$	9.75	7.8	11.7
Stretch Wrap Baler Throughput Capacity	dt/baler	45	36	54

Table 11. Switchgrass Acres and Biomass Production for the Conventional Hay Harvest Scenarios

	The conventional hay harvest Harvest Scenarios			
	100% Round		100% Rectangular	Mixed-bale
	Unprotect	Protect		1/3 Rectangular 2/3 Round
Acres in Production	41,529	40,268	46,661	40,268
Total Harvest Yield (tons)	2,551,124	2,473,662	2,866,398	2,473,662
Total Plant Requried (tons)	2,302,632	2,302,632	2,302,632	2,302,632
Plant Requried per Year (tons)	328,947	328,947	328,947	328,947

Table 12. Estimated Number of Equipment by Operations Sequence for the Conventional Hay Harvest Scenarios

Operation	Equipment	100% Round bale		100% Rectangular bale	Mixed-bale (1/3 rectangular, 2/3 round)
		unprotect	protect		
Mow	mower with tractor	49	48	55	48
Rake	rake with tractor	32	31	36	31
Bale	baler	140	136	72	91 round, 21 rectangular Y4 [a]
Chop	chopper	-	-	-	-
Haul by truck to preprocessing facility	tandem-axle truck	-	-	-	-
Dump in holding area	loader with tractor				
Front-end load into conveyer					
Compact/bale/wrap	compact baler	-	-	-	-
Front-end load to storage	loader with tractor				
Store					
Front-end load to truck	loader with tractor				
Haul by semi-truck to biorefinery	semi-truck	10	10	8	8
	tractor	344	334	302	312
	loader	123	121	140	121

a.The rectangular balers in mixed-bale system are needed until year four.

Table 13. Net Capital Investment for Equipment by Harvest Method for the Conventional Hay Harvest Scenarios

Operation	100% Round Bale		100% Rectangular Bale	Mixed-Bale
	Unprotect	Protect		
Harvest equipments				
Mower [a]	(376,545)	(366,705)	(420,183)	(366,705)
Rake [a]	(98,721)	(96,775)	(112,383)	(96,775)
Baler [b]	(4,388,658)	(4,217,962)	(5,935,694)	(3,586,452) [c]
Loader	(768,273)	(781,215)	(903,885)	(781,215)
sub-total	(5,632,197)	(5,462,657)	(7,372,145)	(4,831,146)
Vehicles				
Tractor	(32,613,637)	(31,681,234)	(28,645,906)	(29,594,446)
Semi-Truck	(155,240)	(160,912)	(128,729)	(128,729)
Tandem axle truck	-	-	-	-
sub-total	(32,768,877)	(31,842,145)	(28,774,635)	(29,723,175)
Total	(38,401,074)	(37,304,803)	(36,146,780)	(34,554,322)

a.Mowers were bought in year zero and year six; and rakes were bought in year zero and seven.
b.Rectangular balers need to be purchased in year zero and year nine; and round balers need to be purchased in year zero, year four, and year eight.
c.For mix system, the rectangular balers were bought once in year three.

Table 14.1 Switchgrass Establishment Operations Schedule [a]

Month	Operation	Equipment	Machine Hours	Labor Hours
August	Fall burn down	Sprayer, 60 foot boom	0.0300	0.0375
May	Spring burn down	Sprayer, 60 foot boom	0.0300	0.0375
	Plant	No tillage drill	0.2400	0.3000
	Spread fertilizer	Tractor	0.0700	0.0875
	Post emerge spray	Sprayer, 60 foot boom	0.0300	0.0375
	Post emerge spray	Sprayer, 60 foot boom	0.0300	0.0375
	Post emerge spray	Sprayer, 60 foot boom	0.0300	0.0375
	Bush hogging	Rotary mower 15'	0.1000	0.1250

a.UT Extension switchgrass budget 2008, Gerloff, 2008.

Table 14.2 Switchgrass Establishment Materials Costs

Item	**Description**	**Units**	**Quantity**	**Price**	**Cost**
Seed	Pure live seed	Pound	8.00[a]	$20.00[b]	$160.00
Fertilizer					
	P_2O_5	Pound	40.00[a]	$0.52[c]	$20.80
	K_2O	Pound	80.00[a]	$0.44[c]	$35.20
Weed control					
Fall burn down	Glyphosate	Quart	1.00[a]	8.76[c]	$8.76
Spring burn down	Glyphosate	Quart	1.50[a]	8.76[c]	$13.14
Post-emerge	Broadleaf herbicide	Pint	2.00[a]	$2.50[a]	$5.00
Post-emerge	Grass herbicide	Acre	1.00[a]	$8.00[a]	$8.00
Post-emerge	Grass herbicide	Acre	1.00[a]	$8.00[a]	$8.00
Total materials cost--seed, fertilizer, chemicals $/acre)					**$258.90**

a. Gerloff, 2008.
b. Mooney et al., 2009.
c. McKinley and Gerloff, 2010.

Table 14.3 Switchgrass Establishment Machinery Costs

Item	Sprayer	Drill	Rotary mower	Tractor	Total
Diesel fuel [a] ($/Acre)				$14.50	$14.50
Lubrication costs [b] ($/Acre)				$2.18	$2.18
Repair [c] ($/Acre)	$0.91	$1.71	$1.37	$7.91	$11.91
Operating costs ($/Acre)	$0.91	$1.71	$1.37	$24.59	$28.58
Capital recovery [d] ($/Acre)	$0.86	$1.00	$0.99	$10.92	$13.77
TIH [e] ($/Acre)	$0.25	$0.29	$0.44	$4.93	$5.91
Ownership costs ($/Acre)	$1.11	$1.29	$1.44	$15.84	$19.68
Total machinery cost ($/acre)	$2.02	$3.01	$2.81	$40.43	**$48.27**

a. A fuel price of $2.75 per gallon (McKinley and Gerloff, 2010), a fuel consumption rate of 6.57 gallons per hour for a 150 HP tractor (ASABE Standards, 2009), and the machine time per acre for each equipment operation (Gerloff, 2008) were used to calculate fuel costs.

b. Lubrication costs were estimated using 15% of diesel fuel costs (ASABE Standards, 2009).

c. Repair and maintenance costs were estimated using the formula and coefficients for each equipment type from the ASABE Standards (2009).

d. Depreciation and interest on equipment were calculated using the capital recovery method (AAEA, 2000), a real interest rate of 3% (AAEA, 2000), and the remaining (salvage) value formula and coefficients for each equipment type from the ASABE Standards (2009).

e. Taxes, insurance, & housing annual expenses were calculated as 2% of the purchase price of equipment (ASABE Standards, 2009).

Table 14.4 Switchgrass Establishment Costs Summary

Item		Amount
Total materials cost--seed, fertilizer, chemicals $/acre)		$258.90
Seed ($/acre)	$160.00	
Fertilizer ($/acre)	$56.00	
Chemicals ($/acre)	$42.90	
Total machinery cost ($/acre)		$48.27
Operating costs ($/acre)	$28.58	
Ownership costs ($/acre)	$19.68	
Labor cost [a] ($/acre)		$6.83
Operating capital--6 months [a]($/acre)	$287.48	$8.62
Total establishment cost ($/acre)		**$322.62**

a.McKinley and Gerloff, 2010.

Table 15.1 Switchgrass Annual Maintenance Operations Schedule [a]

Month	Operation	Equipment	Machine Hours	Labor Hours
May	Herbicide Application	Sprayer, 60 foot boom	0.0300	0.0375
	Herbicide Application	Sprayer, 60 foot boom	0.0300	0.0375
	Spread fertilizer	Tractor	0.0700	0.0875

a.Gerloff, 2008.

Table 15.2 Switchgrass Annual Maintenance Materials Costs

Item	Description	Units	Quantity	Price	Cost
Fertilizer					
	Nitrogen	Pound	60.00[a]	$0.48[b]	$28.80
	P_2O_5	Pound	40.00[a]	$0.52[b]	$20.80
	K_2O	Pound	80.00[a]	$0.44[b]	$35.20
Weed control					
Post-emerge	Grass herbicide	Acre	1.00	$8.00[a]	$8.00
Post-emerge	Grass herbicide	Acre	1.00	$8.00[a]	$8.00
Total machinery cost ($/Acre)					**$100.80**

a.UT Extension recommended fertilization rates for switchgrass. UT Extension does not recommend P_2O_5 and K_2O on medium and high test soils (Gerloff, 2008).
b. McKinley and Gerloff, 2010.

Table 15.3 Switchgrass Annual Maintenance Materials Costs

Item	Sprayer	Tractor	Total
Diesel fuel [a] ($/Acre)		$3.37	$3.37
Lubrication costs [b] ($/Acre)		$0.50	$0.50
Repair [c] ($/Acre)	$0.36	$1.84	$2.20
Operating costs ($/Acre)	$0.36	$5.71	$6.07
Capital recovery [d] ($/Acre)	$0.34	$2.53	$2.88
TIH [e] ($/Acre)	$0.10	$1.14	$1.24
Ownership costs ($/Acre)	$0.44	$3.68	$4.12
Total machinery cost $/Acre)	**$0.81**	**$9.39**	**$10.19**

a. A fuel price of $2.35 per gallon (McKinley and Gerloff, 2010), a fuel consumption rate of 6.57 gallons per hour for a 150 HP tractor (ASABE Standards, 2009), and the machine time per acre for each equipment operation (Gerloff, 2008) were used to calculate fuel diesel costs.
b. Lubrication costs were estimated using 15% of diesel fuel costs (ASABE Standards, 2009).
c. Repair and maintenance costs were estimated using the formula and coefficients for each equipment type from the ASABE Standards (2009).
d. Depreciation and interest on equipment were calculated using the capital recovery method (AAEA, 2000), a real interest rate of 3% (AAEA, 2000), and the remaining (salvage) value formula and coefficients for each equipment type from the ASABE Standards (2009).
e. Taxes, insurance, & housing annual expenses were calculated as 2% of the purchase price of equipment (ASABE Standards, 2009).

Table 15.4 Switchgrass Annual Maintenance Costs Summary

Item			**Amount**
Total materials cost--seed, fertilizer, chemicals ($/Acre)			$100.80
Fertilizer		$84.80	
Chemicals		$16.00	
Total machinery cost ($/Acre)			$10.19
Operating costs ($/Acre)		$6.07	
Ownership costs ($/Acre)		$4.12	
Labor cost [a] ($/Acre)			$0.01
Operating capital--6 months [a] ($/Acre)	$106.87	$18.93	$3.21
Total cost of Maintenance ($/acre)			**$114.21**

a. McKinley and Gerloff, 2010.

Table 16. Summary of Costs by Operation under Each Harvest Method for the Conventional Hay Harvest Scenario

	100% Round Bales				100% Rectangular Bales		Mix Bales	
	Tarp+Pallet	Tarp+Gravel	Pallet	Gravel	Tarp+Pallet	Tarp+Gravel	Tarp+Pallet	Tarp+Gravel
Harvest Cost [e]								
Rake ($/acre)	20.29	20.29	20.29	20.29	20.29	20.29	20.29	20.29
Mow ($/acre)	33.37	33.37	33.37	33.37	33.37	33.37	33.37	33.37
Loader ($/acre)	88.66	88.66	88.66	88.66	88.66	88.66	88.66	88.66
Baler ($/acre)	145.35	145.35	145.35	145.35	182.47	182.47	157.72 [a]	157.72 [a]
Sub Total ($/acre)	287.67	287.67	287.67	287.67	324.79	324.79	300.05	300.05
Storage Cost [d] ($/ton)	8.08	18.68	4.52	14.65	7.28	13.96	8.08 [b]	18.68 [b]
Transportation Cost [c] ($/ton)	21.68	21.68	21.68	21.68	17.37	17.37	20.40	20.40

a. The balers for mixed-bale system are 1/3 rectangular balers and 2/3 round balers from year 4-10, so the harvest cost for baler parts are also 1/3 rectangular baler, and 2/3 round baler.

b. For the mixed-bale system, the storage cost is only for round bales.

c. Transportation cost only happens from year four.

d. Storage cost is used as weighted-average storage cost.

e. Harvest cost is the average cost over the ten years.

Table 17.1 Total Operation Cost of Production Summary for Rectangular Bale Trap+Gravel System

Operation Cost of Production						
Stand Year	**Establishment ($/acre)**	**Maintenance ($/acre)**	**Harvest ($/acre)**	**Storage (S/acre)**	**Transportation ($/acre)**	**Total Cost ($/acre)**
0	425.85					425.85
1		$78.04	128.43	33.91		240.38
2		$60.44	209.72	55.37		325.54
3		$60.44	301.82	79.69		441.95
4		$60.44	314.08	82.93	124.93	582.38
5		$60.44	380.68	100.51	124.93	666.57
6		$60.44	331.15	87.43	124.93	603.95
7		$60.44	406.92	107.44	124.93	699.74
8		$60.44	375.52	99.15	124.93	660.04
9		$60.44	393.96	104.02	124.93	683.35
10		$60.44	405.67	107.11	124.93	698.16
Total	425.85	622.04	3247.94	857.58	874.49	6027.91

Table 17.2 Total Operation Cost of Production Summary for Rectangular Bale Trap+Pallet System

			Operation Cost of Production			
Stand Year	**Establishment ($/acre)**	**Maintenance ($/acre)**	**Harvest ($/acre)**	**Storage (S/acre)**	**Transportation ($/acre)**	**Total Cost ($/acre)**
0	425.85					425.85
1		$78.04	128.43	17.68		224.15
2		$60.44	209.72	28.87		299.04
3		$60.44	301.82	41.55		403.81
4		$60.44	314.08	43.24	124.93	542.69
5		$60.44	380.68	52.41	124.93	618.46
6		$60.44	331.15	45.59	124.93	562.11
7		$60.44	406.92	56.02	124.93	648.32
8		$60.44	375.52	51.70	124.93	612.59
9		$60.44	393.96	54.24	124.93	633.56
10		$60.44	405.67	55.85	124.93	646.90
Total	425.85	622.04	3247.94	447.14	874.49	5617.47

Table 17.3 Total Operation Cost of Production Summary for Round Bale Gravel System

	Operation Cost of Production					
Stand Year	Establishment ($/acre)	Maintenance ($/acre)	Harvest ($/acre)	Storage (S/acre)	Transportation ($/acre)	Total Cost ($/acre)
0	425.85					425.85
1		$78.04	113.75	35.60		227.39
2		$60.44	185.75	58.14		304.33
3		$60.44	267.32	83.67		411.43
4		$60.44	278.18	87.06	175.25	600.94
5		$60.44	337.18	105.53	175.25	678.40
6		$60.44	293.30	91.80	175.25	620.79
7		$60.44	360.42	112.80	175.25	708.91
8		$60.44	332.60	104.10	175.25	672.39
9		$60.44	348.93	109.21	175.25	693.83
10		$60.44	359.31	112.46	175.25	707.46
Total	425.85	622.04	2876.75	900.36	1226.75	6051.75

Table 17.4 Total Operation Cost of Production Summary for Round Bale Pallet System

	Operation Cost of Production					
Stand Year	**Establishment ($/acre)**	**Maintenance ($/acre)**	**Harvest ($/acre)**	**Storage (S/acre)**	**Transportation ($/acre)**	**Total Cost ($/acre)**
0	425.85					425.85
1		$78.04	113.75	10.99		202.79
2		$60.44	185.75	17.95		264.15
3		$60.44	267.32	25.83		353.60
4		$60.44	278.18	26.88	175.25	540.76
5		$60.44	337.18	32.58	175.25	605.45
6		$60.44	293.30	28.34	175.25	557.34
7		$60.44	360.42	34.83	175.25	630.94
8		$60.44	332.60	32.14	175.25	600.44
9		$60.44	348.93	33.72	175.25	618.35
10		$60.44	359.31	34.72	175.25	629.73
Total	425.85	622.04	2876.75	277.99	1226.75	5429.38

Table 17.5 Total Operation Cost of Production Summary for Round Bale Tarp+Gravel System

	Operation Cost of Production					
Stand Year	Establishment ($/acre)	Maintenance ($/acre)	Harvest ($/acre)	Storage (S/acre)	Transportation ($/acre)	Total Cost ($/acre)
0	425.85					425.85
1		$78.04	113.75	45.39		237.18
2		$60.44	185.75	74.12		320.32
3		$60.44	267.32	106.67		434.43
4		$60.44	278.18	111.00	180.74	630.36
5		$60.44	337.18	134.54	180.74	712.90
6		$60.44	293.30	117.03	180.74	651.51
7		$60.44	360.42	143.81	180.74	745.41
8		$60.44	332.60	132.71	180.74	706.50
9		$60.44	348.93	139.23	180.74	729.34
10		$60.44	359.31	143.37	180.74	743.86
Total	425.85	622.04	2876.75	1147.86	1265.16	6337.67

Table 17.6 Total Operation Cost of Production Summary for Round Bale Tarp+Pallet System

	Operation Cost of Production					
Stand Year	**Establishment ($/acre)**	**Maintenance ($/acre)**	**Harvest ($/acre)**	**Storage (S/acre)**	**Transportation ($/acre)**	**Total Cost ($/acre)**
0	425.85					425.85
1		$78.04	113.75	19.64		211.43
2		$60.44	185.75	32.07		278.27
3		$60.44	267.32	46.15		373.92
4		$60.44	278.18	48.03	180.74	567.39
5		$60.44	337.18	58.21	180.74	636.57
6		$60.44	293.30	50.64	180.74	585.12
7		$60.44	360.42	62.22	180.74	663.82
8		$60.44	332.60	57.42	180.74	631.21
9		$60.44	348.93	60.24	180.74	650.36
10		$60.44	359.31	62.03	180.74	662.53
Total	425.85	622.04	2876.75	496.66	1265.16	5686.47

Table 17.7 Total Operation Cost of Production Summary for Mixed-bale Tarp+Gravel System

	Operation Cost of Production					
Stand Year	Establishment ($/acre)	Maintenance ($/acre)	Harvest ($/acre)	Storage (S/acre)	Transportation ($/acre)	Total Cost ($/acre)
0	425.85					425.85
1		$78.04	118.64	45.39		242.07
2		$60.44	193.74	74.12		328.31
3		$60.44	278.82	106.67		445.93
4		$60.44	290.15	111.00	168.75	630.33
5		$60.44	351.68	134.54	168.75	715.41
6		$60.44	305.92	117.03	168.75	652.14
7		$60.44	375.92	143.81	168.75	748.92
8		$60.44	346.91	132.71	168.75	708.81
9		$60.44	363.94	139.23	168.75	732.36
10		$60.44	374.77	143.37	168.75	747.33
Total	425.85	622.04	3000.48	1147.86	1181.22	6377.45

Table 17.8 Total Operation Cost of Production Summary for Mixed-bale Tarp+Pallet System

	Operation Cost of Production					
Stand Year	Establishment ($/acre)	Maintenance ($/acre)	Harvest ($/acre)	Storage (S/acre)	Transportation ($/acre)	Total Cost ($/acre)
0	425.85					425.85
1		$78.04	118.64	19.64		216.32
2		$60.44	193.74	32.07		286.26
3		$60.44	278.82	46.15		385.42
4		$60.44	290.15	48.03	168.75	567.36
5		$60.44	351.68	58.21	168.75	639.08
6		$60.44	305.92	50.64	168.75	585.74
7		$60.44	375.92	62.22	168.75	667.33
8		$60.44	346.91	57.42	168.75	633.52
9		$60.44	363.94	60.24	168.75	653.37
10		$60.44	374.77	62.03	168.75	665.99
Total	425.85	622.04	3000.48	496.66	1181.22	5726.25

Table 18. Net Present Value and Break-even Switchgrass Sale Price for the Conventional Hay Harvest with BCAP Systems

		Price = 75 $/ton with BCAP NPV($) [a]	NPV = 0 with BCAP Break-even Price ($/ton)
Rectangular: tarp+gravel	Purchase	(27,481,276)	97.84
	Custom hire	7,245,345	68.99
Rectangular: tarp+pallet	Purchase	(21,061,498)	92.5
	Custom hire	13,645,998	63.66
Round: gravel	Purchase	(26,243,249)	96.81
	Custom hire	11,051,518	65.81
Round: pallet	Purchase	(15,560,983)	87.93
	Custom hire	21,733,784	56.94
Round: tarp+gravel	Purchase	(27,117,773)	97.54
	Custom hire	9,109,714	67.43
Round: tarp+pallet	Purchase	(15,747,636)	88.09
	Custom hire	19,965,654	58.41
Mix: round tarp+gravel	Purchase	(23,270,414)	94.34
	Custom hire	10,178,977	66.54
Mix: round tarp+pallet	Purchase	(12,432,613)	85.33
	Custom hire	21,016,778	57.53

a.The NPV is calculated based on 10% discount rate, $2.75/gallon fuel price,$9.75/hour wage price.

Table 19. Summary of Sensitivity Analysis for Conventional Hay Systems

			BCAP ($)		Switchgrass Price ($/ton)			
	Purchase	Custom hire	Purchase	Custom hire	Purchase		Custom hire	
					Optimistic	Pessimistic	Optimistic	Pessimistic
	Base [a]		No	No	90.00	60.00	90.00	60.00
Rectangular trap+gravel	(27,481,276.26)	7,245,345.61	(61,686,038.67)	(26,959,416.81)	(9,433,339.84)	(45,529,212.68)	25,293,282.03	(10,802,590.81)
Rectangular trap+Pallet	(21,061,498.72)	13,645,998.76	(55,266,261.14)	(20,558,763.65)	(3,013,562.30)	(39,109,435.15)	31,693,935.19	(4,401,937.66)
Round+ gravel	(26,243,249.17)	11,051,518.43	(58,808,829.46)	(21,514,061.86)	(8,195,312.75)	(44,291,185.59)	29,099,454.85	(6,996,417.99)
Round+ Pallet	(15,560,983.29)	21,733,784.30	(48,126,563.58)	(10,831,795.99)	2,486,953.13	(33,608,919.71)	39,781,720.72	3,685,847.88
Round tarp+gravel	(27,117,773.21)	9,109,714.06	(59,280,608.30)	(23,053,121.03)	(9,069,836.79)	(45,165,709.63)	27,157,650.48	(8,938,222.36)
Rround tarp+pallet	(15,747,636.75)	19,965,654.02	(47,856,055.71)	(12,142,764.94)	2,300,299.67	(33,795,573.17)	38,013,590.44	1,917,717.60
Mix round tarp+gravel	(23,270,414.99)	10,178,977.43	(55,433,250.08)	(21,983,857.66)	(5,222,478.57)	(41,318,351.41)	28,226,913.85	(7,868,958.99)
Mix round tarp+pallet	(12,432,613.74)	21,016,778.68	(44,595,448.83)	(11,146,056.41)	5,615,322.68	(30,480,550.16)	39,064,715.10	2,968,842.26

a.The base system is having the BCAP subsidy, the switchgrass price is $75/ton, the discount rate is 10%, the fuel price is $2.75/gallon, and the wage price is $9.75/hour.

Table 19. Summary of Sensitivity Analysis for Conventional Hay Systems (Countinued)

	Discount Rate (%)				Fuel Price ($/gallon)			
	Purchase		Custom hire		Purchase		Custom hire	
	Optimistic	Pessimistic	Optimistic	Pessimistic	Optimistic	Pessimistic	Optimistic	Pessimistic
	8	12	8	12	2.20	3.30	2.20	3.30
Rectangular trap+gravel	(20,705,885.17)	(33,162,886.95)	10,830,756.63	4,176,090.93	(25,054,088.59)	(29,908,463.92)	9,884,808.67	4,605,882.55
Rectangular trap+Pallet	(13,652,484.76)	(27,295,355.54)	17,867,692.37	10,022,268.93	(18,885,843.24)	(23,237,154.20)	13,698,900.29	13,593,097.24
Round+ gravel	(19,145,028.45)	(32,192,575.07)	14,718,878.78	7,901,438.87	(24,306,892.66)	(28,179,605.68)	15,852,645.01	13,585,112.56
Round+ Pallet	(7,400,849.12)	(22,435,691.48)	26,463,058.11	17,658,322.46	(13,624,626.78)	(17,497,339.80)	21,780,867.22	21,686,701.38
Round tarp+gravel	(20,338,591.97)	(32,795,011.34)	12,557,606.88	6,150,461.19	(25,240,212.19)	(28,995,334.24)	9,155,367.36	9,064,060.76
Round tarp+pallet	(7,843,756.44)	(22,405,099.11)	24,490,921.92	16,067,545.17	(13,870,075.73)	(17,625,197.78)	20,011,307.32	19,920,000.73
Mix round tarp+gravel	(16,513,273.34)	(28,931,580.10)	13,760,490.14	7,104,265.91	(21,392,853.97)	(25,147,976.02)	10,224,630.72	10,133,324.13
Mix round tarp+pallet	(4,598,097.01)	(19,032,634.83)	25,675,666.47	17,003,211.18	(10,555,052.72)	(14,310,174.77)	21,062,431.97	20,971,125.38

Table 19. Summary of Sensitivity Analysis for Conventional Hay Systems (Countinued)

	Wage Rate ($/hour)			
	Purchase		**Custom hire**	
	Optimistic	**Pessimistic**	**Optimistic**	**Pessimistic**
	7.80	**11.70**	**7.80**	**11.70**
Rectangular trap+gravel	(26,974,236.94)	(27,988,315.58)	7,800,987.00	6,689,704.21
Rectangular trap+Pallet	(20,554,459.41)	(21,568,538.04)	13,667,017.30	13,624,980.23
Round+ gravel	(27,630,600.49)	(28,728,610.87)	13,756,798.68	13,413,426.43
Round+ Pallet	(15,011,978.10)	(16,109,988.49)	21,752,491.02	21,715,077.58
Round tarp+gravel	(26,585,438.00)	(27,650,108.42)	9,127,852.77	9,091,575.35
Round tarp+pallet	(15,747,636.75)	(16,812,307.17)	19,965,654.02	19,929,376.60
Mix round tarp+gravel	(22,756,884.00)	(23,783,945.98)	10,197,116.14	10,160,838.72
Mix round tarp+pallet	(11,919,082.75)	(12,946,144.73)	21,034,917.39	20,998,639.97

Table 20. Estimated Number of Equipment by Operations Sequence for Preprocessing Scenarios

Operation	Equipment	Stretch Wrap Baler wWindrow Pickup	Stretch Wrap Baler wRotary Cutter-header	Pellet wWindrow Pickup	Pellet wRotary Cutter-header
Mow	mower with tractor	45	-	45	-
Rake	rake with tractor	30	-	30	-
Chop	chopper [a]	14 Y1, 9 Y2, 22 Y3		14 Y1, 9 Y2, 22 Y3	
Haul by truck to preprocessing facility	tandem-axle truck [b]	66 Y1, sell 22 Y4		66 Y1, sell 22 Y4	
Pre-processing					
Haul bysemi-truck to biorefinery	semi-truck	7	7	5	5
Harvest	tractor	87	12	75	-
Pre-processing	stretch wrap baler	4	4	-	-
	loader	12	12	-	-

a. The choppers should be purchased in increments of 14 in year zero, 9 more in year one, and 22 more in year two.

b. For the tandem-axle trucks, 66 should be purchased in year zero, but 22 should be re-sold in year four.

Table 21. Estimated Number and Costs for Pellet Facilities' Equipment

Processing Equipment	Number of Units	Total Installed Cost ($)
Receiving and scale	1	130,000
Wood hog (for both bales and mill residues)	1	708,884
Grinding receiving belt with magnet and screen	1	174,139
Air-vey system to dryer feed	1	69,347
Dryer (Furnace, rotary drum dryer and fan)	1	1,386,947
Pre pellet storage bin 2700 CU FT	2	215,747
Dry material screener	1	58,560
Milled material conveying system	1	69,347
Explosion Detection	1	69,347
Hammer mill	1	154,105
Pellet-mill steam system	1	53,937
Pellet-mill	3	1,386,947
Air-vey system to pellet cooler	3	138,695
Pellet cooler (with air system)	1	92,463
Pellet shaker/screener	1	29,280
Dust collection system and piping	1	77,053
Wheel loaders	2	339,032
Total processing equipment cost		5,153,832
Other equipment		
Control center, automation, interduction, lab equipment		770,526
Consumable and spare parts		77,053
Storage (silo storage)		5,547,789
Total installed equipment cost		11,549,200

Source: Grbovic (2010).

Table 22. Net Capital Investment for Equipment by Harvest Methods for the Stretch Wrap Baler Systems

Operation	Stretch Wrap Bale wWindrow Pickup	wRotary Header
Harvest equipments		
Mower [a]	(343,786)	-
Rake [a]	(93,653)	-
Chopper [d]	(10,423,757)	(13,323,803)
sub-total	(10,861,196)	(13,323,803)
Preprocessing facility [b]		
Front-end loader [c]	(79,720)	(79,720)
Compactor/Baler/Wrapper	(4,256,301)	(4,256,301)
Building	(2,229,899)	(2,229,899)
Land	(90,676)	(90,676)
sub-total	(6,656,597)	(6,656,597)
Vehicles		
Tractor	(8,252,297)	(1,138,248)
Semi-Truck	(151,918)	(151,918)
Tandem axle truck	(2,278,197)	(2,278,197)
sub-total	(10,682,413)	(3,568,363)
Total	(28,200,205)	(23,548,763)

a.Mowers were bought in year zero and year six; and rakes were bought in year zero and year seven.
b.The preprocessing facilities were built two in year zero, one in year one, and one in year two.
c.The loaders required are 6 in year zero, 3 in year one, 3 in year two; the balers required are 2 in year zero, 1 in year one, 1 in year two.
d.The choppers required to be purchased are 14 in year zero, 9 in year one, 22 in year two.

Table 23. Net Capital Investment for Equipment by Harvest Methods for the Pellet Mill Systems

Operation	Pellet Mill wWindrow Pickup	 wRotary Header
Harvest equipments		
Mower	(343,786)	-
Rake	(93,653)	-
Chopper	(10,423,757)	(13,323,803)
sub-total	(10,861,196)	(13,323,803)
Preprocessing facility		
Pellet and Required Real Estate	(52,817,422)	(52,817,422)
Land and Buildings of Facilities	(3,077,504)	(3,077,504)
sub-total	(55,894,925)	(55,894,925)
Vehicles		
Tractor	(7,114,049)	-
Semi-Truck	(108,513)	(108,513)
Tandem axle truck	(2,278,197)	(2,278,197)
sub-total	(9,500,760)	(2,386,710)
Total	(76,256,881)	(71,605,439)

a.Mowers were bought in year zero and year six; and rakes were bought in year zero and seven.
b.The preprocessing facilities were built two in year zero, one in year one, and one in year two.

Table 24. Summary of Costs by Operation under Each Harvest Method for the Preprocessing Scenarios

	Stretch wrap baler		**Pellet**	
	w/Windrow Pickup	**w/Rotary Cutter-header**	**w/Windrow Pickup**	**w/Rotary Cutter-header**
Harvest Cost [e]				
Rake ($/acre)	20.29	-	20.29	-
Mow ($/acre)	33.37	-	33.37	-
Chopper ($/acre)	65.13	72.14	65.13	72.14
Sub Total ($/acre)	118.79	72.14	118.79	72.14
Pre-processing Cost ($/ton)	20.15	20.15	86.00	86.00
Transportation Cost [c]				
Tandem-axle Trucks ($/ton) [a]	22.94	22.94	22.94	22.94
Semi-truck ($/ton) [b]	12.64	12.64	6.28	6.28
Sub Total ($/ton)	35.58	35.58	29.22	29.22

a.Tandem-axle trucks costs are $31.42/ton in year one, $30.44/ton in year two, $23.49/ton in year three, and $22.94/ton from year four.
b.Semi-truck costs happen from year four.
c.From year 4, 1/3 of the tons of switchgrass transported by tandem-axle trucks, and 2/3 of the tons of switchgrass transported by semi-trucks to the biorefinery.
e.Harvest cost is the average cost over the ten years.

Table 25.1 Total Operation Cost of Production Summary for the Stretch Wrap Bale w/Windrow Pickup System

	Operation Cost of Production					
Stand Year	Establishment ($/acre)	Maintenance ($/acre)	Harvest ($/acre)	Pre-processing (S/acre)	Transportation ($/acre)	Total Cost ($/acre)
0	425.85					425.85
1		$78.04	46.97	48.95	76.35	250.32
2		$60.44	76.71	79.94	120.84	337.92
3		$60.44	110.39	115.04	134.11	419.99
4		$60.44	114.87	119.71	117.91	412.94
5		$60.44	139.24	145.10	127.55	472.33
6		$60.44	121.12	126.22	120.36	428.14
7		$60.44	148.83	155.10	131.37	495.75
8		$60.44	137.35	143.13	126.78	467.70
9		$60.44	144.09	150.16	129.46	484.15
10		$60.44	148.38	154.62	131.14	494.59
Total	425.85	622.04	1187.94	1237.97	1215.87	4689.68

Table 25.2 Total Operation Cost of Production Summary for the Stretch Wrap Bale w/Rotary Cutter-header System

	Operation Cost of Production					
Stand Year	**Establishment ($/acre)**	**Maintenance ($/acre)**	**Harvest ($/acre)**	**Pre-processing (S/acre)**	**Transportation ($/acre)**	**Total Cost ($/acre)**
0	425.85					425.85
1		$78.04	28.53	48.95	76.35	231.87
2		$60.44	46.58	79.94	120.84	307.80
3		$60.44	67.04	115.04	134.11	376.64
4		$60.44	69.76	119.71	117.91	367.83
5		$60.44	84.56	145.10	127.55	417.65
6		$60.44	73.55	126.22	120.36	380.58
7		$60.44	90.39	155.10	131.37	437.30
8		$60.44	83.41	143.13	126.78	413.77
9		$60.44	87.51	150.16	129.46	427.57
10		$60.44	90.11	154.62	131.14	436.32
Total	425.85	622.04	721.43	1237.97	1215.87	4223.17

Table 25.3 Total Operation Cost of Production Summary for the Pellet w/Windrow Pickup System

	Operation Cost of Production					
Stand Year	**Establishment ($/acre)**	**Maintenance ($/acre)**	**Harvest ($/acre)**	**Pre-processing (S/acre)**	**Transportation ($/acre)**	**Total Cost ($/acre)**
0	425.85					425.85
1		$78.04	46.97	210.04	76.35	411.40
2		$60.44	76.71	342.99	120.84	600.98
3		$60.44	110.39	493.60	134.11	798.55
4		$60.44	114.87	513.66	81.42	770.39
5		$60.44	139.24	622.59	91.05	913.32
6		$60.44	121.12	541.57	83.87	807.00
7		$60.44	148.83	665.50	94.88	969.66
8		$60.44	137.35	614.14	90.29	902.22
9		$60.44	144.09	644.30	92.97	941.80
10		$60.44	148.38	663.46	94.65	966.93
Total	425.85	622.04	1187.94	5311.84	960.42	8508.10

Table 25.4 Total Operation Cost of Production Summary for the Pellet w/Rotary Cutter-header System

	Operation Cost of Production					
Stand Year	**Establishment ($/acre)**	**Maintenance ($/acre)**	**Harvest ($/acre)**	**Pre-processing (S/acre)**	**Transportation ($/acre)**	**Total Cost ($/acre)**
0	425.85					425.85
1		$78.04	28.53	210.04	76.35	392.96
2		$60.44	46.58	342.99	120.84	570.85
3		$60.44	67.04	493.60	134.11	755.20
4		$60.44	69.76	513.66	81.42	725.28
5		$60.44	84.56	622.59	91.05	858.64
6		$60.44	73.55	541.57	83.87	759.44
7		$60.44	90.39	665.50	94.88	911.21
8		$60.44	83.41	614.14	90.29	848.29
9		$60.44	87.51	644.30	92.97	885.21
10		$60.44	90.11	663.46	94.65	908.66
Total	425.85	622.04	721.43	5311.84	960.42	8041.59

Table 26. Net Present Value and Break-even Switchgrass Sale Price for the Preprocessing Scenarios with BCAP Incentives

		Price = $75/ton with BCAP NPV [a] ($)	NPV = 0 with BCAP Break-even Price ($/ton)
Compactor Bale-Chopper w/windrow pick up	Purchase	(8,229,687)	81.84
	Custom hire	11,062,972	65.81
Compactor Bale-Chopper w/rotary header	Purchase	756,660	74.37
	Custom hire	15,592,281	62.04
Pellet- Chopper w/windrow pick up	Purchase	(64,660,142)	128.74
	Custom hire	(47,073,860)	114.12
Pellet- Chopper w rotary header	Purchase	(53,132,362)	119.16
	Custom hire	(42,678,825)	110.47

a.The NPV is calculated based on 10% discount rate, $2.75/gallon fuel price,$9.75/hour wage price, and 45 dt/hour stretch wrap baler throughput.

Table 27. Summary of Sensitivity Analysis for the Preprocessing Systems

			BCAP ($)	
	Purchase	Custom hire	Purchase	Custom hire
	Base [a]		No	No
Stretch wrap baler-Chopper w/windrow pickup	(8,229,687.65)	11,062,972.82	(39,747,619.35)	(20,454,958.88)
Stretch wrap baler-Chopper w rotary cutter-header	756,660.29	15,592,281.61	(30,761,333.84)	(15,925,712.52)
Pellet-Chopper w/windrow pickup	(64,660,142.78)	(47,073,860.88)	(96,178,136.91)	(78,591,855.01)
Pellet-Chopper w rotary cutter-header	(53,132,362.59)	(42,678,825.78)	(84,650,356.73)	(74,196,819.91)

a. The base system is having the BCAP subsidy, the switchgrass price is $75/ton, the discount rate is 10%, the fuel price is $2.75/gallon, the wage price is $9.75/hour and the stretch wrap baler throughput is 45 tons/hour.

Table 27. Summary of Sensitivity Analysis for the Preprocessing Systems (Continued)

	Switchgrass Price ($/ton)			
	Purchase		Custom hire	
	Optimistic 90.00	Pessimistic 60.00	Optimistic 90.00	Pessimistic 60.00
Stretch wrap baler-Chopper w/windrow pickup	9,818,248.77	(26,277,624.07)	29,110,909.24	(6,984,963.60)
Stretch wrap baler-Chopper w/rotary cutter-header	18,804,596.72	(17,291,276.13)	33,640,218.03	(2,455,654.81)
Pellet-Chopper w/windrow pickup	(46,612,206.36)	(82,708,079.20)	(29,025,924.46)	(65,121,797.30)
Pellet-Chopper w/rotary cutter-header	(35,084,426.17)	(71,180,299.01)	(24,630,889.36)	(60,726,762.20)

Table 27. Summary of Sensitivity Analysis for the Preprocessing Systems (Continued)

	Discount Rate (%)			
	Purchase		Custom hire	
	Optimistic 8	Pessimistic 12	Optimistic 8	Pessimistic 12
Stretch wrap baler-Chopper w/windrow pickup	(2,559,960.13)	(13,015,793.03)	16,071,440.07	6,787,431.24
Stretch wrap baler-Chopper w/rotary cutter-header	6,004,729.35	(3,699,931.30)	21,015,625.41	10,953,495.69
Pellet-Chopper w/windrow pickup	(49,561,855.90)	(76,602,181.43)	(32,579,662.58)	(58,549,297.19)
Pellet-Chopper w/rotary cutter-header	(37,943,923.95)	(65,163,894.23)	(27,780,131.10)	(54,507,852.43)

Table 27. Summary of Sensitivity Analysis for the Preprocessing Systems (Continued)

	Fuel Price ($/gallon)			
	Purchase		Custom hire	
	Optimistic 2.20	Pessimistic 3.30	Optimistic 2.20	Pessimistic 3.30
Stretch wrap baler-Chopper w/windrow pickup	(6,486,899.67)	(9,972,475.63)	12,880,616.81	9,245,328.83
Stretch wrap baler-Chopper w/rotary cutter-header	1,750,893.29	(237,572.71)	16,586,514.61	14,598,048.61
Pellet-Chopper w/windrow pickup	(63,868,214.58)	(65,452,070.97)	(47,030,496.57)	(47,117,225.18)
Pellet-Chopper w/rotary cutter-header	(53,088,998.29)	(53,175,726.90)	(42,635,461.48)	(42,722,190.08)

Table 27. Summary of Sensitivity Analysis for the Preprocessing Systems (Continued)

	Wage Rate ($/hour)			
	Purchase		**Custom hire**	
	Optimistic 7.80	**Pessimistic 11.70**	**Optimistic 7.80**	**Pessimistic 11.70**
Stretch wrap baler-Chopper w/windrow pickup	(7,989,786.28)	(8,469,589.02)	11,325,141.42	10,800,804.23
Stretch wrap baler-Chopper w/rotary cutter-header	850,433.52	$662,887.07	15,693,709.23	15,490,853.99
Pellet-Chopper w/windrow pickup	(63,628,311.98)	(64,108,117.18)	(47,013,267.31)	(47,047,725.84)
Pellet-Chopper w/rotary cutter-header	(53,038,589.37)	(53,226,135.81)	(42,661,596.52)	(42,696,055.04)

Table 28. Sensitivity of NPV to Stretch Wrap Baler Throughput

	Stretch Wrap Bales Throughput (dt/hour)			
	Purchase		Custom hire	
	Optimistic 54	Pessimistic 36	Optimistic 54	Pessimistic 36
Stretch Wrap Bales-Chopper w/window pick up	(7,815,324.63)	(8,851,232.18)	11,477,335.84	10,441,428.29
Stretch Wrap Bales-Chopper w/rotary header	1,171,025.43	135,112.59	16,006,646.75	14,970,733.90

Table 29. Net Present Value and Break-even Switchgrass Sale Price for the Conventional Hay Harvest Systems without BCAP Incentives

	Equipment Ownership	Price = $90/dt without BCAP NPV [a]($)	Price = $75/dt without BCAP NPV [a]($)	NPV = 0 without BCAP Break-even Price ($/dt)
Rectangular: tarp+gravel	Purchase	(32,751,529)	(53,144,544)	114.09
	Custom hire	(930,000)	(21,323,015)	90.68
Rectangular: tarp+pallet	Purchase	(25,972,811)	(46,365,826)	109.1
	Custom hire	2,698,493	(17,694,522)	88.02
Round: gravel	Purchase	(30,065,310)	(50,458,325)	112.11
	Custom hire	2,396,002	(17,997,012)	88.24
Round: pallet	Purchase	(18,321,130)	(38,714,146)	103.48
	Custom hire	12,900,519	(7,492,495)	80.51
Round: tarp+gravel	Purchase	(30,944,348)	(51,337,363)	112.76
	Custom hire	(610,177)	(21,003,192)	90.45
Round: tarp+pallet	Purchase	(19,029,172)	(39,422,187)	104
	Custom hire	11,304,999	(9,088,016)	81.68
Mix: round tarp+gravel	Purchase	(27,140,277)	(47,533,292)	109.96
	Custom hire	592,705	(19,800,309)	89.56
Mix: round tarp+pallet	Purchase	(15,225,101)	(35,618,116)	101.2
	Custom hire	12,507,882	(7,885,132)	80.8

a.The NPV is calculated based on 8% discount rate, $2.2/gallon fuel price,$7.8/hour wage price, and 54 dt/hour stretch wrap baler throughput.

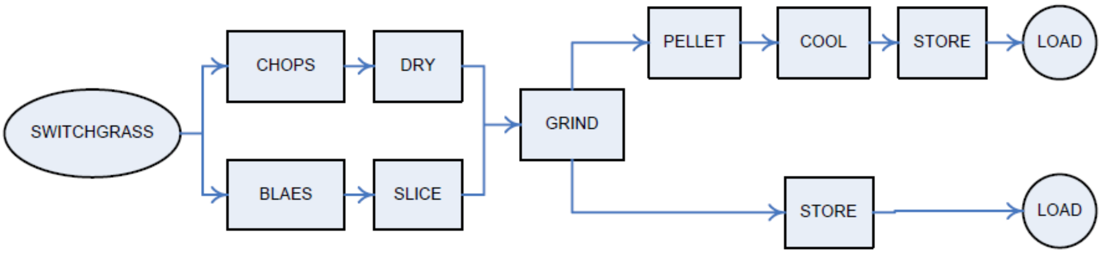
Table 30. Net Present Value and Break-even Switchgrass Sale Price for the Preprocessing Systems without BCAP Incentives

	Equipment Ownership	Price = $90/dt without BCAP NPV [a]($)	Price = $75/dt without BCAP NPV [a]($)	NPV = 0 without BCAP Break-even Price ($/dt)
Stretch Wrap Bales-Chopper w/windrow pick up	Purchase	(12,523,106)	(32,916,121)	99.21
	Custom hire	6,214,355	(14,178,659)	85.43
Stretch Wrap Bales-Chopper w/rotary header	Purchase	(4,935,501)	(25,328,516)	93.63
	Custom hire	10,083,753	(10,309,261)	82.58
Pellet-Chopper w/windrow pick up	Purchase	(61,036,968)	(81,429,983)	134.9
	Custom hire	(45,115,399)	(65,508,414)	123.18
Pellet-Chopper w/rotary header	Purchase	(50,396,072)	(70,789,087)	127.07
	Custom hire	(40,315,868)	(60,708,883)	119.65

a.The NPV is calculated based on 8% discount rate, $2.2/gallon fuel price,$7.8/hour wage price, and 54 dt/hour stretch wrap baler throughput.

Table 31. Optimal System under Alternative Assumptions for BCAP Incentives and Equipment Ownership

	Purchase	Custom hire
with BCAP		
Optimal system	Stretch Wrap Bales-Chopper w/rotary header	Round: pallet
NPV ($)	756,660	21,733,784
without BCAP		
Optimal system	Stretch Wrap Bales-Chopper w/rotary header	Round: pallet
NPV ($)	(4,935,501)	12,900,519



Resource: Sokhansanj and Fenton (2006).

Figure 1. Flow Chart for Preprocess of Biomass to Pellets or to Small Particles

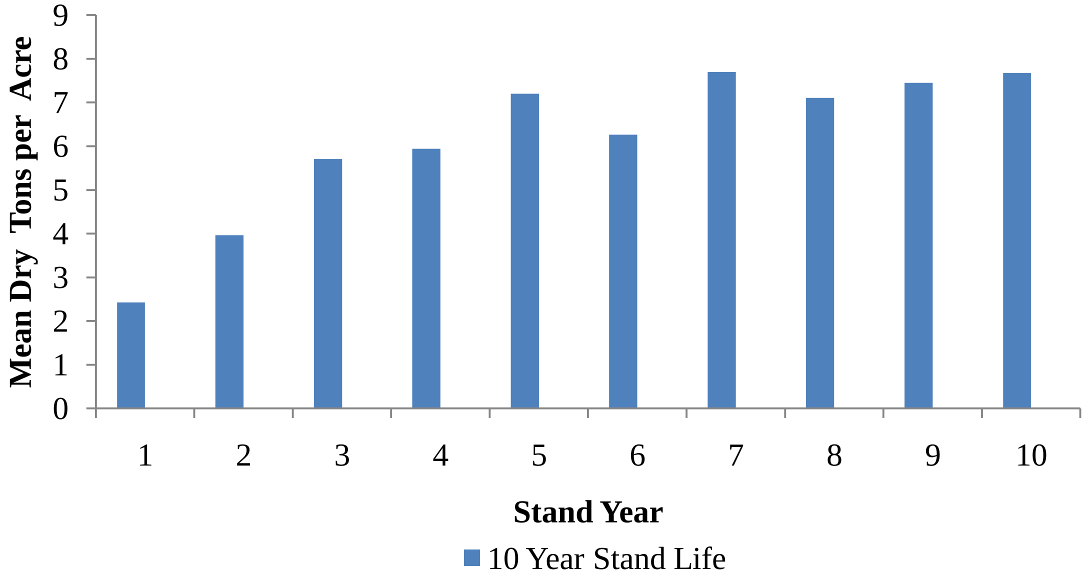
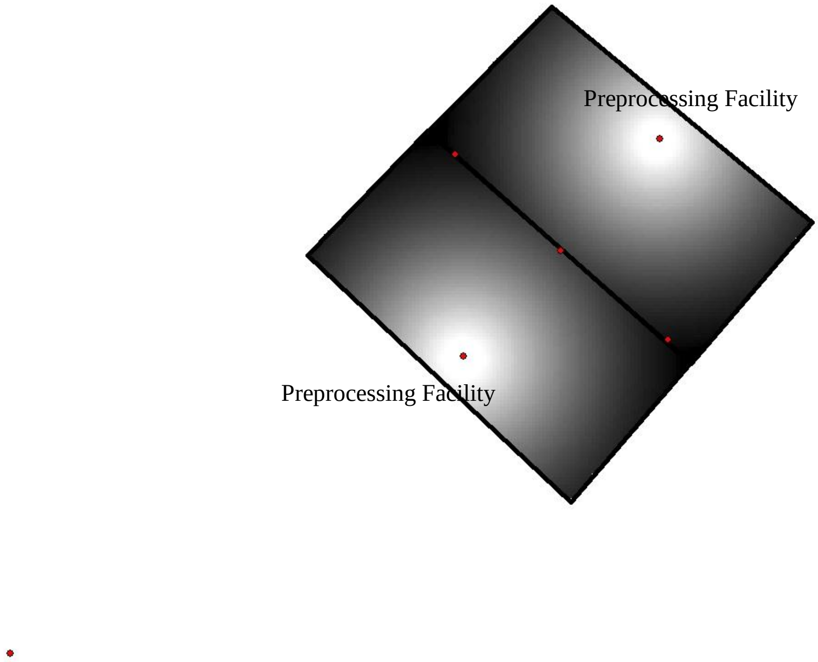
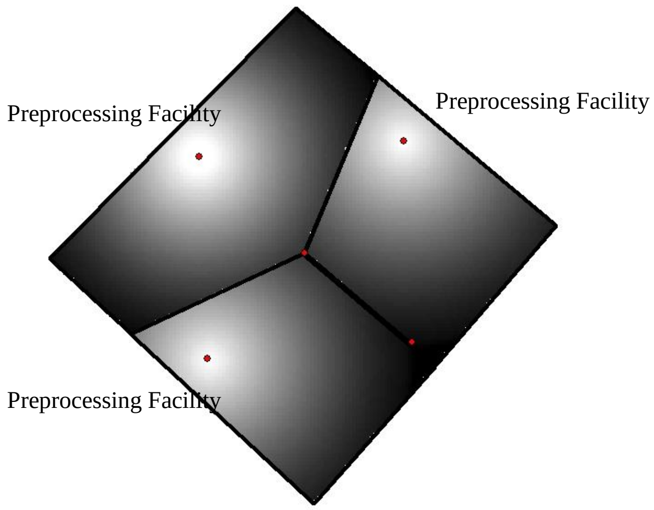


Figure 2. Dandridge Soil 10 Year Stand Life Switchgrass Yield



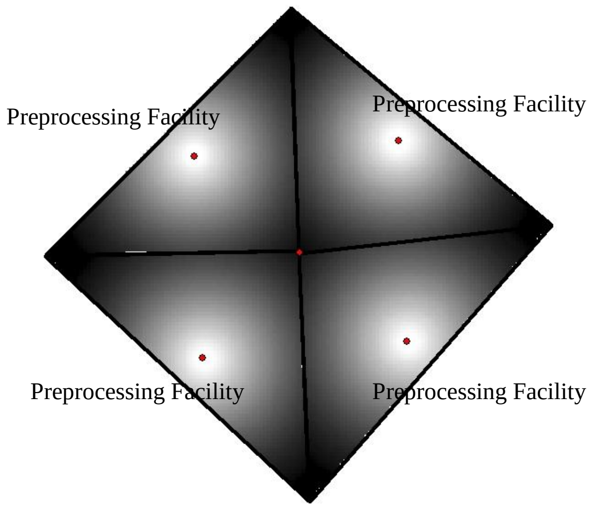
	Travel Distance Within Zone
NW	29.8
SW	30.8

Figure 3.1 Biorefinery and Satellite Preprocessing Facilities Feedstock Draw Areas and Transportation Distance for Preporcessing Scenario Year 1



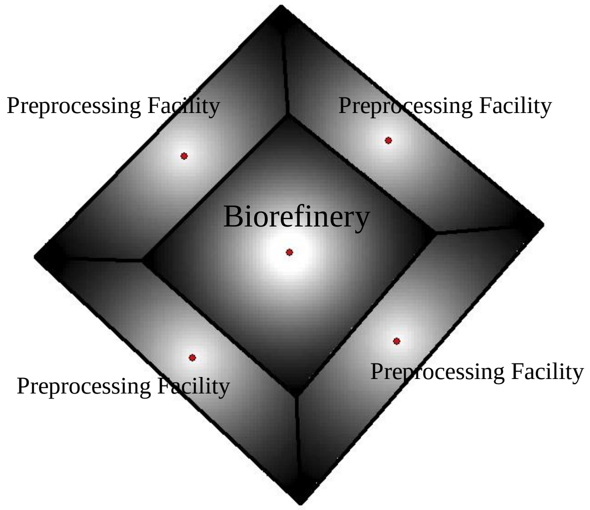
	Travel Distance Within Zone
NW	26.7
NE	27.2
SW	26.8

Figure 3.2 Biorefinery and Satellite Preprocessing Facilities Feedstock Draw Areas and Transportation Distance for Preporcessing Scenario Year 2



	Travel Distance Within Zone
NW	20.23
NE	20.52
SW	20.91
SE	21

Figure 3.3 Biorefinery and Satellite Preprocessing Facilities Feedstock Draw Areas and Transportation Distance for Preporcessing Scenario Year 3



Zone	Average miles road network: To Biorefinery	Average miles road network: Within Zone
Center	NA	20.23
NW	40.00	19.91
NE	40.00	19.08
SW	40.00	20.05
SE	40.00	20.65

Figure 3.4 Biorefinery and Satellite Preprocessing Facilities Feedstock Draw Areas and Transportation Distance for Preporcessing Scenario Year 4-10

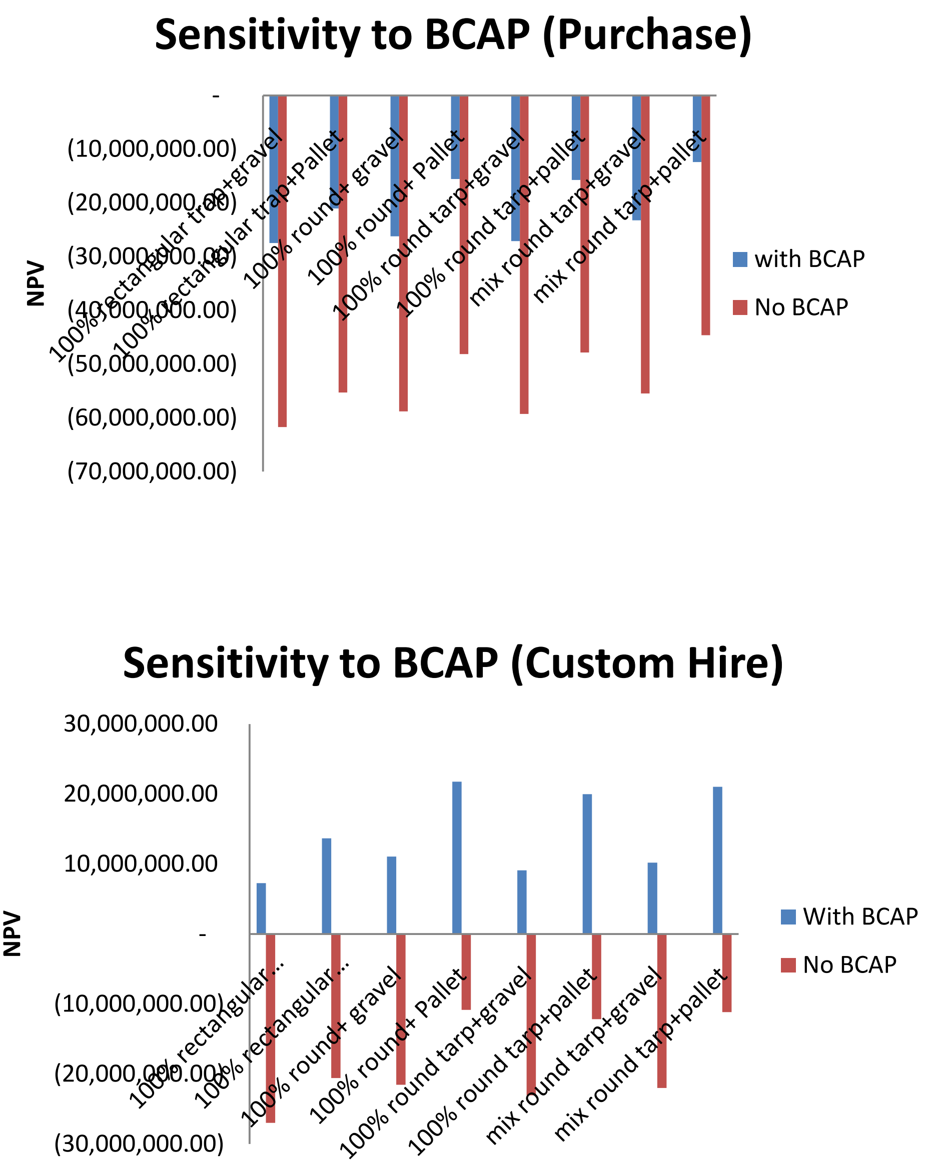
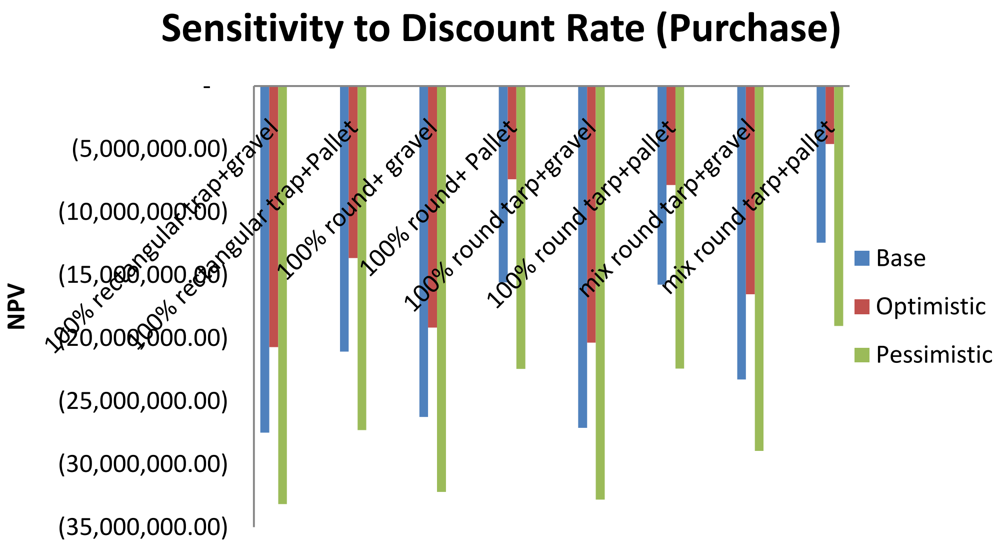


Figure 4.1 Sensitivity of NPV to BCAP for the Conventional Hay Harvest Systems

Figure 4.2 Sensitivity of NPV to Switchgrass Price for the Conventional Hay Harvest Systems



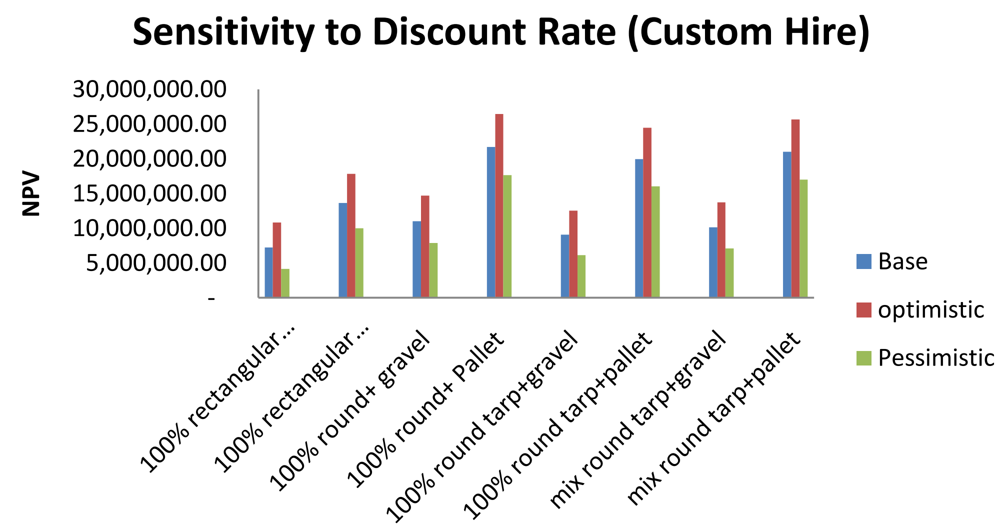
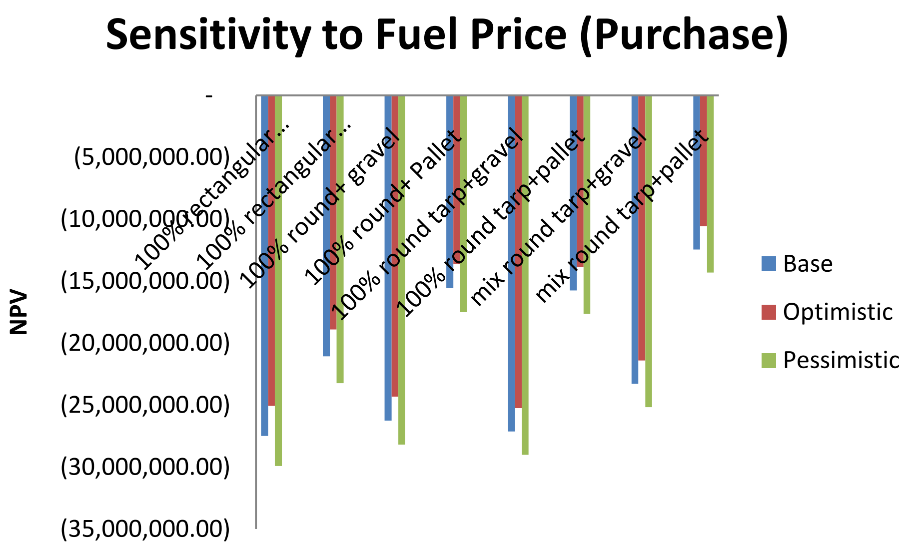


Figure 4.3 Sensitivity of NPV to Discount Rate for the Conventional Hay Harvest Systems



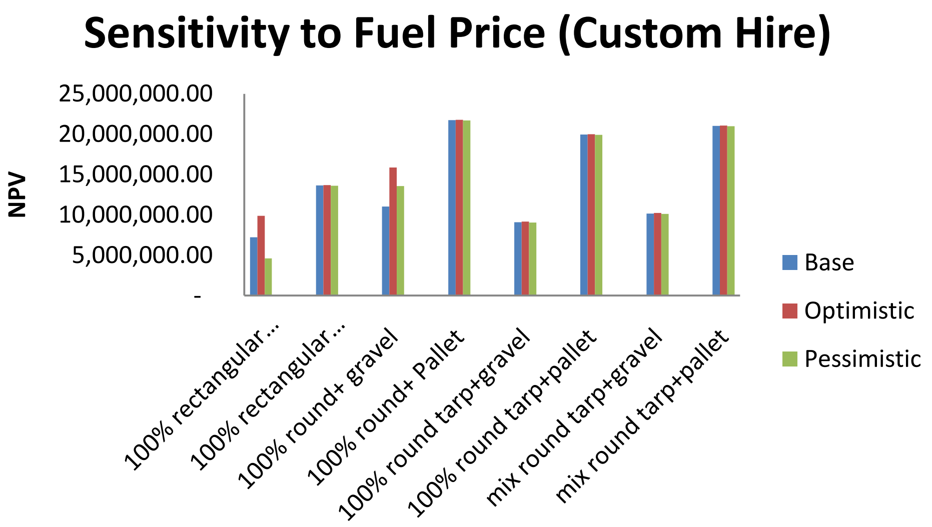
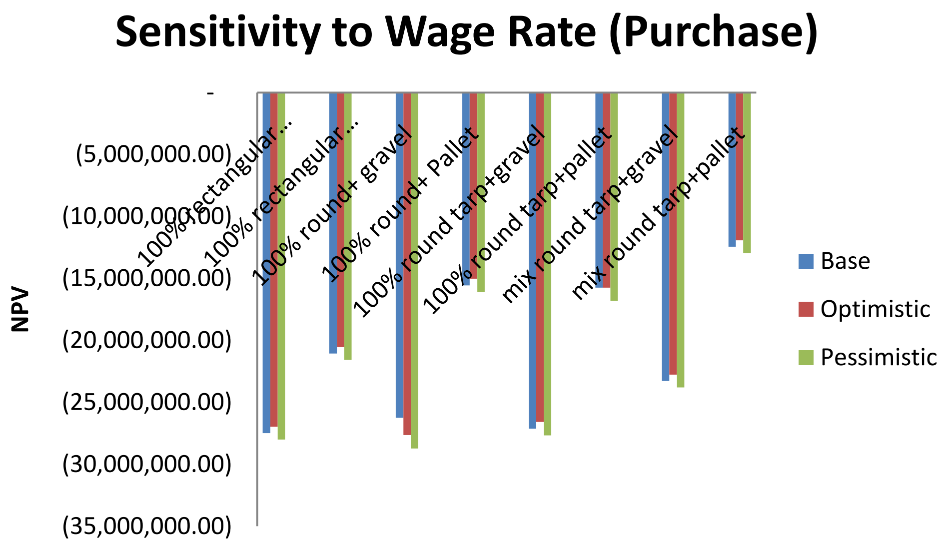


Figure 4.4 Sensitivity of NPV to Fuel Price for the Conventional Hay Harvest Systems



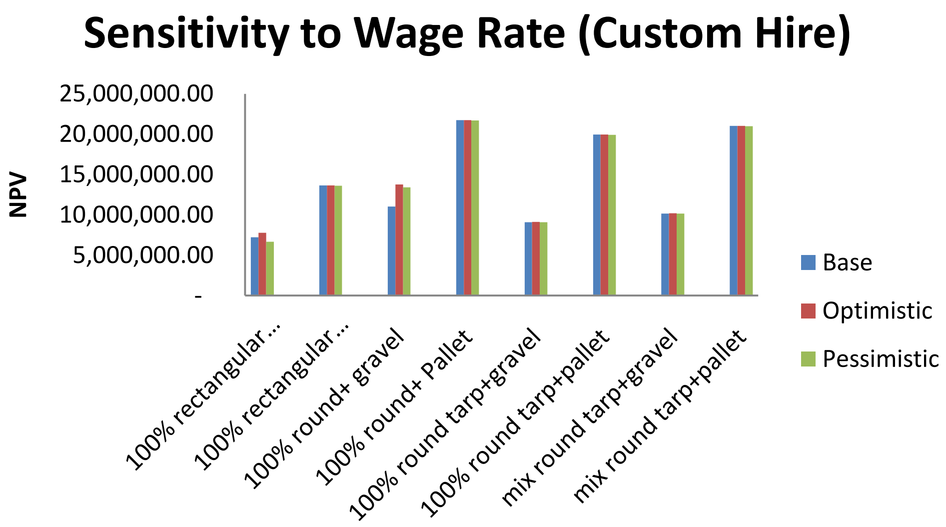


Figure 4.5 Sensitivity of NPV to Wage Rate for the Conventional Hay Harvest Systems

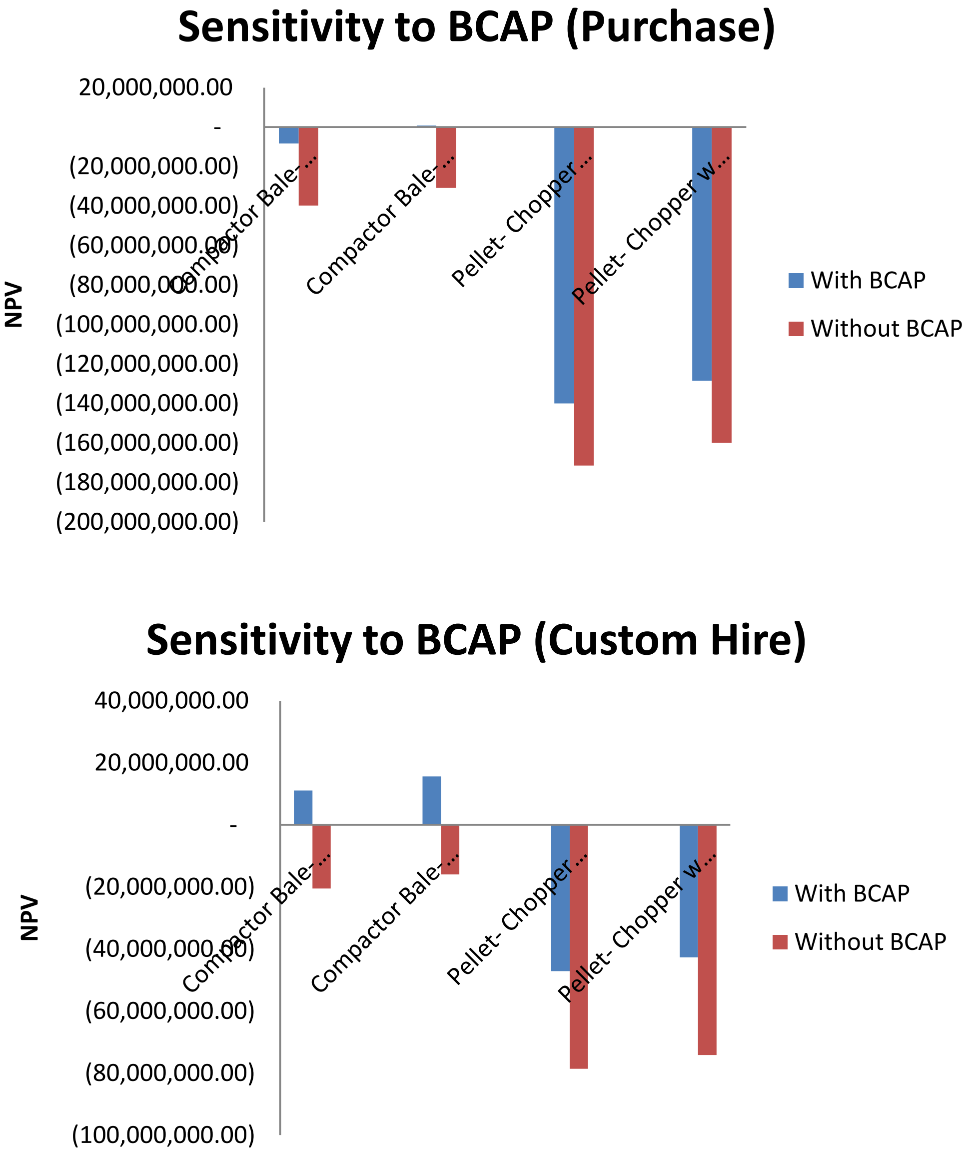
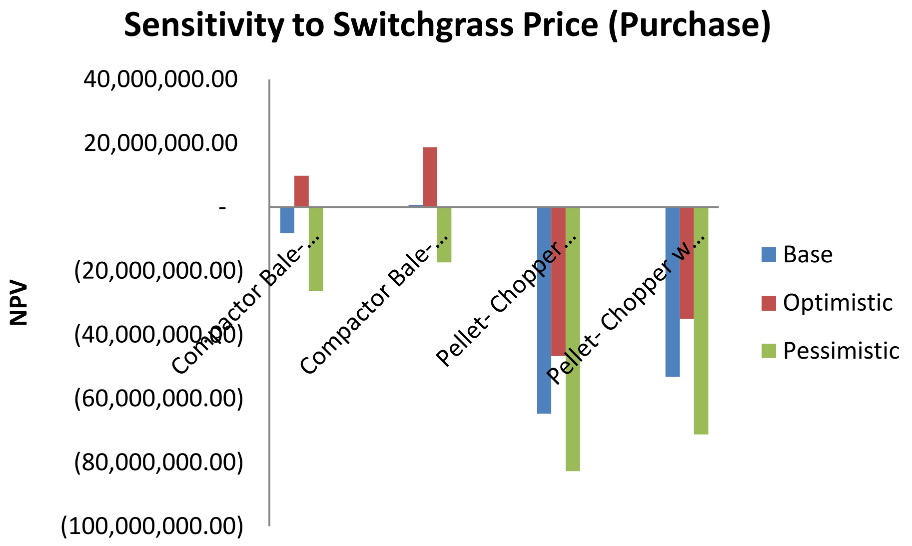


Figure 5.1 Sensitivity of NPV to BCAP for Preprocessing Systems



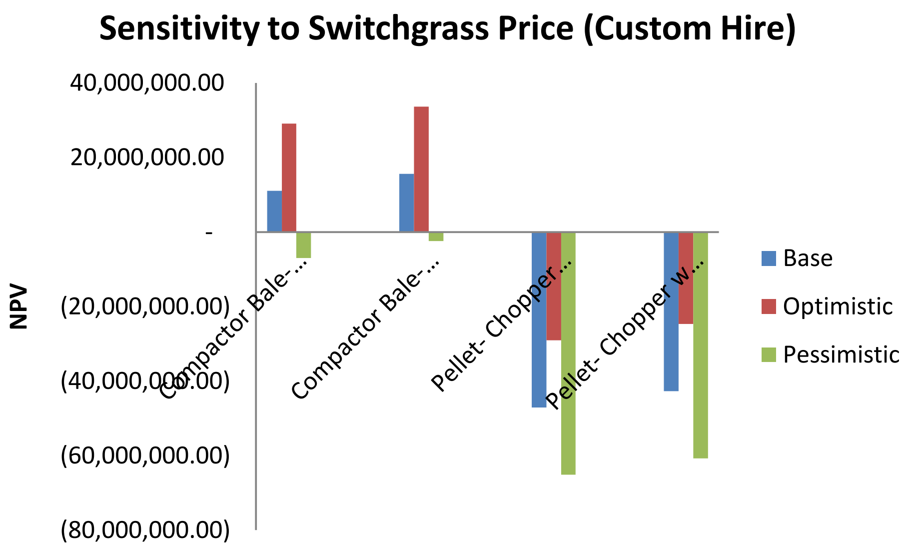
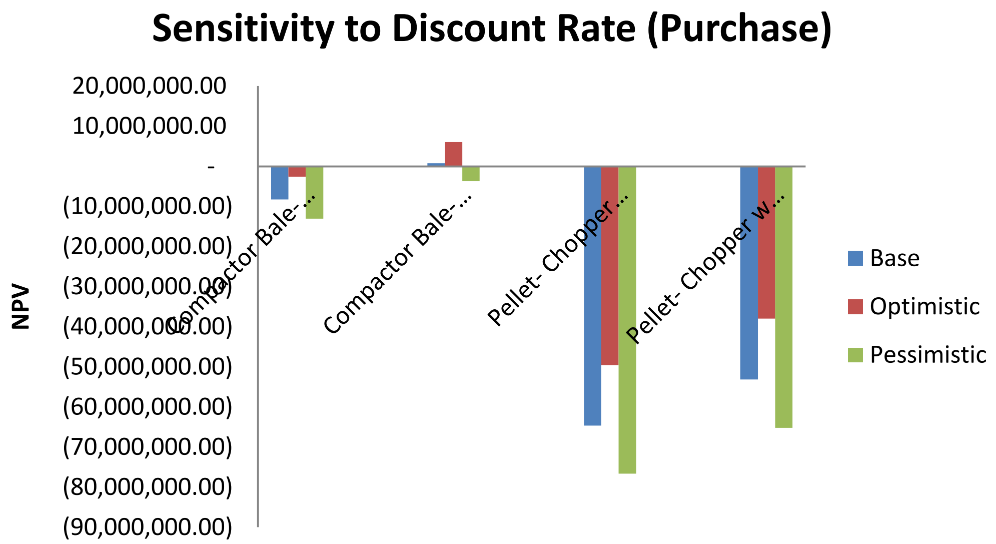


Figure 5.2 Sensitivity of NPV to Switchgrass Sale Price for Preprocessing Systems



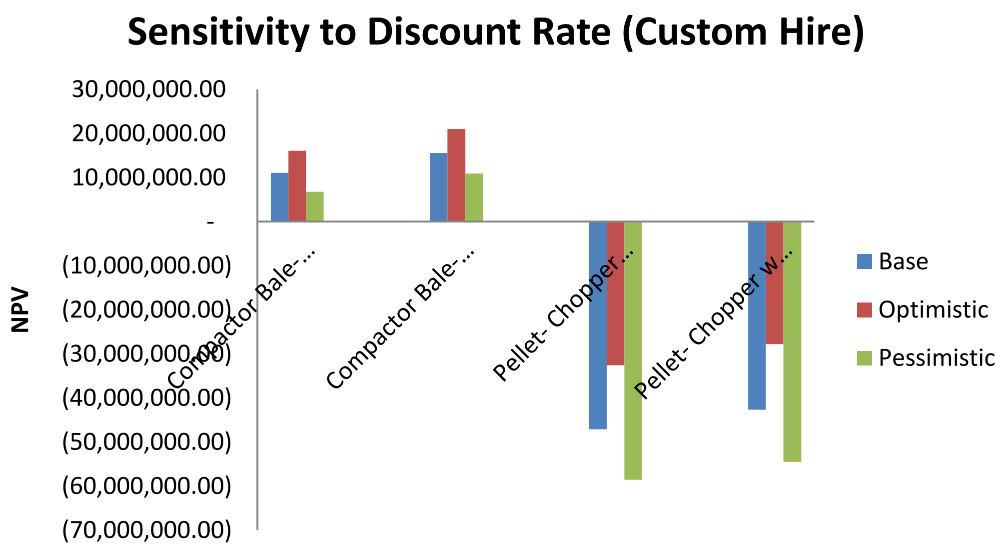
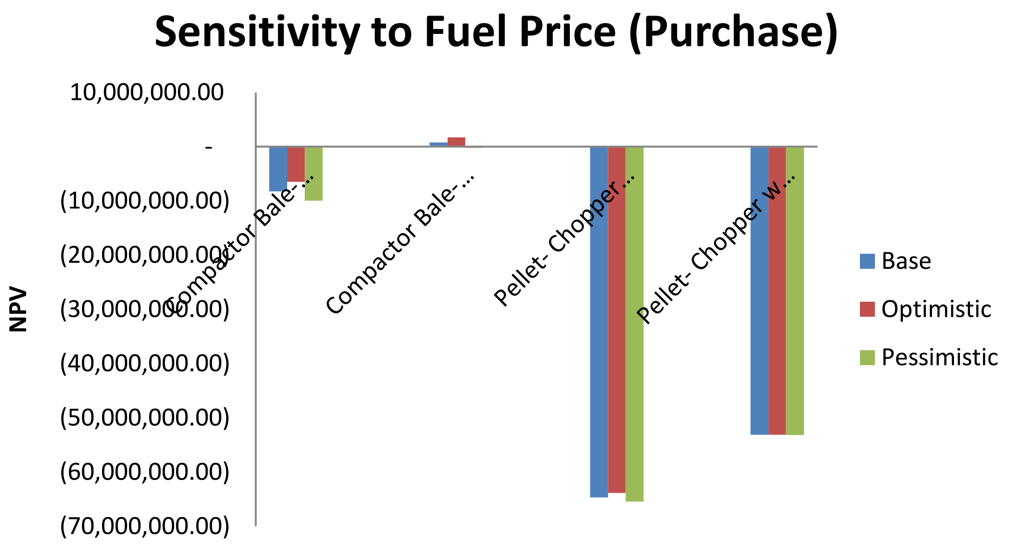


Figure 5.3 Sensitivity of NPV to Discount Rate for Preprocessing Systems



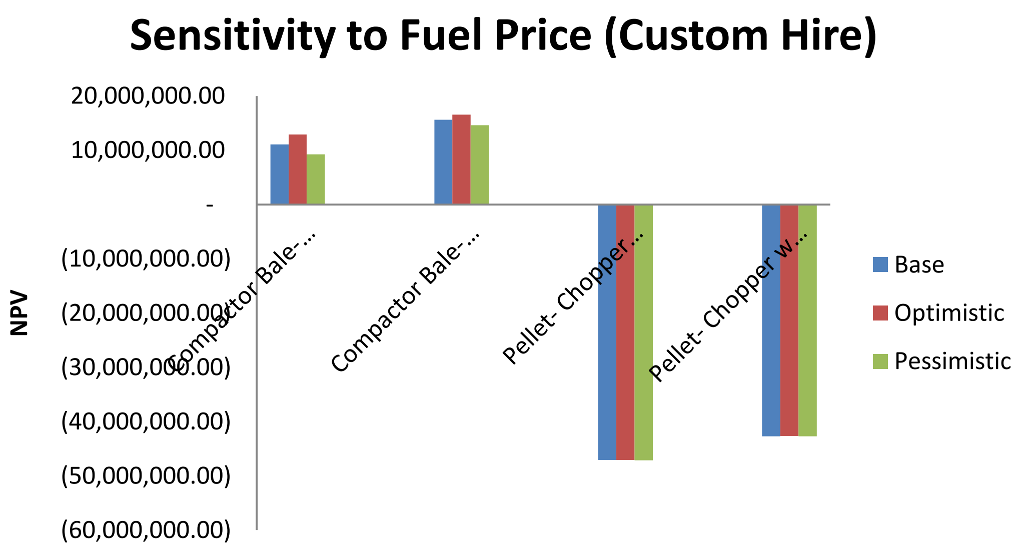
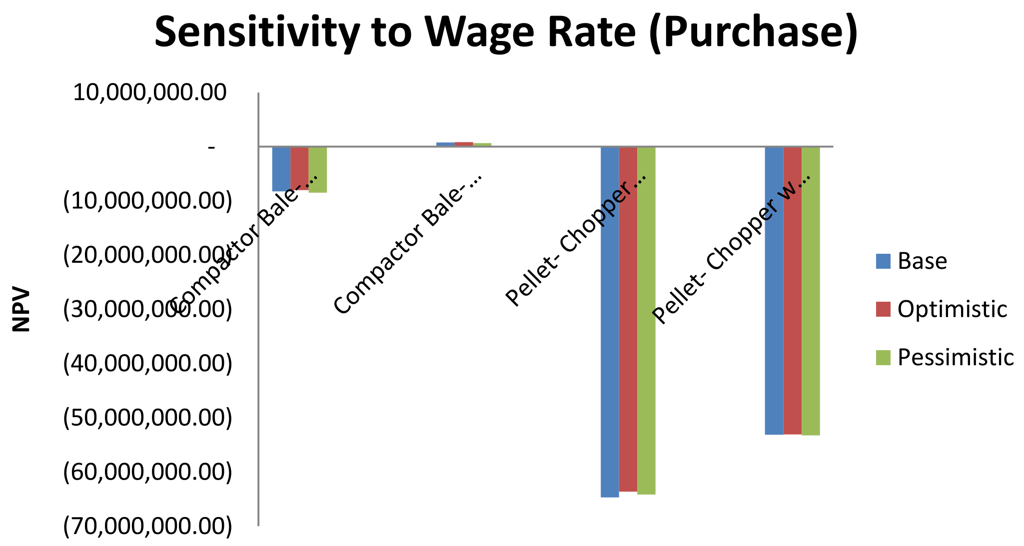


Figure 5.4 Sensitivity of NPV to Fuel Price for Preprocessing Systems



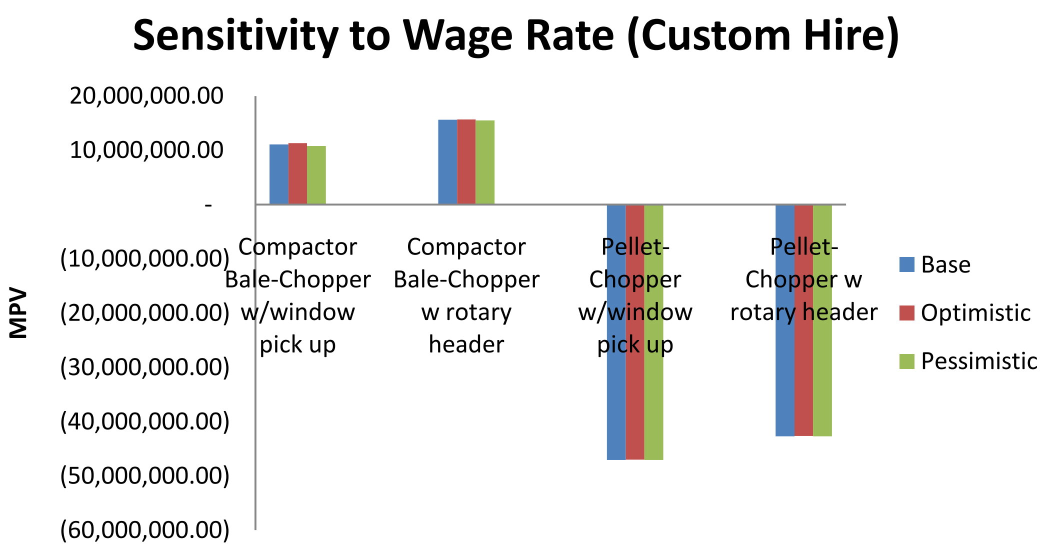


Figure 5.5 Sensitivity of NPV to Wage Rate for Preprocessing Systems

Vita

Jie Chen was born in Beijing, China. She is a graduate assistant at the Department of Agricultural Economics at The University of Tennessee, Knoxville. Jie Chen obtained her Bachelor of Science degree in Economics in 2009 at the Beijing Language and Culture University. She came to UT in 2009 and obtained her Master of Science degree in Agricultural Economics in August 2011.