Optimal Draw Area and Feedstock Delivery Schedule of Biorefineries in the Southeast U.S. Based on Least Cost and Producers' Willingness to Plant a Dedicated Energy Crop

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DEDICATION

I would like to dedicate this research to my parents, Bicheng Tu and Huiling.

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ABSTRACT

To overcome the limitations of starch-based and sugar-based ethanol, scientists propose to expand the use of cellulosic ethanol. Cellulosic ethanol is a biofuel produced from wood, grasses, or the non-edible parts of plants. As the U.S. has a large cellulosic biomass production base (Perlack et al., 2006), production of ethanol from cellulosic feedstock and use of ethanol as a substitute for gasoline could help promote rural development, reduce green house gases emissions, and increase energy independence. This study focuses on the cost of producing cellulosic ethanol along with the amount of carbon sequestered and emitted using switchgrass as a feedstock.

In the first part of this study, willingness to adopt (WTA) switchgrass is evaluated. The amount of farmland available for growing switchgrass was estimated using Probit and Tobit models of switchgrass production survey data developed in the University of Tennessee's Department of Agricultural and Resource Economics. The estimated results from these two models show that when switchgrass prices increase, the probability of farmers to grow switchgrass and land acreages used for switchgrass production will increase.

In the second part of this study, based on the results of estimated, farmland availability within an optimal draw area of 50 miles of a biorefinery and a switchgrass delivery schedule could be determined from the biorefinery's perspective considering different bale types and storage methods. A cost minimization programming model was developed to estimate the year-round switchgrass delivery schedule within fifty miles of three selected biorefinery locations in the southeastern U.S. Also in this study, the carbon credit effect was considered in the model. The results from the programming model suggest that with the carbon credit paid to biorefineries, more marginal land will be used for growing switchgrass, and carbon will be sequestered in the soil at a level that exceeds emitted carbon by at least 1.5 times. Lower feedstock costs would be available to the biorefineries if a carbon payment was available to producers for net carbon sequestered.

Keywords: cellulosic ethanol, willingness to adopt, land use, carbon credit, switchgrass

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CHAPTER I
INTRODUCTION AND GENERAL INFORMATION

Importance of Bio-ethanol

Global climate change is an important issue that affects the earth and its occupants in many ways. Increased levels of green house gas (GHG) are considered by many to be the primary cause of global climate change. Many scientists believe that human activity may be a primary cause for the rapid increase in GHGs in the past several decades (Tilman et al. 2001and Fargione et al. 2008). Those activities include fossil fuel combustion, land use change, animal agriculture and deforestation. As a result, there are significant measures being taken to reduce GHGs. Agriculture plays an important role in both emitting and sequestering GHGs. Currently, input use from fertilizers, fuel use, along with emissions from livestock operations result in carbon emissions; while some consecution management practice results in sequestering carbon in the soil. Historically, as soils developed in their natural state prior to agriculture, carbon accumulated and reached a steady state depending on climate, soil texture, and vegetation type (Wolkowski, 2008). In 2009, the agriculture sector was responsible for emissions of 419.3 teragrams of carbon dioxide (CO_2) equivalents (Tg CO_2 Eq.), or 6.3 percent of total U.S. greenhouse gas emissions (EPA 2011). Houghton (2003) estimated that about one-third of total CO_2 emissions, which is the main source of GHGs, since 1850 come from changes in land use, two-thirds come from fossil fuels. In addition, land use changes cause emissions of other

GHGs. Changes in management either through intensity, crop, or tillage can also lead to changes in soil use and hence in CO_2 and non-CO_2 GHG emissions (Van der Werf and Peterson 2007).

West et al. (2005) mentioned that plants absorb CO_2 from the air and store it as carbon in their tissues. This carbon is returned to the atmosphere as CO_2 when crops are harvested and consumed. Some carbon, they added, could be permanently sequestered in the soil as organic matter through appropriate changes in tillage management. “The effects of climate change on carbon storage vary from place to place because of differences in how soil moisture and soil temperature change as the climate warms” (Kloeppel 2005).

One means of reducing carbon emissions is to rely on fuels that are produced from renewable sources. While carbon is emitted during its production, the process of growing the feedstock sequesters carbon. The use of renewable plant-based feedstocks to replace carbon-based fuels reduces carbon emissions. Lowering the amount of inputs that are used in the production process increases the amount of the displacement (Schipper, Scholl, and Price 1997).

Besides the benefit of storing carbon, some of plants can be used as feedstock for ethanol, which is considered to be renewable, and replaces fossil fuel. Currently, corn, soybean, and sugarcane are the main feedstock sources for ethanol; with corn comprising for more than 90 percent of current U.S. ethanol production. Brazil, the world's second-largest ethanol producer, behind the United States, uses sugar cane as its main feedstock. However, using food crops, such as corn and soybean, for ethanol production raises concerns of food security (Mitchell, 2008) and environmental degradation (Pimentel and Patzek, 2005). Larson et al. (2010) [33] evaluated the impact of increased corn starch ethanol production on agricultural land use and the environment. The results showed that increasing corn ethanol production has a positive effect on net farm income, made substantial shifts in land use throughout the United States, especially in traditional corn-growing areas of the midcontinent region. Production of other crops, such as soybeans and cotton, shifted out of traditional growing areas to accommodate increased corn production. Fertilizer and chemical usage also increased with expanded corn production. Hence, corn-based ethanol is economically sustainable, but may not meet the increasing ethanol demand due to farmland constraints. Besides the corn based ethanol production limit, attention should be paid to the environmental issues caused by expanding corn production. The study done by Larson et al. (2010) [33] indicated that, from an environmental aspect, if conservation tillage at 2007 level was assumed to be used continuously for 10 years, regional tillage intensity, soil erosion, and fossil fuel-based carbon emissions increased, while soil carbon stocks decreased as a result of increased corn production. Besides the study of Larson et al. (2010) [33], several research studies show that corn is no better – and might be worse – than fossil fuel when indirect land use is considered. If increased production of corn-based ethanol raises the corn price and accelerates deforestation, then the GHGs emissions and soil carbon losses caused by deforestation should be counted towards corn ethanol’s total emission (Cimitile, 2009).

Figure 1.1 shows the U.S. corn production and use, from 2004 to 2007. The demand for ethanol increased rapidly, around 2 billion more bushels of corn are needed for ethanol production, but the increase of corn production cannot meet the ethanol production requirement.

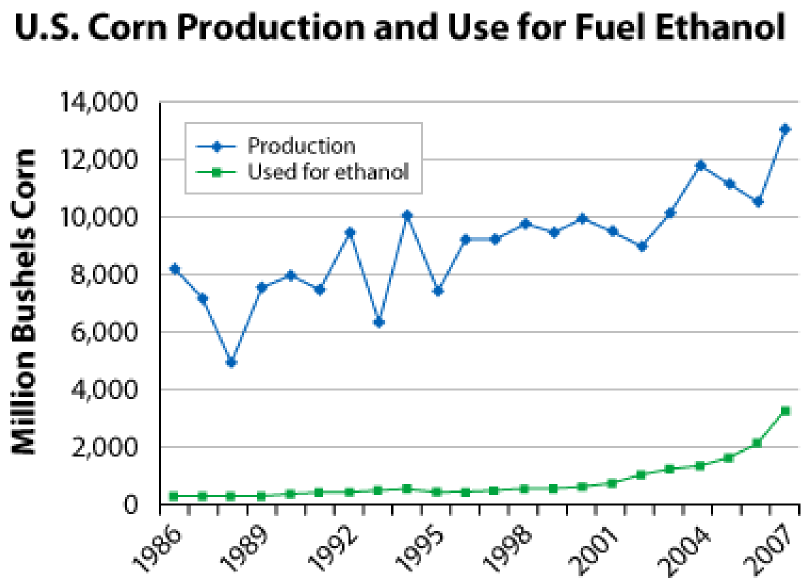

Figure 1.1 U.S. Corn Production and Use for Fuel Ethanol
Source: USDA National Agricultural Statistics Service and Economic Research Service

Introduction to Cellulosic Ethanol

To overcome the limitations of starch-based and sugar-based ethanol, and to help reduce the nation's GHG emissions, scientists and decision-makers propose to expand the use of cellulosic ethanol. Cellulosic ethanol is a biofuel produced from wood, grasses, or the non-edible parts of plants. Since the United States has a large cellulosic biomass production base (Perlack et al. 2006), the production of ethanol from cellulosic feedstocks and the use of ethanol as a substitute for gasoline could help promote rural development, increase farm incomes, reduce GHGs, and decrease energy dependence. Therefore, the federal government has announced various policy targets and incentives to promote the production of cellulosic ethanol in the country. Corn stover, switchgrass, woodchips, tree thinnings, and municipal solid wood waste are some of the more popular feedstocks for cellulosic ethanol production.

Benefits of Cellulosic Ethanol

Cellulosic ethanol production using perennial grasses, such as switchgrass, can have significant positive environmental effects compared to traditional row cropping practices (Sanderson et al. 1996). According to the U.S. Department of Energy (DOE), one of the important benefits of cellulosic ethanol is that it reduces GHGs emissions by 85% over reformulated gasoline. Compared with the significant GHGs reduction resulting from using cellulosic ethanol, corn ethanol has much a smaller effect on GHGs emission reduction. The U.S. DOE found that current corn-based ethanol results in only a 19% reduction in GHGs (DOE 2007).

The main positive environmental effects of using perennial grasses as cellulosic ethanol are: “1) reduced erosion and runoff, which reduces the loss of soil nutrients and organic matter, and 2) increased incorporation of soil carbon, which improves soil texture and chemistry, and 3) reduced use of agricultural chemicals, which leads to reducing pollution of streams and groundwater (McLaughlin et al. 1994; Vaughan et al. 1989; Lynd et al. 1991)” (Sanderson et al. 1996). Another important environmental attribute of using perennial grasses for cellulosic ethanol is the reduction of CO_2 emissions (Bain, 1993; Graham et al. 1992). This results from less CO_2 being released from burning biomass fuels in place of fossil fuels, and also the potential net CO_2 reduction associated with the replacement of soil carbon depleted by replacing row crops by perennial grasses. McLaughlin et al. (1994) have reported high rates of carbon gain when switchgrass is grown as a bioenergy crop (Sanderson et al. 1996).

Perennial grasses develop extensive root systems that in effect transfer atmospheric carbon into soil biomass. If the soil is not tilled and is protected from erosion, the amount of biomass accumulating in the soil can sequester a substantial amount of carbon. A number of studies performed on switchgrass have shown carbon sequestered in the soil at annual rates of 1–10 ton/hectare (t/ha). Low nitrogen requirements and thus low nitrogen losses also implies using perennial crops and forest species may favor certain nitrogen fixing species (Carroll and Somerville 2009).

Two frequently mentioned pathways for a liquid renewable transportation fuel is through either a bio-chemical or thermo-chemical platform. In comparison to fossil fuel, bio-ethanol burns cleaner with greater efficiency, putting less CO_2 and overall pollution into the air. According to the U.S. DOE, when compared to gasoline, ethanol from cellulose reduces GHGs emission by 90 percent and corn-based ethanol decreases emissions by 10 to 20 percent (Montenegro 2006). Cellulosic ethanol contributes little to the greenhouse effect and has a five times better net energy balance than corn-based ethanol (Demain, Newcomb, and Wu 2005).

Switchgrass as Potential Feedstock for Cellulosic Ethanol

Switchgrass, a warm season perennial grass native to U.S., is a hardy, drought resistant plant that can grow in a variety of soils (Mclaughlin 2002). It can grow on marginal agricultural land or low-yielding land that may not be suitable for other crops (Tiller 2008).

A study by the DOE found that that there could be 1.3 billion dry tons of biomass available for ethanol use, by making little changes in agricultural and forestry practices while meeting the demands for forestry products, food, and fiber (DOE 2007). English, et al (2009) reported that for the entire period through 2030, the cumulative cellulosic ethanol production could be as high as 10.48 billion barrels of oil. The estimated accumulated gains in net farm income are estimated at over $210 billion, and the accumulated potential savings in government payments are estimated to be $150 billion under a properly constructed cap-and-trade program. Switchgrass is widely recognized as a potential crop for bio-ethanol production (McLaughlin 2002). Currently, there is only a small amount of switchgrass used as feedstock for cellulosic ethanol production. In order for dedicated energy crops such as switchgrass to exist at a large-scale, they must compete with existing uses of agricultural land.

To use switchgrass as an energy feedstock in large scale, it is important to consider the harvest, storage, and transport costs of switchgrass since switchgrass is a bulky material relative to the energy it contains. Researchers have evaluated the economic feasibility and sustainability of using cellulosic biomass for bio-ethanol production. In Rinehart's study, the projected harvesting time for switchgrass was in the fall after a killing freeze (Rinehart 2006). Cundiff reported that with the large amount of biomass to be harvested, the machinery and labor cost per acre would likely be higher for switchgrass when compared to hay (Cundiff 1996). Analyses by Epplin (1996), Thorsell et al. (2004), Bransby et al. (2005), Popp and Hogan (2007), Wang (2009), Larson et al. (2010) [34], and Mooney et al. (2010) have evaluated some of the aspects of harvest, storage, and transportation costs and risks.

Epplin (1996) estimated that, based on an average yield of 3.64dt/acre, the harvest cost was $12.30/dry-ton (dt), and the loading and transportation cost was $12.18/dt. In Cundiff and Marsh's study (1996), the harvest and storage costs for two types of large bales, round rectangular bales, were compared. Assuming an average yield of 3.64dt/acre, the harvest and storage costs were $19.06/dt and $3.83/dt for large round bale, $14.69/dt and $16.97/dt for large rectangular bale, respectively. They also found that the cost difference became insignificant when the yield was above 3.64dt/acre and the storage losses for round bales stored outside increased above 5 percent. Mooney et al. (2009) showed that the third year switchgrass yields were above 5dt/acre in some selected land in Tennessee, and the average projected annualized dry matter yields for a 5-year and 10 year contract were 4.79dt/acre and 5dt/acre respectively. The estimated breakeven prices ranged from $48.41/dt to $86.93/dt on different farmland.

Problem Statement

In the previous studies, little attention has been paid on the effect of switchgrass dry matter losses during storage and transportation. The dry matter losses from precipitation and weathering during storage may substantially diminish the quantity and quality of switchgrass after harvest and increase the costs of feedstock delivered to the biorefinery (Cundiff and Grisso, 2008). In addition, the production costs might dramatically differ among alternative harvest methods, storage methods, and storage periods that can be used for switchgrass production.

To date, only a few researchers have included the differences between two available harvest technologies, large round bale and large rectangular bale in their studies. In fact, the harvest methods are insignificant factor to estimate the logistics cost of switchgrass. There are advantages and disadvantages of the two harvest methods within a biomass feedstock supply chain. A large round bale is designed to shed water and may have an advantage over a large rectangular bale with respect to dry matter losses when stored outdoors (Mooney, et al. 2010; Cundiff and Grisso 2008). However, a large rectangular bale system, which has a larger throughput capacity than a large round bale system, may have harvest, handling, and storage economies of size advantages over large round bales (Thorsell et al., 2004; English et al., 2008). Larson et al. (2010) [34] estimated the storage dry matter losses for a round bale of switchgrass that was wrapped with twine, covered with a tarp at 9 percent; dry matter loss of a round bale that was left uncovered and stored outdoors was 13 percent, after 360 days in storage under Tennessee weather conditions. By comparison, the estimated dry matter loss after 360 days in storage for rectangular bale covered with a tarp and stored outside was 30 percent. The significant difference between dry matter losses of round and rectangular bales should affect the farmers' storage decisions.

Besides the lack of research on dry matter loss, previous studies also ignored the carbon benefit generated from growing switchgrass. As previously mentioned, using switchgrass as the feedstock for bio-ethanol can lead to CO_2 reductions. There are multiple methods to reduce GHGs. Currently, in most industrial cases, to reduce emissions of any kind, a command and control method is employed. The government provides a maximum limit and if exceeded a fine is levied. The business attempts to control the emission levels. In agriculture, however, incentives have typically been employed. These incentives reimburse a farmer/landowner to adopt certain technologies. Recently market alternatives have been developed such as the Chicago Climate Exchange (CCX), which landowners are paid for adopting a certain technology recognized by the CCX as a means of sequestering carbon. In the study of English et al. (2011), the impact of a carbon payment mechanism to agriculture and forestry sectors was evaluated. The results showed that, when a carbon payment was allowed, the carbon emission from agriculture was significantly reduced. Implementation of this carbon policy would provide positive returns to the agriculture and forestry sectors.

Objectives

To achieve a minimum cost feedstock delivered to the plant door, biorefineries need to determine their feedstock draw area, the cost of the feedstock itself including the farm gate feedstock cost, storage cost, transportation cost, and dry matter loss and then weigh that cost to the return the feedstock will bring to the plant. These costs will be impacted by the density of the feedstock planted around the facility. Defining the amount of acres within the biorefinery's draw area is an important factor in determining the delivered cost. In addition, if a carbon payment mechanism is allowed, farmers could receive carbon credits for the net soil carbon stored growing a dedicated energy crop. This could reduce the cost of the feedstock to the biorefinery. Since the U. S. Department of Agriculture (USDA) has indicated that the Southern United States will be important in providing transportation fuels from biomass, this study will focus on this region. There are two objectives for this study:

1. Identify factors that may affect the farmer's decision for converting current land use to grow switchgrass and incorporate these factors into the analysis. Use the factors to estimate the producer's WTA to grow switchgrass and to predict the potential maximum change in land use.

2. Determine the optimal draw area and delivery schedule to minimize cost to the biorefinery with farm and biorefinery constraints under different switchgrass price levels.

To achieve the second objective, the cost of purchasing switchgrass by the biorefinery will be determined. The cost will be estimated using secondary source material which will include factors such as delivery distance, switchgrass yield, crop density, and other farmer and biorefinery constraints.

This study assumes that farmers are paid for the amount of switchgrass that is picked up at the farm at the time of harvest by the biorefinery. Biorefineries must take all the measurable input costs to deliver switchgrass into consideration. The costs mainly include costs for switchgrass, storage, and transportation. Thus, the biorefineries will choose the optimal draw area and delivery schedule that minimizes costs. The biorefinery is paid for the output produced, mainly ethanol.

CHAPTER II
LITERATURE REVIEW

U.S. Ethanol Production

Ethanol is mainly used in the U.S. as an oxygenate for gasoline in the form of low-level blends up to 10 percent. Nearly all cars in the U.S. can run on blends of up to 10% ethanol, and motor vehicle manufacturers already produce vehicles designed to run on much higher ethanol blends. The U.S. Environmental Protection Agency (EPA) has ruled that cars built after 2006 can burn a 15 percent ethanol mix and is considering this for cars built after 2000. In 2007, Portland, Oregon became the first city in the United States to require all gasoline sold within the city limits to contain at least 10% ethanol. As of January 2008, three states — Missouri, Minnesota, and Hawaii — require ethanol to be blended with gasoline. Many cities also require ethanol blends due to non-attainment of federal air quality goals. As a result of federal and state level policies, the production of ethanol in the United States has grown dramatically during the past decade. The United States has been the world's largest producer of ethanol since 2005. Total ethanol production in the United States in 2010 was 13.5 billion gallons (50.0 billion liters) (Renewable Fuel Association 2011). Production capacity has increased by an average of 1 billion gallons per year during the past decade, from 1.63 billion gallons in 2000 to 13.5 billion gallons in 2010 (Renewable Fuel Association 2011).

Federal Policy

To induce market demand for cellulosic biofuels, the Energy Independence and Security Act of 2007 (EISA) mandates specific renewable energy market targets for 2022 (U.S. Congress). For liquid transportation fuels, the 2022 EISA mandate requires 36 billion gallons per year (bgy) of biofuel, of which 21 bgy must come from feedstocks other than corn starch. The recent Food, Conservation and Energy Act of 2008 includes more than $1 billion in incentives for farmers to grow cellulosic feedstocks and to bio-fuel producers to use cellulosic feedstocks. This includes a $1.01 per gallon tax credit for producers of cellulosic bio-fuels and cost share payments through the Biomass Crop Assistance Program (BCAP) (up to 75% of establishment costs, plus annual payments to cover the cost of the land during establishment and prior to biorefinery demand, and $45 per ton to cover costs of collection, harvest, storage and transport). It also provides assistance for cellulosic biorefineries and for research and development, and incentives for using biomass (instead of fossil fuels) to power existing ethanol plants, thus creating a market for biomass feedstocks.

Federal Ethanol Incentive Program

A major program aimed at promoting the development of the ethanol industry in the U.S. is the Volumetric Ethanol Excise Tax Credit, the federal subsidy for ethanol that is used in gasoline. Other incentive programs include the tariff on imported ethanol, grants, loans, and the renewable fuels standard. In 2006, about $2.5 billion dollars was distributed to gasoline blenders through the tax credit, which initially provided a 51 cent credit against gasoline taxes for every gallon of ethanol blended with gasoline (Hahn 2008) and a $1.01 per gallon for ethanol made from cellulose. As of January 1st, 2009 the original ethanol credit subsidy was reduced to 45 cents per gallon. In June 2011, the United States Senate voted to end the 45 cents tax credit per gallon which supports the U.S. ethanol industry.

Carbon Sequestration

Carbon sequestration is defined as a means of storing carbon by plants that absorb carbon dioxide and release oxygen. Feng et al. (2004) further described carbon sequestration as the capturing and storing of carbon in biomass and soils resulting from agricultural and forest activities. “Such practices include the introduction of cover crops on fallow land, shifting from conventional tillage to conservation tillage (such as no-till), and the retirement of land from active production to a grass cover or trees” (Feng et al. 2004). The DOE (2008) suggested that carbon sequestration is one of the most promising ways for reducing the buildup of GHGs in the atmosphere. The DOE also stated that more research needs to be conducted to identify the most suitable technologies, regulations, and infrastructure for future carbon capture, storage and sequestration. Recently, carbon sequestration has gained widespread acceptance as a potential GHG mitigation strategy.

The agricultural sector offers a great opportunity in reducing environmental disservices by reducing a significant amount of carbon emissions.

However, important issues must be addressed prior to the implementation of a carbon sequestration program (Feng et. al, 2004). In the United States, an average continuous crop could result in sequestering of 337 ± 108 kg Carbon per hectare per year in most agricultural soils by changing from conventional tillage to no-tillage (West and Marland, 2001). However, these sequestration options are known to be temporary in nature, because they depend on isolating GHGs in soils and in the biomass where these gases have the potential to leak back into the atmosphere. For instance, when soils are disturbed or trees are harvested and used, the potential exists for carbon previously captured to be emitted to the atmosphere (Scott et al. 2001). It is estimated that 5 percent of carbon sequestered begins to leak back into the atmosphere after 50 years in place annually. Carbon sequestration is not separable from other environmental effects of a given land-use practice (Feng et al. 2004).

Carbon sequestration reduces CO_2 emissions from agricultural soils or plant material by producing more biomass within a given time period than is respirated by soil microbes. Also, reducing tillage can maintain or increase soil organic matter, depending on plant species, soil type, regional climate, topography and management practices (Pendell et al., 2006). In the US, for instance, values for carbon sequestration rates are well-established and available for most tree species but variation in rates of soil carbon sequestration based on soil type and cropping practices are less documented. Pine plantations in the Southeast can accumulate almost 100 metric tons of carbon per acre after 90 years, or roughly one metric ton of carbon per acre per year (US–EPA, 2006).

However, changes in forest management (e.g., lengthening the harvest-regeneration cycle) generally result in less carbon sequestration per acre. Similarly, changes in cropping practices, such as from conventional to conservation tillage could potentially sequester about 0.1 – 0.3 metric tons of carbon per acre per year (US EPA, 2006).

Tillage Practice and Carbon Sequestration

There are different kinds of conservation tillage systems, including no till, ridge till, minimum till and mulch till. These cultivation practices increase carbon storage through enhanced soil carbon sequestration, and may reduce energy-related CO_2 emissions from farm equipment, and help minimize N_2O runoff (US-EPA, 2006). No-tillage is defined as planting of crops through direct seeding without disturbing the soil by plowing or disking. Typical agricultural management plans use chemical or biological herbicides to control weeds instead of mechanical means. A heavy seeder capable of penetrating residue and placing seed at a constant depth is utilized. Generally, no-tillage production reduces the potential for soil erosion by mitigating the effects of wind and water on soil movement (Thomason et al., 2004). No tillage disturbs the soil less, and therefore allows soil carbon to accumulate. No till cultivation not only helps restore carbon in the soil but also reduces labor requirements, increases soil porosity and yield (in well-drained soil), and decreases soil run-off and leaching. Soil carbon content is sensitive to tillage method (McCarl, et. al, 2001).

Similarly, important land uses and practices with the potential to sequester soil organic carbon include conversion of cropland to pastoral and forest lands, and a conversion from conventional tillage to no tillage (Hao et. al, 2001). Cultivated U.S. agricultural soils are estimated to contain around 20-40% less soil carbon than soils that are never cultivated (Sperow et al. 2001). Lost carbon due to continuous cultivation of field crops could be restored with appropriate land use and management. West and Marland (2001) cited several studies estimated the amount of carbon lost from soils as a consequence of humans disturbing natural ecosystems. Besides the amount of carbon lost, those studies predicted the amount of carbon that might be returned to soils with improved management practices, including efficient use of fertilizers and irrigation water, use of crop rotations and changing from conventional tillage to no-till practices. Since 1990, no-till acreage has increased by more that 25 percent and the adoption of no tillage continues to increase. This increase has occurred primarily as a result of technological advances in plant traits as well as improvements in chemicals available to fight weeds and pests. Increased acres of no-till provides a potential for soil carbon sequestration to increase over 30.3 MMTC per year (Hill and Mannering, 1995) The net gain of soil carbon sequestration with no-till is considerably higher in the temperate, moist climatic zones. On average, complete no-till management increases soil carbon by 13.0 MMTC per year (Sperow et. al, 2001). Paustian et al. (2001) mentioned that carbon sequestration in general will be favored under management systems that minimize soil disturbance and erosion, maximize the amount of crop-residue return, and maximize water- and nutrient-use efficiency of crop production. They added that long-term field experiments showed that adoption of no-tillage practices to annual crop systems would result in an increase in soil carbon by 0.1 to 0.7 metric ton per hectare over a period of ten to thirty years.

Switchgrass and Environmental Sustainability

Switchgrass, as a perennial dedicated energy feedstock, is thought to be environmentally sustainable. Studies by McLaughlin et al. (1994), Vaugham et al (1989), and lynd et al. (1991) showed that grow dedicated biomass feedstock could reduce soil erosion, increase soil carbon content, and reduce pollution of streams and groundwater. Graham, Downing, and Welsh (1996) presented a framework to assess the potential soil, water, and biodiversity impacts that may result from the large-scale production of dedicated energy crops. The research showed that growing dedicated energy crops instead of conventional crops would significantly reduce erosion and chemical runoff. Compared to conventional crops, perennial energy crops could provide several environmental services/benefits, including reduced erosion, reduced carbon emission, and decreased chemical (fertilizer and pesticide) contamination of water supply.

Mooney et al. (2010) studied the relation between switchgrass yield and the farm input system. They concluded that switchgrass had lower fertilizer input requirements, reduced the risk of chemical runoff and leaching, and could reduce the energy and carbon footprint of bioethanol production. They also addressed the sustainability of a low-input switchgrass production system long term at locations similar to those included in their experiment.

However, even after many research projects regarding sustainability of switchgrass, questions regarding how farmers would respond in providing biomass feedstock remained (Jiang and Swinton 2008). Jiang and Swinton developed an economic model of farmers' production decisions and how those decisions were affected by the energy market. They found that farmers in the Midwest were unlikely to convert current cropland to grow a dedicated cellulosic biomass crop such as switchgrass. The model established that dedicated energy crops could compete with food crops only if the maximum price that biorefineries could afford to pay for energy crop was greater than then the minimum price that farmers would accept to grow dedicated energy crops. However, the financial incentives to produce cellulosic biomass provided by the 2008 farm bill may influence this decision. To ensure using a dedicated crop as feedstock to bioethanol that can offer environmental sustainability, environmental policies are required to complement existing bioenergy initiatives. The analysis also showed that without policy incentives, farmers were unlikely to grow switchgrass when they could grow corn or other food crops with comparable profit levels. Comparisons were made between traditional bioenergy feedstock, such as corn, sorghum, sugarcane, and perennial cellulosic crop. Table 2.1 summarizes the comparison. From the table, miscanthus and switchgrass are shown to have the advantages of higher per acre ethanol yield, more GHGs reductions, and lower input cost over corn and sorghum. If corn stover can be used sustainably, then the advantages of miscanthus and switchgrass will disappear gradually with technological improvements. But compared to sugarcane, which is grown in

South America, miscanthus and switchgrass have a similar ethanol yield and GHG savings. As long as sugarcane can only be grown in tropical climate, it would not be considered as a bioethanol feedstock for large scale biorefineries in the United States.

Delivered Costs of Switchgrass as Feedstock

Methods to model the logistics involved in establishing, maintaining, harvesting, storing, and transporting switchgrass can be categorized into three parts: enterprise budgeting analysis, linear programming optimization analysis, and simulation analysis. Both enterprise budgeting and linear programming have been used for scenario and sensitivity analysis. Assuming a 3.64 dt/acre yield, Epplin (1996) estimated that the annual cost for producing switchgrass was \$12.30/dt and cost for loading and transportation was predicted to be \$12.18/dt, the total delivered cost was \$24.48/dt. Bransby, et al. (2005) established an enterprise budget model to compare the different scenarios, which are differentiated by whether the harvest material was baled, chopped, pelleted etc. Popp and Hogan (2007) adopted two alternative harvesting and transportation methods (round bale and module harvested) that may be suitable for Arkansas conditions with the assumptions that the use of labor, storage protection (bale wrap and tarps), equipment intensity and final product (chopped or merely conditioned) were differentiated in these two systems.

Table 2.1 Bio-ethanol Feedstock Yields and Environmental Effects

Crop	Annual yield (Liters/hectare, US gal/acre)	Greenhouse-gas savings vs. petrol	Comments
Miscanthus	7300 L/ha 780 g/acre	37%–73%	Low-input perennial grass. Ethanol production depends on development of cellulosic technology.
Switchgrass	3100–7600 L/ha 330–810 g/acre	37%–73%	Low-input perennial grass. Ethanol production depends on development of cellulosic technology. Breeding efforts underway to increase yields. Higher biomass production possible with mixed species of perennial grasses.
Poplar	3700–6000 L/ha 400–640 g/acre	51%–100%	Fast-growing tree. Ethanol production depends on development of cellulosic technology. Completion of genomic sequencing project will aid breeding efforts to increase yields.
Sugar cane	6800–8000 L/ha 727–870 g/acre	87%–96%	Long-season annual grass. Used as feedstock for most bioethanol produced in Brazil. Newer processing plants burn residues not used for ethanol to generate electricity. Only grows in tropical and subtropical climates.
Sweet sorghum	2500–7000 L/ha 270–750 g/acre	No data	Low-input annual grass. Ethanol production possible using existing technology. Grows in tropical and temperate climates, but highest ethanol yield estimates assume multiple crops per year (only possible in tropical climates). Does not store well.
Corn	3100–4000 L/ha 330–424 g/acre	10%–20%	High-input annual grass. Used as feedstock for most bioethanol produced in U.S. Only kernels can be processed using available technology; development of commercial cellulosic technology would allow stover to be used and increase ethanol yield by 1,100 - 2,000 liters/ha.

Source: Wikipedia-Ethanol Fuel

Besides the enterprise budgeting method, some researchers use linear programming to optimize the harvest, transport and storage process. Cundiff, Dias, and Sherali (1997) estimated the optimal schedules for delivering biomass feedstock from farmers' storage facilities to the biorefinery under weather uncertainty. Tembo, Epplin, and Huhnke (2003) use their mixed integer model to determine the draw areas which are the most cost efficient for Oklahoma, harvest and storage schedule, inventory management, biorefinery's capacity and location as well as the breakeven price of ethanol. A multi-criteria assessment model was developed by Kumar, Sokhansanj and Flynn (2006) to rank alternative systems for biomass collection and transportation.

Simulation analysis has also been used in estimating the logistical costs. Lowenberg, DeBoer and Cherney (1989) simulated switchgrass yield, cost and return based on several uncertain factors such as weather and fertilizer application. Cundiff (1996) found that the harvest and transportation cost of switchgrass is equipment-intensive, contributing to two-thirds of the total cost, while production costs account for the other one-third. Cundiff and Marsh (1996) compared harvest and storage costs for large round bales and rectangular bales. At a 3.64 dt/acre yield, harvest costs were $19.06/dt for round bale and $14.68/dt rectangular bale. However, the storage costs were $3.83/dt and $16.97/dt for round and rectangular bales, respectively. When switchgrass yield and storage dry matter loss were changed for the sensitivity analysis, the difference in cost for round and rectangular bale was affected. If switchgrass yield is above 3.64dt/acre and storage losses for round bales stored outside increase above 5 percent, the cost different became less significant. Sokhansanj, Eng and Fenton (2006) found that the most important factors that influence the total delivery cost were the bulk density of the biomass, moisture content and the distance to be transported using the Integrated Biomass Supply and Logistics (IBSAL) model. Sokhansanj, Kumar and Turhollow (2006) used the IBSAL model to simulate the switchgrass harvest, storage, transport and pre-processing costs. Kumar and Sokhansanj (2007) estimated the delivered cost, energy input, and carbon emissions with the IBSAL model. Wang (2009) used both simulation analysis and a programming model in her research of switchgrass production costs in Tennessee. The simulation results showed that rectangular bales could minimize the delivered cost if the switchgrass was processed immediately after harvest while round bales minimized the cost if switchgrass was put into storage. The programming model in Wang's study provided the minimized delivered cost, harvest and delivery schedule of switchgrass for a biorefinery in east Tennessee under several different scenarios.

Besides these three mainly used cost analysis methods, geographic information is used to estimate the total delivered cost for a biorefinery. Graham, English, and Noon (2000) adopted a Geographic Information System model (GIS) to estimate costs and environmental implications of supplying specified amounts of energy crop feedstock across a state. The system considered where energy crops could be grown, the variability in their yield, and transportation costs associated with acquiring the feedstock for a biorefinery. The results showed that transportation costs increased with an increase in the biorefinery's capacity. The authors also pointed out the limitations of using GIS modeling. While GIS models could capture geographic variation that may influence biomass costs and supplies, they were not likely to handle uncertainty well and were limited by the lack of spatially explicit data. Yu et al. (2011) evaluated the potential value in a biomass supply chain for a biorefinery in east Tennessee using a high-resolution geo-spatial industrial siting model developed by the Department of Agricultural and Resource Economics at the University of Tennessee. The results showed that using a stretch-wrap baling preprocessing technology could reduce the total delivered cost of switchgrass for a large scale biorefinery. The savings in feedstock costs contributed by this preprocessing technology could result in a reduction in ethanol production costs by $0.16/gallon to $0.19/gallon.

CHAPTER III
CONCEPUTAL FRAMEWORK

Carbon Payment Program

In order to evaluate the impact that rewarding environmental services might have on using a dedicated energy crop for energy, a carbon payment program is developed. Growing switchgrass can increase the soil carbon content by absorbing CO_2 from the atmosphere and sequestering carbon in the soil, however, carbon is emitted from equipment fuel use, fertilizer and chemical application during switchgrass production. A carbon payment can either be made directly to the farmer or to the user of the switchgrass in this case the biorefinery. Arguments can be made for either case. If a payment is made to the farmer, for net carbon sequestered, then it would seem that the biorefinery price for the dedicated energy crop would be lower as the payment would offset a portion of the crop production costs. If the biorefinery received the payment for the net carbon sequestered by thoughout the system, then the demander of the feedstock could increase the price, thus, increasing the incentive for producers to plant the crop. In this analysis, we assume the biorefinery receives the payment for net carbon sequestered and that payment would cover the carbon stored in the soil, the carbon emitted during the farm activity, and the carbon emitted from switchgrass transportation. Thus, the biorefinery will receive a carbon payment for the carbon stored in the soil which can be considered as a benefit for the biorefinery to reduce the total delivered feedstock cost. The biorefinery needs to pay for the carbon emitted during farm activities and transportation to get the permit to emit carbon, which will increase the delivered feedstock cost. If the net carbon stored in soil (subtract emitted carbon amount from amount of carbon stored in soil) is positive, using switchgrass as feedstock has a positive environmental effect during the bioethanol's feedstock production and transportation procedure.

Cost Minimization Model

Previous studies have either focused on switchgrass production, fertilization, harvest, storage, and transportation strategies that maximize the net present worth of a cellulosic biorefinery system or that minimize the cost to deliver feedstock to an optimally located biorefinery (Tembo, Epplin, and Huhnke, 2003; Epplin et al., 2007; Mapemba et al., 2007; Mapemba et al., 2008). Epplin et al. (2007) introduced two structures for supplying switchgrass to the biorefinery. The first structure assumed a vertical integrated system; the biorefinery leased the land and would manage the switchgrass production, harvest, storage, and transportation. The second structure assumed the biorefinery contracted with individual farmers in long-term. The farmers would be responsible for switchgrass establishment, maintenances, and harvest, while the biorefinery paid for the transportation cost for transporting switchgrass form the farm to the biorefinery.

Larson et al. (2008) analyzed the potential of farms in West Tenneessee to supply biomass to a biorefinery under contract agreement. The objective function used in the study of Larson et al. (2008) was to maximize the farm net revenue. In this study, the biorefinery needs to determine the optimal draw area, switchgrass harvest and transportation schedule, and switchgrass storage under with long-term contract with farmers. When a plant or firm optimizes their production and delivery schedule, minimizing costs of a target level of output is equivalent to maximizing the profit of the plant. So, instead of using the profit maximization model presented in Larson et al. (2008), a cost minimization model will be used to help the biorefinery make the decisions.

Based on the contract arrangement structure proposed by Epplin et al. (2007), the biorefinery contracts with farmers to grow switchgrass in long-term and offers farmers a fixed switchgrass price. Using the estimated amount of land a farmer would be willing to plant if a prespecified price were guaranteed (land share) (See appendix A) and other coefficients, the biorefinery can determine the optimal draw area, feedstock harvest and deliver schedule, and storage method. This would provide the biorefinery information on where to contract with farmers. Storage is assumed to be located on farm, with the biorefinery paying a higher price per ton of switchgrass delivered to cover storage and dry matter losses

A linear programming model is developed to determine the optimal draw area and feedstock deliver schedule for the biorefinery with multiple constraints. The objective function minimizes delivered feedstock cost for the biorefinery. It is composed of the feedstock price to the farmers for producing and harvesting the switchgrass, storage costs including dry matter losses, and transportation costs, along with a possible carbon payment. The constraints include farmland availability, storage, transportation, and the biorefineries capacity. It is assumed that farmers are willing to use part of their land to grow switchgrass if they accept a given switchgrass price. The total farmland acreage available in the potential draw area is determined using the estimated land share and current farmland acreage. There are additional constraints that reflect the condition of the switchgrass over time as it is stored, andconstraints that restrict the amount of switchgrass transported to be less than the amount of switchgrass available in the storage. Last, the biorefinery has a maximum capacity to produce ethanol. Figure 3.1 shows the procedure of the programming model.

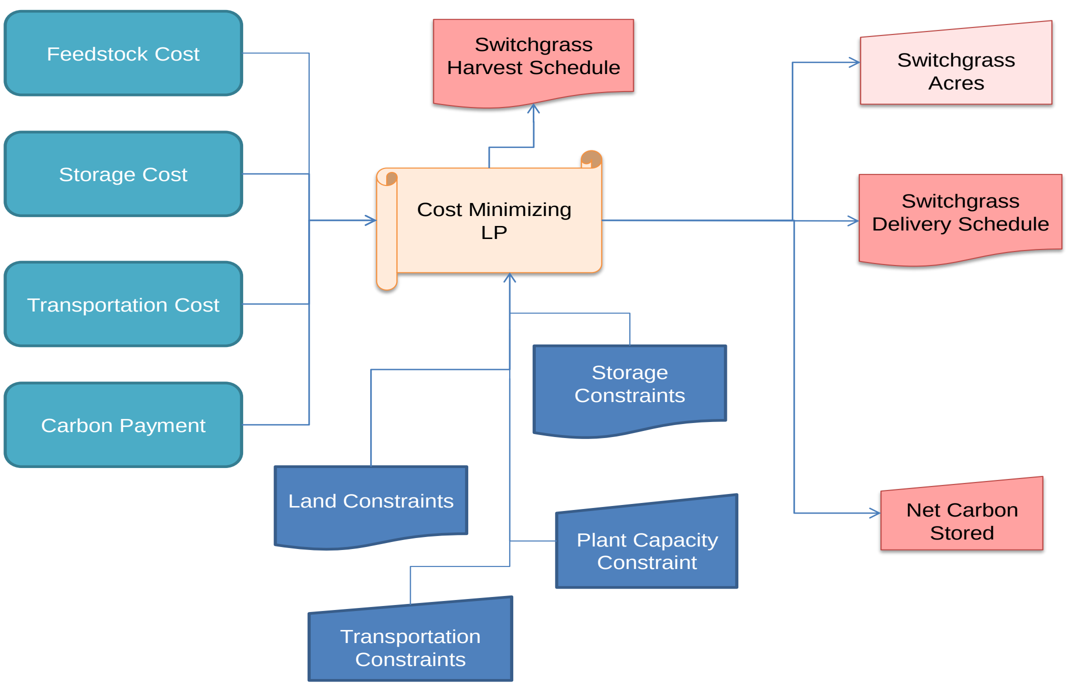

Figure 3.1 Linear Programming Procedures

CHAPTER IV
MATERIALS AND METHODS

From the model description presented in Chapter 3, a significant number of coefficients must be estimated or simulated. The process used is displayed in Figure 4.1. These steps require other simulation models to develop many of the coefficients used in the analysis. First, the Biofuel Facility Location Analysis Modeling Endeavor (BioFLAME) provides information on where a facility might be located by minimizing annual production and opportunity costs. From the output of BioFLAME, three locations in the southeastern U.S. are selected as research targets. Second, switchgrass yields for the selected locations are simulated with ALMANAC using appropriate regional weather data, tillage data, and soil data. Then, using switchgrass survey data collected by Jensen et al. (2009), farmer willingness to adopt (WTA) switchgrass is estimated by a Probit model. This model's results provide guidelines of switchgrass unit price. A Tobit model is developed to predict the proportion of land that might be available at a pre-specified price required by the cost minimizing linear programming model. Other data used as parameters in linear programming model are collected from secondary sources. Finally, the programming model can be developed to determine the optimal draw area and switchgrass delivery schedule for the selected locations.

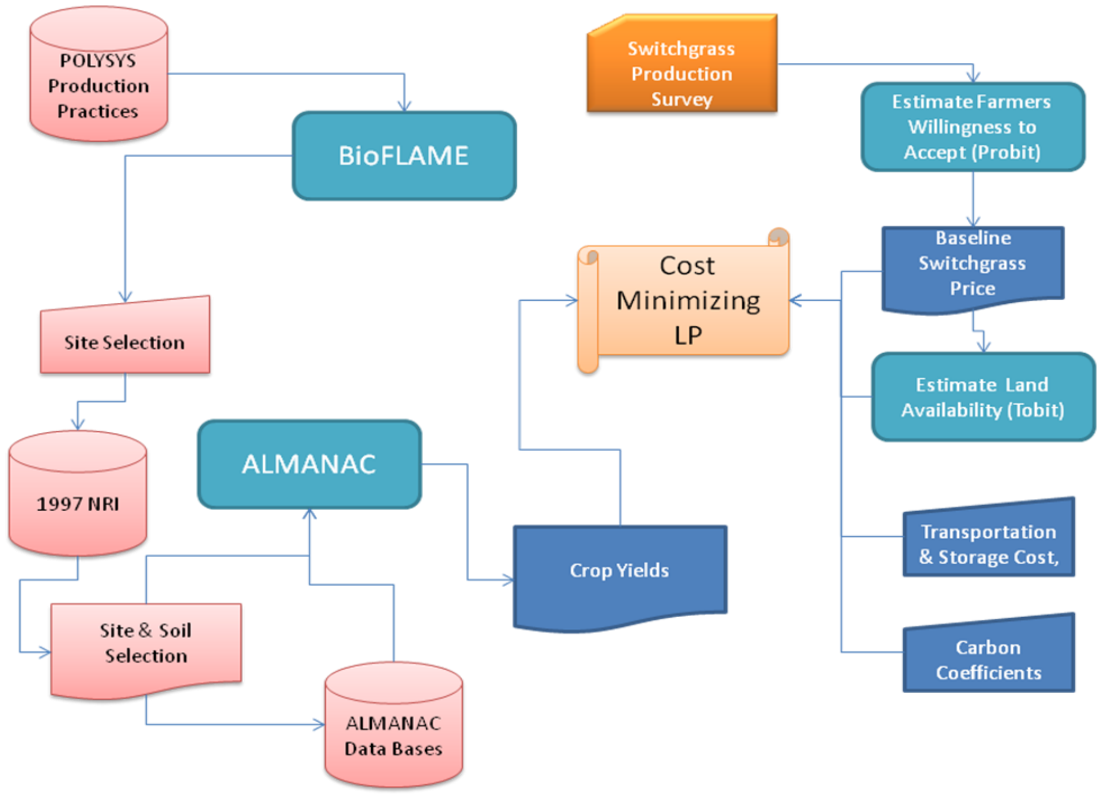

Figure 4.1 Flow Diagram of the Data and Models Incorporated in this Study

Biofuel Facility Location Analysis Modeling Endeavor

Locations for three biorefineries in the southeastern U.S. were selected using BioFLAME. This modeling system allows the user to perform an analysis on any combination of counties within a 16 state region in the southeastern U.S. given parameters such as biorefinery capacity, crop prices, transportation cost, feedstock yield adjustments, the proportion of pasture and hay land that can switch to dedicated energy crops, driving distance limit, required profit level (Wilson et al. 2011). The BioFLAME model calculates the total annual delivered feedstock cost, average cost per ton, and the marginal cost of the feedstock surrounding each candidate site based primarily on production costs derived from POLYSYS, a U.S. agricultural simulation model (Wilson et al. 2011). The ideal facility location is determined by minimizing one of the above values, depending on the objective function selected by the user. The model was run using the minimized cost of delivered feedstock objective function selecting 180 different potential sites. Figure 4.2 shows the 180 selected sites with low-cost feedstock, the red dots in the maps represent the 180 potential biorefinery locations. Among those 180 sites, two sites in Tennessee and one site in South Carolina were chosen for further analysis. The centers of these locations are represented by Shelby (Tennessee), Davidson (Tennessee), and Marion (South Carolina) counties. Any of the 180 sites could have been selected. The sites selected were selected because of their locations. Shelby was selected because it is located in Tennessee and in the Mississippi Delta. Davidson was selected because it is located in central Tennessee. Marion County was selected because it was located in the coastal plain. All three sites were ranked in the 24th, 6th, 68th from the BioFlame study. Assuming a draw area of 50 miles radius surrounding a selected biorefinery location, the geographic centers of candidate counties that supply switchgrass to the biorefinery should be contained inside the circle. The candidate counties around Davidson, TN are Cannon, Cheatham, Dickson, Hickman, Macon, Marshall, Maury, Montgomery, Robertson, Rutherford, Smith, Sumner, Trousdale, Williamson, Wilson, Logan, Simpson, and Todd. The candidate counties around Shelby, TN are Fayette, Haywood, Lauderdale, Shelby, Tipton, De Soto, Marshall, Tate, Tunica, Crittenden, Cross, Mississippi, Poinsett, and St Francis. The candidate counties around Marion, SC are Columbus, Robeson, Darlington, Dillon, Florence, Georgetown, Horry, Marion, Marlboro, and Williamsburg. Figure 4.3, 4.4, and 4.5 show the selected sites with candidate counties around them. The smaller circle represents the 50-mile area and the larger one represents the 100-mile area.

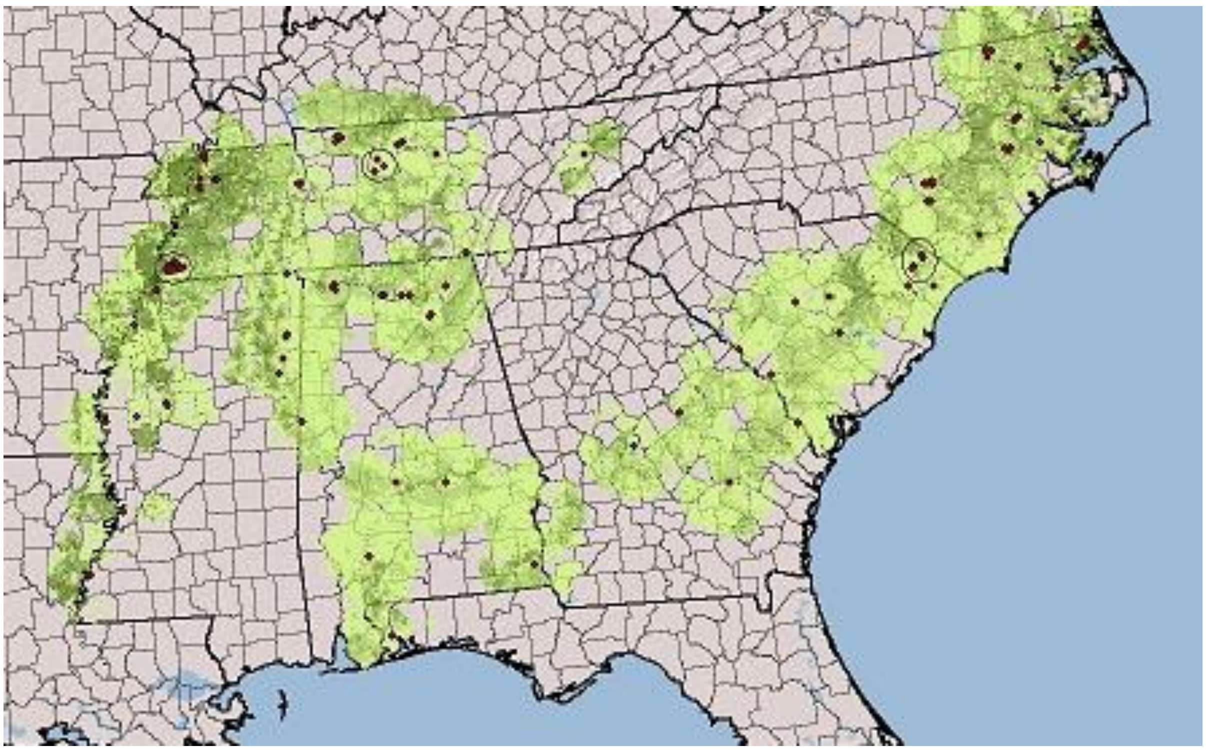

Figure 4.2 180 facilities sited across the southeast with feedstock supply
Source: Wilson et al. 2011

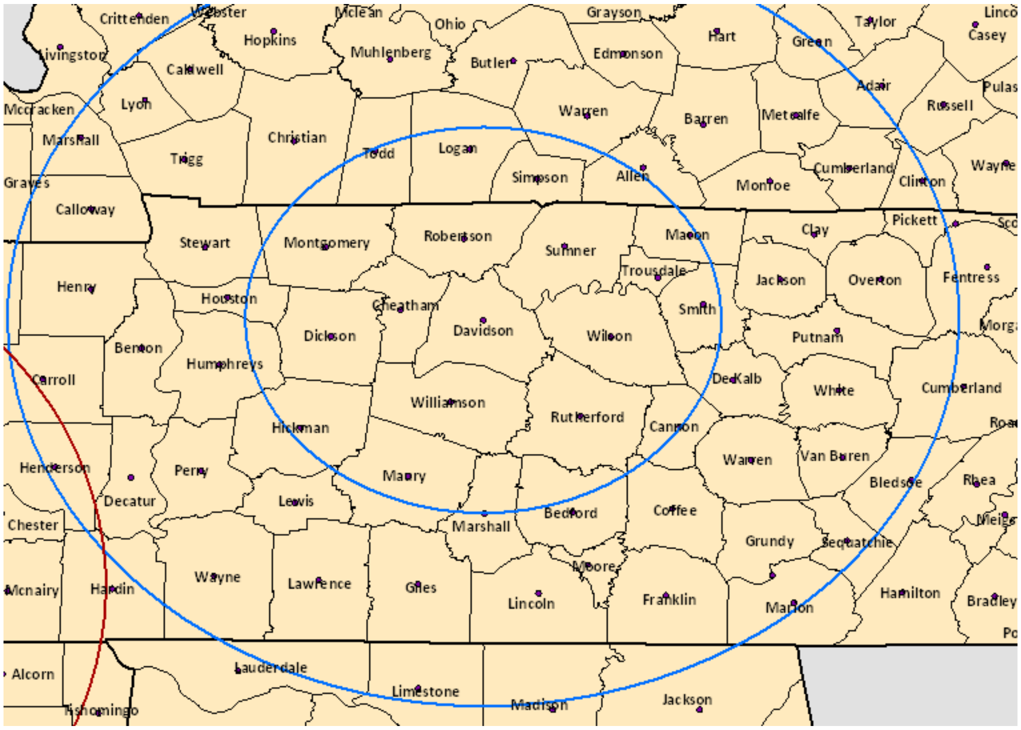

Figure 4.3 Davidson Site Map

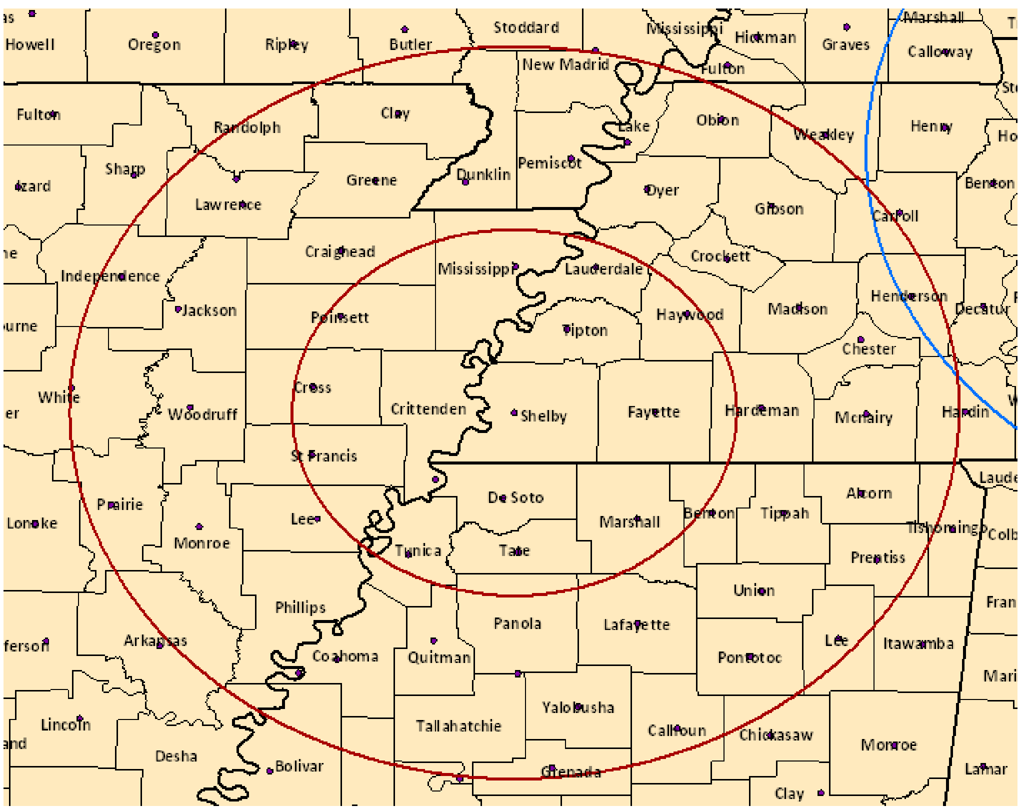

Figure 4.4 Shelby Site Map

Figure 4.5 Marion Site Map

Switchgrass Production Survey

The Department of Agricultural and Resource Economics at The University of Tennessee conducted a survey in 2009 to collect information from farmers in the Southeastern U.S. regarding their views on switchgrass production. One of the purposes of this survey was to ascertain producers' willingness to adopt switchgrass as an energy feedstock crop. The study also examines producers' attitudes toward the development of a switchgrass market (Menard et al. 2011). This survey was sent to 7,000 farmers (at least $10,000 in sales) randomly selected by the U.S. Department of Agriculture's National Agricultural Statistics Service (NASS) from the following states: Alabama, Arkansas, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. A total of 1,300 surveys were returned and recorded (see Figure 4.6 for survey response rate by state). “There were five major areas addressed in the survey: 1) the respondent’s knowledge of, and interest in, switchgrass as an energy crop; 2) the respondent’s opinion on topics related to switchgrass production as a biomass feedstock, including conversion of acreage in response to a specified switchgrass price; 3) characteristics of the farm operation, including farm size, types of enterprises, and use of various agricultural practices; 4) financial information, including on and off-farm income; and 5) demographic characteristics of the respondents (Menard et al. 2011).”

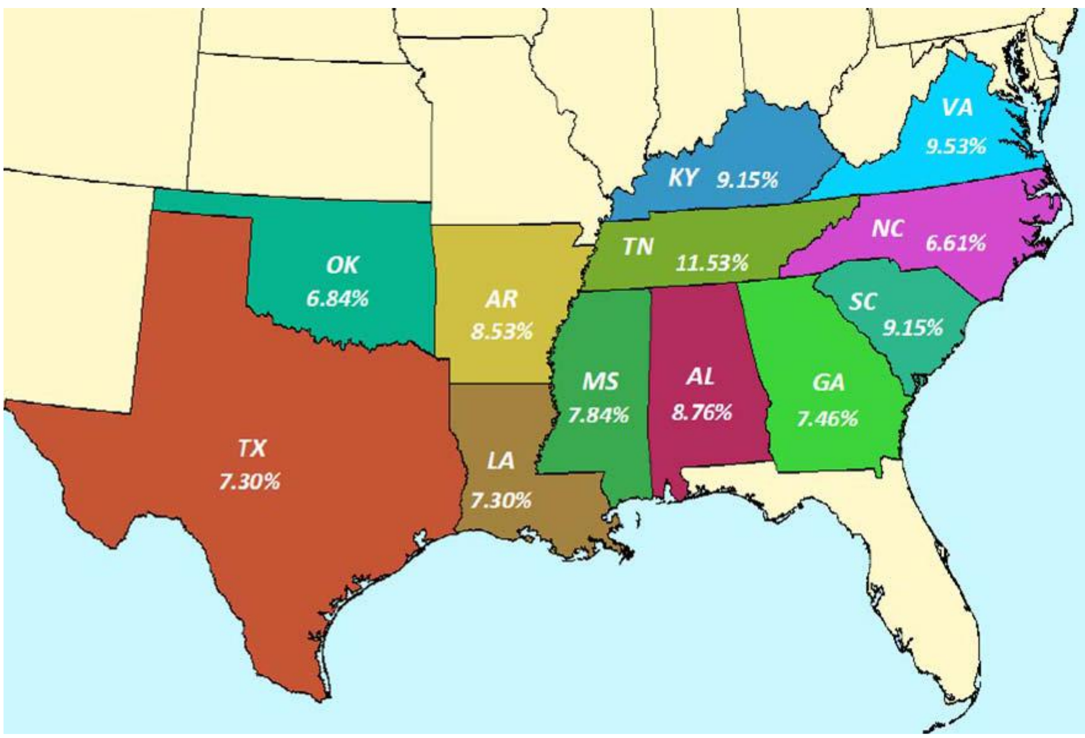

Figure 4.6 Switchgrass Survey Response Rate by Selected State
Source: Menard et al. 2011

Estimated Willingness to Accept and Land Availability

The methodology used in developing the willingness to accept (PROBIT) and the amount of land available (TOBIT) is presented in Appendix A along with variable definitions (Appendix Table A1). The dependent variable in the WTA model is the response to the question "Are you willing to grow switchgrass under a given price?", the price was assumed to be $40/ton, $60/ton, $80/ton, $100/ton, and $120/ton. There are six independent variables in the WTA model. Producers' demographic and views on switchgrass are hypothesized to have major effects on farmers' WTA to grow switchgrass. It is assumed that the switchgrass price (Price) has a positive effect on the probability of growing switchgrass. If farmers are interested in switchgrass (Interest), they are assumed to have a higher probability to grow switchgrass. Farmers with more education (Education) are hypothesized to be more likely to be willing to grow switchgrass, while farmers over age 60 (Age60) are less likely to be willing to grow switchgrass. Those over age 60 may have more thoughtful considerations and probably will not be willing to make a long term investment to grow switchgrass. It is expected that higher off farm income (Off_farm) would have a positive effect on the probability of growing switchgrass, because farmers have major income from other sources other than farm, they might want to take the risk to plant new crop. Also, the farm location (State) is assumed to have some effects on the farmer's decision. From the survey, there were 622 valid observations, among which about 72% farmers wanted to grow switchgrass given the price listed in the survey. The average price offered to the farmers was $83.54 /dt. Most farmers were somewhat interested in switchgrass. Almost all the farmers had a high school degree or higher. Around 45% farmers were over 60-years old. And about 82% farmers had off farm income which was higher than the farm income.

In the Tobit model, the dependent variable, proportion, is calculated by taking the ratio between land acreage that farmers want to grow switchgrass and the total land acreage farmers have using the survey results. There are six variables in the land use (Tobit) model. The producers' demographic information and price of switchgrass are hypothesized to have major effects on farm land use. It is assumed that the switchgrass price (Price) has a positive effect on the switchgrass land acreages. Farmers with higher on farm income (Farminc) are hypothesized to be less likely to convert their land to grow switchgrass. Those that have a high income may be satisfied with their current crop planting plan which brings them a higher income with more certainty; they probably would not want to take the risk of growing switchgrass. Farmers who have higher off farm income (Off_farm) are hypothesized to be more likely to convert their land to grow switchgrass because their major income is not from farm work; they might take the risk to convert the land to grow new crop. If farmers have pasture (Pasture) on their land, the land will be less likely to grow switchgrass. Also, the farm location (State) is assumed to have some effect on a farmer's decision. There are 570 valid observations in the data set. On average, the responders will use about 46% of their farm land to grow switchgrass. The average price offered to the farmers is $83 /dt. Around 40% of farmers surveyed had an income from farming of less than $10,000, 24% had an income from farming between $10,000 and $25,000, 14% had an income from farming between $25,000 and $50,000, and the remaining 22% had an on farm income of $50,000 or more. Around 82% of farmers had more off farm income than on farm income. 69% of farmers had pasture land on their farm. After collecting the results from the Tobit model, different switchgrass prices and farm income data from the 2007 Census of Agriculture were used, along with data from the switchgrass survey to predict the average land proportion used for switchgrass production using the estimated Tobit model.

Farmers' WTA model

The estimated model for the probability of growing switchgrass is displayed in Table C.1 (tables and figures of econometrics models and yield simulation results are showed in appendix C). Of all the survey responders, 622 of them answered all the questions that were needed to conduct the econometric modeling. As can be seen from the table, the Wald Chi-squared was 84.22, which is significant at the 1% level, this shows the model is significant overall. The variable PRICE has a significant positive effect on the probability of growing switchgrass, meaning that as the price of switchgrass increased, the probability for farmers to grow switchgrass would increase. Compared to the farmers with an elementary school degree, farmers with higher degrees are more likely to grow switchgrass. The results also show that farmers over 60 year old are less willing to grow switchgrass, but the variable is not significant. As discussed before, farmers with higher off frm income have a higher probability to grow switchgrass. Some of the farm locations in the southeastern U.S. had significant effects to the probability of growing switchgrass. Compared to farmers in Alabama, farmers in Kentucky, Louisiana, and North Carolina are less likely to grow switchgrass.

Farmer's mean WTA is estimated with the given results for those states where candidate counties of programming model locate. Table C.2 shows the predicted mean WTA for Arkansas, Kentuky, Mississippi, North Carolina, South Carolina, and Tennessee. For instance, mean WTA of farmers in Tennessee is $116/dt, which is significant at the 1% level. As the survey results show, the average price offered to Tennessee farmers is $82.50/dt. Since the price is less than the estimated mean WTA, farmers in Tennessee are less likely to grow switchgrass. By contrast, the predicted mean WTA for farmers in Southe Carolina is $81.71/dt, which is lower than the average price of $83.82/dt suggested in the survey. Farmers in South Carolina are more likely to be willing to grow switchgrass given the comparison between average price paid and mean WTA predicted. Similarly, as results suggest, farmers in Arkansa, Kentucky, Mississippi, North Carolina, and Tennessee are less likely to grow switchgrass with relatively high mean WTA. Farmers in South Carolina had a high probability to grow switchgrass since the switchgrass price proposed in the survey was high enough for them to be willing to adopt.

The estimated mean WTAs provided a guideline to determine the switchgrass price used to predicted the switchgrass land share. The estimated mean WTA ranges from $81.71/dt to $116/dt. To test the price impact on the feedstock cost, switchgrass prices were assumed to be $75/dt, $90/dt, and $110/dt, based on the range of estimated mean WTAs.

Land Use Model

The estimated model for land use for switchgrass is displayed in Table C.3. The survey data indicated that the average land proportion expected for switchgrass production was around 30%. Among the 570 observations, 158 observations did not want to grow switchgrass. The model is significant overall, as indicated by the F test. As expected, the price of switchgrass has a significant positive effect on switchgrass land acreage. Farm related income had a significant negative effect, as farm related income increased, less land would be used for switchgrass. This result is consistent with the hypothesis made. Farmers with higher farm incomes are less likely to change their land use which already brings them a high income with more certainty. Farmers with higher off farm income are more likely to convert their land to grow switchgrass. If farmers grow pasture on their land, then they are less likely to use land to grow switchgrass. However, variables Off_farm and Pasture are not significant in the model. Compared to farmers in Alabama, those in Kentucky, Louisiana, North Carolina, Tennessee, Texas, and Virginia had less land proportion used for switchgrass.

The projected average land proportion used for switchgrass can be predicted with the Tobit model results. The estimated average land proportion used for switchgrass of candidate states are presented in Table C.4. Land proportions at different switchgrass prices are given in Figure 4.7. Since the coefficient of Price in the Tobit model is significantly positive, with an increase in the price of switchgrass, the estimated land proportion increases.The estimated land proportions for Arkansa, Mississippi, South Carolina, and Tennessee with different price level were significant at 1% level. When the switchgrass price was set at $110/dt, South Carolina had the highest switchgrass land proportion, 0.52, among the six states, while Kentucky had the lowest switchgrass land proportion, 0.16.

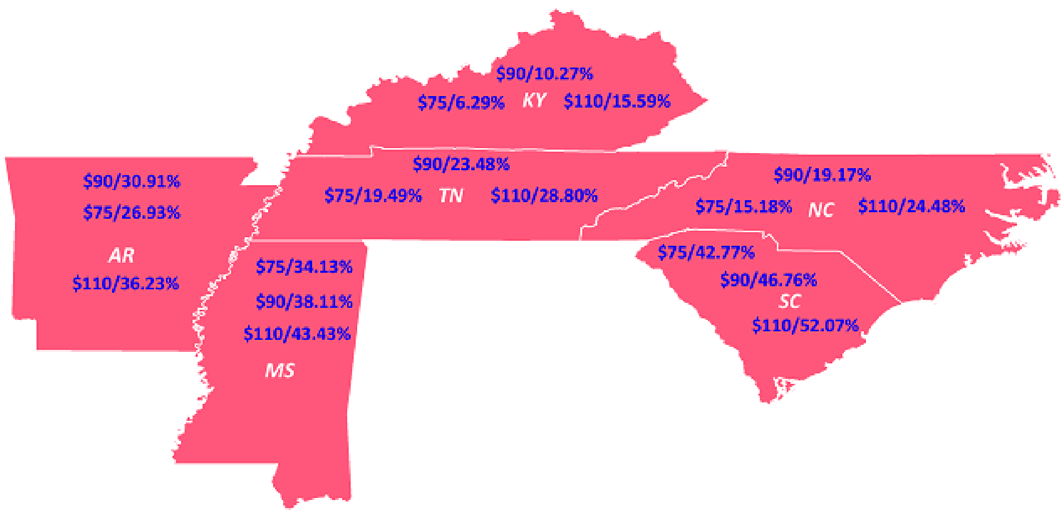

Figure 4.7 Predicted Average Land Proportion Used for Switchgrass Production

Switchgrass Yield and Land Availability

Switchgrass yield varies from location to location, with different weather, soil, tillage conditions. Center for integrated Agricultural Systems at University of Wisconsin (2001) announced that, form field study, switchgrass from 6 to 8 ton/acre were possible with appropriate fertilization. A study for USDA showed that the maximum switchgrass yield was 5.6 ton/acre in North Dakota (Berdahl et al. 2005). The Switchgrass peak yield was assumed to be 6 dry tons per acre in a study conducted by University of Kentucky Cooperative Extension Service (2009). University of Tennessee Extension (2009) provided a guideline for farmers who interested in growing switchgrass. The guideline suggested a 6 ton/acre peak annual yield of switchgrass when switchgrass production reached a mature stand.

Agricultural Land Management Alternative with Numerical Assessment Criteria

The Agricultural Land Management Alternative with Numerical Assessment Criteria (ALMANAC) model will be used to simulate switchgrass yields for one hundred years. “The ALMANAC model is a process-oriented simulator of plant communities with several competing species. It simulates growth of one plant species or several competing species in a general way. ALMANAC includes subroutines and functions from the Erosion Productivity Impact Calculator (EPIC) and has additional details for plant growth. Required climate and soil inputs are readily available in ALMANAC. Parameters for many crop species are available with the model” (Kiniry et al. 2005). The model simulates crop growth and competition for more than 20 crop species with different crop parameters. Drainage, irrigation, fertilization, furrow diking, and liming are simulated. Figure 4.8 shows the inputs and outputs of the ALMANAC model.

Some important determinants for this simulation are weather station locations, soil type, and nitrogen rate. With the selected potential locations, weather stations near these locations are found from data available at the

National Climate Data Center (NCDC) along with the longitude and latitude of the selected biorefinery locations. The fertilizer rates for switchgrass in different counties can be found in the POLYSYS (Policy Analysis System) database.

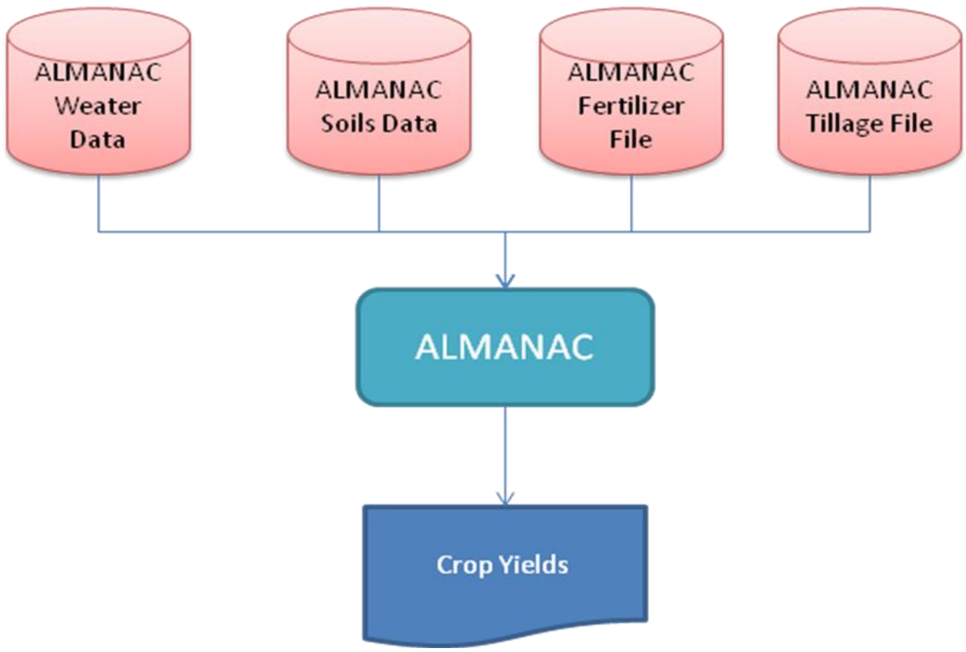

Figure 4.8 ALMANAC Model Inputs and Expected Outputs

Simulated switchgrass yields in candidate counties from the three selected location are presented in Tables C.5, C.6, and C.7. The ALMANAC model simulated the switchgrass yields for 100 years in each county of the study area. Since switchgrass is establish 10 times over the 100 years and yields in the initial two years are lower than average, a weighting scheme is employed to develop representative yields that might occur as a mature stand that yields 6 tons per acre or 5.1 dt/acre. To do this, the average county switchgrass yields from ALMANAC were normalized so that the weighted average yield including the establishment years would be 5.1 dry tons per acre, maintaining county level productivity differentials. The highest average yield of the Davidson, TN location is 6.71dt/acre on Dickson soil in Smith County, the lowest average yield is 3.73dt/acre on Sengtown soil in Robertson County. The average yield of the Shelby, TN location ranges from 3.27dt/acre to 7.4dt/acre. The maximum and minimum average yields for Marion, SC were 4.44dt/acre and 7.34dt/acre, respectively. For the candidate counties in Tennessee, the average yield of counties near the Shelby location is higher than that of counties near the Davidson location..

Land Availability

The 2007 Census of Agriculture data were used to obtain the available farmland acreage. Soil data from the 1997 NRI database (NRCA, 1999) were used to determine typical agricultural soils. Soils were aggregated to 305 Crop Reporting Districts (POLYSYS Regions) in the United States. These soils are then matched to the ALMANAC soils database and up to 3 soils with the largest share are selected to be used in ALMANAC. In addition, the shares from the POLYSYS database assist in estimating the soil acreage of cropland and pastureland in a candidate county. For instance, from the Census 2007 data, the total harvested cropland and pastureland available in Davidson, TN were 7,815 and 6,599 acres, respectively. From the POLYSYS data, the shares of Armour soil for cropland and pastureland were 0.5549 and 1 in that region. Using these shares and the acreage data, the available cropland and pastureland acreages of Armour soil in Davidson County are assumed to be 4,336.83 and 6,599 acres. Nearby available acreages of farmland for three biorefineries are displayed in Table B.1, B.2, B.3.

Switchgrass Storage and Transportation Costs

Biorefinery input costs include feedstock cost (switchgrass price times quantity), storage cost, transportation cost over a one year time frame, and the carbon payment[1]. Since the dry matter loss occurs, feedstock costs increase as time in storage increases. To get an accurate estimation of storage costs, dry matter loss data for different types of bales stored within one year are needed. Also, transportation costs for the two types of bales from different locations to the biorefineries need to be determined.

Dry Matter Loss during the Storage and Storage Material Cost

In 2009, an experiment was conducted by English, Larson, and Tyler to obtain the storage dry matter loss data for different bale types and storage treatments. There were two types of harvest methods: large round bale (5' x 4') and large rectangular bale (4' x 8'). Bale storage treatments in the experiment include covered and uncovered bales on different surfaces: well-drained ground, gravel and wood pallets. For the large round bale, there were six treatments: 1) uncovered on well-drained ground, 2) uncovered on gravel, 3) uncovered on wooden pallets, 4) covered on well-drained ground, 5) covered on gravel, and 6) covered on wooden pallets. For the large rectangular bale, there were four

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[1] It can be assumed that the carbon payment can go to the producer also. If the payment went to the producer then the switchgrass price would be reduced. It is unclear yet as to the proportion of the reduction that the producer would get. In this case, the producer gets a price that satisfies his/her profit margin based on estimates provided from the Switchgrass Survey Data.

treatments: 1) uncovered on gravel, 2) uncovered on wooden pallets, 3) covered on gravel, and 4) covered on wooden pallets. The five target bale storage times in the experiment were: 1) 100 days, 2) 200 days, 3) 300 days, 4) 400 days, and 5) 500 days. The detailed procedure for the sampling of switchgrass bales and estimation of storage dry matter loss for different treatments using wet and dry weights from the sample is presented in English et al. (2008) and Wang (2009). Larson et al. (2010) [34] used storage dry matter loss equations with data from the experiment to model dry matter loss during storage. They found that the surface on which the bales were stored did not impact dry matter loss, but whether the bale was covered or not did matter.

This study assumed a harvest period of switchgrass from November 1st.to March 1st. The biorefinery is assumed to operate 360 days per year. Given that switchgrass would be harvested during a limited time each year, the switchgrass would need to be stored when harvesting is not taking place. Dry matter loss during transportation is assumed to be 2 percent for round bales and rectangular bales (Kumar and Sokhansanj 2007). Table B.4 shows the estimated dry matter losses of round and rectangular bales for different storage time periods. Table B.5 shows the storage material cost for each treatment.

Transportation Cost

The distance to the biorefinery for switchgrass delivery is assumed to be the distance from the center of a candidate county to the center of the selected county (Davidson, Shelby, and Marion). The distance data were obtained from GIS data. The cost per hour of the semi-tractor trailer and loading time were obtained from Wang's study (2009) and updated with higher diesel prices. The average travel speed of the semi-tractor trailer is assumed to be 50 miles/hour (Brechbill et al. 2008). Wages for drivers and loaders were collected from the Bureau of Labor Statistics website. In 2010, the average cost of diesel fuel for a semi-tractor trailer in Tennessee and South Caroline are $3.14/gallon and $3.30/gallon, respectively (U.S. Energy Information Administration). The capacity of the trailer is assumed to be 36 large round bales or 24 large rectangular bales. Each round and rectangular bale weighs approximately 0.366 tons and 0.667 tons respectively. Table B.6 shows how to calculate the cost per ton of transportation, assuming the distance is 50 miles in Tennessee. Table B.7, B.8, and B.9 contain the estimated delivery cost from candidate counties to the biorefinery location

Carbon Payment

Hellwinckel et al. (2008) estimated changes in net carbon flux induced by incentives provided for conservation tillage on nine major crops. Data from the baseline of the study will be used to calculate the amount of carbon sequestered in the soil and carbon emitted from the planting and harvesting activities. The detailed procedure can be found in Hellwinckel et al. (2008). The annual change in soil carbon per acre was estimated by multiplying base weighted soil carbon levels with adjusted carbon response rates. The amount of carbon emitted from farm activities was estimated by adding carbon emitted from equipment fuel use and fertilizer and chemical use.

Besides the carbon emitted from farm activities, carbon is emitted from switchgrass transportation. Wang (2009) indicated that, for a semi-tractor, around 22 gallons diesel were used every hour. With the speed assumption and distance data, gallons of diesel used for transportation can be calculated. From EPA records, a gallon of diesel emits 22.2 pounds of CO_2, which means carbon emitted from burning diesel is 6.05 pounds. Then, total carbon emitted from transportation annually can be estimated.

Net carbon can be calculated by subtracting carbon emitted from farm activities and transportation from carbon sequestered in the soil from planting switchgrass. The carbon price is assumed to be $27 per ton (English et al. 2011). If net carbon stored is negative, then, the biorefinery needs to pay extra to the government to get a permit to emit carbon. If net carbon stored is positive, the biorefinery will receive a payment from the government for positive carbon sequestration. Tables B.10, B.11, and B.12 show the net carbon stored from farm activities and carbon emitted from diesel fuel during transportation.

Optimal Draw and Delivery Schedule for a Biorefinery

Wang (2009) developed a programming model to optimize the delivered feedstock cost for a biorefinery in East Tennessee. For this model, it was assumed that the biorefinery contracted with farmers and paid for the opportunity cost of the land (land rental rate), switchgrass establishment, and crop maintenance, along with the harvest, storage, and transportation costs. The biorefinery was responsible for the arrangement of the schedule for the switchgrass harvest, storage, and transportation. Wang also included dry matter loss in the model. Dry matter losses influence the quantity and quality of switchgrass. As the period of storage increases, dry matter losses increase. Wang adjusted the switchgrass production costs with dry matter losses in the programming model. Based on Wang's model, this research develops a programming model for biorefineries in three different locations in the southeastern U. S. Instead of paying the opportunity cost of the land, switchgrass establishment, and crop maintenance cost along with the harvest, storage, and transportation cost, the biorefineries pay a fixed switchgrass unit price to farmers. A government carbon payment is included in the model as a benefit to the biorefineries. As discussed in the first chapter, growing switchgrass can increase soil carbon content. If a carbon payment mechanism is allowed in the model, biorefineries may have different decisions for farm selection, harvest and storage schedules.

For the selected regions in the southeastern U.S., it is assumed that the biorefinery contracts with individual farmers and pays a fixed unit price for the switchgrass produced. The biorefinery's objective function incorporates the costs of switchgrass (switchgrass price times quantity delivered), the carbon credit, along with on-farm storage costs and the annual transportation costs incurred when delivering the switchgrass to the biorefinery. The objective of the biorefinery is to minimize the delivered cost of switchgrass, including contract prices paid to the farmers, costs associated with switchgrass storage and transportation, under constraints related to land use, harvest, biorefinery's capacity, and other logical considerations, to achieve high profits. The annual delivered cost is comprised of six major components:

1) the dry matter loss adjusted post storage cost for switchgrass that is delivered to the biorefinery after a period of storage,

$$\sum_{m=1}^{M}\sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{t=1}^{T}\sum_{c=1}^{C}\sum_{i=1}^{I} P*(\frac{XTONov_{mbsltci}}{1-cv_{mbtc}}+\frac{XTODec_{mbsltci}}{1-cv_{m-1btc}}+\frac{XTOJan_{mbsltci}}{1-cv_{m-2btc}}+\frac{XTOFeb_{mbsltci}}{1-cv_{m-3btc}})$$

where:

XTONov: tons of switchgrass harvested in November, transported from storage during the period from December to October

XTODec: tons of switchgrass harvested in December, transported from storage during the period from January to October

XTOJan: tons of switchgrass harvested in January, transported from storage during the period from February to October

XTOFeb: tons of switchgrass harvested in February, transported from storage during the period from March to October

P: price of switchgrass per ton

cv: cumulative storage dry matter loss (%)

2) the cost for switchgrass that is delivered immediately after harvest,

$$\sum_{m=1}^{M}\sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{i=1}^{I} P*XTN_{mbsli}$$

where

XTN: tons of switchgrass transported immediately after harvest during the period from November to February

3) the storage material cost for switchgrass that was placed into storage after harvest,

$$\sum_{m=1}^{M}\sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{t=1}^{T}\sum_{c=1}^{C}\sum_{i=1}^{I}\gamma_{btc} * (XSNov_{mbsltci} + XSDec_{mbsltci} + XSJan_{mbsltci} + XSFeb_{mbsltci})$$

where

XSNov: tons of switchgrass harvested in November stored through November to October

XSDec: tons of switchgrass harvested in December stored through December to October

XSJan: tons of switchgrass harvested in January stored through January to October

XSFeb: tons of switchgrass harvested in February stored through February to October

γ: storage material cost per ton

4) the transportation costs for all switchgrass delivered to the biorefinery,

$$\sum_{b=1}^{B}\sum_{i=1}^{I}\theta_{bi} * (\sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{l=1}^{L} XTN_{mbsli} + \sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{t=1}^{T}\sum_{c=1}^{C}(XTONov_{mbsltci} + XTODec_{mbsltci} + XTOJan_{mbsltci} + XTOFeb_{mbsltci}))$$

where

θ: transport cost per dry ton ($/dt)

5) the carbon payment received from the government for the net carbon stored in soil from switchgrass production,

$$\rho * \sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{i=1}^{I} NSC_{li} * A_{bsli}$$

where

A: acres of switchgrass harvested annually

ρ: carbon incentive ($/ton)

NSC: net carbon stored in the soil from switchgrass production (ton)

6) and the carbon payment paid to government for the carbon emitted from the diesel fuel during transportation.

$$\rho * \sum_{b=1}^{B}\sum_{i=1}^{I} CE_{bi} * (\sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{l=1}^{L} XTN_{mbsli} + \sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{t=1}^{T}\sum_{c=1}^{C} (XTONov_{mbsltci} + XTODec_{mbsltci} + XTOJan_{mbsltci} + XTOFeb_{mbsltci}))$$

where

CE: carbon emitted from diesel fuel during transportation (ton)

Combining the cost function reflecting the delivered cost of switchgrass can be written as:

Min

$$Cost = \sum_{m=1}^{M}\sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{t=1}^{T}\sum_{c=1}^{C}\sum_{i=1}^{I} P * (\frac{XTONov_{mbsltci}}{1-cv_{mbtc}} + \frac{XTODec_{mbsltci}}{1-cv_{m-1btc}} + \frac{XTOJan_{mbsltci}}{1-cv_{m-2btc}} + \frac{XTOFeb_{mbsltci}}{1-cv_{m-3btc}})$$
$$+ \sum_{m=1}^{M}\sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{i=1}^{I} P * XTN_{mbsli}$$
$$+ \sum_{m=1}^{M}\sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{t=1}^{T}\sum_{c=1}^{C}\sum_{i=1}^{I} \gamma_{btc} * (XSNov_{mbsltci} + XSDec_{mbsltci} + XSJan_{mbsltci} + XSFeb_{mbsltci})$$
$$+ \sum_{b=1}^{B}\sum_{i=1}^{I} \theta_{bi} * (\sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{l=1}^{L} XTN_{mbsli} + \sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{t=1}^{T}\sum_{c=1}^{C} (XTONov_{mbsltci} + XTODec_{mbsltci} + XTOJan_{mbsltci} + XTOFeb_{mbsltci}))$$
$$- \rho * \sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{i=1}^{I} NSC_{li} * A_{bsli}$$
$$+ \rho * \sum_{b=1}^{B}\sum_{i=1}^{I} CE_{bi} * (\sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{l=1}^{L} XTN_{mbsli} + \sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{t=1}^{T}\sum_{c=1}^{C} (XTONov_{mbsltci} + XTODec_{mbsltci} + XTOJan_{mbsltci} + XTOFeb_{mbsltci}))$$

Subject to:

Land constraints

$$\sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L} A_{slbi} \le p_i * \sum_{s=1}^{S}\sum_{l=1}^{L} aa_{sli} \qquad \forall \cdot i \quad (1)$$

$$\sum_{b=1}^{B} A_{bsli} \leq p_i * aa_{sli} \qquad \forall \cdot s,l,i \quad (2)$$

Harvest constraints

$$\sum_{m=1}^{12} XH_{mbsli} \leq y_{bsli} * A_{bsli} \qquad \forall \cdot b,s,l,i \quad (3)$$

$$XH_{mbsli} \leq y_{bsi} * AH_{mbsli} \qquad \forall \cdot i,s,b,m \quad (4)$$

$$\sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L} XH_{mbsli} \leq \frac{1}{4} * \sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{l=1}^{L} (y_{bsi} * AH_{mbsli}) \qquad \forall \cdot i,m \quad (5)$$

$$XH_{mbsli} = 0 \qquad m \geq March \,\&\, \forall \cdot b,s,l,i \quad (6)$$

$$XH_{mbsli} \geq XTN_{mbsli} \qquad Feb \geq m \geq Nov \,\&\, \forall \cdot b,s,l,i \quad (7)$$

Storage constraints

$$\sum_{t=1}^{T}\sum_{c=1}^{C} XSNov_{mbsltci} = XH_{mbsli} - XTN_{mbsli} \qquad m = Nov \,\&\, \forall \cdot b,s,l,i \quad (8)$$

$$\sum_{t=1}^{T}\sum_{c=1}^{C} XSDec_{mbsltci} = XH_{mbsli} - XTN_{mbsli} \qquad m = Dec \,\&\, \forall \cdot b,s,l,i \quad (9)$$

$$\sum_{t=1}^{T}\sum_{c=1}^{C} XSJan_{mbsltci} = XH_{mbsli} - XTN_{mbsli} \qquad m = Jan \,\&\, \forall \cdot b,s,l,i \quad (10)$$

$$\sum_{t=1}^{T}\sum_{c=1}^{C} XSFeb_{mbsltci} = XH_{mbsli} - XTN_{mbsli} \qquad m = Feb \,\&\, \forall \cdot b,s,l,i \quad (11)$$

$$XSDec_{mbsltci} = 0 \qquad m \leq Dec \,\&\, \forall \cdot b,s,l,t,c,i \quad (12)$$

$$XSJan_{mbsltci} = 0 \qquad m \leq Jan \,\&\, \forall \cdot b,s,l,t,c,i \quad (13)$$

$$XSFeb_{mbsltci} = 0 \qquad m \leq Feb \,\&\, \forall \cdot b,s,l,t,c,i \quad (14)$$

$$XSNov_{mbsltci} \leq \frac{1-cv_{btcm}}{1-cv_{m-1btc}} * XSNov_{m-1bsltci} - XTONov_{mbsltci} \qquad m \geq Dec \,\&\, \forall \cdot b,s,l,t,c,i \quad (15)$$

$$XSDec_{mbsltci} \leq \frac{1-cv_{m-1btc}}{1-cv_{m-2btc}} * XSDec_{m-1bsltci} - XTODec_{mbsltci} \qquad m \geq Jan \,\&\, \forall \cdot b,s,l,t,c,i \quad (16)$$

$$XSJan_{mbsltci} \leq \frac{1-cv_{m-2btc}}{1-cv_{m-3btc}} * XSJan_{m-1bsltci} - XTOJan_{mbsltci} \qquad m \geq Feb \,\&\, \forall \cdot b,s,l,t,c,i \quad (17)$$

$$XSFeb_{mbsltci} \leq \frac{1-cv_{m-3btc}}{1-cv_{m-4btc}} * XSFeb_{m-1bsltci} - XTOFeb_{mbsltci} \qquad m \geq Mar \,\&\, \forall \cdot b,s,l,t,c,i \quad (18)$$

$$XSNov_{"Nov"bsltci} \geq \sum_{m=1}^{M} \frac{XTONov_{mbsltci}}{1-cv_{mbtc}} \qquad \forall \cdot m,b,s,l,t,c,i \quad (19)$$

$$XSDec_{"Nov"bsltci} \geq \sum_{m=1}^{M} \frac{XTODec_{mbsltci}}{1-cv_{m-1btc}} \qquad \forall \cdot m,b,s,l,t,c,i \quad (20)$$

$$XSJan_{"Nov"bsltci} \geq \sum_{m=1}^{M} \frac{XTOJan_{mbsltci}}{1-cv_{m-2btc}} \qquad \forall \cdot m,b,s,l,t,c,i \quad (21)$$

$$XSFeb_{"Nov"bsltci} \geq \sum_{m=1}^{M} \frac{XTOFeb_{mbsltci}}{1-cv_{m-3btc}} \qquad \forall \cdot m,b,s,l,t,c,i \quad (22)$$

$$\frac{1-cv_{btcm}}{1-cv_{m-1btc}} * XSNov_{m-1bsltci} \geq XSNov_{mbsltci} \qquad m \geq Dec \ \& \forall \cdot b,s,l,t,c,i \quad (23)$$

$$\frac{1-cv_{btcm}}{1-cv_{m-1btc}} * XSDec_{m-1bsltci} \geq XSDec_{mbsltci} \qquad m \geq Jan \ \& \forall \cdot b,s,l,t,c,i \quad (24)$$

$$\frac{1-cv_{btcm}}{1-cv_{m-1btc}} * XSJan_{m-1bsltci} \geq XSJan_{mbsltci} \qquad m \geq Feb \ \& \forall \cdot b,s,l,t,c,i \quad (25)$$

$$\frac{1-cv_{btcm}}{1-cv_{m-1btc}} * XSFeb_{m-1bsltci} \geq XSFeb_{mbsltci} \qquad m \geq Mar \ \& \forall \cdot b,s,l,t,c,i \quad (26)$$

Transportation constraints

$$\frac{1-cv_{btcm}}{1-cv_{m-1btc}} * XSNov_{m-1bsltci} \geq XTONov_{mbsltci} \qquad m \geq Dec \ \& \forall \cdot b,s,l,t,c,i \quad (27)$$

$$\frac{1-cv_{btcm}}{1-cv_{m-1btc}} * XSDec_{m-1bsltci} \geq XTODec_{mbsltci} \qquad m \geq Jan \ \& \forall \cdot b,s,l,t,c,i \quad (28)$$

$$\frac{1-cv_{btcm}}{1-cv_{m-1btc}} * XSJan_{m-1bsltci} \geq XTOJan_{mbsltci} \qquad m \geq Feb \ \& \forall \cdot b,s,l,t,c,i \quad (29)$$

$$\frac{1-cv_{btcm}}{1-cv_{m-1btc}} * XSFeb_{m-1bsltci} \geq XTOFeb_{mbsltci} \qquad m \geq Mar \ \& \forall \cdot b,s,l,t,c,i \quad (30)$$

$$XTN_{mbsli} = 0 \qquad m \geq March \ \& \forall \cdot b,s,l,i \quad (31)$$

$$XTONov_{mbsltci} = 0 \qquad m = Nov \ \& \forall \cdot b,s,l,t,c,i \quad (32)$$

$$XTODec_{mbsltci} = 0 \qquad m \leq Dec \ \& \forall \cdot b,s,l,t,c,i \quad (33)$$

$$XTOJan_{mbsltci} = 0 \qquad m \leq Jan \ \& \forall \cdot b,s,l,t,c,i \quad (34)$$

$$XTOFeb_{mbsltci} = 0 \qquad m \leq Feb \ \& \forall \cdot b,s,l,t,c,i \quad (35)$$

Processing plant

$$Q_m = \lambda * \sum_{b=1}^{B} \sum_{s=1}^{S} \sum_{l=1}^{L} \sum_{i=1}^{I} (1-\alpha) * (\sum_{t=1}^{T} \sum_{c=1}^{C} XTO_{mbsltci} + XTN_{mbsli}) \qquad \forall \cdot m \quad (36)$$

$$XTO_{mbsltci} = XTONov_{mbsltci} + XTODec_{mbsltci} + XTOJan_{mbsltci} + XTOFeb_{mbsltci} \qquad \forall \cdot m \quad (37)$$

$$Q_m = cap_m \qquad \forall \cdot m \quad (38)$$

Variables:

A: acres of switchgrass harvested annually

AH: acres of switchgrass harvested through November to February

XH: tons of switchgrass harvested through November to February

XSNov: tons of switchgrass harvested in November stored through November to October

XSDec: tons of switchgrass harvested in December stored through December to October

XSJan: tons of switchgrass harvested in January stored through January to October

XSFeb: tons of switchgrass harvested in February stored through February to October

XTN: tons of switchgrass transported immediately after harvest during the period from November to February

XTONov: tons of switchgrass harvested in November, transported from storage during the period from December to October

XTODec: tons of switchgrass harvested in December, transported from storage during the period from January to October

XTOJan: tons of switchgrass harvested in January, transported from storage during the period from February to October

XTOFeb: tons of switchgrass harvested in February, transported from storage during the period from March to October

XTO: tons of switchgrass transported from storage during the period from March to October

Q: gallons of ethanol produced in each month

Parameters:

P: price of switchgrass per ton

γ: storage material cost per ton

cv: cumulative storage dry matter loss (%)

θ: transport cost per dry ton ($/dt)

α: dry matter loss during transportation

ρ: carbon incentive ($/ton)

NSC: net carbon stored in the soil from switchgrass production (ton)

CE: carbon emitted from diesel fuel during transportation (ton)

y: switchgrass yield (dt)

p: percentage of total cropland available to switchgrass across counties

λ: conversion rate to ethanol (gallons/dt)

D: monthly demand of ethanol

aa: cropland available on soil *s* in county *i*

cap: capacity of the biorefinery

Subscripts:

m: month

b: harvest method (round baler, square baler)

s: soil type

l: land type

t: storage cover type (no cover, tarp)

c: storage surface type (bare ground, gravel, pallet)

i: production region (county)

There are several constraints related to land, harvest, storage, delivery, and biorefinery capacity. These constraints attempt to quantify resource availability. The constraints attempt to provide production limit and are briefly described below:

- First, there are constraints about land usage: (1) agricultural land used to grow switchgrass should not exceed the available farmland; (2) acres contracted in each soil in that location should not exceed the available acres on the soil.
- Second, there are constraints about harvest. The constraints include: (3, 4) total amount of switchgrass harvested should be less than or equal to the total yield; (5) the switchgrass harvested each month in the harvest window should not exceed one fourth of the total yield; (6) the harvest window is from November to February; (7) and the net harvest should be greater than zero, in other words, the tonnage of switchgrass transported immediately after harvest should be less than or equal to the total tonnage harvested in the same month.
- Third, there are constraints of storage: (8, 9, 10, 11) newly stored switchgrass in the harvest month is equal to the amount of switchgrass harvested minus the amount of switchgrass transported immediately; (12, 13, 14) no newly harvested switchgrass stored before the harvest month;

(15, 16, 17, 18) switchgrass inventory in the next month should be no more than the inventory in current month minus the amount of switchgrass delivered to the biorefinery from storage; (19, 20, 21, 22) total stored switchgrass should be no less than the total switchgrass transported after the harvest month; (23, 24, 25, 26) switchgrass stored in one month should be no greater than the switchgrass stored in the previous month.

- Fourth, the transportation constraints include: (27, 28, 29, 30) the switchgrass transported from storage should not exceed the switchgrass that is available in storage in any given month; (31) no newly harvested switchgrass will be transported after the harvest months; and (32, 33, 34, 35) no stored switchgrass will be transported before it is placed into storage.
- Fifth, there are three biorefinery plant capacity constraints: (36) total amount of switchgrass delivered to plant should not be greater than the capacity of the plant; (37) total amount of switchgrass delivered from storage is equal to the sum of the switchgrass harvested from Noverber to Feburary transported from storage; and (38) ethanol produced by plant should meet the capacity for the biorefinery plant.

All the parameters and variables in this programming model are non-negative. Losses for harvest are assumed to be zero. A linear programming model will be developed to minimize the total feedstock cost of a biorefinery with the above constraints. The results of this model can show the optimal acres to grow switchgrass, acres of switchgrass harvested in different months, amount of switchgrass put into storage, and delivery schedules for switchgrass.

Sensitivity Analysis

A sensitivity analysis was performed on three different factors -- plant size, switchgrass price, and land share. On each sensitivity level, carbon payment is considered and evaluated for each location. Table B.13 shows all of the scenarios analyzed for a single site. The analysis was then conducted for the three sites. For the base scenario (scenario 8), the size of the biorefinery is 50 million gallons per year with the price of switchgrass set at $75/dt, estimated land share from Tobit model, and no carbon payment. The additional 21 scenarios assume an annual capacity range from 15 million to 100 million gallons, a switchgrass price between $90/dt and $110/dt, 5% change in estimated land share, and either a carbon payment or not. The scenarios of different plant sizes are imposed to evaluate how harvest and delivery schedules change as plant size increases. Increasing the price of switchgrass is used to look at the impact that the input cost would have on the cost of delivered feedstock. Changes in land share (5% more land share and 5% less land share along with estimated land share) shows how transportation cost affect the total delivered cost. Finally, the scenarios with and without carbon payments are used to evaluate how carbon payments impact the cost of the feedstock at the plant gate.

CHAPTER V
RESULTS AND DISCUSSION

Analysis of the Base Scenarios

A summary of the assumptions used and the basic results for each scenario for Shelby, Davidson, and Marion sites are presented in Tables D.1 to D.3 (tables and figures for the programming model results are showed in appendix D), respectively. The soil types and land acreage selected by county, harvest schedule and arrangement of harvested switchgrass, and the delivery schedule of switchgrass in the base scenario of the three selected locations are shown in Tables D.4 to D.12. There was not enough biomass available within the 50 mile growing zone for the 100 million gallon facility in Davidson County at a switchgrass price of $75/ton.

Total delivered costs for a 50 million gallon capacity biorefinery without a carbon payment and at a switchgrass price of $75/dt did not vary much between locations and were estimated at $51,908,850 for the Davidson location, $50,929,970 for the Shelby location, and $50,358,160 for the Marion location. Acres required to supply the base solution are 127,140 acres, 132,762 acres, and 116,944.26 acres for the Davidson, Shelby, and Marion county sites, respectively. There is no payment for carbon in these solutions (See Appendix tables D.1 – D.3).

In the Davidson, TN location, the selected counties are Cheatham, Davidson, Dickson, Maury, Montgomery, Robertson, Rutherford, Sumner, Trousdale, Williamson, Wilson, and Simpson. The selected soil types are Armour, Dellrose, Dickson, Loring, Pembroke, Sengtown, and Zanesville. Given an annual capacity of 50 million gallons, the biorefinery will pay $1.04/gallon for switchgrass delivered to the plant gate when the switchgrass price is $75/dt without a carbon payment.

Results show that pastureland and distance are factors in deciding what land to convert. The pastureland with higher yields and shorter distance to the biorefinery location is initially converted. Furthermore, dry matter loss is minimized as evidenced by the transportation schedule. From November to February, the switchgrass bales that are transported immediately after harvest to the biorefinery are harvested by rectangular balers, switchgrass that is to be placed into storage is harvested by round balers. The storage method chosen by the model is to store the switchgrass round bales uncovered on the ground. Among the switchgrass stored, switchgrass harvested in February will be transported to the biorefinery first. After all switchgrass harvested in February is transported, switchgrass harvested in January will begin to be used for ethanol production. Switchgrass harvested in November will be used last.

Soil types of Adler, Collins, Crowley, Loring, Memphis, and Sharkey in the counties of Shelby, Tipton, De Soto, and Crittenden were selected for the Shelby, TN location. The biorefinery needs to pay $1.02/gallon for delivered switchgrass. Since the high yield soil acreage in Shelby location is less than that near the Davidson location. More acreage is used in the Shelby location. However, because of high land proportions used to grow switchgrass near Shelby, the biorefinery can pay less for feedstock due to the reduction in transportation costs.

The selected counties are Dillon, Florence, Horry, and Marion with soil types of Ailey, Emporia, and Norfolk for the Marion biorefinery location. 116,944 acres of land was used for switchgrass production in this area. The feedstock cost at the plant gate was $1.01/gallon. With higher yields and a higher proportion of land used for switchgrass, the biorefinery in Marion can use less land and pay lower costs to produce the same amount of ethanol in the base scenarios.

Sensitivity Analysis of Plant Size

It is uncertain what capacity is optimal for a biorefinery. Following Wang's assumptions, three capacities were used; 15 and 100 million gallons were used for a sensitivity analysis around the base case of 50 million gallons. This increase in total delivered cost is primarily caused by the increasing transportation and storage costs. When the biorefinery size is small, the more productive land located near the plant was chosen by the model. As the plant size expanded, the lower yielding land and land that was further away from the biorefinery was selected to grow switchgrass as well. More acreage is required since the low yielding land is used; and therefore, results in increased transportation costs per ton. As the optimal draw area increases, the transportation cost is more than doubled since the distance traveled to the biorefinery increases rapidly as additional land is placed into switchgrass. In addition, more switchgrass is placed into storage after harvest, causing the increase of storage costs. Thus, as the plant capacity increases, the delivered feedstock cost per gallon also increases.

Assuming all other variables are set at their base scenario value, when plant size increase from 15 million gallons to 50 million gallons, the average feedstock delivered cost at the plant gate rises from $1.01/gallon to $1.04/gallon at the Davidson location. The plant area of switchgrass increased from 37,374 acres to 127,140 acres. When the plant's capacity expands to 100 million gallons, at the base scenario price of $75/dt, the draw area within 50 miles from the Davidson location can't meet the feedstock requirement of the biorefinery. A larger draw area would be needed to produce more switchgrass to meet the feedstock demand. As plant size expanded, more carbon is sequestered, but the amount of carbon abated in every million gallon ethanol produced decreases. This may be caused by the rapid increased carbon emission during transportation, since the transportation mileage increases.

In the Shelby, TN location, when plant capacity increased from 15 million gallons to 50 million gallons, the average feedstock cost rises from $0.99/gallon to $1.02/gallon. When plant size increases to 100 million gallons, the feedstock cost at the plant gate increased to $1.04/gallon. Land acreage rises from 34,766 acres to 132,762 acres, as the plant capacity increases from 15 million gallons to 50 million gallons. Although the land acreage under the 100 million gallon capacity less than doubled to 225,555 acres when compared to 50 million gallon capacity, the total delivered cost is more than doubled to $104,359,500. The plant size increase results in more carbon sequestration in Shelby location, but the carbon abated from every million gallon ethanol doesn’t change too much.

Similar results were generated for the Marion location. The corresponding feedstock costs at the plant gate for plant sizes 15 million gallons, 50 million gallons, and 100 million gallons are $0.97/gallon, $1.01/gallon, and $1.05/gallon, respectively. The land acreages used for switchgrass were 35,944 acres, 116,944 acres, and 225,315 acres, respectively. Also, the increase of feedstock costs was driven by the increase of the storage and transportation costs. Similar as Shelby location, the net carbon abated from every million gallon ethanol produced does not have too much difference among scenarios, although the total amount of carbon sequestered rises with the plant size increase.

Sensitivity Analysis of Switchgrass Price

The price of switchgrass impacts the feedstock cost to the biorefinery from two aspects. On one aspect, the price affects the direct cost of purchasing switchgrass. On the other aspect, a switchgrass price increase can lead to an increase in the amount of land a farmer will convert to switchgrass. The transportation costs will decrease as the switchgrass price increases. When plant size is relatively small, the cost of buying the switchgrass is the primary cost to the biorefinery. In addition, since land requirements are small, relatively speaking, the switchgrass price effect on reducing transportation is not significant. However, as the plant size increases, the influence of switchgrass cost on total delivered feedstock costs will decrease, and the impact that transportation costs play increases. As switchgrass price increasing, the transportation cost reduces, since more land near the biorefinery location can be used to grow switchgrass. Therefore, generally speaking, a switchgrass price increase will cause the total delivered feedstock cost to increase at a decreasing rate as the plant capacity expands. For instance, in the Davidson location, when annual plant capacity is 15 million gallons and no carbon payments exist, the price per gallon as the switchgrass price changes, scenarios go from $75/dt to $90/dt, and to $110/dt, the delivered feedstock cost increases from $1.01/gallon to $1.19/gallon, and $1.43/gallon, respectively. When the plant capacity is 50 million gallons, the change in feedstock costs was $0.4/gallon as price increases from $75/dt to $110/dt.

Sensitivity Analysis of Land Share

To explore the impact of land share change on delivered feedstock cost and carbon sequestration, the land proportion used in base scenario is increased or decreased by 0.05. The results show that with low land proportion used for switchgrass, total delivered cost will increase. By contrast, high land share leads to the delivered feedstock cost reduction. The difference between the low land share and high land share scenarios is mainly caused by the transportation cost. Since the biorefinery need to use land that far away from plant location to meet the production requirement with low land share for switchgrass, the transportation cost increases as the total travel mileage rises. It is unclear how net carbon sequestration changes with land proportion change. As discussed before, the amount of carbon stored in soil is determined by the land acreage and land type used in production. If a biorefinery has lots of high yield land in its draw area, plant will use less acreage to grow switchgrass comparing to a biorefinery with low yield land around. Then, less carbon will be stored in soil for the biorefinery. If a biorefinery has more pastureland around, the net carbon stored will be less than the biorefinery with more cropland around.

In Davidson location, the total delivered cost is $52,944,020 with low land share, while high land share reduce the delivered feedstock cost to $51,303,170. More net carbon stored in soil with high land share, since the land near the biorefinery is mainly the low yield cropland. The scenario with high land share sequesters 1,678.62 metric ton more carbon than the scenario with low land share.

In Shelby location, compared to the total cost in the base scenario, the delivered cost increases by $441,310 in low land share scenario. On the other hand, delivered cost decreases by $180,720 with high land share. Similar with Davidson location, the scenario with high land proportion used for switchgrass has more net carbon store than the scenario with low land proportion.

The effect of land share change on total feedstock cost is not significant in Marion location. Since the total mileage changes little among the base and other two scenarios, the change in transportation cost does not influence the total cost too much. Differing from the other two locations, more carbon is stored in soil with low land share scenario. Table B.3 and C.7 shows that the land near Marion location is low yield pastureland, although the acreage used to grow switchgrass is more than the acreage used in low land share scenario, the amount of carbon sequestered is less. Thus, scenario with low land shore can store more carbon in soil.

Sensitivity Analysis of Carbon Payment

The summaries of carbon flux for all scenarios are presented in Appendix Tables D.13 to D.15. From the summary of delivered costs for all scenarios, scenarios with a carbon payment have lower total delivered costs and higher amounts of net carbon stored than those without a carbon payment, when other variables are the same. Since the farmer receives a payment for net carbon stored in the soil from the government, the switchgrass price is lower than that in non-carbon payment scenarios. The feedstock costs at plant gate per gallon from carbon payment scenarios are one or two cents lower than the costs from other scenarios without a carbon payment. Besides the delivered feedstock cost reduction, a carbon payment mechanism affects land use change; more cropland is used to grow switchgrass instead of pastureland, since carbon sequestration rate of switchgrass planted on cropland is higher than the rate on pastureland. Growing switchgrass can increase the soil carbon content, the more land used in switchgrass production, the more carbon stored in the soil. If the benefit from carbon payment program can cover the loss of the higher transportation cost resulting from the larger planting area, the biorefinery would like to use more yield land to grow switchgrass. Thus, with a carbon payment mechanism, in order to obtain a larger carbon payment from the government, the biorefinery uses more low-yield land to grow switchgrass to increase the acreage used. Also, since the carbon sequestration rate by switchgrass growing in cropland is more than carbon sequestration rate in pastureland (Tables B.10, B.11, and B.12), with a carbon payment in the scenarios, a biorefinery tends to use cropland over pastureland. Generally speaking, in scenarios with a carbon payment, low yield land and cropland are selected to grow switchgrass first by the biorefinery in the programming model.

To make a detailed comparison between the scenarios with and without a carbon payment, Tables D.16 to D.24 show the results from the programming model for the scenarios with 50 million gallon capacity, switchgrass price of $75/dt, and carbon payment. Results of the soil type, land type, and land acreage selected by county, the harvest schedule and arrangement of harvested switchgrass, and the delivery schedule of switchgrass are presented in those tables.

Comparing Table D.16 to D.4, at the same price level and plant capacity, the scenario with a carbon payment use 3,280 acres of cropland in Logan County instead of 2,805 acres pastureland in Maury County; around 475 more acres are used in the scenario. The total delivered cost to the biorefinery is $51,392,060 with a government payment of $515,694. The net carbon stored annually in the soil is estimated to be 19,100 metric tons. The scenario without a carbon payment needs to pay $51,908,850 to cover the total delivered cost, and has 18,297 metric tons of carbon stored in the soil.

Land use and acreage results for the 50 million gallon size, a $75 switchgrass unit price with a carbon payment scenario in the Shelby area are shown in Table D.19. Compared to the base scenario, this scenario only uses 1,632 acres of cropland under Memphis soil in Tipton County instead of the 1,614 acres of pastureland and 5,409 acres cropland of Memphis soil shown in the base scenario results. And more cropland of Cowley and Loring soil, for a total of 5,914 acres, are used in Crittenden County, in the mean time, no pastureland in Crittenden County is chosen to grow switchgrass. The total delivered cost decreases by $510,640. And the net soil carbon increases from 18,041 to 18,698 metric tons.

Table D.22 shows the results of the scenario with a carbon payment for a 50 million gallon capacity plant at a $75 switchgrass price level in Marion area. Compared to 1,032 and 3,942 acres of pastureland used in the base scenario in Dillon and Horry County, no pastureland was selected to grow switchgrass in Dillon or Horry County. Moreover, the cropland acreage of Norfolk soil in Dillon County decreases 4,969 acres from the base scenario. Instead, the model uses more cropland under Norfolk soil in Horry County. The yield results (Table C.7) show that a Norfolk soil in Horry County has lower productivity than in Dillon County. However, from Table B.12, the amount of carbon stored in the soil after growing switchgrass in Horry can be found to be higher than the amount of carbon stored in Dillon. Since the carbon payment can be higher to grow switchgrass in Horry, which can cover the higher transportation costs, the biorefinery would like to use cropland in Horry County under a carbon payment mechanism. The results also indicate that around 2,000 more metric tons of carbon is stored and the total feedstock cost decreases by $985,260.

CHAPTER VI
SUMMARY, LIMITATIONS, AND CONCLUSIONS

There were two objectives in this study. The overarching objective was to determine the optimal draw area and delivery schedule for a biorefinery assuming a carbon program paid to the facility for the amount of carbon sequestered less the amount of carbon emitted. In order to achieve this, factors were identified that may affect the farmers' decision for converting current land use from conventional land uses to growing switchgrass and incorporating these factors into the analysis.

This study uses a cost minimizing linear program (LP) to trace out, from the biorefinery's point of view, the least cost delivery schedule for three biorefinery locations. The locations were selected using a GIS site selection model, BioFLAME. For each site the LP model has production of switchgrass incorporated for up to three soils in each county within a 50 mile radius of the plant. Competition for land is depicted using farmer perceptions from survey data and estimating the proportion of land that a producer is willing to convert to switchgrass production at a pre-specified switchgrass price. These perceptions are modeled using Probit and Tobit equations. A baseline solution is developed for each plant and a sensitivity analysis was conducted around that baseline on switchgrass price, and plant capacity. Finally, an analysis examining carbon payments was conducted.

The results from this study suggest that farmers are interested in switchgrass (over 96% in the study group) and are willing to grow switchgrass (over 72%). These farmers, who have more favorable view of switchgrass, generally have at least a high school degree, are over 50 years old, own a storage facility, and have little or no farm debt. Among those farmers who want to grow switchgrass, the average land proportion they want to use for switchgrass production is 0.30, which means, on average, those farmers will use about 30% of their land to grow switchgrass. Changing land use is influenced by level of farm related income. Farmers who have higher farm related income will use a smaller proportion of their land in switchgrass production. In addition, switchgrass prices play an important role in a farmers' decision on whether to convert his/her land to switchgrass. As switchgrass prices increase, more farmers are willing to grow switchgrass, and more land will be converted to grow switchgrass.

To maintain a steady switchgrass supply flow and to minimize costs, the biorefinery needs to estimate an optimal draw area, a harvest schedule, and a delivery schedule. In addition, if carbon payments are involved, then an understanding of the carbon program and its requirements is needed.

In this analysis, carbon sequestration and emissions from planting and transporting switchgrass were tracked. The delivered cost of switchgrass was sensitive to plant size, switchgrass price, land share for switchgrass, and the carbon payment mechanism. As plant size and switchgrass price increases, the delivered feedstock cost increases. The total delivered cost decreases as the proportion of land available for switchgrass increases. The biorefinery will have lower feedstock costs, if a carbon program that rewards the production system for sequestering carbon while penalizing the system for carbon emissions exists. Under all scenarios when comparing carbon payment to no carbon payment, the amount of carbon sequestered increase an average of 63.73 per million gallons produced. Davidson location has 78.72 tons/million gallons more carbon stored, carbon sequestered amount increases by 63 tons/million gallons in Shelby location, and Marion location can abate 54.96 tons/million gallons more with carbon payment.

The model constructed for the analysis chooses productive land close to the biorefinery to grow switchgrass when the plant size is small (15 million gallon capacity). With the carbon payment mechanism, land with a high carbon sequestration rate will get selected before lands with low carbon sequestration rates. Another factor that may affect the total delivered feedstock cost is dry matter loss. Low dry matter losses can decrease the amount of acres required for switchgrass production. Besides, low dry matter loss can result in less switchgrass harvested. As a result, the total delivered feedstock cost will decrease. Also, the model results indicate that newly-harvested rectangular bales will be delivered to the biorefinery immediately, round bales will be put into storage without any protection.

In the Davidson location, since the proportion of land allowed to be converted for switchgrass is lower than the other two sites, lands further away from the biorefinery were selected. This results in increased transportation costs, which make the delivered costs higher than other biorefinery locations. When the price of switchgrass was at $75/ton, Davidson cannot meet the feedstock amount required for the large (100 million gallon) biorefinery. The biorefinery in the Shelby location has a lower delivered cost as less land is required to meet feedstock demands if the carbon payment is not incorporated into the analysis. Shelby is a better location for a biorefinery, considering minimizing total feedstock cost. However, when taking carbon payments into account, Davidson is a more suitable location, since estimated carbon benefits per dry ton of switchgrass in all scenarios are higher than the prices in Shelby. The results show that for Davidson location, the higher carbon benefits occur in 15 Million gallon size scenarios (Scenarios 1 to 6). From an environment aspect, it is suggested that if the size of the biorefinery is not large (less than 50 million gallon capacity), Davidson will be a suitable location.

Among the three locations studied in this paper, Marion had lower plant gate feedstock costs in all scenarios except the two scenarios of a 100 million gallon plant size. From an environmental side, farmland used for switchgrass production in Marion can store at least 30% more carbon in the soil than the other two locations. Hence, Marion has advantages over the other two locations if only the delivered feedstock cost is considered. However, biorefinery location selection needs to consider many other factors, such as infrastructure needs, ethanol transportation, and labor and management costs.

Limitations

There are several limitations in this optimization analysis. The linear programming model that was used in this analysis has coefficients that are assumed to be known with certainty. However, weather, production variability, input and output prices, biorefinery capacity, conversion rate of switchgrass to ethanol, government policy influences, and many other factors are really best guesses at this point. While a sensitivity analysis was conducted on switchgrass price, biorefinery capacity, and the existence of a carbon program, a sensitivity analysis could have been performed on the other variables as well.

Pre-processing and processing costs were not included in this study. The processing cost will be an important factor in determining the cost of ethanol production. This cost will likely change as plant capacity increases due to economics of scale. No attempt has been made to incorporate this and therefore no attempt was made to estimate optimal plant capacity.

Fixed switchgrass prices were assumed in the model. It is possible to attract additional lands by increasing the price to those that have to transport the feedstock over longer distances. Currently, there is no switchgrass market. Hence, the switchgrass market price is undefined. A similar situation exists for a carbon market.

Some data for the programming model came from the predictions of econometric models. Some caution should be mentioned, the survey from which these models were developed was sent to the randomly selected southeastern farmers with at least $10,000 in sales. If the region selected included significant amounts of landowners that have little agricultural activity on their land, then adjustments in the proration of those willing to switch land uses should be adjusted to reflect their willingness. Also, it is possible that farmers that had an interest in switchgrass were more likely to respond to the survey than those not interested.

The results of the programming model can be applied for real to use only if the econometrics model is validated or replaced with more complete studies on farmers' willingness to change their cropping practices to include switchgrass. Further studies on the pre-processing cost may disclose more information on the feasibility of using switchgrass as a bioenergy feedstock. Also, studies on switchgrass and carbon pricing and land use change can help to get a more accurate cost estimate for a biorefinery.

Last but not the least, this study focused on the feedstock cost of a biorefinery. Carbon activities considered in the model were limited to carbon stored in the soil from switchgrass production and carbon emissions from switchgrass transportation. Other carbon activities like carbon emissions from the conversion process and transporting ethanol to market were not included in the model. Moreover, the CO_2 emissions reduction from fossil fuel replacement was not considered. If the total cost of a biorefinery needed to be estimated, all carbon activities mentioned above should be considered in the model as the environmental benefit gained from producing cellulosic ethanol using switchgrass as a feedstock.

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APPENDIX A

Farmers' Land Conversion Decision

Farmers' WTA

To produce more switchgrass, more land is needed. So, farmers will face the question of whether it is worth to spend the conversion cost to start growing switchgrass given the price of switchgrass. The answer is based on the WTA for different individual. If the unit price of switchgrass is higher than the individual' WTA for growing switchgrass, he will want to convert his land to grow switchgrass to make a positive profit. Cameron and James' WTP/WTA model (1987) based on differences in expenditure function can be used to analysis the problem.

Specify a linear functional form of WTA:

$$WTA_i = \beta + S_i^{'} * \beta_s + FO_i^{'} * \beta_{FO} + PI_i^{'} * \beta_{PI} + \mu_i$$

Where

S_i is the vector of variables representing the individual's knowledge about switchgrass

FO_i is the vector of farming operation variables

PI_i is the vector of personal information variables

β_s, β_{FO}, β_{PI} are the corresponding parameters for the explanatory variables

μ_i is the error term

then,

$$prob(Y_i = 1) = prob(WTA_i < P_i)$$
$$= prob(\beta + S_i^{'} * \beta_s + FO_i^{'} * \beta_{FO} + PI_i^{'} * \beta_{PI} + \mu_i < P_i)$$
$$= prob(P_i - (\beta + S_i^{'} * \beta_s + FO_i^{'} * \beta_{FO} + PI_i^{'} * \beta_{PI}) > \mu_i)$$

Where

P_i is the unit price of switchgrass

Y_i is the dummy variable

=1, individual is willing to grow switchgrass

=0, individual is not willing to grow switchgrass

Let Var (μ_i) = σ^2, and let F_z be cdf of standardized variable $z_i = \mu_i/\sigma$, then

$$prob(Y_i = 1)$$
$$= prob(\frac{P_i - (\beta + S_i^{'} * \beta_s + FO_i^{'} * \beta_{FO} + PI_i^{'} * \beta_{PI})}{\sigma} > \frac{\mu_i}{\sigma})$$
$$= prob(\frac{P_i - (\beta + S_i^{'} * \beta_s + FO_i^{'} * \beta_{FO} + PI_i^{'} * \beta_{PI})}{\sigma} > z_i)$$
$$= F_z(\frac{P_i - (\beta + S_i^{'} * \beta_s + FO_i^{'} * \beta_{FO} + PI_i^{'} * \beta_{PI})}{\sigma})$$

Construct a Probit model,

$$\ln L = \sum_{i=1}^{n} \{Y_i * F_z(\frac{P_i - (\beta + S_i^{'} * \beta_s + FO_i^{'} * \beta_{FO} + PI_i^{'} * \beta_{PI})}{\sigma})$$
$$+ (1 - Y_i) * [1 - F_z(\frac{P_i - (\beta + S_i^{'} * \beta_s + FO_i^{'} * \beta_{FO} + PI_i^{'} * \beta_{PI})}{\sigma})]\}$$

The results of the Probit model can show how the variables affect the farmer's decision of whether or not to grow switchgrass.

After estimating of the parameters, mean WTA can be calculated with:

$$meanWTA = \int_{-\infty}^{0} prob(WTA > P)dP + \int_{0}^{\infty} prob(WTA < P)dP$$

Compare the mean WTA with price of switchgrass. If the mean WTA is greater than the price, farmers are less likely to produce switchgrass. In order to encourage switchgrass production, regulators need to increase the incentive level to offset the farmers' loss. If the mean WTA is less than the price cost, regulators don't need to change the current incentive program, or they can even lower the incentive level.

Land Use for Switchgrass

Also, the percentage of land that the individual farmer wants to convert to grow switchgrass can be estimated with the Tobit model (Tobit, 1958). The Tobit model is appropriate when the dependent variable is censored. The Tobit model is used to estimate the farmer's decision regarding how much land to devote to growing switchgrass under a given switchgrass price.

$$LU_i = \beta_0 + P_i^{'} * \beta_P + S_i^{'} * \beta_s + FO_i^{'} * \beta_{FO} + PI_i^{'} * \beta_{PI} + \mu = \beta^{'} Z_i + \mu_i \quad \text{if } \beta^{'} Z_i + \mu_i > 0$$

$$LU_i = 0 \quad \text{if } \beta^{'} Z_i + \mu_i \leq 0$$

where

LU_i is the vector of land use variables

P_i is the vector of prices paid to farmers

S_i is the vector of variables representing an individual's knowledge about switchgrass

FO_i is the vector of farming operation variables

PI_i is the vector of personal information variables

Z_i is the variable matrix

B_p, β_s, β_{FO}, β_{PI} are the corresponding parameters for the explanatory variables

μ_i is the error term

The error term μ_i is assumed to be normally distributed with zero mean and constant variance σ^2

Let

$$\lambda_i = \frac{\varphi(\beta' Z_i / \sigma)}{\Phi(\beta' Z_i / \sigma)}$$

then the conditional mean of LU_i (conditional on LU_i>0) is

$$E(LU_i | X) = \beta' Z_i + \sigma * \lambda_i$$

the unconditional mean is

$$E(LU_i) = \Phi(\frac{\beta' Z_i}{\sigma})\beta' Z_i + \sigma * \varphi(\frac{\beta' Z_i}{\sigma})$$

The marginal effect of X on the mean is

$$\partial E(LU | X) / \partial X = \beta * \Phi(\frac{\beta' Z}{\sigma})$$

Combine the survey data and the estimated land use for growing switchgrass, the total acreage used to grow switchgrass can be calculated. The land acreage available to grow switchgrass will be used as a constraint in linear programming model.

Table A.1 Variable Names, Definitions, and Means

	Definition	Mean
Probit Model (N = 622):		
Join	1 if producer agrees to grow switchgrass; 0 otherwise	0.7186
Price	price of switchgrass per ton provided by bio-refinery	83.5367
Interest	1 if producer is not interested in switchgrass	0.0354
	2 if producer is somewhat interested in switchgrass	0.6913
	3 if producer is very interested in switchgrass	0.2733
Education	1 if producer's education level is elementary/middle school	0.0129
	2 if producer's education level is some high school	0.0289
	3 if producer's education level is high school	0.2556
	4 if producer's education level is some college	0.2605
	5 if producer's education level is college	0.2942
	6 if producer's education level is post graduate	0.1479
Age60	1 if producer is at least age 50; 0 otherwise	0.4453
Off_farm	1 if 50% or more of producer’s income in 2009 came from off-farm sources; 0 otherwise	0.8264
State	producer's location, use state fips code	
Tobit Model (N = 570):		
Proportion	the proportion of land that producer will use to grow switchgrass	0.3026
Price	price of switchgrass per ton provided by bio-refinery	83.3333
Farminc	10 if net income from farming in 2009 < $10,000; 0 otherwise	0.3982
	1025 if net income from farming in 2009 = $10,000-$25,000; 0 otherwise	0.2439
	2550 if net income from farming in 2009 = $25,000-$50,000; 0 otherwise	0.1439
	50 if net income from farming in 2009 > $50,000; 0 otherwise	0.2140
Off_farm	1 if 50% or more of producer’s income in 2009 came from off-farm sources; 0 otherwise	0.8158
Pasture	1 if producer has pasture land; 0 otherwise	0.6807
State	producer's location, use state fips code	

APPENDIX B

Table B.1 Available Land in Farms According to Use in Davidson TN Location

County	Soil	Cropland Acreage	Pastureland Acreage	Total Acreage
Cannon TN	Armour	17447.23	14587.00	45,834.09
	Dellrose	6101.37	0.00	
	Dickson	7698.49	0.00	
Cheatham TN	Pembroke	10819.21	0.00	24,851.00
	Sengtown	6511.79	7520.00	
Davidson TN	Armour	4336.83	6599.00	14,366.05
	Dellrose	1516.61	0.00	
	Dickson	1913.60	0.00	
Dickson TN	Pembroke	18855.43	0.00	48,918.00
	Sengtown	11348.57	18714.00	
Hickman TN	Pembroke	16935.18	0.00	39,687.00
	Sengtown	10192.82	12559.00	
Macon TN	Armour	17154.77	18723.00	49,446.32
	Dellrose	5999.10	0.00	
	Dickson	7569.45	0.00	
Marshall TN	Armour	21982.73	17540.00	56,909.94
	Dellrose	7687.45	0.00	
	Dickson	9699.76	0.00	
Maury TN	Armour	35728.52	33072.00	97,059.96
	Dellrose	12494.42	0.00	
	Dickson	15765.02	0.00	
Montgomery TN	Pembroke	37409.34	0.00	80,180.00
	Sengtown	22515.66	20255.00	
Robertson TN	Pembroke	78067.38	0.00	144,562.00
	Sengtown	46986.62	19508.00	
Rutherford TN	Armour	28867.28	18256.00	69,955.82
	Dellrose	10095.01	0.00	
	Dickson	12737.53	0.00	
Smith TN	Armour	14595.40	19057.00	45,196.62
	Dellrose	5104.08	0.00	
	Dickson	6440.14	0.00	
Sumner TN	Armour	31795.13	24142.00	81,085.45
	Dellrose	11118.89	0.00	
	Dickson	14029.43	0.00	

Table B.1 Available Land in Farms According to Use in Davidson TN Location (Con'd)

County	Soil	Cropland Acreage	Pastureland Acreage	Total Acreage
Trousdale TN	Armour	7159.25	5925.00	18,746.84
	Dellrose	2503.62	0.00	
	Dickson	3158.98	0.00	
Williamson TN	Armour	24765.74	19403.00	63,757.17
	Dellrose	8660.68	0.00	
	Dickson	10927.75	0.00	
Wilson TN	Armour	23130.34	22437.00	63,862.25
	Dellrose	8088.78	0.00	
	Dickson	10206.14	0.00	
Logan KY	Loring	35001.98	0.00	179,284.00
	Pembroke	120805.02	0.00	
	Zanesville	0.00	23477.00	
Simpson KY	Loring	17925.02	0.00	85,475.00
	Pembroke	61865.98	0.00	
	Zanesville	0.00	5684.00	
Todd KY	Loring	25063.49	0.00	122,610.00
	Pembroke	86503.51	0.00	
	Zanesville	0.00	11043.00	

Table B.2 Available Land in Farms According to Use in Shelby TN Location

County	Soil	Cropland Acreage	Pastureland Acreage	Total Acreage
Fayette TN	Collins	51180.38	0.00	124,350.25
	Lexington	0.00	23072.00	
	Loring	50097.87	0.00	
Haywood TN	Collins	87098.90	0.00	179,296.57
	Lexington	0.00	6941.00	
	Loring	85256.67	0.00	
Lauderdale TN	Adler	90589.46	0.00	142,172.62
	Memphis	43869.16	7714.00	
Shelby TN	Adler	36749.27	0.00	61,631.60
	Memphis	17796.33	7086.00	
Tipton TN	Adler	85334.86	0.00	134,941.40
	Memphis	41324.54	8282.00	
De Soto MS	Collins	57498.37	0.00	85,652.17
	Loring	23675.80	4478.00	
Marshall MS	Collins	29568.52	0.00	56,322.80
	Loring	12175.27	14579.00	
Tate MS	Collins	39731.66	0.00	65,276.76
	Loring	16360.10	9185.00	
Tunica MS	Memphis	0.00	973.00	175,893.20
	Sharkey	174920.20	0.00	
Crittenden AR	Crowley	181356.35	0.00	273,990.15
	Loring	13933.53	690.15	
	Sharkey	78010.13	0.00	
Cross AR	Crowley	161140.39	0.00	247,057.27
	Loring	12380.35	4222.27	
	Sharkey	69314.27	0.00	
Mississippi AR	Foley	292091.78	0.00	440,239.50
	Linker	3160.69	5288.00	
	Sharkey	139699.03	0.00	
Poinsett AR	Foley	209456.08	0.00	315,904.34
	Linker	2266.50	4005.00	
	Sharkey	100176.77	0.00	
St Francis AR	Crowley	141783.77	0.00	219,495.38
	Loring	10893.19	5830.38	
	Sharkey	60988.05	0.00	

Table B.3 Available Land in Farms According to Use in Marion SC Location

County	Soil	Cropland Acreage	Pastureland Acreage	Total Acreage
Columbus NC	Norfolk	93628.78	0.00	97,203.78
	Rains	0.00	3575.00	
Robeson NC	Norfolk	188451.44	0.00	193,150.44
	Rains	0.00	4699.00	
Darlington SC	Ailey	0.00	3867.00	101,162.97
	Emporia	1775.82	0.00	
	Norfolk	95520.16	0.00	
Dillon SC	Ailey	0.00	2413.00	77,103.90
	Emporia	1363.23	0.00	
	Norfolk	73327.66	0.00	
Florence SC	Ailey	0.00	6994.00	99,480.36
	Emporia	1688.03	0.00	
	Norfolk	90798.33	0.00	
Georgetown SC	Ailey	0.00	3776.00	14,809.52
	Emporia	201.38	0.00	
	Norfolk	10832.14	0.00	
Horry SC	Ailey	0.00	9217.00	83,135.47
	Emporia	1349.14	0.00	
	Norfolk	72569.34	0.00	
Marion SC	Ailey	0.00	5344.00	36,913.56
	Emporia	576.20	0.00	
	Norfolk	30993.37	0.00	
Marlboro SC	Ailey	0.00	1756.00	63,570.83
	Emporia	1128.22	0.00	
	Norfolk	60686.60	0.00	
Williamsburg SC	Ailey	0.00	11784.00	86,840.84
	Emporia	1369.91	0.00	
	Norfolk	73686.92	0.00	

Table B.4 Storage Dry Matter Loss (%)

	Round Bale						Square Bale		
Days	Uncoverd	pallet	gravel	tarp	tarp+pallet	tarp+gravel	Uncoverd	tarp+pallet	tarp+gravel
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	2.86	2.86	2.86	0.96	0.96	0.96	11.98	6.81	6.81
60	5.12	5.12	5.12	1.87	1.87	1.87	20.98	12.16	12.16
90	6.90	6.90	6.90	2.74	2.74	2.74	27.74	16.37	16.37
120	8.31	8.31	8.31	3.57	3.57	3.57	32.81	19.68	19.68
150	9.43	9.43	9.43	4.36	4.36	4.36	36.62	22.28	22.28
180	10.31	10.31	10.31	5.12	5.12	5.12	39.48	24.33	24.33
210	11.00	11.00	11.00	5.84	5.84	5.84	41.63	25.94	25.94
240	11.55	11.55	11.55	6.52	6.52	6.52	43.24	27.21	27.21
270	11.98	11.98	11.98	7.18	7.18	7.18	44.46	28.20	28.20
300	12.33	12.33	12.33	7.80	7.80	7.80	45.36	28.99	28.99
330	12.60	12.60	12.60	8.40	8.40	8.40	46.05	29.60	29.60
360	12.81	12.81	12.81	8.96	8.96	8.96	46.56	30.09	30.09

Table B.5 Storage Material Cost ($/dt/year)

Round		Square	
Uncovered	0	Uncovered	0
Pallet	4.33	Tarp+Pallet	5.64
Gravel	13.92	Tarp+Gravel	10.75
Tarp	4.84		
Tarp+Pallet	7.75		
Tarp+Gravel	17.78		

Table B.6 The Cost per Dry-ton of Transportation (Distance = 50 miles, Tennessee)

Cost of Item	Round	Rectangular
Semi-Tractor Trailer ($/hour)	106.61	110.15
Speed (miles/hour)	50	50
Distance (miles)	50.0	50.0
Driver Wage ($/hour)	18.17	17.68
Labor Wage ($/hour)	11.37	11.52
Loading Time (hours/load)	0.75	0.75
Travel Hours	2.00	2.00
Bales/Load (#)	36	24
Bale Weight (tons/bale)	0.37	0.67
Weight Per Load (tons)	13.18	16.01
Weight Transported (tons/hour)	6.59	8.00
Semi-Tractor Trailer Cost ($/ton)	16.18	13.76
Driver ($/ton)	3.79	3.04
Loader/Unloader Cost ($/ton)	0.65	0.54
Transportation Cost ($/ton)	20.62	17.34

Table B.7 Annual Transportation Cost for Switchgrass around Davidson TN

County	Transportation cost ($/dry-ton)	
	Round	Rectangular
Cannon TN	20.47	16.85
Cheatham TN	8.31	6.84
Davidson TN	0	0
Dickson TN	14.07	11.58
Hickman TN	19.94	16.41
Macon TN	20.09	16.54
Marshall TN	20.62	16.97
Maury TN	18.16	14.95
Montgomery TN	16.15	13.29
Robertson TN	10.02	8.24
Rutherford TN	9.83	8.09
Smith TN	19.30	15.88
Sumner TN	11.30	9.30
Trousdale TN	16.23	13.36
Williamson TN	10.17	8.37
Wilson TN	11.99	9.86
Logan KY	18.42	15.17
Simpson KY	16.23	13.36
Todd KY	20.21	16.63

Table B.8 Annual Transportation Cost for Switchgrass around Shelby TN

County	Transportation cost ($/dry-ton)	
	Round	Rectangular
Fayette TN	14.98	12.33
Haywood TN	19.45	16.01
Lauderdale TN	18.24	15.01
Shelby TN	0	0
Tipton TN	11.42	9.40
De Soto MS	10.70	8.80
Marshall MS	16.76	13.79
Tate MS	16.11	13.26
Tunica MS	19.03	15.66
Crittenden AR	11.42	9.40
Cross AR	19.07	15.70
Mississippi AR	16.91	13.92
Poinsett AR	19.49	16.04
St Francis AR	19.60	16.13

Table B.9 Annual Transportation Cost for Switchgrass around Marion SC

County	Transportation cost ($/dry-ton)	
	Round	Rectangular
Columbus NC	18.66	15.36
Robeson NC	17.03	14.02
Darlington SC	17.18	14.14
Dillon SC	11.01	9.07
Florence SC	9.31	7.66
Georgetown SC	17.81	14.66
Horry SC	11.44	9.42
Marion SC	0	0
Marlboro SC	17.38	14.30
Williamsburg SC	17.26	14.21

Table B.10 Carbon Stored and Emitted during Farm Activities and Transportation in Davidson TN Location

County	Carbon Stored		Carbon Emitted	
	Crop land (metric ton/acre)	Pasture Land (metric ton/acre)	Round (metric ton/acre)	Rectangular (metric ton/acre)
Cannon TN	0.1655	0.0097	0.0091	0.0075
Cheatham TN	0.1911	0.0225	0.0032	0.0027
Davidson TN	0.1954	0.0247	0.0000	0.0000
Dickson TN	0.2218	0.0379	0.0060	0.0050
Hickman TN	0.1769	0.0154	0.0089	0.0073
Macon TN	0.1826	0.0183	0.0090	0.0074
Marshall TN	0.1622	0.0081	0.0092	0.0076
Maury TN	0.2390	0.0464	0.0080	0.0066
Montgomery TN	0.2484	0.0512	0.0070	0.0058
Robertson TN	0.2382	0.0460	0.0041	0.0033
Rutherford TN	0.1696	0.0118	0.0040	0.0033
Smith TN	0.1910	0.0225	0.0086	0.0071
Sumner TN	0.2152	0.0345	0.0047	0.0039
Trousdale TN	0.1781	0.0160	0.0071	0.0058
Williamson TN	0.2202	0.0370	0.0041	0.0034
Wilson TN	0.1425	-0.0018	0.0050	0.0041
Logan KY	0.2848	0.0694	0.0082	0.0067
Simpson KY	0.2590	0.0565	0.0071	0.0058
Todd KY	0.2525	0.0532	0.0090	0.0074

Table B.11 Carbon Stored and Emitted during Farm Activities and Transportation in Shelby TN Location

County	Carbon Stored		Carbon Emitted	
	Crop land (metric ton/acre)	Pasture Land (metric ton/acre)	Round (metric ton/acre)	Rectangular (metric ton/acre)
Fayette TN	0.109	-0.018	0.0065	0.0053
Haywood TN	0.109	-0.018	0.0086	0.0071
Lauderdale TN	0.123	-0.012	0.0081	0.0066
Shelby TN	0.121	-0.012	0.0000	0.0000
Tipton TN	0.120	-0.013	0.0047	0.0039
De Soto MS	0.136	-0.001	0.0044	0.0036
Marshall MS	0.129	-0.004	0.0073	0.0060
Tate MS	0.133	-0.002	0.0070	0.0058
Tunica MS	0.229	0.046	0.0084	0.0070
Crittenden AR	0.185	0.024	0.0047	0.0039
Cross AR	0.182	0.022	0.0085	0.0070
Mississippi AR	0.217	0.040	0.0074	0.0061
Poinsett AR	0.153	0.008	0.0087	0.0071
St Francis AR	0.180	0.021	0.0087	0.0072

Table B.12 Carbon Stored and Emitted during Farm Activities and Transportation in Marion SC Location

County	Carbon Stored		Carbon Emitted	
	Crop land (metric ton/acre)	Pasture Land (metric ton/acre)	Round (metric ton/acre)	Rectangular (metric ton/acre)
Columbus NC	0.422	0.138	0.0081	0.0066
Robeson NC	0.310	0.082	0.0073	0.0060
Darlington SC	0.337	0.096	0.0074	0.0061
Dillon SC	0.244	0.049	0.0044	0.0037
Florence SC	0.399	0.127	0.0036	0.0030
Georgetown SC	0.430	0.142	0.0077	0.0063
Horry SC	0.375	0.115	0.0046	0.0038
Marion SC	0.284	0.069	0.0000	0.0000
Marlboro SC	0.284	0.069	0.0075	0.0061
Williamsburg SC	0.326	0.090	0.0074	0.0061

Table B.13 Scenarios for Base[a] and Alternative[b] Models

Scenario	Plant size (gallons/year)	Switchgrass Price ($/dry-ton)	Land Share[c]	Carbon Credit
1	15	75	Mean	Yes
2	15	75	Mean	No
3	15	90	Mean	Yes
4	15	90	Mean	No
5	15	110	Mean	Yes
6	15	110	Mean	No
7	50	75	Mean	Yes
8	50	75	Mean	No
9	50	90	Mean	Yes
10	50	90	Mean	No
11	50	110	Mean	Yes
12	50	110	Mean	No
13	100	75	Mean	Yes
14	100	75	Mean	No
15	100	90	Mean	Yes
16	100	90	Mean	No
17	100	110	Mean	Yes
18	100	110	Mean	No
19	50	75	Low	Yes
20	50	75	Low	No
21	50	75	High	Yes
22	50	75	High	No

[a] In the base scenario, plant size is assumed to be 50 million gallons per year, switchgrass price is assumed $75/dry ton, and no carbon.
[b] Other scenarios except the base scenario shown in this table are alternative scenarios.
[c] In scenarios 1 -18, land share are the mean land share estimated by the Tobit model. Scenario 19 uses land share that is 5% lower than the estimated land share. Scenarios 20 uses land share that is 5% higher than the estimated land share.

APPENDIX C

Table C.1 Probit Model for Probability of Being Interested in Growing Switchgrass for Biorefinery (N=642)

Variable	Estimated Coefficient	Standard Error
Price	0.0104***	0.0021
Interest		
somewhat interested	2.0740***	0.4611
very interested	2.6863***	0.4755
Education		
some high school	1.5498***	0.5977
high school	0.8370*	0.4742
some college	0.9048*	0.4750
college	0.9095*	0.4725
post graduate	0.8965*	0.4869
Age60	-0.0490	0.1187
Off_farm	0.3152**	0.1471
State		
Arkansas	(0.0408)	0.2978
Georgia	(0.2833)	0.2814
Kentucky	(0.6375)**	0.2552
Louisiana	(0.8100)***	0.3125
Mississippi	(0.2881)	0.2766
North Carolina	(0.6301)**	0.2815
Oklahoma	(0.1547)	0.2922
South Carolina	(0.2427)	0.2784
Tennessee	(0.2359)	0.2672
Texas	(0.2837)	0.3031
Virginia	(0.3179)	0.2550
cons	(3.2011)	0.7240
Wald $chi^2(22)$= 84.22***		

Notes: *, **, and *** denote statistical significance at the10%, 5%, and 1% levels, respectively.

Table C.2 Estimated Farmers' WTA to Plant Switchgrass

State	Estimated WTA ($/dry-ton)	Standard Error	95% Confidence Interval	
Arkansas	98.81***	29.39	41.79678	156.4153
Kentucky	103.71***	21.12	62.31370	145.1064
Mississippi	97.39***	24.70	48.98432	145.7927
North Carolina	106.49***	22.61	62.17349	150.8040
South Carolina	81.71***	23.77	35.12132	128.2916
Tennessee	116.00***	27.22	62.65141	169.3415

Notes: *, **, and *** denote statistical significance at the10%, 5%, and 1% levels, respectively.

Table C.3 Tobit Model for Land Share Used to Grow Switchgrass for Biorefinery (N=570)

Variable	Estimated Coefficient	Standard Error
Price	0.0027***	0.0010
Farminc		
Farminc50	(0.1745)**	0.0761
Farminc1025	(0.0823)	0.0662
Farminc2550	(0.1626)**	0.0691
Off_farm	0.0393	0.0752
Pasture	(0.0738)	0.0585
State		
Arkansas	(0.1104)	0.0951
Georgia	(0.0651)	0.1048
Kentucky	(0.3216)***	0.0933
Louisiana	(0.3116)**	0.1227
Mississippi	(0.0425)	0.1506
North Carolina	(0.2403)*	0.1231
Oklahoma	(0.1172)	0.1016
South Carolina	0.0523	0.1063
Tennessee	(0.1962)**	0.0964
Texas	(0.2438)**	0.1039
Virginia	(0.2665)***	0.0845
cons	0.2298	0.1416
Sigma= .5379		
F(17,553)= 2.55***		

Notes: *, **, and *** denote statistical significance at the10%, 5%, and 1% levels, respectively.

Table C.4 Estimated Average Land Proportion Used for Switchgrass

State	Switchgrass Price ($/dry-ton)	Estimated Land Proportion	Standard Error
Arkansas	75	26.93%***	0.0695
	90	30.91%***	0.0695
	110	36.23%***	0.0740
Kentucky	75	6.29%	0.0717
	90	10.27%	0.0713
	110	15.59%**	0.0753
Mississippi	75	34.13%**	0.1367
	90	38.11%***	0.1432
	110	43.43%***	0.1536
North Carolina	75	15.18%	0.1037
	90	19.17%*	0.1060
	110	24.48%**	0.1119
South Carolina	75	42.77%***	0.1028
	90	46.76%***	0.1023
	110	52.07%***	0.1048
Tennessee	75	19.49%***	0.0708
	90	23.48%***	0.0696
	110	28.80%***	0.0726

Notes: *, **, and *** denote statistical significance at the10%, 5%, and 1% levels, respectively.

Table C.5 Simulated Switchgrass Yield in Davidson TN Location

County	Soil	Avg dt/Acre	Index	Adj Avg dt/Acre
Cannon TN	Armour	5.07	1.07	5.47
	Dellrose	4.23	0.89	4.56
	Dickson	5.51	1.17	5.94
Cheatham TN	Pembroke	4.44	0.94	4.79
	Sengtown	3.52	0.75	3.80
Davidson TN	Armour	4.09	0.87	4.41
	Dellrose	3.65	0.77	3.94
	Dickson	4.37	0.93	4.72
Dickson TN	Pembroke	4.96	1.05	5.35
	Sengtown	3.90	0.83	4.21
Hickman TN	Pembroke	4.80	1.02	5.18
	Sengtown	3.95	0.83	4.26
Macon TN	Armour	5.86	1.24	6.33
	Dellrose	4.56	0.96	4.92
	Dickson	5.48	1.16	5.91
Marshall TN	Armour	4.94	1.04	5.33
	Dellrose	4.18	0.88	4.51
	Dickson	5.33	1.13	5.75
Maury TN	Armour	4.92	1.04	5.31
	Dellrose	4.11	0.87	4.44
	Dickson	5.01	1.06	5.41
Montgomery TN	Pembroke	5.21	1.10	5.62
	Sengtown	4.09	0.87	4.41
Robertson TN	Pembroke	4.33	0.92	4.67
	Sengtown	3.49	0.74	3.77
Rutherford TN	Armour	5.22	1.10	5.63
	Dellrose	4.32	0.91	4.66
	Dickson	5.20	1.10	5.62
Smith TN	Armour	5.87	1.24	6.33
	Dellrose	5.11	1.08	5.52
	Dickson	6.28	1.33	6.78
Sumner TN	Armour	4.01	0.85	4.32
	Dellrose	3.66	0.77	3.95
	Dickson	4.28	0.91	4.62

Table C.5 Simulated Switchgrass Yield in Davidson TN Location (con'd)

County	Soil	Avg dt/Acre	Index	Adj Avg dt/Acre
Trousdale TN	Armour	5.53	1.17	5.96
	Dellrose	4.62	0.98	4.98
	Dickson	5.72	1.21	6.17
Williamson TN	Armour	4.63	0.98	4.99
	Dellrose	4.09	0.87	4.42
	Dickson	5.14	1.09	5.54
Wilson TN	Armour	3.95	0.84	4.26
	Dellrose	3.70	0.78	4.00
	Dickson	4.60	0.97	4.96
Logan KY	Loring	4.47	0.95	4.83
	Pembroke	4.21	0.89	4.54
	Zanesville	3.72	0.79	4.01
Simpson KY	Loring	6.10	1.29	6.58
	Pembroke	6.05	1.28	6.53
	Zanesville	5.17	1.09	5.58
Todd KY	Loring	5.02	1.06	5.41
	Pembroke	4.54	0.96	4.90
	Zanesville	3.75	0.79	4.05

Table C.6 Simulated Switchgrass Yield in Shelby TN Location

County	Soil	Avg dt/Acre	Index	Adj Avg dt/Acre
Fayette TN	Collins	3.99	1.22	6.24
	Lexington	4.27	1.31	6.68
	Loring	4.73	1.45	7.40
Haywood TN	Collins	2.93	0.90	4.59
	Lexington	3.52	1.08	5.51
	Loring	3.64	1.12	5.70
Lauderdale TN	Adler	3.04	0.93	4.76
	Memphis	3.20	0.98	5.01
Shelby TN	Adler	3.50	1.07	5.48
	Memphis	4.16	1.28	6.51
Tipton TN	Adler	2.91	0.89	4.55
	Memphis	3.31	1.02	5.18
De Soto MS	Collins	2.66	0.82	4.17
	Loring	3.75	1.15	5.87
Marshall MS	Collins	4.12	1.26	6.45
	Loring	4.52	1.39	7.08
Tate MS	Collins	2.66	0.82	4.17
	Loring	3.63	1.11	5.68
Tunica MS	Memphis	2.65	0.81	4.15
	Sharkey	2.37	0.73	3.72
Crittenden AR	Crowley	2.79	0.86	4.37
	Loring	3.55	1.09	5.55
	Sharkey	2.37	0.73	3.71
Cross AR	Crowley	2.91	0.89	4.56
	Loring	4.02	1.23	6.29
	Sharkey	2.67	0.82	4.17
Mississippi AR	Foley	4.36	1.34	6.83
	Linker	2.15	0.66	3.37
	Sharkey	2.48	0.76	3.88
Poinsett AR	Foley	3.99	1.22	6.24
	Linker	2.09	0.64	3.27
	Sharkey	2.41	0.74	3.77
St Francis AR	Crowley	2.84	0.87	4.45
	Loring	3.49	1.07	5.46
	Sharkey	2.37	0.73	3.71

Table C.7 Simulated Switchgrass Yield in Marion SC Location

County	Soil	Avg dt/Acre	Index	Adj Avg dt/Acre
Columbus NC	Norfolk	4.91	1.44	7.34
	Rains	2.97	0.87	4.44
Robeson NC	Norfolk	4.00	1.17	5.99
	Rains	3.58	1.05	5.36
Darlington SC	Ailey	3.25	0.95	4.87
	Emporia	3.30	0.97	4.94
	Norfolk	3.87	1.14	5.79
Dillon SC	Ailey	3.26	0.96	4.88
	Emporia	3.25	0.95	4.87
	Norfolk	3.66	1.07	5.48
Florence SC	Ailey	3.14	0.92	4.71
	Emporia	3.12	0.92	4.68
	Norfolk	3.42	1.00	5.12
Georgetown SC	Ailey	3.20	0.94	4.79
	Emporia	3.20	0.94	4.80
	Norfolk	3.42	1.00	5.12
Horry SC	Ailey	3.14	0.92	4.70
	Emporia	3.16	0.93	4.73
	Norfolk	3.42	1.00	5.12
Marion SC	Ailey	3.18	0.93	4.77
	Emporia	3.19	0.94	4.77
	Norfolk	3.42	1.00	5.12
Marlboro SC	Ailey	3.26	0.96	4.88
	Emporia	3.28	0.96	4.91
	Norfolk	3.84	1.13	5.74
Williamsburg SC	Ailey	3.25	0.95	4.87
	Emporia	3.27	0.96	4.89
	Norfolk	3.42	1.00	5.12

APPENDIX D

Table D.1 Sensitivity Analysis of the Total Delivered Costs in All Scenarios in Davidson Area

Scenario	Plant size (gal/year)	Switchgrass Price ($/dt)	Land Share	Carbon Credit	Carbon Price ($/dt)	Acreage planted (acre/year)	Tonnage harvested (dt/year)	Total delivered costs ($/year)	Government Payment ($/year)	Feedstock Cost at plant gate ($/gal)
1	15	75	Mean	Yes	1.20	40,943.03	181,602.06	14,923,020.00	217,762.95	0.99
2	15	75	Mean	No	0	38,374.10	181,602.06	15,126,860.00	0	1.01
3	15	90	Mean	Yes	1.23	41,867.08	181,602.06	17,612,450.00	223,864.30	1.17
4	15	90	Mean	No	0	38,297.62	181,602.06	17,821,570.00	0	1.19
5	15	110	Mean	Yes	1.24	42,405.05	181,602.06	21,207,650.00	225,102.56	1.41
6	15	110	Mean	No	0	37,420.57	181,602.06	21,414,860.00	0	1.43
7	50	75	Mean	Yes	0.85	127,615.28	605,340.23	51,392,060.00	515,694.16	1.03
8	50	75	Mean	No	0	127,139.60	605,340.23	51,908,850.00	0	1.04
9	50	90	Mean	Yes	0.87	131,082.24	605,340.23	59,968,280.00	526,591.86	1.20
10	50	90	Mean	No	0	131,975.89	605,340.23	60,499,290.00	0	1.21
11	50	110	Mean	Yes	0.86	132,345.53	605,340.23	71,604,250.00	518,484.13	1.43
12	50	110	Mean	No	0	132,345.53	605,340.23	72,127,260.00	0	1.44
13	100	75	Mean	Yes						
14	100	75	Mean	No						
15	100	90	Mean	Yes	0.82	244,751.30	1,210,680.32	124,137,600.00	992,188.48	1.24
16	100	90	Mean	No	0	244,769.53	1,210,680.32	125,118,400.00	0	1.25
17	100	110	Mean	Yes	0.87	250,091.87	1,210,680.32	146,899,100.00	1,051,531.74	1.47
18	100	110	Mean	No	0	249,903.79	1,210,680.32	147,959,600.00	0	1.48
19	50	75	Low	Yes	0.78	123,812.64	605,340.23	52,469,110.00	474,437.90	1.05
20	50	75	Low	No	0	123,673.63	605,340.23	52,944,020.00	0	1.06
21	50	75	High	Yes	0.86	132,089.87	605,340.23	50,776,400.00	522,423.97	1.02
22	50	75	High	No	0	132,358.61	605,340.23	51,303,170.00	0	1.03

Table D.2 Sensitivity Analysis of the Total Delivered Costs in All Scenarios in Shelby Area

Scenario	Plant size (gal/year)	Switchgrass Price ($/dt)	Land Share	Carbon Credit	Carbon Price ($/dt)	Acreage planted (acre/year)	Tonnage harvested (dt/year)	Total delivered costs ($/year)	Government Payment ($/year)	Feedstock Cost at plant gate ($/gal)
1	15	75	Mean	Yes	0.74	39,438.20	181,602.06	14,663,330.00	133,936.16	0.98
2	15	75	Mean	No	0	34,765.85	181,602.06	14,781,160.00	0	0.99
3	15	90	Mean	Yes	0.65	37,705.94	181,602.06	17,265,800.00	118,691.61	1.15
4	15	90	Mean	No	0	33,185.85	181,602.06	17,383,100.00	0	1.16
5	15	110	Mean	Yes	0.61	36,204.15	181,602.06	20,739,920.00	110,861.98	1.38
6	15	110	Mean	No	0	33,723.10	181,602.06	20,852,350.00	0	1.39
7	50	75	Mean	Yes	0.83	133,098.95	605,340.23	50,419,330.00	504,859.31	1.01
8	50	75	Mean	No	0	132,762.28	605,340.23	50,929,970.00	0	1.02
9	50	90	Mean	Yes	0.88	133,697.13	605,340.23	59,333,900.00	533,047.52	1.19
10	50	90	Mean	No	0	130,618.15	605,340.23	59,865,940.00	0	1.20
11	50	110	Mean	Yes	0.88	134,206.83	605,340.23	71,250,660.00	531,922.24	1.43
12	50	110	Mean	No	0	126,321.50	605,340.23	71,780,570.00	0	1.44
13	100	75	Mean	Yes	0.58	231,494.59	1,210,680.32	103,652,100.00	701,184.39	1.04
14	100	75	Mean	No	0	225,555.14	1,210,680.32	104,359,500.00	0	1.04
15	100	90	Mean	Yes	0.76	256,882.84	1,210,680.32	121,472,700.00	923,644.63	1.21
16	100	90	Mean	No	0	238,815.49	1,210,680.32	122,370,000.00	0	1.22
17	100	110	Mean	Yes	0.67	248,315.34	1,210,680.32	144,878,000.00	814,701.38	1.45
18	100	110	Mean	No	0	244,208.13	1,210,680.32	145,698,400.00	0	1.46
19	50	75	Low	Yes	0.74	127,321.17	605,340.23	50,918,360.00	447,944.43	1.02
20	50	75	Low	No	0	126,411.59	605,340.23	51,371,280.00	0	1.03
21	50	75	High	Yes	0.89	133,756.75	605,340.23	50,212,410.00	538,035.95	1.00
22	50	75	High	No	0	128,717.14	605,340.23	50,749,250.00	0	1.01

Table D.3 Sensitivity Analysis of the Total Delivered Costs in All Scenarios in Marion

Scenario	Plant size (gal/year)	Switchgrass Price ($/dt)	Land Share	Carbon Credit	Carbon Price ($/dt)	Acreage planted (acre/year)	Tonnage harvested (dt/year)	Total delivered costs ($/year)	Government Payment ($/year)	Feedstock Cost at plant gate ($/gal)
1	15	75	Mean	Yes	1.73	35,704.28	181,602.06	14,248,630.00	313,974.84	0.95
2	15	75	Mean	No	0	35,943.81	181,602.06	14,564,170.00	0	0.97
3	15	90	Mean	Yes	1.70	35,726.20	181,602.06	16,925,610.00	309,046.20	1.13
4	15	90	Mean	No	0	35,988.06	181,602.06	17,236,200.00	0	1.15
5	15	110	Mean	Yes	1.67	35,755.43	181,602.06	20,494,930.00	302,474.67	1.37
6	15	110	Mean	No	0	36,047.07	181,602.06	20,798,910.00	0	1.39
7	50	75	Mean	Yes	1.64	116,921.92	605,340.23	49,372,900.00	991,140.37	0.99
8	50	75	Mean	No	0	116,944.26	605,340.23	50,358,160.00	0	1.01
9	50	90	Mean	Yes	1.69	117,524.08	605,340.23	58,332,370.00	1,021,527.59	1.17
10	50	90	Mean	No	0	116,824.33	605,340.23	59,326,880.00	0	1.19
11	50	110	Mean	Yes	1.75	118,326.97	605,340.23	70,278,580.00	1,062,040.81	1.41
12	50	110	Mean	No	0	116,663.44	605,340.23	71,285,170.00	0	1.43
13	100	75	Mean	Yes	1.51	226,315.61	1,210,680.32	102,817,100.00	1,828,679.03	1.03
14	100	75	Mean	No	0	225,315.05	1,210,680.32	104,635,500.00	0	1.05
15	100	90	Mean	Yes	1.54	228,571.84	1,210,680.32	120,527,800.00	1,860,856.45	1.21
16	100	90	Mean	No	0	223,155.64	1,210,680.32	122,348,500.00	0	1.22
17	100	110	Mean	Yes	1.56	230,945.28	1,210,680.32	144,145,800.00	1,884,861.83	1.44
18	100	110	Mean	No	0	224,535.32	1,210,680.32	145,977,100.00	0	1.46
19	50	75	Low	Yes	1.59	117,134.80	605,340.23	49,663,320.00	963,676.78	0.99
20	50	75	Low	No	0	116,409.84	605,340.23	50,618,170.00	0	1.01
21	50	75	High	Yes	1.70	117,676.96	605,340.23	49,221,640.00	1,029,242.33	0.98
22	50	75	High	No	0	116,793.88	605,340.23	50,218,500.00	0	1.00

Table D.4 Land Acre Planted on Soil Type and Land Use for Base Scenario in Davidson

Soil	Land Use	County					
		Cheatham	Davidson	Dickson	Maury	Montgomery	Robertson
Armour	Crop		845.38				
	Pasture		1,286.34		2,804.62		
Dellrose	Crop		295.63				
Dickson	Crop		373.02				
Loring	Crop						
Pembroke	Crop	2,108.99		3,675.49		7,292.20	15,217.67
Sengtown	Crop	1,269.34		2,212.18		4,388.98	9,159.10
	Pasture	1,465.87		3,647.92		3,948.31	3,802.69
Zanesville	Pasture						
Total Acre		4,844.20	2,800.37	9,535.58	2,804.62	15,629.48	28,179.46

Table D.4 Land Acre Planted on Soil Type and Land Use for Base Scenario in Davidson (con'd)

Soil	Land Use	County					
		Rutherford	Sumner	Trousdale	Williamson	Wilson	Simpson
Armour	Crop	5,627.10	6,197.82	1,395.55	4,827.58	4,508.80	
	Pasture	3,558.64	4,706.00	1,154.96	3,782.23	4,373.64	
Dellrose	Crop	1,967.82	2,167.40	488.03	1,688.23	1,576.75	
Dickson	Crop	2,482.93	2,734.76	615.78	2,130.15	1,989.48	
Loring	Crop						1,126.62
Pembroke	Crop						3,888.39
Sengtown	Crop						
	Pasture						
Zanesville	Pasture						357.25
Total Acre		13,636.48	15,805.98	3,654.32	12,428.18	12,448.66	5,372.27

Table D.5 Harvest Schedule and Arrangement for Switchgrass from November to February for Base Scenario in Davidson Area

Month	Soil Type	Land Use	County						Harvest Method		Arrangement Activity
			Cheatham		Davidson		Dickson				
			Acre	Dry-ton	Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Armour	Crop			698.77	3,081.58			√		Store
	Pembroke	Crop	1,230.95	4,677.62					√		
		Pasture	117.46	446.35					√		
	Sengtown	Pasture					251.85	1,060.28	√		
	Pembroke	Crop					1,603.77	8,580.14		√	Deliver
	Sengtown	Crop					342.82	1,443.29		√	
Dec	Armour	Pasture			698.77	3,081.58			√		Store
	Sengtown	Pasture	1,348.41	5,123.97			251.85	1,060.28	√		
	Pembroke	Crop					1,873.54	10,023.43		√	Deliver
Jan	Armour	Crop			35.41	156.14			√		Store
	Dellrose	Crop			295.63	1,164.79			√		
	Dickson	Crop			373.02	1,760.64			√		
	Pembroke	Crop	1,039.27	4,978.08					√		
	Sengtown	Crop	38.39	145.88					√		
		Pasture					251.85	1,060.28	√		
		Crop					1,869.35	7,869.97		√	Deliver
		Pasture					511.51	2,153.46		√	
Feb	Armour	Crop			111.20	490.39			√		Store
		Pasture			587.57	2,591.19			√		
	Pembroke	Crop	1,069.72	5,123.97			198.18	1,060.28	√		
		Pasture							√		
	Sengtown	Pasture					2,380.86	10,023.43		√	Deliver

Table D.5 Harvest Schedule and Arrangement for Switchgrass from November to February for Base Scenario in Davidson Area (Con'd)

Month	Soil Type	Land Use	County						Harvest Method		Arrangement Activity
			Maury		Montgomery		Robertson				
			Acre	Dry-ton	Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Pembroke	Crop					5,446.77	25,436.43	√		Store
	Sengtown	Crop					1,206.02	4,546.68	√		
	Armour	Pasture	701.16	3,723.14						√	Deliver
	Pembroke	Crop			374.98	2,107.38				√	
	Sengtown	Crop			3,929.71	17,330.02				√	
Dec	Pembroke	Crop					3,350.53	15,646.96	√		Store
	Sengtown	Pasture					3,802.69	14,336.15	√		
	Armour	Pasture	701.16	3,723.14						√	Deliver
	Pembroke	Crop			3,458.61	19,437.39				√	
Jan	Pembroke	Crop					6,420.37	29,983.11	√		Store
	Armour	Pasture	701.16	3,723.14						√	Deliver
	Pembroke	Crop			3,458.61	19,437.39				√	
Feb	Sengtown	Crop					7,953.08	29,983.11	√		Store
	Armour	Pasture	701.16	3,723.14						√	Deliver
	Sengtown	Crop			459.27	2,025.37				√	
		Pasture			3,948.31	17,412.03				√	

Table D.5 Harvest Schedule and Arrangement for Switchgrass from November to February for Base Scenario in Davidson Area (Con'd)

Month	Soil Type	Land Use	County						Harvest Method		Arrangement Activity
			Rutherford		Sumner		Trousdale				
			Acre	Dry-ton	Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Armour	Crop	2,303.84	12,970.61					√		Store
		Pasture			3,952.57	17,075.08			√		
	Dickson	Crop	1,021.23	5,739.34					√		
	Armour	Crop					496.61	2,959.79		√	Deliver
		Pasture					256.02	1,525.86		√	
	Dellrose	Crop					175.11	872.05		√	
Dec	Armour	Crop			3,199.13	13,820.25			√		Store
		Pasture	3,323.26	18,709.94	753.43	3,254.83			√		
	Armour	Crop					898.94	5,357.70		√	Deliver
Jan	Armour	Crop	3,323.26	18,709.94	1,970.80	8,513.83			√		Store
	Dellrose	Crop			2,167.40	8,561.25			√		
	Dellrose	Crop					312.92	1,558.34		√	Deliver
	Dickson	Crop					615.78	3,799.36		√	
Feb	Armour	Crop			1,027.90	4,440.51			√		Store
		Pasture	235.38	1,325.20					√		
	Dellrose	Crop	1,967.82	9,170.04					√		
	Dickson	Crop	1,461.69	8,214.71	2,734.76	12,634.57			√		
	Armour	Pasture					898.94	5,357.70		√	Deliver

Table D.5 Harvest Schedule and Arrangement for Switchgrass from November to February for Base Scenario in Davidson Area (Con'd)

Month	Soil Type	Land Use	County						Harvest Method		Arrangement Activity
			Williamson		Wilson		Simpson				
			Acre	Dry-ton	Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Armour	Crop			853.44	3,635.67			√		Store
		Pasture	752.60	3,755.47					√		
	Dickson	Crop	2,130.15	11,801.00	1,989.48	9,867.83			√		
	Pembroke	Crop					1,332.23	8,699.46		√	Deliver
Dec	Armour	Crop	3,117.53	15,556.48	485.52	2,068.30			√		Store
		Pasture			1,203.81	5,128.22			√		
	Dellrose	Crop			1,576.75	6,306.98			√		
	Pembroke	Crop					1,026.95	6,706.00		√	Deliver
	Zanesville	Pasture					357.25	1,993.46		√	
Jan	Armour	Crop	87.91	438.65	3,169.84	13,503.50			√		Store
		Pasture	3,029.63	15,117.83					√		
	Loring	Crop					1,126.62	7,413.17		√	Deliver
	Pembroke	Crop					196.98	1,286.29		√	
Feb	Armour	Crop	1,622.15	8,094.52					√		Store
		Pasture			3,169.84	13,503.50			√		
	Dellrose	Crop	1,688.23	7,461.96					√		
	Pembroke	Crop					1,332.23	8,699.46		√	Deliver

Table D.6 Delivery Schedule for Stored Switchgrass for Base Scenario in Davidson Area

Month	Harvested Month	Soil	Land Use	County			
				Cheatham	Davidson	Dickson	Robertson
Mar	Feb	Armour	Crop		476.37		
			Pasture		2,517.09		
		Pembroke	Crop	4,977.43			
		Sengtown	Crop				21,095.35
Apr	Feb	Sengtown	Crop				7,843.57
	Feb	Pembroke	Crop			987.09	
May	Jan	Armour	Crop		143.16		
		Dellrose	Crop		1,067.96		
		Dickson	Crop		1,614.28		
		Pembroke	Crop	4,564.26			17,282.36
		Sengtown	Crop	133.76			
Jun	Jan	Pembroke	Crop				10,084.30
	Jan	Sengtown	Pasture			951.01	
Jul	Dec	Armour	Pasture		2,742.58		
		Pembroke	Crop				13,925.65
		Sengtown	Pasture	4,560.28			3,825.55
Aug	Dec	Sengtown	Pasture				8,878.40
	Dec	Sengtown	Pasture			933.22	
Sep	Nov	Armour	Crop		2,701.75		
		Pembroke	Crop				20,278.15
		Sengtown	Crop	4,101.06			
			Pasture	391.33			
Oct	Nov	Pembroke	Crop				2,016.77
		Sengtown	Crop				3,973.96
			Pasture			926.72	

Table D.6 Delivery Schedule for Stored Switchgrass for Base Scenario in Davidson Area (Con'd)

Month	Harvested Month	Soil	Land Use	County			
				Rutherford	Sumner	Williamson	Wilson
Mar	Feb	Armour	Pasture	1,287.30			
		Dellrose	Crop	8,907.80			
		Dickson	Crop	7,979.78			
Apr	Feb	Armour	Crop		4,213.21	7,680.18	
			Pasture				8,436.33
		Dellrose	Crop			7,080.00	
		Dickson	Crop		11,987.83		
May	Feb	Armour	Pasture				4,293.65
	Jan	Armour	Crop	17154.6			
Jun	Jan	Armour	Crop		7,711.28	397.30	7,601.27
			Pasture				13,692.76
		Dellrose	Crop		7,754.22		
		Dickson	Crop				
Jul	Jan	Armour	Crop				4,584.37
	Dec	Armour	Pasture	16,651.68			
Aug	Dec	Armour	Crop		12,224.04	13,759.73	
			Pasture		2,878.90		3,921.52
		Dellrose	Crop				5,578.54
Sep	Dec	Armour	Crop				1,820.45
			Pasture				611.39
	Nov	Armour	Crop	11,371.86			
		Dickson	Crop	5,031.91			
Oct	Nov	Armour	Crop				3,177.70
			Pasture		14,924.22	3,282.42	
		Dickson	Crop			10,314.50	8,624.83

Table D.7 Land Acre Planted on Soil Type and Land Use for Base Scenario in Shelby

Soil	Land Use	County			
		Shelby	Tipton	De Soto	Crittenden
Adler	Crop	7,163.53	16,634.32		
Collins	Crop			19,621.77	
Crowley	Crop				45,558.63
Loring	Crop			8,079.55	1,111.97
	Pasture			1,528.15	185.83
Memphis	Crop	3,469.04	5,408.54		
	Pasture	1,381.27	1,614.41		
Sharkey	Crop				21,005.27
Total Acre		12,013.84	23,657.27	29,229.47	67,861.70

Table D.8 Harvest Schedule and Arrangement for Switchgrass from November to February for Base Scenario in Shelby Area

Month	Soil Type	Land Use	County				Harvest Method		Arrangement Activity
			Shelby		Tipton				
			Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Adler	Crop	700.79	3,840.32	6,157.42	28,016.26	√		Store
	Memphis	Crop	748.93	4,875.51			√		
		Pasture	1,381.27	8,992.09			√		
Dec	Adler	Crop	3,231.37	17,707.92			√		Store
	Memphis	Pasture			1,614.41	8,362.64	√		
	Adler	Crop			4,319.48	19,653.62		√	Deliver
Jan	Adler	Crop	3,231.37	17,707.92	6,157.42	28,016.26	√		Store
Feb	Memphis	Crop	2,720.11	17,707.92			√		Store
		Crop			5,408.54	28,016.26		√	Deliver

Table D.8 Harvest Schedule and Arrangement for Switchgrass from November to February for Base Scenario in Shelby Area (Con'd)

Month	Soil Type	Land Use	County				Harvest Method		Arrangement Activity
			De Soto		Crittenden				
			Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Collins	Crop	3,048.63	12,712.77			√		Store
	Loring	Crop	2,192.84	12,871.97			√		
		Pasture	1,528.15	8,970.26	185.83	1,031.37	√		
	Sharkey	Crop			6,141.08	22,783.39	√		
	Crowley	Crop			4,504.00	19,682.46		√	Deliver
	Sharkey	Crop			7,428.21	27,558.67		√	
Dec	Crowley	Crop			9,947.00	43,468.38	√		Store
	Loring	Crop	5,886.71	34,555.00			√		
	Sharkey	Crop			7,435.99	27,587.50		√	Deliver
Jan	Collins	Crop	8,286.57	34,555.00			√		Store
	Crowley	Crop			4,037.38	17,643.35	√		
	Loring	Crop			1,111.97	6,171.41	√		
	Crowley	Crop			10,810.33	47,241.12		√	Deliver
Feb	Collins	Crop	8,286.57	34,555.00			√		Store
	Crowley	Crop			11,860.65	51,831.02	√		
		Crop			4,399.28	19,224.86		√	Deliver

Table D.9 Delivery Schedule for Stored Switchgrass for Base Scenario in Shelby Area

Month	Harvested Month	Soil	Land Use	County			
				Shelby	Tipton	De Soto	Crittenden
Mar	Feb	Collins	Crop			30,039.61	
		Memphis	Crop	17,201.52			
Apr	Feb	Collins	Crop			3,445.18	
		Crowley	Crop				43,795.95
May	Feb	Crowley	Crop				5,280.73
	Jan	Adler	Crop	16,235.87			
		Collins	Crop			25,724.52	
Jun	Jan	Adler	Crop		25,375.32		
		Collins	Crop			5,885.59	
		Crowley	Crop				15,980.21
Jul	Jan	Loring	Crop				5,535.38
	Dec	Adler	Crop	15,759.88			
		Loring	Crop			25,945.86	
Aug	Dec	Crowley	Crop				38,447.87
		Loring	Crop			4,778.12	
		Memphis	Pasture		4,015.14		
Sep	Dec	Memphis	Pasture		3,365.06		
	Nov	Adler	Crop	3,366.96			
		Collins	Crop			11,145.81	
		Loring	Crop			11,285.38	
			Pasture			5,919.61	
		Memphis	Crop	4,274.56			
			Pasture	7,883.73			
Oct	Nov	Adler	Crop		24,487.20		
		Loring	Pasture			1,938.98	901.45
		Sharkey	Crop				19,913.49

Table D.10 Land Acre Planted on Soil Type and Land Use for Base Scenario in Marion Area

Soil	Land Use	County			
		Dillon	Florence	Horry	Marion
Ailey	Pasture	1,032.00	2,991.22	3,941.96	2,285.54
Emporia	Crop	583.03	721.94	577.01	246.43
Norfolk	Crop	31,361.02	38,832.94	21,115.82	13,255.35
Total Acre		32,976.05	42,546.10	25,634.79	15,787.32

Table D.11 Harvest Schedule and Arrangement for Switchgrass from November to February for Base Scenario in Marion Area

Month	Soil Type	Land Use	County				Harvest Method		Arrangement Activity
			Dillon		Florence				
			Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Norfolk	Crop	5,480.79	30,034.72	10,561.13	54,072.99	√		Store
	Ailey	Pasture	451.48	2,203.21				√	Deliver
	Norfolk	Crop	2,316.71	12,695.55				√	
Dec	Emporia	Crop			721.94	3,378.69	√		Store
	Norfolk	Crop	5,480.79	30,034.72	9,901.23	50,694.30	√		
	Norfolk	Crop	2,718.75	14,898.76				√	Deliver
Jan	Ailey	Pasture			2,991.22	14,088.64	√		Store
	Norfolk	Crop	5,480.79	30,034.72	7,809.45	39,984.36	√		
	Norfolk	Crop	2,718.75	14,898.76				√	Deliver
Feb	Ailey	Pasture	580.52	2,832.95			√		Store
	Emporia	Crop	583.03	2,839.36			√		
	Norfolk	Crop	4,445.70	24,362.41	10,561.13	54,072.99	√		
	Norfolk	Crop	2718.752	14,898.76				√	Deliver

Table D.11 Harvest Schedule and Arrangement for Switchgrass from November to February for Base Scenario in Marion Area (Con'd)

Month	Soil Type	Land Use	County				Harvest Method		Arrangement Activity
			Horry		Marion				
			Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Ailey	Pasture			2,285.54	10,902.03	√		Store
	Norfolk	Crop			1,774.26	9,084.20	√		
	Norfolk	Crop	6,316.87	32,342.36				√	Deliver
Dec	Emporia	Crop			246.43	50,694.30	√		Store
	Norfolk	Crop			3,673.97	18,810.75	√		
	Norfolk	Crop	6,316.87	32,342.36				√	Deliver
Jan	Norfolk	Crop			3,903.56	19,986.22	√		Store
	Ailey	Pasture	3,941.96	18,527.20				√	Deliver
	Norfolk	Crop	2,698.27	13,815.16				√	
Feb	Norfolk	Crop			3,903.56	19,986.22	√		Store
	Emporia	Crop	577.005	2,729.23				√	Deliver
	Norfolk	Crop	5783.814	29613.128				√	

Table D.12 Delivery Schedule for Stored Switchgrass for Base Scenario in Marion Area

Month	Harvested Month	Soil	Land Use	County		
				Dillon	Florence	Marion
Mar	Feb	Norfolk	Crop		27,826.46	19,414.67
Apr	Feb	Norfolk	Crop	23,115.35	24,125.77	
May	Feb	Ailey	Pasture	2,637.38		
		Emporia	Crop	2,643.35		
	Jan	Ailey	Pasture		12,917.46	
		Norfolk	Crop		10,718.15	18,324.78
Jun	Jan	Norfolk	Crop	21,613.85	25,627.28	
Jul	Jan	Norfolk	Crop	5,535.38		
	Dec	Emporia	Crop		3,007.00	1,046.16
		Norfolk	Crop		20,911.19	16,741.39
Aug	Dec	Norfolk	Crop	23,184.13	24,056.99	
Sep	Dec	Norfolk	Crop	3,365.06		
	Nov	Ailey	Pasture			9,558.25
		Norfolk	Crop		26,353.32	7,964.49
Oct	Nov	Norfolk	Crop	26,251.41	20,989.71	

Table D.13 Sensitivity Analysis of the Carbon Flux in All Scenarios in Davidson Area

Scenario	Plant size (gal/year)	Switchgrass Price ($/dt)	Land Share	Carbon Credit	Carbon Stored (Metric ton)	Carbon Emitted from Farm Activities (Metric ton)	Total Mileage (Miles)	Carbon Emitted from Transportation (Metric ton)	Net Carbon Stored (Metric ton)	Net Carbon Abated (Metric ton/million gallons)
1	15	75	Mean	Yes	14,635.03	5,980.72	484,701.25	589.01	8,065.29	537.69
2	15	75	Mean	No	11,702.88	5,605.47	478,782.42	581.82	5,515.59	367.71
3	15	90	Mean	Yes	14,982.57	6,115.70	473,664.49	575.60	8,291.27	552.75
4	15	90	Mean	No	11,051.30	5,594.29	467,463.40	568.07	4,888.94	325.93
5	15	110	Mean	Yes	15,090.26	6,194.28	459,878.91	558.85	8,337.13	555.81
6	15	110	Mean	No	9,884.72	5,466.18	452,505.65	549.89	3,868.65	257.91
7	50	75	Mean	Yes	40,381.38	18,641.30	2,172,766.46	2,640.30	19,099.78	382.00
8	50	75	Mean	No	39,507.90	18,571.81	2,171,464.02	2,638.72	18,297.37	365.95
9	50	90	Mean	Yes	41,059.45	19,147.73	1,981,841.69	2,408.31	19,503.40	390.07
10	50	90	Mean	No	40,473.88	19,278.27	1,981,841.69	2,408.31	18,787.30	375.75
11	50	110	Mean	Yes	40,718.32	19,332.27	1,796,352.84	2,182.94	19,203.12	384.06
12	50	110	Mean	No	40,599.24	19,332.27	1,796,352.84	2,182.94	19,084.03	381.68
13	100	75	Mean	Yes						
14	100	75	Mean	No						
15	100	90	Mean	Yes	79,264.52	35,751.85	5,567,026.26	6,764.95	36,747.72	367.48
16	100	90	Mean	No	77,600.44	35,754.51	5,559,133.65	6,755.36	35,090.57	350.91
17	100	110	Mean	Yes	81,587.07	36,531.97	5,027,627.95	6,109.48	38,945.62	389.46
18	100	110	Mean	No	80,692.45	36,504.49	5,027,627.95	6,109.48	38,078.48	380.78
19	50	75	Low	Yes	38,785.35	18,085.83	2,573,903.19	3,127.74	17,571.77	351.44
20	50	75	Low	No	37,950.09	18,065.53	2,572,415.44	3,125.94	16,758.63	335.17
21	50	75	High	Yes	40,997.71	19,294.92	1,936,936.40	2,353.75	19,349.04	386.98
22	50	75	High	No	40,125.18	19,334.18	1,936,936.40	2,353.75	18,437.25	368.74

Table D.14 Sensitivity Analysis of the Carbon Flux in All Scenarios in Shelby Area

Scenario	Plant size (gal/year)	Switchgrass Price ($/dt)	Land Share	Carbon Credit	Carbon Stored (Metric ton)	Carbon Emitted from Farm Activities (Metric ton)	Total Mileage (Miles)	Carbon Emitted from Transportation (Metric ton)	Net Carbon Stored (Metric ton)	Net Carbon Abated (Metric ton/million gallons)
1	15	75	Mean	Yes	10,910.67	5,522.73	351,675.49	427.34	4,960.60	330.71
2	15	75	Mean	No	9,039.82	4,880.80	344,803.87	418.99	3,740.03	249.34
3	15	90	Mean	Yes	10,065.02	5,306.08	298,697.89	362.95	4,395.99	293.07
4	15	90	Mean	No	8,530.72	4,685.07	297,535.49	361.54	3,484.11	232.27
5	15	110	Mean	Yes	9,519.16	5,128.21	234,510.95	284.94	4,106.00	273.73
6	15	110	Mean	No	8,574.86	4,787.34	234,510.95	284.94	3,502.58	233.51
7	50	75	Mean	Yes	39,425.33	18,549.38	1,791,844.57	2,177.46	18,698.49	373.97
8	50	75	Mean	No	38,768.54	18,549.95	1,791,844.57	2,177.46	18,041.14	360.82
9	50	90	Mean	Yes	40,382.59	18,527.27	1,738,657.11	2,112.82	19,742.50	394.85
10	50	90	Mean	No	37,745.92	18,263.72	1,736,048.04	2,109.65	17,372.56	347.45
11	50	110	Mean	Yes	40,316.43	18,592.76	1,664,625.66	2,022.84	19,700.82	394.02
12	50	110	Mean	No	35,334.85	17,774.70	1,661,652.62	2,019.23	15,540.92	310.82
13	100	75	Mean	Yes	64,424.36	32,920.83	4,553,780.79	5,533.73	25,969.79	259.70
14	100	75	Mean	No	52,144.42	32,053.23	4,553,780.79	5,533.73	14,557.45	145.57
15	100	90	Mean	Yes	75,635.07	35,947.46	4,508,418.26	5,478.55	34,209.06	342.09
16	100	90	Mean	No	65,762.12	33,465.19	4,494,015.54	5,461.05	26,835.87	268.36
17	100	110	Mean	Yes	70,139.60	34,918.56	4,153,205.95	5,046.92	30,174.12	301.74
18	100	110	Mean	No	68,309.22	34,354.27	4,151,145.69	5,044.41	28,910.54	289.11
19	50	75	Low	Yes	36,835.99	17,859.95	1,963,064.94	2,385.51	16,590.53	331.81
20	50	75	Low	No	34,955.43	17,727.08	1,963,064.94	2,385.51	14,842.84	296.86
21	50	75	High	Yes	40,530.83	18,507.89	1,724,560.75	2,095.69	19,927.26	398.55
22	50	75	High	No	36,546.65	18,082.20	1,721,882.38	2,092.43	16,372.02	327.44

Table D.15 Sensitivity Analysis of the Carbon Flux in All Scenarios in Marion Area

Scenario	Plant size (gal/year)	Switchgrass Price ($/dt)	Land Share	Carbon Credit	Carbon Stored (Metric ton)	Carbon Emitted from Farm Activities (Metric ton)	Total Mileage (Miles)	Carbon Emitted from Transportation (Metric ton)	Net Carbon Stored (Metric ton)	Net Carbon Abated (Metric ton/million gallons)
1	15	75	Mean	Yes	17,161.07	5,215.47	260,797.48	316.90	11,628.70	775.25
2	15	75	Mean	No	16,475.94	5,250.46	260,797.48	316.90	10,908.57	727.24
3	15	90	Mean	Yes	16,957.27	5,218.68	240,670.49	292.44	11,446.16	763.08
4	15	90	Mean	No	16,208.26	5,256.93	240,670.49	292.44	10,658.89	710.59
5	15	110	Mean	Yes	16,685.54	5,222.95	213,834.48	259.83	11,202.77	746.85
6	15	110	Mean	No	15,851.35	5,265.55	213,834.48	259.83	10,325.97	688.40
7	50	75	Mean	Yes	55,702.01	17,079.28	1,574,925.58	1,913.84	36,708.90	734.18
8	50	75	Mean	No	53,700.63	17,082.54	1,570,490.99	1,908.45	34,709.65	694.19
9	50	90	Mean	Yes	56,872.95	17,167.24	1,539,978.52	1,871.36	37,834.36	756.69
10	50	90	Mean	No	52,961.74	17,065.02	1,527,373.76	1,856.05	34,040.67	680.81
11	50	110	Mean	Yes	58,434.21	17,284.52	1,493,476.84	1,814.85	39,334.85	786.70
12	50	110	Mean	No	51,976.04	17,041.52	1,469,884.09	1,786.18	33,148.34	662.97
13	100	75	Mean	Yes	106,459.06	33,058.87	4,667,080.61	5,671.34	67,728.85	677.29
14	100	75	Mean	No	103,627.76	32,912.71	4,658,747.75	5,661.22	65,053.83	650.54
15	100	90	Mean	Yes	107,783.97	33,388.45	4,505,453.57	5,474.91	68,920.61	689.21
16	100	90	Mean	No	103,504.93	32,597.28	4,485,476.61	5,450.64	65,457.01	654.57
17	100	110	Mean	Yes	108,750.74	33,735.14	4,284,106.52	5,205.90	69,809.70	698.10
18	100	110	Mean	No	103,522.53	32,798.82	4,258,968.74	5,175.36	65,548.36	655.48
19	50	75	Low	Yes	54,839.68	17,110.37	1,676,762.58	2,037.58	35,691.73	713.83
20	50	75	Low	No	53,877.38	17,004.47	1,671,175.19	2,030.79	34,842.11	696.84
21	50	75	High	Yes	57,170.23	17,189.57	1,531,106.13	1,860.58	38,120.09	762.40
22	50	75	High	No	52,774.15	17,060.57	1,516,427.13	1,842.74	33,870.83	677.42

Table D.16 Land Acre Planted on Soil Type and Land Use for $75, 50 Million Gallon, with Carbon Payment Scenario in Davidson Area

Soil	Land Use	County					
		Cheatham	Davidson	Dickson	Montgomery	Robertson	Rutherford
Armour	Crop		845.38				5,627.10
	Pasture		1,286.34				3,558.64
Dellrose	Crop		295.63				1,967.82
Dickson	Crop		373.02				2,482.93
Pembroke	Crop	2,108.99		3,675.49	7,292.20	15,217.67	
Sengtown	Crop	1,269.34		2,212.18	4,388.98	9,159.10	
	Pasture	1,465.87		3,647.92	3,948.31	3,802.69	
Total Acre		4,844.20	2,800.37	9,535.58	15,629.48	28,179.46	13,636.48

Table D.16 Land Acre Planted on Soil Type and Land Use for $75, 50 Million Gallon, with Carbon Payment Scenario in Davidson Area (Con'd)

Soil	Land Use	County					
		Sumner	Trousdale	Williamson	Wilson	Logan	Simpson
Armour	Crop	6,197.82	1,395.55	4,827.58	4,508.80		
	Pasture	4,706.00	1,154.96	3,782.23	4,373.64		
Dellrose	Crop	2,167.40	488.03	1,688.23	1,576.75		
Dickson	Crop	2,734.76	615.78	2,130.15	1,989.48		
Loring	Crop						1,126.62
Pembroke	Crop					3,280.30	3,888.39
Zanesville	Pasture						357.25
Total Acre		15,805.98	3,654.32	12,428.18	12,448.66	3,280.30	5,372.27

Table D.17 Harvest Schedule and Arrangement for Switchgrass from November to February for $75, 50 Million Gallon, with Carbon Payment Scenario in Davidson Area

Month	Soil Type	Land Use	County						Harvest Method		Arrangement Activity
			Cheatham		Davidson		Dickson				
			Acre	Dry-ton	Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Armour	Crop			111.20	490.39			√		Store
	Dellrose	Crop			587.57	2,591.19			√		
	Pembroke	Crop	1,039.27	4,978.08					√		
	Sengtown	Crop	38.39	145.88					√		
		Pasture					251.85	1,060.28	√		
	Sengtown	Pasture					2,380.86	10,023.43		√	Deliver
Dec	Armour	Crop			698.77	3,081.58			√		Store
	Pembroke	Crop					198.18	1,060.28	√		
	Sengtown	Crop	1,230.95	4,677.62					√		
		Pasture	117.46	446.35					√		
	Pembroke	Crop					1,873.54	10,023.43		√	Deliver
Jan	Armour	Crop			35.41	156.14			√		Store
	Dellrose	Crop			295.63	1,164.79			√		
	Dickson	Crop			373.02	1,760.64			√		
	Pembroke	Crop					198.18	1,060.28	√		
	Sengtown	Pasture	1,348.41	5,123.97					√		
	Pembroke	Crop					1,405.58	7,519.86		√	Deliver
	Sengtown	Pasture					594.67	2,503.57		√	
Feb	Armour	Pasture			698.77	3,081.58			√		Store
	Pembroke	Crop	1,069.72	5,123.97					√		
	Sengtown	Crop					251.85	1,060.28	√		
							1,960.33	8,252.98		√	Deliver
		Pasture					420.54	1,770.45		√	

Table D.17 Harvest Schedule and Arrangement for Switchgrass from November to February for $75, 50 Million Gallon, with Carbon Payment Scenario in Davidson Area (Con'd)

Month	Soil Type	Land Use	County						Harvest Method		Arrangement Activity
			Montgomery		Robertson		Rutherford				
			Acre	Dry-ton	Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Amour	Crop					2,303.84	12,970.61	√		Store
		Pasture					235.38	1,325.20	√		
	Dellrose	Crop					947.24	4,414.14	√		
	Pembroke	Crop			2,376.93	11,100.28			√		
	Sengtown	Crop			1,206.02	4,546.68			√		
		Pasture			3,802.69	14,336.15			√		
	Pembroke	Crop	374.98	2,107.38						√	Deliver
	Sengtown	Crop	3,929.71	17,330.02						√	
Dec	Amour	Pasture					3,323.26	18,709.94	√		Store
	Pembroke	Crop			6,420.37	29,983.11			√		
	Sengtown	Crop	459.27	2,025.37						√	Deliver
		Pasture	3,948.31	17,412.03						√	
Jan	Dellrose	Crop					1,020.58	4,755.90	√		Store
	Dickson	Crop					2,482.93	13,954.04	√		
	Pembroke	Crop			6,420.37	29,983.11			√		
			3,458.61	19,437.39						√	Deliver
Feb	Amour	Crop					3,323.26	18,709.94	√		Store
	Sengtown	Crop			7,953.08	29,983.11			√		
	Pembroke	Crop	3,458.61	19,437.39						√	Deliver

Table D.17 Harvest Schedule and Arrangement for Switchgrass from November to February for $75, 50 Million Gallon, with Carbon Payment Scenario in Davidson Area (Con'd)

Month	Soil Type	Land Use	County						Harvest Method		Arrangement Activity
			Trousdale		Sumner		Williamson				
			Acre	Dry-ton	Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Armour	Crop					1710.05	8,533.16	√		Store
		Pasture			1,970.80	8,513.83	1407.48	7,023.31	√		
	Dellrose	Crop			2,167.40	8,561.25			√		
	Armour	Crop	752.63	4,485.65						√	Deliver
	Dickson	Crop	141.34	872.05						√	
Dec	Armour	Pasture			2,735.20	11,816.08	2,374.75	11,849.99	√		Store
	Dellrose	Crop					838.57	3,706.49	√		
	Dickson	Crop			1,138.31	5,259.00			√		
	Armour	Pasture	898.94	5,357.70						√	Deliver
Jan	Armour	Crop			3,952.57	17,075.08			√		Store
	Dellrose	Crop					849.65	3,755.47	√		
	Dickson	Crop					2,130.15	11,801.00	√		
	Dellrose	Crop	488.03	2,430.39						√	Deliver
	Dickson	Crop	474.44	2,927.31						√	
Feb	Armour	Crop			2,245.26	9,699.51	3,117.53	15,556.48	√		Store
	Dickson	Crop			1,596.44	7,375.57			√		
	Armour	Crop	642.93	3,831.84						√	Deliver
		Pasture	256.02	1,525.86						√	

Table D.17 Harvest Schedule and Arrangement for Switchgrass from November to February for $75, 50 Million Gallon, with Carbon Payment Scenario in Davidson Area (Con'd)

Month	Soil Type	Land Use	County						Harvest Method		Arrangement Activity
			Wilson		Logan		Simpson				
			Acre	Dry-ton	Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Armour	Crop	1,966.03	8,375.28					√		Store
		Pasture	1,203.81	5,128.22					√		
	Pembroke	Crop			820.07	3,723.14	1,026.95	6,706.00		√	Deliver
	Zanesville	Pasture					357.25	1,993.46		√	
Dec	Armour	Crop	1,689.32	7,196.52					√		Store
	Dellrose	Crop	1,576.75	6,306.98					√		
	Pembroke	Crop			820.07	3,723.14	1,332.23	8,699.46		√	Deliver
Jan	Armour	Crop	853.44	3,635.67					√		Store
	Dickson	Crop	1,989.48	9,867.83					√		
	Pembroke	Crop			820.07	3,723.14	1,332.23	8,699.46		√	Deliver
Feb	Armour	Pasture	3,169.84	13,503.50					√		Store
	Loring	Crop					1,126.62	7,413.17		√	Deliver
	Pembroke	Crop			820.07	3,723.14	196.98	1,286.29		√	

Table D.18 Delivery Schedule for Stored Switchgrass for $75, 50 Million Gallon, with Carbon Payment Scenario in Davidson Area

Month	Harvested Month	Soil	Land Use	County			
				Cheatham	Davidson	Dickson	Robertson
Mar	Feb	Armour	Pasture		2,993.46		
		Pembroke	Crop	4,977.43			
		Sengtown	Crop				21,095.35
Apr	Feb	Sengtown	Crop				7,843.57
May	Feb	Sengtown	Crop			987.09	
	Jan	Armour	Crop		143.16		
		Dellrose	Crop		1,067.96		
		Dickson	Crop		1,614.28		
		Pembroke	Crop				17,282.36
		Sengtown	Pasture	4,698.02			
Jun	Jan	Pembroke	Crop				10,084.30
	Jan	Pembroke	Crop			951.01	
Jul	Dec	Armour	Crop		2,742.58		
		Pembroke	Crop				17,751.20
		Sengtown	Crop	4,163.04			
			Pasture	397.25			
Aug	Dec	Pembroke	Crop				8,878.40
	Dec	Pembroke	Crop			933.22	
Sep	Nov	Armour	Crop		429.95		
			Pasture		2,271.80		
		Pembroke	Crop	4,364.49			9,732.07
		Sengtown	Crop	127.90			
			Pasture				10,546.08
Oct	Nov	Sengtown	Crop				3,973.96
			Pasture	926.72			2,016.77

Table D.18 Delivery Schedule for Stored Switchgrass for $75, 50 Million Gallon, with Carbon Payment Scenario in Davidson Area (Con'd)

Month	Harvested Month	Soil	Land Use	County			
				Rutherford	Sumner	Williamson	Wilson
Mar	Feb	Armour	Crop	18,174.89			
Apr	Feb	Armour	Crop		9,203.01	14,760.17	
			Pasture				8,436.33
		Dickson	Crop		6,998.03		
May	Feb	Armour	Pasture				4,293.65
	Jan	Dellrose	Crop	4360.548			
		Dickson	Crop	12,794.05			
Jun	Jan	Armour	Crop		15,465.51		
		Dellrose	Crop			3,401.46	
		Dickson	Crop			10,688.59	7,601.27
Jul	Jan	Armour	Crop				3,260.97
		Dickson	Crop				1,323.40
	Dec	Armour	Pasture	16,651.68			
Aug	Dec	Armour	Crop				6,365.33
			Pasture		10,451.34	10,481.34	
		Dellrose	Crop			3,278.39	3,134.72
		Dickson	Crop		4,651.60		
Sep	Dec	Dellrose	Crop				2,431.84
	Nov	Armour	Crop	11,371.86			
			Pasture	1,161.86			
		Dellrose	Crop	3,870.05			
Oct	Nov	Armour	Crop			7,458.29	7,320.29
			Pasture		7,441.39	6,138.62	4,482.24
		Dellrose	Crop		7,482.83		

Table D.19 Land Acre Planted on Soil Type and Land Use for $75, 50 Million Gallon, with Carbon Payment Scenario in Shelby Area

Soil	Land Use	County			
		Shelby	Tipton	De Soto	Crittenden
Adler	Crop	7,163.53	16,634.32		
Collins	Crop			19,621.77	
Crowley	Crop				48,832.63
Loring	Crop			8,079.55	3,751.79
	Pasture			1,528.15	
Memphis	Crop	3,469.04	1,631.63		
	Pasture	1,381.27			
Sharkey	Crop				21,005.27
Total Acre		12,013.84	18,265.95	29,229.47	73,589.69

Table D.20 Harvest Schedule and Arrangement for Switchgrass from November to February for $75, 50 Million Gallon, with Carbon Payment Scenario in Shelby Area

Month	Soil Type	Land Use	County				Harvest Method		Arrangement Activity
			Shelby		Tipton				
			Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Adler	Crop	2,341.68	12,832.41	2,765.42	12,582.64	√		Store
	Memphis	Crop	748.93	4,875.51	1,631.63	8,451.86	√		
Dec	Adler	Crop	3,231.37	17,707.92	4,622.97	21,034.50	√		Store
Jan	Adler	Crop			4,622.97	21,034.50	√		Store
	Memphis	Crop	2,720.11	17,707.92			√		Deliver
Feb	Adler	crop	1,590.48	8,715.83	4,622.97	21,034.50	√		Store
	Memphis	Pasture	1,381.27	8,992.09			√		Store

Table D.20 Harvest Schedule and Arrangement for Switchgrass from November to February for $75, 50 Million Gallon, with Carbon Payment Scenario in Shelby Area (Con'd)

Month	Soil Type	Land Use	County				Harvest Method		Arrangement Activity
			De Soto		Crittenden				
			Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Collins	Crop	6,135.43	25,584.74			√		Store
	Loring	Pasture	1,528.15	8,970.26			√		
	Sharkey	Crop			8,300.95	30,796.52	√		
	Crowley	Crop			10,810.33	47,241.12		√	Deliver
Dec	Collins	Crop	5,199.77	21,683.03			√		Store
	Loring	Crop	2,192.84	12,871.97	2,605.41	14,460.00	√		
	Sharkey	Crop			4,403.37	16,336.52	√		
	Crowley	Crop			10,810.33	47,241.12		√	Deliver
Jan	Loring	Crop	5,886.71	34,555.00			√		Store
	Sharkey	Crop			8,300.95	30,796.52	√		
	Crowley	Crop			10,810.33	47,241.12		√	Deliver
Feb	Collins	Crop	8,286.57	34,555.00			√		Store
	Crowley	Crop			5,591.33	24,434.09	√		
	Loring	Crop			1,146.38	6,362.43	√		
	Crowley	Crop			10,810.33	47,241.12		√	Deliver

Table D.21 Delivery Schedule for Stored Switchgrass for $75, 50 Million Gallon, with Carbon Payment Scenario in Shelby Area

Month	Harvested Month	Soil	Land Use	County			
				Shelby	Tipton	De Soto	Crittenden
Mar	Feb	Adler	Crop	8,466.58			
		Collins	Crop			30,039.61	
		Memphis	Pasture	8,734.94			
Apr	Feb	Adler	Crop		19,957.79		
		Collins	Crop			3,445.18	
		Crowley	Crop				23,183.36
		Loring	Crop				654.80
May	Feb	Loring	Crop				5,280.73
	Jan	Loring	Crop			25,724.52	
		Memphis	Crop	16,235.87			
Jun	Jan	Adler	Crop		19,051.69		
		Loring	Crop			5,885.59	
		Sharkey	Crop				22,303.84
Jul	Jan	Sharkey	Crop				5,535.38
	Dec	Adler	Crop	15,759.88			
		Collins	Crop			14,489.93	
		Loring	Crop			11,455.93	
Aug	Dec	Adler	Crop		15,223.42		
		Collins	Crop			4,778.12	
		Loring	Crop				12,789.90
		Sharkey	Crop				14,449.68
Sep	Dec	Adler	Crop		3,365.06		
	Nov	Adler	Crop	11,250.70			
		Collins	Crop			22,431.19	
		Loring	Pasture			5,919.61	
		Memphis	Crop	4,274.56			
Oct	Nov	Adler	Crop		10,997.67		
		Loring	Pasture			1,938.98	
		Memphis	Crop		7,387.22		
		Sharkey	Crop				26,917.25

Table D.22 Land Acre Planted on Soil Type and Land Use for $75, 50 Million Gallon, with Carbon Payment Scenario in Marion Area

Soil	Land Use	County			
		Dillon	Florence	Horry	Marion
Ailey	Pasture		2,991.22		2,285.54
Emporia	Crop	583.03	721.94	577.01	246.43
Norfolk	Crop	26,391.76	38,832.94	31,036.70	13,255.35
Total Acre		26,974.79	42,546.10	31,613.71	15,787.32

Table D.23 Harvest Schedule and Arrangement for Switchgrass from November to February for $75, 50 Million Gallon, with Carbon Payment Scenario in Marion Area

Month	Soil Type	Land Use	County				Harvest Method		Arrangement Activity
			Dillon		Florence				
			Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Ailey	Pasture			2,991.22	14,088.64	√		Store
	Emporia	Crop	583.03	2,839.36	721.94	3,378.69	√		
	Norfolk	Crop	4,962.66	27,195.36	7,149.54	36,605.67	√		
		Crop	1,246.69	6,831.84				√	Deliver
	Norfolk	Crop	5,480.79	30,034.72	10,561.13	54,072.99	√		Store
		Crop	1,246.69	6,831.84				√	Deliver
Jan	Norfolk	Crop	5,480.79	30,034.72	10,561.13	54,072.99	√		Store
		Crop	1,246.69	6,831.84				√	Deliver
	Norfolk	Crop	5,480.79	30,034.72	10,561.13	54,072.99	√		Store
		Crop	1246.685	6,831.84				√	Deliver

Table D.23 Harvest Schedule and Arrangement for Switchgrass from November to February for $75, 50 Million Gallon, with Carbon Payment Scenario in Shelby Area (Con'd)

Month	Soil Type	Land Use	County				Harvest Method		Arrangement Activity
			Horry		Marion				
			Acre	Dry-ton	Acre	Dry-ton	Round	Square	
Nov	Emporia	Crop			246.43	1,175.48	√		Store
	Norfolk	Crop			3,673.97	18,810.75	√		
		Crop	7,892.44	40,409.29				√	Deliver
Dec	Ailey	Pasture			2,285.54	10,902.03	√		Store
	Norfolk	Crop			1,774.26	9,084.20	√		
	Norfolk	Crop	7,892.44	40,409.29				√	Deliver
Jan	Norfolk	Crop			3,903.56	19,986.22	√		Store
		Crop	7,892.44	40,409.29				√	Deliver
Feb	Norfolk	Crop			3,903.56	19,986.22	√		Store
	Emporia	Crop	577.01	2,729.23				√	Deliver
	Norfolk	Crop	7359.386	37680.054				√	

Table D.24 Delivery Schedule for Stored Switchgrass for $75, 50 Million Gallon, with Carbon Payment Scenario in Shelby Area

Month	Harvested Month	Soil	Land Use	County		
				Dillon	Florence	Marion
Mar	Feb	Norfolk	Crop		27,826.46	19,414.67
Apr	Feb	Norfolk	Crop	23,115.35	24,125.77	
May	Feb	Norfolk	Crop	5,280.73		
	Jan	Norfolk	Crop		23,635.61	18,324.78
Jun	Jan	Norfolk	Crop	21,613.85	25,627.28	
Jul	Jan	Norfolk	Crop	5,535.38		
	Dec	Ailey	Pasture			9,702.70
		Norfolk	Crop		23,918.19	8,084.85
Aug	Dec	Norfolk	Crop	23,184.13	24,056.99	
Sep	Dec	Norfolk	Crop	3,365.06		
	Nov	Ailey	Pasture		12,352.08	
		Emporia	Crop		2,962.24	1,030.59
		Norfolk	Crop		11,039.00	16,492.15
Oct	Nov	Emporia	Crop	2,481.70		
		Norfolk	Crop	23,769.71	20,989.71	

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