OPTIMIZATION OF CELLULOSIC BIOMASS ANALYSIS

by

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Abstract

Ethanol has become an important source of energy for transportation purposes in the U.S. The majority of the feedstock for this ethanol is corn grain. The use of crop residues and perennial grasses has been proposed as an alternative feedstock for ethanol production using cellulosic conversion processes. Commercial scale production of cellulosic ethanol is still on the horizon. In the meantime a wide variety of studies examining both the technical and economic feasibility of cellulosic ethanol production have been conducted. This is the first study that combines both county level cellulosic feedstock production and farmer participation rates to determine the feasibility of supplying it to cellulosic ethanol plants. This research determines the economic feasibility of supplying cellulosic feedstocks to seven potential add-on cellulosic ethanol plants of 25 million gallons per year at seven existing starch ethanol plants in Kansas. The feedstocks considered are corn stover, sorghum stalks, wheat straw, and perennial switchgrass. A mixed integer programing model determines the amount and mix of cellulosic feedstocks that can be delivered to these plants over a range of plant-gate feedstock prices given transportation costs and farm-gate production costs or breakeven prices. The variable costs of shipping are subtracted from the difference between plant-gate price and farm-gate price to find savings to the plant. The objective function of the model minimizes transportation costs which in turn maximizes savings to the plant. The role switchgrass may have as a feedstock given various switchgrass production subsidies is examined.

The results indicate the minimum plant-gate price that must be paid to feedstock producers for all plants to have enough cellulosic feedstocks is $75 per dry ton. Switchgrass feedstocks were only a minor portion of biomass supplied and used without a production subsidy. A Biomass Crop Assistance Program payment increased the supply of switchgrass more than other production subsidies.

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Chapter 1 - Introduction

A growing world population and limited oil reserves mean the United States must eventually transition the economy from petroleum-based fuels to alternative fuels such as ethanol from sugar cane, corn and biomass. While hydraulic fracturing (fracking) has opened the door to tap more oil and natural gas resources than previously thought, the use of bio-based fuels is also necessary for environmental quality. The food-versus-fuel debate has been accelerated by EPA regulations for ethanol mandates. Figure 1.1 shows how average farm corn prices have increased over time. Livestock producers and consumers have complained that these mandates have increased corn prices and therefore many price of consumer goods, however use for feed has dramatically increased. While this increase in demand for corn (Figure 1.2) has increased corn prices, elimination of these mandates would have only a small effect in reducing corn price (Irwin and Good, 2012). According to Irwin and Good (2012), corn would need to have been above $10 per bushel in 2012-2013, ceteris paribus, to lower the demand for starch ethanol below the blend wall as a result of the RFS. This blend wall is a stipulation of the RFS, stating that gasoline must contain 10% ethanol or approximately 13.3 billion gallons (Irwin and Good, 2012).

Refineries have moved to blending 84 octane which is considered "conventional gasoline" with higher octane ethanol (around 113) in order to produce 87 octane gasoline, which is most popular at the retail level in the U.S. Ethanol is the cheapest available high-octane product that blenders have available now that the domestic ethanol industry is well established (Irwin and Good, 2012). This indicates companies will continue to blend gasoline with ethanol even if the Renewable Fuel Standards were repealed. Many argue cellulosic ethanol will not have the same effect of driving up food and feed grain prices because it is not produced from grain, and perennial crop options can be grown on marginal lands which are not used for crop production (Herron, 2012). Marginal lands that are not capable of growing corn and other crops are prime candidates for biomass crops such as switchgrass and *Miscanthus*.

Biofuel production is not only intended to decrease dependence on foreign oil, but also to maintain the health and well-being of its citizens and environment. Historically, domestic fuel consumption has been dominated by foreign diplomacy as evidenced by the oil crises of the 1970's and 1980's. Fuel prices are reflected in practically every facet of the economy, therefore affecting everyone. Biofuels not only aid in making the U.S. economy more sustainable by reducing imports, but also diminish the carbon footprint from the utilization of fossil fuels. Nelson (2011) notes a potential 60% reduction in green-house gasses attributed to cellulosic ethanol, whereas conventional ethanol accounts for only a 20% reduction. Tilman et al. (2009) suggested that harvesting of crop residues would result in little to no competition for food crop production. The EPA Renewable Fuel Standard Program (see Figure 1.3) calls for 36 million gallons of biofuel to be blended with gasoline by 2022 (Schnepf and Yacobucci, 2013). The advanced ethanol portion of this mandate, which is to be derived from cellulosic material, has not come close to being met, mainly to economic infeasibility (Wisner, 2013).

Wisner (2013) indicates that challenges to the EPA proposed biofuels mandates challenges arise compared to the partly because of the huge short-fall in cellulosic biofuel production compared to the mandated levels specified in the 2007 EISA (Energy Independence and Security Act).

> *"EPA has authority to reduce both the advanced biofuels mandate and the total biofuels mandate by up to the amount cellulosic biofuels mandate falls short of the EISA mandate. For 2013, that could be a reduction of up to 986 million gallons (corn-starch equivalent). However, EPA is proposing to leave mandates for these biofuel categories at the EISA levels rather than reducing them" (pg. 4 Wisner, 2013).*

The anticipated commercially available quantities of advanced biofuels that were to be produced in 2013 are mainly from cellulosic ethanol, bio-based diesel, and imported sugar cane ethanol. By not reducing the total biofuels mandate, the EPA has provided a means for bio-based diesel fuel to help fill the short-fall from cellulosic ethanol. In February of 2012, the World Agricultural Supply and Demand Report (WASDE) projected U.S. soybean oil use for biodiesel in the 2012-13 marketing year to increase by only 30 million pounds from the previous year, which included the last four months of 2012 and eight months of 2013. The WASDE report also projected both U.S. soybean and soybean oil ending carryover stocks to be near bare minimum levels (USDA, 2012). The WASDE report notes that in order for a large part of the gap created by the increased mandate for advanced biofuels to be filled by biodiesel, substantially increased U.S. vegetable oil imports would be necessary or other U.S. uses of vegetable oils would need to be reduced substantially. A lowered consumer supply of vegetable oil and animal fat due to demand for biofuel production would almost certainly increase feedstock prices and also affect prices of fats and oils used for animal feeds. These would result in an increase of consumer prices for foods containing these goods. Wisner (2013) indicates that it is doubtful that a major part of the gap in advanced biofuels in 2013 will be filled by biodiesel.

Purpose Statement

The purpose of this research is to establish a supply chain model to determine the economic feasibility of farmers' ability to produce enough biomass supplies to meet cellulosic ethanol production demand for seven cellulosic add-on plants at currently existing corn ethanol plants in Kansas. Risk and technical feasibility are the two main dilemmas hindering the cellulosic industry. In 2010, the EPA reduced the required volume of cellulosic biofuels specified by the EISA from 100 million gallons to 5 million gallons, since practically no cellulosic based biofuels were commercially available. In 2011, the EPA lowered the required volume of cellulosic biofuels specified by the EISA from 250 million gallons to 6.6 million gallons (McPhail, Westcott, and Lutman, 2011). As of 2013, only two stand-alone commercial cellulosic plants exist in the U.S. These are located in Florida and Mississippi with an estimated production capacity of 19 MGY. Two additional stand-alone plants are under construction in Kansas and Iowa with capacities totaling 30 MGY (Paulson, 2013). By incorporating or co-locating cellulosic plants with existing starch ethanol plants, the Department of Energy states that these facilities will benefit from "combining utilities, combining ethanol purification, and combining C6 fermentation while selling the C5 stream realizes an economic benefit" when compared to a stand-alone stover to ethanol plant (Wallace et al., 2005 pg. 28).

This research focuses on production at add-on facilities for seven existing plant locations in Kansas. The EPA reduced the initial one billion gallon cellulosic ethanol mandate for 2013 to 14 million gallons, indicating there was a lack of industry production capacity and then 6 million gallons after speaking with the two commercial plants (Paulson, 2013). According to ICM, a construction company based in Colwich, Kansas that offers proprietary ethanol production technology, a plant size of at least 25 MGY (million gallons per year) is required to capture minimum economies of scale dictated by existing literature and their experience for cellulosic ethanol plants. Predictions of supply, transport costs, and production costs are evaluated under various corn, wheat, sorghum, and switchgrass yields, as well as varied participation rates of farmers. In this way, the economic feasibility of farmers' ability to supply the required cellulosic biomass to these seven ethanol plants is evaluated using a mixed integer linear programming model which minimizes transport cost. Distance matrices from county centroids to the nearest existing plant are used to assess transport cost. The nodes in the developed transportation model with the minimal transportation cost are determined, as well as the optimal amount and type of biomass to be shipped from each of these centroids. Multiple feedstocks are evaluated, including corn stover, wheat straw, sorghum silage, and switchgrass.

Research Objectives

The following research objectives are addressed in this study:

1. Determine how many tons of cellulosic biomass on a county level can be harvested. This is used to determine the maximum amounts of corn stover, wheat straw, sorghum silage, and switchgrass able to be collected at the farm-gate in each county to potentially supply each of the seven cellulosic ethanol add-on plants.
2. Use previous research incorporating farmers' willingness-to-harvest agricultural residues and produce a dedicated perennial to estimate potential biomass quantities available for cellulosic ethanol production in the study region.
3. Determine the optimal amount quantities of biomass to ship from county centroids to the seven determined plant locations using a linear programming transport model. This will be done at various ethanol plant-gate prices ($/dry ton) and farm-gate prices ($/dry ton).
4. Identify the minimum plant-gate price where economies of scale (25 MGY) are met for all plants and which counties will provide each of the seven plants the minimum required cellulosic biomass.

5. Evaluate impacts of various price changes and derive input demand curves for each plant at various price levels.

6. Determine how the expansion of the Biomass Crop Assistance Program (BCAP) or ability to grow switchgrass on CRP land (while maintaining CRP payments) may increase production of switchgrass by farmers.

Methods of Analysis

Analysis of industry and data collection

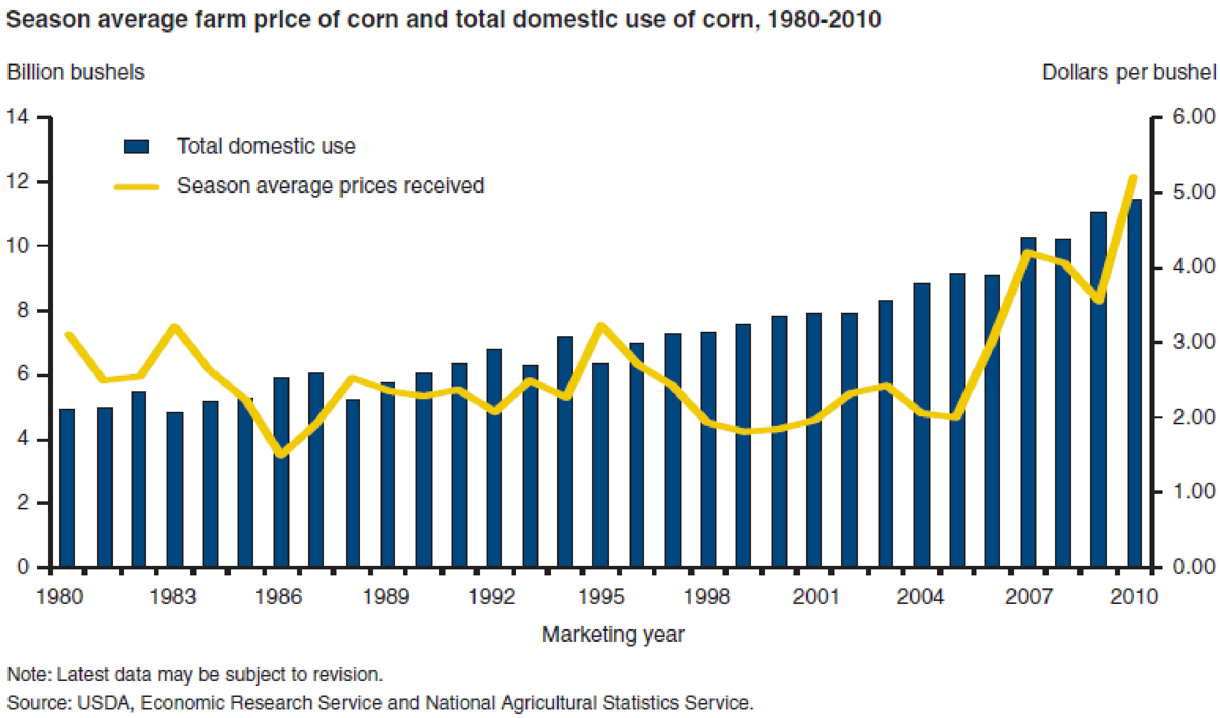
Evaluation of the current cellulosic industry and potential supply of cellulosic crops is imperative to establishing a realistic model. ICM states that their feasible plant-gate price range of $60 to $80 per dry ton accounts for the current market price of ethanol, as well as input costs for crops and residues, which determine what prices are necessary to break-even for different levels of production from field to fuel (Rivers, 2012). If ethanol prices fall, the feasible plant-gate price would decrease also. The amount of corn stover, wheat straw, and sorghum silage that can potentially be harvested were calculated for each of 202 counties in the study region based on a five-year average of acreages from total crop production and county yields. The minimum amount of crop residue for each of these crops was estimated using the crop grain yield and conversion factors. Residue and switchgrass estimates were adjusted for farmer participation estimates using prior studies. These factors are integral in determining how many tons per acre of residue could potentially be removed, as well as predicting how many acres of marginal CRP land may be converted to cellulosic biomass production.

Construction of the Mixed Integer Model

These models assumes a fixed farm-gate price as the cost to the plant per dry ton of biomass under various plant-gate and farm-gate price scenarios. The difference between these two prices is comprised of variable total transportation costs consisting of a fixed cost per ton-mile and loading rate per ton. With this method, it does not matter whether the plant or farmer pays the transportation cost and for this study the remainder between plant-gate price and farm-gate price less transportation and loading cost is assumed to be saving to the plant. Thus, through minimizing transport cost, savings to the plant are maximized. A scenario evaluating the impact of expanding and modifying the Biomass Crop Assistance Program (BCAP) is also examined. This program was intended to cover 75% of the establishment cost of perennial stands and up to $45 per ton of biomass (CRS and USDA, 2010) from the perennial production sites when delivered to an approved processing facility in addition to what the plant pays.

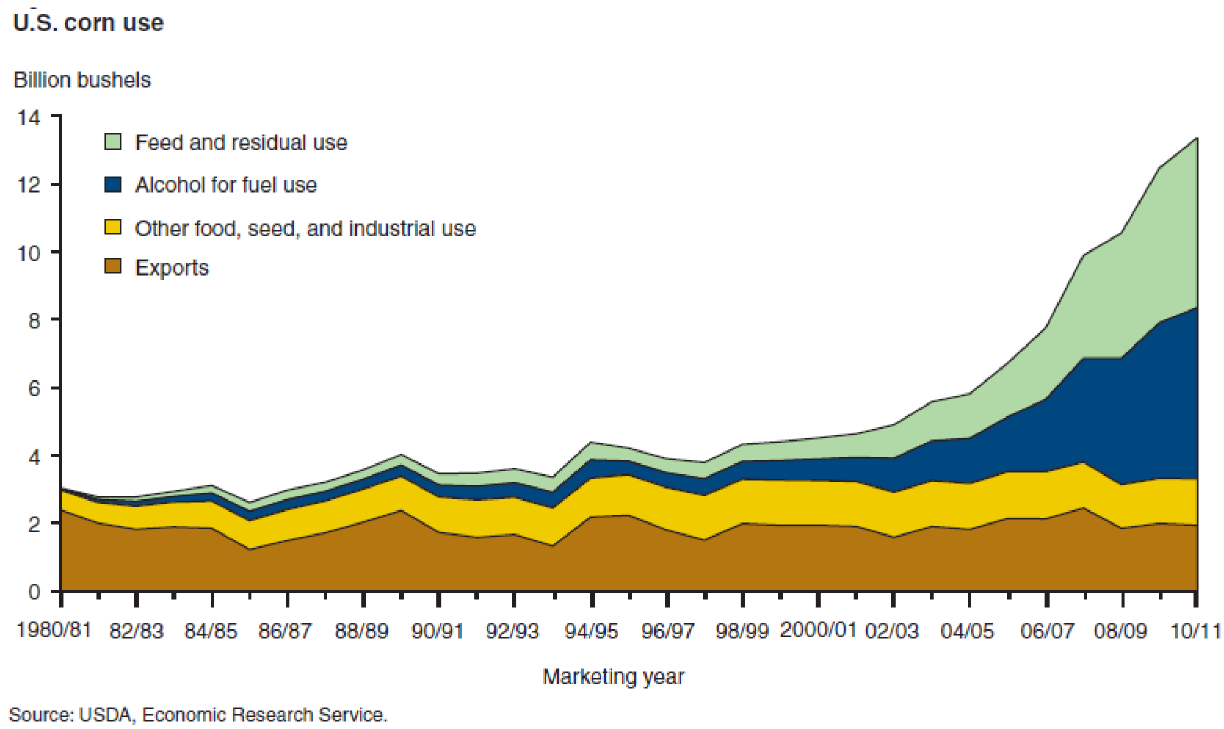
Each crop type and residue is evaluated to determine if minimum economies of scale dictated by ICM were met for add-on plants to determine limiting factors for biomass availability. Optimal mixtures of crops and residues will be found through the model to minimize transport cost. Farm enterprise budgets are used to determine the costs at which farmers are able to supply the feedstock to the refinery. The marginal effects of input variables on production costs such as fertilizer cost, harvest cost, changes in yield, and transportation costs are the focus of this model and are simulated through varying price levels. Chapter 2 includes a literature review of pertinent research relating to this study. Data and this model are discussed in further detail in Chapter 3 with results shown in Chapter 4 and conclusions in Chapter 5.

Figure 1.1 Corn Grain Use and Price in the United States



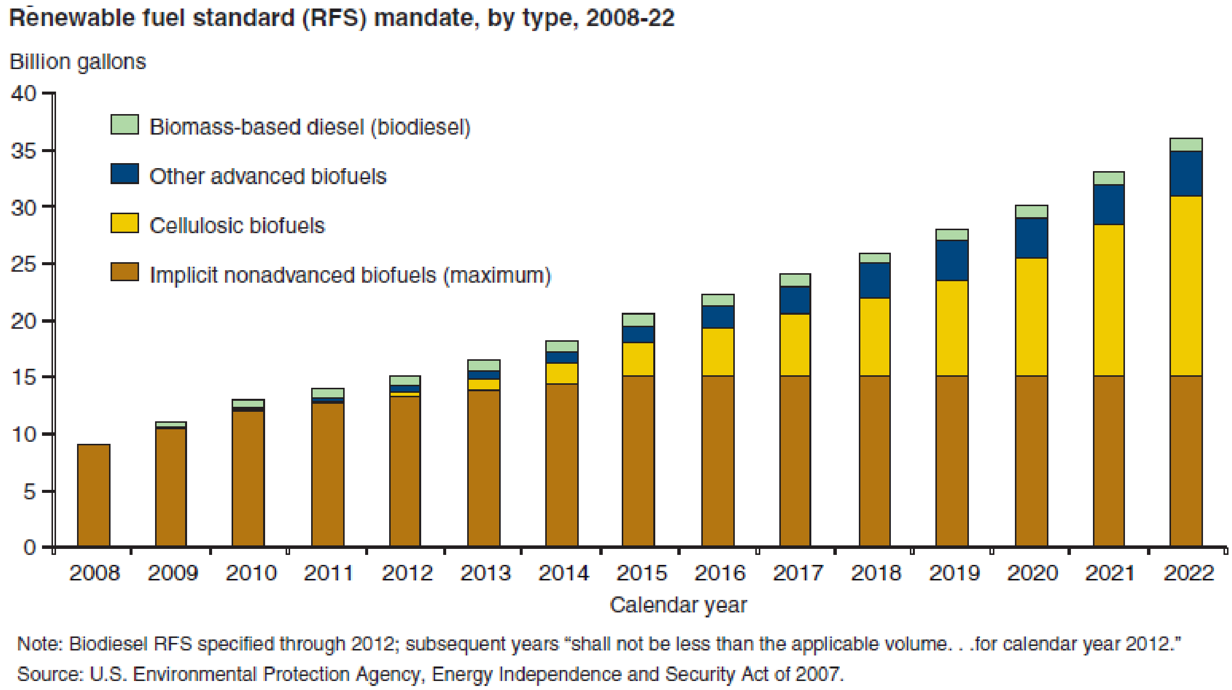
(Source: McPhail, Westcott, and Lutman 2011)

Figure 1.2 Corn Grain Use in the United States 1980-2010



(Source: McPhail, Westcott, and Lutman 2011)

Figure 1.3 Breakdown of Renewable Fuel Standard (RFS)



(Source: McPhail, Westcott, and Lutman 2011)

Chapter 2- Literature Review

Much has been written on the various aspects of cellulosic ethanol production. This chapter aims to briefly summarize these aspects in order to provide critical background information to aid in a general understanding of this complex issue.

Biomass Markets

The Energy Independence and Security Act of 2007 states that by 2016, any new biofuels produced must originate from cellulosic feedstocks (Lynes et al. 2012; U.S. Congress, House of Representatives, 2007). Cellulosic ethanol production has significantly fallen below the projected levels. Establishment of a large-scale biomass market using corn stover as a feedstock could increase monetary returns to corn production, since it is essentially a value-added enterprise if the value of harvesting the stover is greater than harvest, fertilizer replacement, lost soil value, and opportunity costs. Expansion of corn acreage would occur, although average yields may decline since less productive cropland may get planted into corn production, accelerating a trend already seen with corn grain (Dodder et al., 2011; Searchinger, Heimlich et al., 2008; Kurkalova, Secchi et al., 2010). This additional revenue from residues could potentially be invested into dedicated bioenergy crops with established biomass markets.

Crop residues are a value-added product in that they are byproducts of a crop which are sold in liquid markets. Costs include swathing, raking, and baling, as well as opportunity costs of potential feed value or used to improve soil quality. The harvest cost or opportunity cost represents the minimum willingness-to-accept price at which a farmer will sell their residue, whether it is utilized for livestock feed, biomass production, or organic material for soil quality. This price must also take transportation into account, whether the plant pays a lower farm-gate price and picks up the biomass or the farmer commands a higher price for delivery of the biomass to the ethanol plant. Gallagher and Baumes (2012) note that corn stover remains the lowest-cost biomass source in the Midwest. Wallace et al. (2005) cited that feedstock collection studies performed by Oak Ridge National Laboratory (ORNL) and Idaho National Energy and Environmental Laboratory (INEEL) along with their industrial partners found a range of \$30-\$53 per dry ton for delivered plant-gate prices, however this was in the early 2000's.

Nelson et al. (2010) estimated corn and sorghum stover amounts available along with winter wheat straw on individual soil types for typical commodity crop rotations in six different Kansas Farm Management Association districts. On non-irrigated farm land, quantities ranged from 0.72 to 1.5 million dry tons (MDT) for corn stover; 1.6 to 3.3 MDT for sorghum stover; and 5.4 to 10.2 MDT of wheat straw. Delivered edge-of-field costs in $/dry ton for corn stover, sorghum stover, and winter wheat straw throughout all counties ranged from $17 to $30.50; $23 to $31; and $14 to $26, respectively.

Mandates

The gap between ethanol mandates and production is due to the fact that it is not economically feasible to produce cellulosic ethanol and sell it at the current market price for ethanol. Contributing factors are the high cost of producing and transporting cellulosic feedstocks, as well as a lack of technological advances in actual ethanol production. Unlike grain, cellulosic material is bulky and deteriorates in a short period of time. Cellulosic plants require more water for conversion, as well as having higher fixed costs to produce (Herron, 2012). Using 2012 as a base year for evaluation of cellulosic add-on plants, this research will highlight all the agricultural issues which have hindered commercial viability of cellulosic ethanol in the U.S.

Even though a plant may be a fixed size, there is always future potential for expansion, which has often happened in the starch ethanol market. There are no commercial cellulosic gallons currently being sold and the EPA standards have not been met since their implementation in 2007. Therefore, it is reasonable to assume that a plant will produce as many gallons of cellulosic ethanol as possible up until their capacity to maximize profits since there is essentially a perfectly elastic demand at the current wholesale price of ethanol. Currently, gasoline must be blended with 10% ethanol and if no cellulosic gallons are available, these credits must still be purchased with no product gain, essentially turning into a per gallon tax on gasoline. The market size created by the 10% ethanol blend wall is determined through the RFS which calls for approximately 13.3 gallons (Irwin and Good, 2012) and this has been achieved through starch ethanol. This maximum amount of starch called for by the RFS has been achieved leaving cellulosic ethanol to fill the gap for higher percentage ethanol blends like E85 (Wisner, 2013).

Nutrient Replacement

There may be some adverse effects of removing crop residues such as loss of soil organic carbon (SOC) which impacts GHG emissions; soil fertility and productivity decline, which negatively impacts nutrient cycling and results in nutrient losses; soil erosion; reduced populations of soil organisms; water infiltration reductions; and lowered water quality (Anand et al., 2011, Anderson-Teixeira et al., 2009; Blanco-Canqui and Lal, 2009; Kim et al., 2009; Melillo et al., 2009; Tarkalson et al., 2009). Farmers must be compensated for the opportunity cost of reduced yields in order to harvest crop residues. Net returns would need to be increased on a per acre basis if these are accounted for. Anand et al. (2008) determined a $55 per dry ton was the average amount farmers were willing to accept for cellulosic crop residue once they decided they were willing to harvest biomass. Anand et al. (2011) found that by keeping the minimum residue for soil conservation cover of 30%, net returns would decrease to farmers by $14.52 per acre as opposed to 100% residue removal when the ethanol plant paid a farm-gate price of $50 per dry ton. With crop residue harvest, the study found that no-till was the most profitable crop production method, as well.

Nitrogen, phosphorus, and potassium are removed with stover harvest and farmers must be compensated for this loss since it will result in reduced yields for the following year. O'Brien, Dumler, and Jones (2010) indicate 17 lbs. N, 4 lbs. P_2O_5, and 50 lbs. K_2O are removed for every one ton of corn stover or grain sorghum stover harvested whereas 11 lbs. N, 3 lbs. P_2O_5, and 15 lbs. K_2O are removed per ton of wheat straw harvested. These are the values which were used for estimation of nutrient replacement costs. Anand, et al. (2011) calculated that eighty-one percent of stover could be removed from land using no-till practices to maximize profits; and that it was more profitable to keep the nutrient payments and take the loss in yield rather than purchase extra fertilizer the following year. This same study found that seventy-six percent of residues could be removed with strip tilling and farmers would potentially remove one hundred percent if they used conventional till. An incentive through a government program in order to compensate farmers for their opportunity cost might be necessary to prevent maximum harvest of stover especially in protected watersheds. This research used EPIC (Erosion-productivity impact calculator) to model the soil content and maintain nutrient levels while keeping a positive soil organic carbon level. The impact on soil organic carbon or SOC from stover removal is still widely debated (Anand et al., 2011).

Morey et al. (2010) found that soil organic carbon (SOC) reductions have implications for the sustainability of the production process in addition to increasing greenhouse gas emissions. While the amount of residue left on the soil has a significant impact on soil organic matter (SOM), the causation behind SOC changes have not yet been proven. Comparing research on corn grain versus corn silage production over a 35 year period, soil carbon does not seem to depend on the presence of residues, but instead is loosely related to the tillage system choice (Reicosky et al., 2001; Gale and Cambardella, 2000). Due to the fact that carbon credits are not regulated and there are many discrepancies relating SOC removal to the other nutrients removed with corn stover, SOC will be disregarded for this study.

Switchgrass Production

Switchgrass is a low input perennial that many favor over other crops since it has a widely distributed natural range. It is high-yielding in certain regions with sufficient rainfall compared to some other naturally occurring species and will survive with a minimum of 20-25 inches of rainfall per year (Christenson et al., 2010). Switchgrass growth stabilizes soils, reduces erosion, improves water quality, and increases wildlife habitat (Mitchel, Vogel, and Sarath, 2008). Planting the seed with a drill or no-till drill in the winter or early spring will naturally stratify the seed or this can be achieved by frost-seeding in January to March. Air flow planters may also be used (Duffy and Nanhou, 2001). Some farmers use companion crops such as alfalfa, grass pastures, and hayfields. These are very useful on slopes to prevent erosion, which is problematic when establishing switchgrass and *Miscanthus* stands (Rinehart, 2006). Probabilities of reseeding for Iowa have been around 25% for frost seeding and 50% for spring seeding (Duffy and Nanhou, 2001).

Stand yield the first year ranges from 30-40% of the maximum potential and second year yields are typically 70-80% of potential with 100% being achieved by the third year. This is similar for *Miscanthus* (Christenson et al., 2010). Christenson et al. (2010) states harvesting should be done at least 60 days before a killing frost to allow regrowth or following senescence and a killing frost. Establishment for the Midwest currently costs approximately $200-300 per acre (Herron, 2012). Christenson et al. (2010) indicates that a dormant application of glyphosate can be used to control winter weeds and atrazine may be used to control annual grass weeds. Mowing or 2,4-D are helpful for controlling broadleaf weeds once the switchgrass stands have reached the four to five-leaf stage.

Switchgrass is typically harvested in mid to late October, but waiting until later can aid in translocation (Rinehart 2006). Short stubble of four to six inches is desirable, although it has been reported to puncture tires due to its stiffness (Christenson et al., 2010). Rinehart (2006) notes that forage research has indicated leaving stubble will help trap snow which protects the root crowns from winter kill. Standard hay equipment can be used to mow and bale switchgrass. By raking the biomass into windrows and using a mower-conditioner instead of a conventional mower, the drying process can be sped up (Christenson et al., 2010). Single-pass harvesting equipment for switchgrass (as well as *Miscanthus* and energy sorghum) has been developed by AGCO. This is currently the most efficient machinery and can be adapted for various other crops and residues; however the machinery has a hefty price tag due to it being a new technology. This single pass system reduces labor time by approximately 30% and fuel usage by 7% (Herron, 2012).

Perrin et al. (2008) evaluated switchgrass produced for biomass on a commercial scale by ten contracting farms. These were located in North Dakota and Nebraska. Switchgrass production costs varied and the overall average cost was found to be $65.86/Mg ($59.75/ton) for dry matter biomass with a yield of 5.0 Mg/ha (2.23 tons/ac). The lower range was $51.95/Mg ($41.97/ton) over a five year period. Once this was projected to ten years, the cost decreased to $46.26/Mg ($41.97/ton). Average costs of around $50/Mg ($45.36/ton) are expected, thus translating to $0.13 per liter or $0.49 per gallon of ethanol. The authors note that current production estimates range from $25 to $100/Mg or $22.68 to $90.72/ton depending on geographic location however these prices have increased since the study year of 2008.

Farmer Participation

Crop Residue

Lynes et al. (2012) utilized a probit model in order to determine farmers' willingness to harvest crop residue. Lynes et al. (2012) states that positive, statistically significant factors on farmers' decisions to harvest crop residue in Kansas are irrigation of crops, allowing a custom harvester access to harvest crop residue, storing biomass on-farm, and off-farm employment. Farmers willing to hold biomass on their farm longer than six months were more likely to harvest crop residue, as well. This study also confirmed the findings of Paulrud and Laitila (2010) that leased land is insignificant, implying farmers are indifferent between harvesting crop residue on owned or leased land. Risk aversion was also found to be insignificant, perhaps indicating farmers do not see residue removal as a risk-changing activity.

Gustafson (2008) highlighted a key point which was corroborated by numerous other studies that $30-40 per ton is usually the budgeted feedstock cost in feasibility studies for cellulosic ethanol plants, however producer supply costs may be double that value. Crop residues, namely corn stover, are currently the most feasible feedstock for cellulosic ethanol production. Corn stover is substantially cheaper than switchgrass (Brechbill and Tyner, 2008) and has the benefit of being a byproduct, so farmers do not have to devote fields specifically to cellulosic crops. It is easily stored and does not degrade significantly over time like other perennial feedstocks. Many farmers leave this agricultural residue in the field where it has been known to aid in the prevention of wind and water erosion, as well as returning nitrogen, phosphorous, and potassium back to the soil, thus reducing fertilizer requirements. While there is potential to add to farm incomes through harvesting residues, some key environmental factors must also be taken into consideration. Soil organic matter (SOM) is crucial to productive soil and with reduction of residue on the top of the soil, yield reduction will occur (Wilhelm et al., 1986). Wilhelm et al. (2004) highlighted the primary consequences of removing corn stover are yield loss and soil degradation. The most important is the loss of soil organic carbon (SOC) along with changes in nutrient balances, temperature, and water infiltration. When calculating the cost to the farmer of biomass harvested, it is essential to capture nutrient loss due to the opportunity cost associated with the corresponding reduction in yield, which will take place the following year. Removing residue before planting leads to herbicides working more effectively (Lynes et al., 2012; Hess et al., 2009) however these cost savings were not captured in this authors' model.

In actuality, the two main deciding factors on how much stover, straw or silage will be harvested are whether the farmer is even willing to sell their residue as well as the minimum amount necessary to maintain soil quality. This varies widely among regions and tillage practices. Land erosion in most instances occurs primarily from water in areas that receive substantial rainfall but wind erosion must often be accounted for especially in the Midwest in places such as Western Kansas. The amount of erosion can be modeled through programs such as RUSLE II and is dependent upon soil type and slope. Crop residues greatly aid in preventing this erosion. Potential exists for future policies regarding these issues in addition to nutrient and pesticide runoff and wildlife cover (Anand et al., 2011). For conservation payments, at least thirty percent of the field must remain covered with residues, which typically means 950 pounds per acre for corn.

Annuals

In Lynes et al. (2012), a two-stage Heckman selection model was used examining farmers' willingness to grow dedicated bioenergy crops. The first stage was to determine farmers' willingness to produce and the second stage examines how many acres the farmer might initially plant. Farm size, percent of land leased, grazing of crop residue, baling of crop residue, willingness to use a custom harvester, willingness to store biomass, and willingness to lease land to grow an annual crop were all statistically significant and positive on growing annuals. The positive effect of total acres contradicts the findings of Jensen et al. (2006) and Paulard and Laitila (2010); however this may differ according to region. Since no markets for dedicated bioenergy crops exist, increasing on-farm risk would most likely indicate a lower chance of dedicated annual crop adoption (Lynes, et al., 2012; Pannell et al., 2006; Rajagopal et al., 2007). Risk aversion lowers the likelihood of growing a dedicated annual crop by 16% (Lynes et al., 2012). It is also interesting to note that if a farmer decides they are willing to lease land to someone else for production of an annual bioenergy crop, they are 24% more likely to allow a third party to grow that crop (Lynes, et al., 2012). Summary statistics indicate that the farms from the survey typically rented more than half their acres. The study also found that farmers with irrigation are willing to plant 52.74 more acres of a dedicated annual bioenergy crop initially than farmers without irrigation. Farmers with off-farm income are likely to plant 39.89 acres more initially than farmers who do not have off-farm income.

Perennials

When harvesting biomass, previous use of a baler has a positive impact on adoption as does college education, according to the findings by Lynes et al. (2012). Relying on market information has a negative impact on growing a perennial crop, most likely due to the uncertainty of the market. If farmers increase the percentage of CRP land by 1%, the marginal effect of the increase would indicate the farmer is 2.66% more willing to grow a dedicated perennial crop. If a manager begins using a baler, is willing to use a custom harvester, is willing to lease their land for production, or if they are a college graduate, then the farmer would be more likely to grow a dedicated perennial energy crop by 30%, 32%, 42%, and 18% respectively. Relying on the market to make decisions indicates they are 18% less likely to grow a dedicated perennial bioenergy crop. The mean number of acres farmers were willing to dedicate to a perennial crop was 97.04. Farmers in the western region of Kansas were willing to plant 96.77 more acres initially than farmers in the northeast region. In the central region, farmers are willing to plant 42.69 more initial acres than those in the northeast. If they are a risk-avoider, managers are willing to plant 55.91 acres more than someone who is not which may reduce exposure to risk by providing an economically viable alternative for less productive or marginal lands (Lynes et al., 2012).

Expiring CRP land was considered viable for switchgrass production. Nelson et al. (2010) stated that generally, 50% of the total root biomass is located in approximately the top 12 inches of the soil and the root system of switchgrass has the potential to lower soil erosion rates by 30% in the establishment year and by 600% after in comparison with annual crop production (Nelson et al., 2010; McLaughlin et al., 2002).

Contracting

Many have argued that mass production of biomass will be feasible only with cooperatives and there are significant cost savings in comparison with individual farmers. Basnet and Kenkel (2012) found that the total fixed cost was almost the same for cooperatives and individual producers. Total variable cost was almost twice that individual producers in the cooperative. Cost per ton for baling and raking however in the individual producer scenario was almost twice the cost as for the cooperative scenario. Infield transportation cost was found to be higher in the cooperative (stacker) than in the individual producer’s since the equipment was oversized. Fewer machinery days in the cooperative structure lowered overall variable costs compared to individual producers helping to achieve economies of scale (Basnet and Kenkel, 2012).

Biomass is generally sold on an ad hoc basis, with farmers selling residue some years and selling no biomass in others. Altman, Boessen, and Sanders (2006) indicate that in potential biomass industries, farmers and processers are independent. "However once they make specialized investments that support the biomass transaction, they typically become bilaterally dependent on each other's actions" (Altman, Boessen, and Sanders, 2006 pgs. 4-5). This is particularly true of perennial energy crops such as switchgrass. Asset specificity, frequency, and uncertainty indicate the traits of transactions (Williamson, 1979). Asset specificity is significant in the ethanol industry for biomass such as switchgrass, which has limited alternative uses; however residues such as corn stover have multiple opportunity costs associated with them. In order for ethanol plants to have a steady flow of biomass, at least some long-term contracting will be necessary due to year-round production of ethanol. Starch ethanol plants have a constant feedstock that is easily stored year-round, whereas cellulosic biomass is only seasonally available with significant storage losses occurring. Altman, Boessen, and Sanders (2006) state:

> *"The choice facing the processor is between entering a new area where spot markets are less likely and administrative costs are higher (because long term contracts are more likely), or entering an established biomass area where spot markets can be expected (and transaction costs lower) but the processor will have to compete with other buyers" (Altman, Boessen, and Sanders ,2006 pg. 5).*

Contracting with cooperatives has been considered a more efficient option than contracting with individuals to reduce administrative costs (Altman, Boessen, and Sanders, 2006). Contractual components such as timeframes, acreage commitments, timing of harvest, feedstock quality issues, biomass harvest responsibility, technical assistance, nutrient replacement costs, water use and conservation, soil erosion, and other environmental stewardship considerations are all necessary to ensure successful contracts (Anand et al., 2011; Altman et al, 2008; Epplin et al., 2008; Glassner et al., 1998; Larson et al., 2007; Stricker et al., 2000). Alexander et al. (2012) state that the farmers' goal to minimize costs may conflict with the refinery's goal of maximizing yield and minimizing moisture, therefore specific contracting is needed.

"Conceptualizing these issues within the participation/incentive compatibility constraints framework allows us to quickly recognize the key tradeoff: relaxing the participation constraint typically implies a tightening of incentive compatibility and vice versa" (Alexander et al., 2012 pg. 3). Optimal contracts balance this tradeoff so the marginal benefit of relaxing one constraint is balanced against the marginal cost of tightening the other constraint. In the case of bioenergy crops, asymmetric information becomes more of an issue since grading and quality standards are not as commonplace as with other crops such as corn (Alexander et al., 2012). Revealing information that is privately known by the farmer allows the contractor or biorefinery to better match payments to quality and yield, therefore strengthening incentives for participation and producing high quality biomass. When outside factors such as poor weather negatively affect yield, it is often impossible to distinguish how much of a role bad practices played in crop performance.

Alexander et al. (2012) specify contracts must contain some incentives for the use of good practices, however they cannot over detract from contract payments for poor performance when outside factors are evident. Risk-tolerant growers might be more inclined to accept contracts with more significant performance incentives. More risk-averse growers will accept lower average returns for price stability and desire more stable contracts. An optimal pay-for-performance contract occurs when the incremental gain from strengthening the pay-for-performance plan equals the incremental increase in the risk premium (Alexander et al., 2012). Providing the correct incentive for production to maximize both profits and participation is an area in which little research has been done for the cellulosic industry. Alexander et al. (2012) indicate when deciding between an acreage versus a yield contract, it is important for the contractor to assess whether the marginal incentive gains from a yield contract will offset the marginal risk premium savings from an acreage contract. Acreage contracts buffer a farmer's revenue from yield fluctuations, but offer weak incentives for yield maximizing activity, whereas yield contracts are more risky to farmers. An excerpt from Alexander et al. (2012) regarding incentives and premiums follows (in Alexander et al., 2012 pg. 14):

1. *"There is a tradeoff between strong pay-for-performance incentives and risk premiums. Implementing strong incentives means that higher average payments must be promised to the grower or the grower will reject the contract. This has implications for acreage versus yield contracts.*

2. *In highly volatile environments, it may not be cost effective to use pay-for-performance incentives. Farmers will reject contracts unless a very large risk premium is provided. It may be more effective to use production contracting with input control, monitoring, and joint management of production and harvesting."*

Holmstrom and Milgrom (1991) identify key points regarding multi-task principal-agent models (in Alexander et al., 2012 pg. 15):

- *"If tasks are independent of each other (not complements or substitutes), then there is no need to worry about incentive conflicts.*
- *If tasks are complements, then rewarding one task will indirectly incentivize other complementary tasks. For example, yield incentives will also induce growers to use efficient harvest methods. However, the strongest incentives should be applied to the task that would generate the lowest risk premium.*
- *If task are substitutes, then there are incentive conflicts. Then the contract must,*

1) *Balance incentives so that one task is not rewarded significantly more than another task.*
2) *Weaken incentives for both tasks or eschew pay-for-performance altogether and use production contracting where the contractor is more involved in the production process."*

Harvesting and transportation of biomass by the farmer will greatly increase the variable cost to the farmer. This, combined with the need to find adequate equipment for biomass harvest, will undoubtedly lead to a lower participation rate (Altman, Boessen, and Sanders, 2006). Some ethanol plants contract for biomass and offer various options such as payments per tonnage removed and nutrient replacement costs. In their contracting scenarios, the ethanol plant pays for all the associated costs with harvesting and transport. The Canadian corporation Iogen determined that a custom harvest and delivery system was cheaper than the alternative of negotiating delivery prices with farmers after harvest. A minimum amount of biomass is contracted using the three options with a maximum moisture content of 18% (Altman, Boessen, and Sanders, 2006).

According to Altman, Boessen, and Sanders (2006), Iogen is an industry leader in cellulosic ethanol production. Standard production contracts offered a 5-6 year option to purchase biomass with three pricing options. It is likely that farmers producing perennial crops would demand a much longer contract due to establishment period and stand lifespan. Iogen gave the choice of a fixed price option of $8 per ton; a variable price option linking the price paid for the biomass to the price of oil; and a mixture of fixed and variable price options. As with co-operative agreements, variable prices offer a way to minimize risk based on the fluctuations of necessary input costs such as fertilizer. Entering areas where biomass is not harvested for livestock, Iogen expects "savings from the lower value of biomass to be higher than the transaction costs of managing and enforcing contracts which would not be necessary if they entered a more established biomass area and could utilize spot markets" (Altman, Boessen, and Sanders, 2006 pg. 10). The contracting agreements indicate storage must be supplied by the farmer for up to twelve months following harvest and biomass must meet standards for straw quality, storage, and access for delivery. Contractors attempt to require almost perfect information in regards to the farmer's actions towards the biomass crops to maintain efficiency.

> *"Specific items listed for producer activities include: estimate crop acres by March 15th, provide access to the Producer's Farm Service Agency (FSA) reports, provide a forecast of straw production by June 15, provide access to property and information as required by the processor, provide notice of all changes to acres farmed, crop rotation, or any other pertinent information for straw volume or yields, provide notice of address change, and a catch-all item stating that the farmer must meet any requirement the processor states will reduce risk, streamline operations or administering any matter"* under the agreement. *(Altman, Boessen, and Sanders, 2006 pg. 13)*

The terms also stated that the stacks of biomass must be accessible to loading and transport equipment year round twenty-four hours a day indicating snow removal is the producer's responsibility should their field be selected for biomass pickup. Stacks must also be in well drained areas and a substantial distance from power lines. The contract calls for three payments:

> *"First, one third of the order value will be paid within 30 days of the processor's receipt of the producer's FSA commodity report. The second payment will occur after storage at an appropriate site and a processor inspector has verified the estimated tonnage. The final payment will be made on delivery and certified measurement of the tons delivered." (Altman, Boessen, and Sanders, 2006 pg. 14)*

Risk of biomass loss remains entirely the farmer's until the biomass is delivered. If land is sold or leased land is not renewed, the farmer is obligated to transfer the obligations under the agreement, if at all possible. The producer and successor operators cannot sell straw to competing firms unless the obligations of the original agreement have already been met and contractual obligations must still be met by heirs. Acts of God remove responsibility of the contract when weather conditions are severe enough. A general outline of the contract terms are found in the Appendix A. These conditions serve as a general layout of what can be expected in any given biomass contract to minimize producer and processor risk.

Cellulosic Biomass Risk

Risk analysis is an important topic of consideration with biomass harvesting. Larson, et al. (2005) used a quadratic programming model for a representative grain firm in Tennessee. USDA-NRCS data was used to project crop rotation and soil types for biomass enterprises. Net revenues were calculated using data USDA-NRCS from 1977 to 2001. A forward contracting mechanism was used to provide incentive for farmers to supply certain quantities of biomass to user facilities. Various crop growth simulation models were used, but government payment programs were not incorporated into the model. The authors generated a base set of risk efficient crop enterprises for five levels of absolute risk aversion using the quadratic programming model. Alternative forward contract price scenarios and the three price levels were $30.00/DT, $32.50/DT, and $35.00/DT. Energy ratios per biomass type were used to account for the different conversion rates to ethanol. “The three forward contract yield levels evaluated with the model were 50%, 75%, and 100% of expected yield and the portion of yield not contracted was priced at the energy equivalent value of ethanol as a substitute for gasoline” (Larson et al., 2005, pg.11). Switchgrass production provided the best risk-return tradeoff in the analysis over corn stover production, and wheat straw production was not a risk efficient alternative for the representative grain firm. These prices seem somewhat low, especially with today’s prices, however switchgrass is often considered a way to diversify farms and utilize marginal lands. Having an established market in which to sell switchgrass must be an assumption considering the risk-return tradeoff the greatest of the three: corn stover, wheat straw, and switchgrass. The study also concluded a forward contracting mechanism that provides a guaranteed biomass price on a portion of expected production may provide positive risk management to farmers and move farmers to increase biomass production. When contracting, plants should spread out the acreage they lease in order to curb the risk of disease and pests.

Yang, Paulson, and Khanna (2012) indicate production of energy crops will inevitably expose farmers to volatility in energy markets since prices of biomass will most likely be tied to the price of oil.

"With the same level of land quality, farmers with higher risk aversion are more willing to choose the first type of contract because a leasing contract pays them a fixed per acre payment every year they are not exposed to yield risk and price risk. Farmers with a small risk aversion coefficient are more likely to choose a profit sharing contract. Farmers who have an intermediate level of risk aversion are likely to choose the fixed payment contract because they only need to bear the yield risk and not the price risk" (Yang, Paulson, and Khanna, 2012 pgs. 12-13).

Using the interval method to estimate risk aversion of Kansas farmers, Schurle and Tierney (1990) found 80% of Kansas farmers to be risk averse, 18% risk loving, and 2% risk neutral. Under the risk assumptions of Schurle and Tierney (1990), Yang, Paulson, and Khanna (2012) found that under optimal contracts, 31% of farmers would choose a leasing contract; 12% of farmers would choose a fixed price contract; and 5% of farmers would choose a profit sharing contract; and 53% of farmers in the study would still plant traditional row crops. The terms of the optimal contracts were $90 per acre for a leasing contract, $65 per ton for fixed price contract, and 34% for a profit sharing contract.

Plant sizing under uncertainty is only 1 MGY less than plant sizing under certainty according to Zhou (2013). This implies the optimal plant size is almost the same under different transportation costs and production costs. This was determined by setting price equal to marginal costs given various corn stover yield scenarios. Surveys have shown that higher levels of vertical integration are evident when specific assets must be purchased or there are substantial sources of uncertainty (Yang, Paulson, and Khanna, 2012; Lafontaine and Slade, 2007; Lajili, et al, 1997; Sykuta and Parcell, 2003).

Financing Cellulosic Ethanol

Gustafson (2008) indicated that for cellulosic ethanol, there is a lack of industry capital, limited availability of performance benchmarks, concerns regarding future industry prospects, and general uncertainty in U.S. financial markets. If the domestic market is not able to capitalize and develop enough advanced biofuels, Brazil and Mexico will most likely fill consumers' demand. After the Renewable Fuel Standard was passed under the Energy Policy Act of 2005, a

$0.51/gallon of blended ethanol tax credit was passed, in addition to a $0.54 tariff on imported ethanol to enhance supply and demand for ethanol in the U.S. (Gustafson, 2008). These subsidies have since expired and so far, the market has determined there is too much risk and not enough incentive to spark development of a commercial cellulosic industry.

Cellulosic ethanol will most likely take the path of corn starch ethanol once a “cookie-cutter” plant is able to be achieved with standardized benchmarks. Initially, profits soared with investment returns being $2.25 per gallon when investment costs were close to $1.00 per gallon in the starch ethanol industry (Gustafson, 2008). If commercial plants are located in areas with lower priced biomass due to the lack of established markets or see further lower fixed and variable costs, they will likely see substantial profitability to return initial investments. Returns in starch ethanol have consistently declined after peaking in mid-2006. The rise in cellulosic ethanol demand has not seen a comparable rise in supply. Increased numbers of plants have rising feedstock costs, in turn raising production cost and thus lowering profits (Gustafson, 2008).

According to Kenkel and Holcomb (2009), the 36 billion gallons of ethanol called for by the EPA, of which 16 billion gallons must be cellulosic ethanol, will require capital investments of over $100 billion for production facilities alone without factoring in feedstock investment and transportation costs. Failure to invest has been caused by unproven profit potential, lack of commercialized and standardized conversion technology, high capital cost for constructing plants, feedstock establishment, feedstock logistics, and the difficulties in attracting capital to an emerging, unproven industry (Kenkel and Holcomb, 2009). The authors indicate that in order to overcome these industry barriers, a policy environment providing continuing and stable incentives, rapid standardization of technology, and development of business models which simultaneously stimulate investment in feedstock and processing facilities is necessary.

DDGs and Other Byproducts

Tejada (2012) studied the dynamic effects of a market influx of distiller’s dried grains (DDGs) due to ethanol mandates in relation to other market feeds such as corn, grain sorghum, and soybean meal. DDG’s have a larger protein content than corn and have filled the gap in available livestock feed stemming from ethanol mandates. Before the U.S. ethanol mandates, more than half of the corn produced was utilized as feed for livestock (Tejada, 2012). This working paper found a substantial impact from the ethanol mandates of DDGs on corn, soybean meal, and grain sorghum markets. Being close to a perfectly competitive market, economic profits are currently close to zero in the starch ethanol market which will eventually occur in cellulosic markets. This high level of competition combined with the immense capital requirement for startup, acts as a barrier to entry. According to ICM, the sale of DDGs are keeping starch plants open and profitable and those derived from the cellulosic process currently sell for an equivalent value but are projected to command a higher price in the future. An example given by a chemical engineer in research and development at ICM was approximately $70 million worth of DDGs were sold by a 100 MGY starch plant in 2011 (Javers, 2012).

The DDGs resulting from the cellulosic process currently sell for the same price as those from the corn starch process although they contain higher protein and less fiber. They contain approximately 40% wet and 85% dry highly digestible protein. This higher digestibility enables cellulosic DDGs to be used in higher ratios for mono-gastric animals (Javers, 2012). One caveat is their color, which is a darker reddish brown and therefore cannot be used to feed laying hens due to the potential discoloration of yolks. ICM projects cellulosic DDG's will eventually command a greater price than regular DDGs due to the lower fiber content. Captive fiber, the process of making cellulosic ethanol with corn fiber from the starch process, reduces DDGs, however the ethanol price earned has a higher value (Javers, 2012). Other byproducts from cellulosic ethanol include purified sugars for other fuels and chemicals, oil, CO_2, Zane proteins, food grade protein products, and 50% animal protein products.

Chapter 3- Methods and Data

This chapter provides explains the details of the model design, underlying concepts, and assumptions used in the model. A detailed description of the data including any conversions are also provided. There have been many factors hindering the production of cellulosic ethanol. A substantial difference exists between what has been projected, what was mandated, and what was actually produced in the domestic market of cellulosic ethanol (IER, 2013). The EPA first reduced the initial one billion gallon cellulosic ethanol mandate for 2013 to 14 million gallons, indicating there was a lack of industry production capacity. The only two existing commercial plants estimated their potential cellulosic production at 6 million gallons which is what the RFS standards were lowered to for 2013 (Paulson, 2013). Many cellulosic plants have gone out of business immediately due to a lack of extensive economic planning and contracting necessary for year-round production, which is the primary focus of this paper.

Mixed Integer Transportation Model

The base transport model was set up as a feasibility model with the main goal being to determine if an add-on plant size equivalent to the existing size of each of the seven plants under consideration would be economically feasible. Breakeven prices were used for farm-gate prices and one hundred percent participation was assumed. Enterprise budgets were compiled to determine farm-gate breakeven costs. O'Brian, Dumler, and Madl (2009) reported the nutrient replacement amounts for corn stover, sorghum stover, and wheat straw, as well as conversion rates from grain to stover. The nutrient replacement costs were calculated using 2012 values along with custom rates for swathing, raking, and baling. By setting farm-gate production cost equal to price, marginal cost was set equal to price, signifying a perfectly competitive market. The difference between plant-gate and farm-gate price divided by the transportation cost per loaded mile represented the maximum distance biomass can be transported with net returns being greater than or equal to zero under the assumptions of the model. This is what the model considers feasible under the assumption a farmer will not produce and deliver biomass or a plant will not pick up biomass if they will be receiving negative profits in order to do so. The USDA Office of the Chief Economist used a transportation cost of $0.14 per loaded ton mile for corn stover in their 2012 report, therefore this was the cost utilized in this study. A custom loading rate was used in the same study of $0.78 per ton which was also incorporated in the transport cost of this model (as shown in equation 5) (Gallagher and Baumes, 2012).

Study Region

Figure 3.1 shows all 202 counties within the study region as well as the seven ethanol plant locations. The study region was chosen by selecting the portion of Kansas that had the most rainfall which accounts for approximately the eastern two-thirds of the state. Only ethanol plants located within this approximate region were considered to be potential locations for add-on facilities. A general three county distance away from ethanol plants into western Kansas and three county distance into the bordering states was chosen to include all potential biomass able to be transported within a reasonable plant radius. This was also to find how far into bordering states from which the model would need to deliver biomass. Table 3.7 shows what region each county was assigned for pricing from district yield estimates.

Linear Program Model

The seven plant locations used for the theoretical cellulosic plant construction are shown in Table 3.1. The transportation model is outlined below. Total cost of shipping the feedstock was represented by variable Z and the positive variables used were $\mathrm{X}_{i,j}$ for the amount of feedstock shipped from the county centroid j to Plant_i and P_i the production at Plant_i. There were 202 counties from Kansas, Nebraska, Iowa, Missouri, and Oklahoma within the study region. Transportation costs in loaded per ton mile were 2012 custom rates for haying operations. The model is:

$$\text{Min: } \sum_{i=1}^{7} \sum_{j=1}^{220} \mathrm{TC}_{i,j} * (\mathrm{XC}_{i,j} + \mathrm{XW}_{i,j} + \mathrm{XS}_{i,j} + \mathrm{XG}_{i,j})$$

Subject to the constraints:

i. $\sum_{i=1}^{7} \mathrm{XC}_{i,j} \le \mathrm{C}_j * \mathrm{AdoptC}_j$ for all j

ii. $\sum_{i=1}^{7} \mathrm{XW}_{i,j} \le \mathrm{W}_j * \mathrm{Adopt\,W}_j$ for all j

iii. $\sum_{i=1}^{7} \mathrm{XS}_{i,j} \le \mathrm{S}_j * \mathrm{AdoptS}_j$ for all j

iv. $\sum_{i=1}^{7} \mathrm{XG}_{i,j} \le \mathrm{G}_j * \mathrm{AdoptG}_j$ for all j

v. $\sum_{j=1}^{202} \mathrm{E} * (\mathrm{XC}_{i,j} + \mathrm{XW}_{i,j} + \mathrm{XS}_{i,j} + \mathrm{XG}_{i,j}) = \mathrm{P}_i$ for all i

vi. $\mathrm{XC}_{i,j} \le \mathrm{SupplyC}_{i,j}$ for all (i,j)

vii. $\mathrm{XW}_{i,j} \le \mathrm{SupplyW}_{i,j}$ for all (i,j)

viii. $XS_{i,j} \leq SupplyS_{i,j}$ for all (i,j)
ix. $XG_{i,j} \leq SupplyG_{i,j}$ for all (i,j)
x. Plant1=25,000,000*Capadj
xi. Plant2=25,000,000*Capadj
xii. Plant3=25,000,000*Capadj
xiii. Plant4=25,000,000*Capadj
xiv. Plant5=25,000,000*Capadj
xv. Plant6=25,000,000*Capadj
xvi. Plant7=25,000,000*Capadj

Parameter Definitions

i Index for plants 1 through 7

j Index for counties 1 through 202

C_j Amount of corn stover available for county j in tons

W_j Amount of wheat stover available for county j in tons

S_j Amount of sorghum stover available for county j in tons

G_j Amount of switchgrass available for county j in tons

E 80 gallons per ton biomass to cellulosic ethanol conversion factor

$D_{i,j}$ Distance to ethanol plant i from county centroid j in miles

$FGPC_j$ Farm-gate price of corn stover for each county in dollars

$FGPW_j$ Farm-gate price of wheat stover for each county in dollars

$FGPS_j$ Farm-gate price of sorghum stover for each county in dollars

$FGPG_j$ Farm-gate price switchgrass for each county in dollars

$YieldC_j$ Yield of corn stover per acre in tons in county j

$YieldW_j$ Yield of wheat stover per acre in tons in county j

YieldS_j	Yield of sorghum stover per acre in tons in county j
YieldG_j	Yield of switchgrass per acre in tons in county j
AdoptC_j	Adoption percentage rate by farmers for harvesting corn stover in county j
AdoptW_j	Farmers' percentage adoption for harvesting wheat stover in county j
AdoptS_j	Farmers' percentage adoption for harvesting sorghum stover in county j
AdoptG_j	Farmers' percentage adoption for harvesting switchgrass in county j
PGP	Plant-gate price offered in dollars per ton
Capadj	Percentage adjustment factor for maximizing plant capacity
Trans	Transportation cost per loaded mile

Variable Definitions

$\text{XC}_{i,j}$	Amount of corn stover shipped from county centroid j to plant i
$\text{XW}_{i,j}$	Amount of wheat stover shipped from county centroid j to plant i
$\text{XS}_{i,j}$	Amount of sorghum stover shipped from county centroid j to plant i
$\text{XG}_{i,j}$	Amount of switchgrass shipped from county centroid j to plant i
P_i	Production at plant i

Indicator Values

Dummy variables for county designation correlation coefficients are utilized from Bergtold, Fewell, and Williams (2013) since adoption rates vary by agricultural regions. The beta value is different for each of the agricultural regions therefore these dummy variables prove useful and provide more realism in the model. County designations are listed in Table 3.7. The boundaries for these regions is extended into bordering states therefore enabling values to be assigned for counties outside the Kansas border.

Central_j = 0

West_j = 0

CW_j Designation as a county in central or western region

If CW_j = 2 then Central_j = 1

If CW_j = 1 then West_j = 1

Adoption Equations

The adoption equations discussed next are additional constraints. Adoption rate equations were derived from stated choice experiments using a random utility framework predicting willingness-to-participate from Bergtold, Fewell, and Williams (2013) for corn stover, which was then assumed to be the same for all crop residues. Equations were derived assuming similar functional forms for wheat and sorghum. The nutrient replacement variable Nutr had a value of -1 when there was no nutrient replacement and a value of 1 when there was. Cost share for switchgrass represented by "Share" was a percentage value with 0 being the option with no cost sharing.

$$(1)\ \text{AdoptC}_j = \frac{2e^{-4.49-1.26*\text{West}_j+0.99*\text{Central}_j+0.13*(\text{FGPC}_j*\text{YieldC}_j-\text{VC})-0.21*2+0.73+0.74*\text{Nutr}}}{1+2e^{-4.49-1.26*\text{West}_j+0.99*\text{Central}_j+0.13*(\text{FGPC}_j*\text{YieldC}_j-\text{VC})-0.21*2+0.73+0.74*\text{Nutr}}}$$

$$(2)\ \text{AdoptW}_j = \frac{2e^{-4.49-1.26*\text{West}_j+0.99*\text{Central}_j+0.13*(\text{FGPW}_j*\text{YieldW}_j-\text{VW})-0.21*2+0.73+0.74*\text{Nutr}}}{1+2e^{-4.49-1.26*\text{West}_j+0.99*\text{Central}_j+0.13*(\text{FGPW}_j*\text{YieldW}_j-\text{VW})-0.21*2+0.73+0.74*\text{Nutr}}}$$

$$(3)\ \text{AdoptS}_j = \frac{2e^{-4.49-1.26*\text{West}_j+0.99*\text{Central}_j+0.13*(\text{FGPS}_j*\text{YieldS}_j-\text{VS})-0.21*2+0.73+0.74*\text{Nutr}}}{1+2e^{-4.49-1.26*\text{West}_j+0.99*\text{Central}_j+0.13*(\text{FGPS}_j*\text{YieldS}_j-\text{VS})-0.21*2+0.73+0.74*\text{Nutr}}}$$

VC Variable cost of corn stover per acre

VW Variable cost of wheat stover per acre

VS Variable cost of sorghum stover per acre

VG Variable cost of switchgrass per acre

Nutr Nutrient replacement option for residues

Share   Cost share for switchgrass for seed establishment

Adoption rate equations for switchgrass from Bergtold, Fewell, and Williams (2013) differed than those of corn stover and variable cost was assumed to be $181 per acre for switchgrass. The equation was:

$$(4)\ \mathrm{AdoptG}_j = \frac{2e^{-6.96+1.94*\mathrm{West_j}+3.74*\mathrm{Central_j}+0.16*(\mathrm{FGPG_j}*\mathrm{YieldG_j}-\mathrm{VG}-40)-0.16*7+0.33+0.23+0.025*\mathrm{Share}}}{1+2e^{-6.96+1.94*\mathrm{West_j}+3.74*\mathrm{Central_j}+0.16*(\mathrm{FGPG_j}*\mathrm{YieldG_j}-\mathrm{VG}-40)-0.16*7+0.33+0.23+0.025*\mathrm{Share}}}$$

Transportation Limits and Supply Constraints

$\mathrm{TC}_{i,j}$ represents the total transportation cost per ton from county i to plant j. The constant "Trans" equals $0.14 per loaded ton mile and each ton costs a rate of $0.78 per ton to load (Gallagher and Baumes, 2012).

$$(5)\ \mathrm{TC}_{i,j} = \mathrm{D}_{i,j}*\mathrm{Trans}+\$0.78$$

The model uses the maximum transportation cost to determine feasible distance for biomass to travel to ensure that profits are greater than or equal to zero. This eliminates pulling biomass tonnage from counties where it is not profitable to do so. If it is profitable, the total tonnage available in the county is multiplied by the adoption rate percentage which is a willingness to participate function for farmers at a given price for the specified feedstock. The following equations help to define supply limits for each county as they did with corn stover.

$$(6)\ \mathrm{LimitC}_j = (\mathrm{PGP}-\mathrm{FGPC}_j)/\mathrm{Trans}$$

$$(7)\ \mathrm{SupplyC}_{i,j} = \mathrm{AC}_j*\mathrm{AdoptC}_j \text{ if } \mathrm{D}_{i,j} \leq \mathrm{LimitC_j}$$

$$(8)\ \mathrm{SupplyC}_{i,j} = 0 \text{ if } \mathrm{D}_{i,j} > \mathrm{LimitC_j}$$

$$(9)\ \mathrm{SupplyW}_{i,j} = W_j*\mathrm{AdoptW}_j \text{ if } \mathrm{D}_{i,j} \leq \mathrm{LimitW_j}$$

$$(10)\ \mathrm{SupplyW}_{i,j} = 0 \text{ if } \mathrm{D}_{i,j} > \mathrm{LimitW_j}$$

$$(11)\ \mathrm{SupplyS}_{i,j} = S_j*\mathrm{AdoptS}_j \text{ if } \mathrm{D}_{i,j} \leq \mathrm{LimitS_j}$$

$$(12)\ \mathrm{SupplyS}_{i,j} = 0 \text{ if } \mathrm{D}_{i,j} > \mathrm{LimitS_j}$$

$$(13)\ \text{SupplyG}_{i,j} = G_j * \text{AdoptG}_j \text{ if } \text{D}_{i,j} \leq \text{LimitG}_\text{j}$$

$$(14)\ \text{SupplyG}_{i,j} = 0 \text{ if } \text{D}_{i,j} > \text{LimitG}_\text{j}$$

Objective Function

$$(15)\ \text{COST} = \sum_{i=1}^{7} \sum_{j=1}^{202} \text{TC}_{i,j} * (\text{XC}_{i,j} + \text{XW}_{i,j} + \text{XS}_{i,j} + \text{XG}_{i,j})$$

The objective function minimizes the transport cost for each type of biomass and sums the total costs to all refineries for transportation.

Maximum County Supply Constraints

These constraints limit the amount available to ship from the county centroid j to what the total amount of tons available multiplied by adoption percentage are for each feedstock examined.

$$(16)\ \text{MaxC}_j = \sum_i \text{XC}_{i,j} \leq \text{C}_j * \text{AdoptC}_j$$

This constraint limits the amount available to ship from the county centroid j to what the total amount of tons available multiplied by adoption percentage are for wheat stover.

$$(17)\ \text{MaxW}_j = \sum_i \text{XW}_{i,j} \leq \text{W}_j * \text{AdoptW}_j$$

This constraint limits the amount available to ship from the county centroid j to what the total amount of tons available multiplied by adoption percentage are for sorghum stover.

$$(18)\ \text{MaxS}_j = \sum_i \text{XS}_{i,j} \leq \text{S}_j * \text{AdoptS}_j$$

This constraint limits the amount available to ship from the county centroid j to what the total amount of tons available multiplied by adoption percentage are for switchgrass.

$$(19)\ \text{MaxG}_j = \sum_i \text{XG}_{i,j} \leq \text{G}_j * \text{AdoptG}_j$$

Total production at plant i is equal to the total summation of tons of biomass multiplied by a conversion factor of 80 gallons per dry ton of biomass obtained from ICM and AGCO.

$$(20)\ \text{Cap}_i = \text{G} * \sum_j \text{XC}_{i,j} + \text{XW}_{i,j} + \text{XS}_{i,j} + \text{XG}_{i,j}$$

Maximum Shipment Constraints

These constraints limit the amount of feedstock able to be shipped from each county to the "Supply" available which represents the "Limit" of the feedstock for the respective county. In this way the transitive property links these values to XC(i,j) so that the following holds true:

$$(21)\ \text{ShipmentMaxC}_{i,j} = \text{XC}_{i,j} \leq \text{SupplyC}_{i,j}(23)$$

$$(22)\ \text{ShipmentMaxW}_{i,j} = \text{XW}_{i,j} \leq \text{SupplyW}_{i,j}$$

$$(23)\ \text{ShipmentMaxS}_{i,j} = \text{XS}_{i,j} \leq \text{SupplyS}_{i,j}$$

$$(24)\ \text{ShipmentMaxG}_{i,j} = \text{XG}_{i,j} \leq \text{SupplyG}_{i,j}$$

Plant Capacity Constraints

These constraints signify the initial 25MGY for the base case multiplied by a capacity adjustment factor which is utilized when the maximum capacity is unable to be achieved as the farm-gate price per ton climbs or is exceeded as farm-gate prices decrease per ton. All seven plant capacities (PlantCap1 through PlantCap7) were kept the same by keeping the same base plant size of 25 MGY and varying the CapAdj factor which was not varied between plants. This would represent a perfect competition simulating if all plants were constructed and would compete for biomass. Since almost no commercial cellulosic gallons are currently produced, it is a reasonable assumption that plants would only be built to the minimum size dictated by economies of scale until markets are established.

$$(25)\ \text{PlantCap}_i = 25{,}000{,}000 *\ \text{CapAdj}_i \text{ for all i}$$

Data

Before finding how much biomass will be utilized for cellulosic ethanol at the seven locations in Kansas, it must be determined how much is available within the specific region where the existing plant is located. In order to accomplish this accurately, Farm Service Agency (FSA) data was obtained providing the dry land acreages planted to corn, wheat, and grain sorghum from the study years 2007 through 2011. CRP is assumed to be the most likely candidate to be planted with switchgrass due to the large opportunity cost associated with planting traditional crop fields with a perennial. Yields for the traditional crops were gathered from the National Agriculture Statistical Service (NASS) for the study years. The yields obtained were for corn, wheat, and grain sorghum on non-irrigated land. When yield data was missing, agricultural district averages were used to fill in the gaps if there was a significant amount of acreage dedicated to the specified crop. If an average of less than 1,000 acres was planted to a specific crop in the five year window, the county was disregarded for that specific crop and a value of 0 tons available was assigned. The 1,000 acre limit was not applied for CRP land. A list of data required for the research includes all the following categories:

Acreage of Corn, Wheat, and Grain Sorghum

This data was obtained from the FSA and can be found in the thesis file Optimization of Cellulosic Biomass Analysis on worksheets Iowa, Kansas, Missouri, Nebraska, and Oklahoma.

Grain Yields of Corn, Wheat, and Grain Sorghum

This data was obtained from NASS and can be found in the thesis file Optimization of Cellulosic Biomass Analysis on worksheets Iowa, Kansas, Missouri, Nebraska, and Oklahoma.

CRP Acreage

> *"In the United States, perennial grasses could likely be grown on land that is currently not in use or is part of the Conservation Reserve Program (CRP), which protects land from erosion and environmental damage by maintaining vegetative cover such as native grasses" (Schnepf, 2010 pg. 15).*

Therefore, expiring CRP land was considered the primary land that would be considered for growing switchgrass because at current rates, traditional crops far exceed profitability of switchgrass and maintain much lower risk. The only CRP acreages considered for switchgrass production were codes 1, 2, and 10: establishment of permanent introduced grasses and legumes, establishment of permanent native grasses, and vegetative cover already established (grass), respectively. These are the most likely Farm Service Agency codes to be removed from the program as contracts expire and have the best potential for perennial stand production. Also, negative impacts to wildlife and wetlands would be mitigated through these being planted as switchgrass stands. This FSA CRP acreage data is found in the thesis spreadsheet on worksheet CRP.

Grain Yield to Crop Residue Conversion

Grain yields were multiplied by a crop residue factor obtained from the University of Nebraska-Lincoln Extension. Amounts of crop residue (tons/acre) are known to be a function of the amount of grain produced and Wortmann et al. (2008) found the conversion rate to be one ton of residue at 10% moisture for every 40 bushels of corn or grain sorghum equation (26) and 20 bushels of wheat (equation 27). The average grain yield per acre was divided by the conversion rate and multiplied by 0.9 in order to estimate the amount of dry tons that would be available in the field.

(26) Corn and sorghum residue tons/acre = $\frac{\text{grain yield } (\frac{\text{bu}}{\text{ac}})}{40 \text{ bu/ton}}$

(27) Wheat residue tons/acre = $\frac{\text{grain yield } (\frac{\text{bu}}{\text{ac}})}{20 \text{ bu/ton}}$

Gallagher and Baumes (2012) indicate that 1,430 lbs must be left on a field to maintain 30% cover and thus achieve conservation guidelines. This 1,430 pound constraint was utilized for each type of residue for every respective acre per county before participation was taken into account, to maintain conservation standards. Following equation (28) the amount of crop residue that could be removed per acre to still maintain enough residue for soil conservation and soil quality was calculated for each crop for all counties. While the upper limit on plant size is a rather large capacity with even small participation rates, these values may not be realized unless contracting is done and technology is further improved. Many risk neutral farmers will most likely opt for at least the conservation amount, which in Kansas could be up to 38 percent rather than 30 percent due to higher wind erosion factors (Anand et al., 2011).

(28) Maximum Residue Removed (tons/ac) =

$$\mathbf{\frac{Tons\ residue}{ac} - \frac{(0.715\ tons - Tons\ residue/ac * 0.1)}{0.88}}$$

The adjusted amount of residue (tons/acre) was multiplied by the total acreage for crops in all counties to find total tonnage available to the ethanol plants on a per county basis. The 0.715 tons left for conservation was subtracted by 0.1 multiplied by the amount of residue in tons due to harvest inefficiency since no machinery available is able to harvest one hundred percent of residue. Therefore, a ten percent harvest efficiency loss was assumed. An 88% residue retention rate was utilized to account for winter decay and based off data from Anand et al. (2011). Subtracting the amount of residue necessary for conservation from the amount of residue initially left in the field resulted in the total amount of residue available to be harvested. Utilizing these tons available per acre, enterprise budgets for each agricultural district in Kansas were constructed based off district average yields, utilizing the grain to residue conversions, and equation (28). Tables 3.3, 3.4, and 3.5 show corn, wheat, and sorghum residue enterprise budgets respectively.

Nutrients Removed (Replacement Rates)

Table 3.6 shows the amount of nutrients assumed to be removed in pounds per ton of crop residue (biomass) removed according to O'Brien, Dumler, and Jones (2010). The full enterprise budgets are found in the grain stover yields and costs worksheet in the thesis spreadsheet. If carbon markets become part of regulation, this could dramatically increase the cost to farmers and thus refineries. Large amounts of carbon are found in corn stover and the release of this carbon would be costly. Selling carbon credits as a commodity has been the focus of governments in an attempt to mitigate climate change, however current economic conditions have halted these efforts.

Cost of Corn, Wheat, and Sorghum Residue Production and Harvest

Kansas Farm Management Association (KFMA) costs for the base year of 2012 were used ($0.47/lb anhydrous N, $0.48/lb P, and $0.50/lb K). KFMA 2012 rates for swathing were $13.11 per acre, $4.15 per acre for sideraking, and $0.75 per ton for baling. Continuous wheat was assumed in all but western Kansas, where wheat was assumed to be fallow rotation meaning one crop is produced every two years. Table 3.2 shows the average break-even costs of residues. These costs can be found in the thesis file Optimization of Cellulosic Biomass Analysis on Grain Stover Yields and Costs worksheet.

Switchgrass Yield Estimates

Simulated average annual yields of non-irrigated switchgrass stands on two soil types fertilized with 80 lbs N in every county within Kansas are from Nelson, et al. (2010). These yields were assumed to be what could be achieved on expiring CRP land which could potentially go into crop production. Two different soil types common to each county were utilized and their yields were averaged. Yield predictions were unavailable for bordering states so the counties that bordered Kansas were assumed to be able to produce the same yields as their closest counterparts. Soil types between these counties are generally similar and average annual rainfall is very close between adjacent counties. If switchgrass is viable on expiring CRP in those areas and at those distances from the ethanol plants, then the model output will indicate that tons have been shipped from those bordering counties. These costs can be found in the thesis file Optimization of Cellulosic Biomass Analysis on Switchgrass Yields and Costs worksheet.

Switchgrass Cost Estimates

The enterprise budgets for switchgrass assumed a ten year projected stand life span, although switchgrass stands are often known to last longer. This study also assumed an eight percent per year amortization of establishment and annual operating cost over a 10 year growing period. These enterprise budget prices in dry dollars per ton can be found in the thesis file Optimization of Cellulosic Biomass Analysis on Switchgrass Yields and Costs worksheet.

Ethanol Plant-gate Prices

The head of research and development at ICM Douglas Rivers (Rivers, 2012) cited a profitable plant-gate price range of $60-80 as long as other costs were in line with their feasibility plan. These residues can be grazed or sold as feed after being baled on some markets. If a farmer could already sell their residue for livestock feed on a local market, the plant would need to at least match the price offered for the same biomass as feed. Table 3.2 shows the 2012 and 2013 average prices for these residues in local biomass markets for feed obtained from the USDA Agricultural Marketing Service (USDA, 2013) along with calculated averages from regional enterprise budgets. Opportunity costs to the farmer of selling in biomass markets yielded approximately the same price range as the $60 to $80 range given by ICM. These coinciding price ranges paid by the plant were therefore considered for this study. A $60, $80, $100, and $120 plant-gate pricing scenario were run to find input demand curves over various plant-gate prices.

Transportation Costs

Equation 5 represents the total transportation cost per ton. The constant "Trans" equals $0.14 per loaded ton mile and each ton costs a rate of $0.78 per ton to load (Gallagher and Baumes, 2012).

Transportation Distances

An easy comparison is not possible between the amount of biomass able to be harvested and that which farmers are willing to harvest; however, a comparison between what the seven ethanol plants demand and what is available under the participation assumptions can be made. Various participation rates are found throughout literature. It is intuitive that the higher the fixed cost or transportation cost per mile, the lower the distance the farmer is willing to travel to sell biomass. As price paid by the refinery increases or transportation costs are lowered, the amount of residue able to be supplied increases exponentially due to a theoretical circular radius. As the radius increases, the area available to pull biomass from increases by more acres. Straight line distances from county centroids to plants are utilized after being multiplied by a tortuosity factor (τ) in order to account for average road curvature (denoted by f_w) since field level data is not yet available. This tortuosity factor is defined by the following equation (30):

$$(30)\ \tau=1+f_w$$

Road curvature factors can range from f_w= 0.27 for developed agricultural regions with roads that are laid out in a rectangular grid or f_w= 2.0 for less-developed regions (Leboreiro and Hilaly, 2011; Overend, 1982). Leboreiro and Hilaly (2011) note that a similar lower limit of f_w= 0.20 was found by Wright and Brown (2007). For roads in a fairly well developed grid system such as Kansas, it was assumed that the tortuosity factor was 0.27, therefore all centroid to plant distances, $D_{i,j}$, were multiplied by 1.27.

Farm-gate Prices

Farm-gate price is the assumed price farmers are paid per dry ton at the edge of field. In the base case scenario, these prices are set equal to the break-even costs derived from enterprise budgets. The farm-gate prices of $50 per dry ton and higher were used to find the various plant capacities and biomass necessary to meet this demand that would be feasible for scenarios including nutrient replacement. Farm-gate prices of $35 per dry ton and higher were used when there was no nutrient replacement. The mean price farmers were willing to accept in order to harvest cover crop residues was found by Anand et al. (2008) to be $55 per dry ton (Anand et al., 2011; Anand et al., 2008).

Adoption Rates

The Kansas farmers who completed surveys summarized in Lynes et al. (2012) measured the willingness-to-produce any combination of three different bioenergy crops: crop residues as a value-added product; a dedicated annual bioenergy crop option such as sweet sorghum; and a dedicated perennial bioenergy crop such as switchgrass. Independent variables included farm characteristics, farm practices, bioenergy custom farming and land use options, and farmer characteristics. Based on literature, economic theory, and other studies, the independent variables that were hypothesized to affect farmer's adoption and initial acreage allocation were used.

Allowing a custom harvester, willingness to store biomass on farm, and relying on market information would make farmers 28%, 16%, and 8% more likely to harvest their crop residue and sell it to a biorefinery. Lynes et al. (2012) found that 77% of survey respondents were willing to harvest crop residue, 61% were willing to grow a perennial bioenergy crop, and 44% were willing to grow a perennial bioenergy crop. These were all at given price levels. This survey found the initial acreage farmers were willing to devote to an annual bioenergy crop was 121 acres, whereas farmers were only willing to dedicate 97 acres to a perennial bioenergy crop. Since farm level data is not yet available for the region, all crop acreage was considered possible for crop residue removal, and expiring CRP land was considered for switchgrass production.

The only statistically significant positive variable across all three models was allowing a custom harvester, indicating an increased likelihood farmers would harvest crop residue or grow a dedicated bioenergy crop. Therefore, in this model, custom harvest rates were used. Storage of biomass was also positive in all models, however only statistically significant in two. With the exception of storing biomass in the annual crop model, all the bioenergy custom farming and land use variables were positive and statistically significant (Lynes et al., 2012).

The willingness to participate varies per crop at various price levels as well as between each county due to removal rates being different. The model endogenously solves for participation rate using equations (1) thru (4) which are derived from Bergtold, Fewell, and Williams (2013).

A willingness to produce switchgrass percentage was endogenously found using equation (4) from Bergtold, Fewell, and Williams (2013) in order to determine how much would potentially replace CRP under various scenarios.

Percentage Adjustment factors on Plant Capacity

Sizing is based off of the minimum economies of scale size of 25 MGY and all plants were assumed to be the same size with the exception of the plant-scale matching scenario. The percentage adjustment factor CapAdj is varied throughout various farm-gate and plant gate price levels to find the maximum demand for biomass which translates into maximum capacity.

Cost share and Incentives for Switchgrass

The head of research and development for ICM, a company whose technology accounts for 70% of domestic ethanol production, says there is a minimum economies of scale for cellulosic plants of 25 MGY (Rivers, 2012). Both AGCO and ICM use a conversion rate to ethanol of 80 gallons per dry ton of biomass for crop residues and switchgrass (Herron, 2012; Rivers, 2012). This translates to approximately 312,500 dry tons per year to reach the minimum economies of scale required currently in the industry. This is a very feasible benchmark in most areas with sufficient rainfall. Altman, Boessen, and Sanders (2006) indicate that Iogen determined a custom harvest and delivery system was cheaper than the alternative of negotiating delivery prices with farmers after harvest. Therefore, the model assumes fixed per ton payments for all types of biomass by each plant. Transportation costs are subtracted from this plant-gate price as a means to derive farm-gate prices, which is indicative of a quasi-producer surplus. Depending on contractual obligations between bio-refineries, farmers could incur the cost of harvest, moving, loading, storage, and transportation of residue (Anand et al., 2011; Epplin et al., 2007). Storage was assumed to take place at the plant and the varied farm-gate prices signify how price increases affect input demand and supply curves.

Scenarios

Table 3.8 shows the names of each scenario and a brief description. The last two characters in the names are "S" for scenario along with a number representing which number the scenario was. The base case scenario or BCS1 evaluates whether all cellulosic plants of 25 MGY can obtain the amount of biomass needed minimum plant-gate price ranging from $60 and $80 per dry ton. The $60 to $80 per dry ton is the plant-gate price range suggested by ICM. Farm-gate prices are break-even prices for this scenario and are determined from enterprise budgets for each region. The total cost factoring in transport cost is what limits whether or not feedstocks are purchased by the plant from farms in each county.

The matching scale scenario or MSS2 evaluates whether or not each of the seven plant locations would be able to obtain enough biomass for a plant size matching the existing starch plant at each location. This scenario had a plant size upper limit of 50 MGY which is the existing size of Plants 4 and 5 (see Table 3.1) and was evaluated at a plant-gate price of $80 representing the maximum ICM reported their customers could pay for delivered biomass and still be profitable.

The maximum plant size scenario for the seven plants was evaluated under various farm-gate prices ranging from $50 per dry ton and increased in $5 increments up to $80, $100, and $120 per dry ton respectively until plant size approached zero. For instance, the first of these ranged from $50 to $80 per dry ton in $5 increments given a plant-gate price of $80 per dry ton. This scenario was referred to as PGP80S3. The second of these ranged from $50 to $100 per dry ton and the third ranged from $50 to $120 per dry ton. At prices lower than $50 per dry ton, nutrient replacement was not being included in the price farmers received therefore the no nutrient replacement scenario is utilized for these lower ranges below a farm-gate price of $50 per dry ton in the no nutrient replacement scenario NNRS6. Input demand curves were therefore found assuming a perfectly elastic demand for the plant up until plant capacity was reached. Feasible farm-gate price ranges per dry ton and sizes in MGY were selected and the remaining objectives evaluating residues and switchgrass under multiple equivalent price scenarios were accomplished. Edge of field supply was also determined by comparing production costs and utilizing breakeven prices to cover the cost of these residues and switchgrass. The willingness-to-participate at various farm-gate price levels was also used to arrive at the supply curve. This determined what was available without taking transportation cost into effect.

The final two scenarios (CRPS7 and BCAPS8) evaluated various impacts on switchgrass demand by the plant and supply at the farm-gate. At current production costs, additional payment programs or cost-sharing was necessary in order to increase the returns per acre for switchgrass. This was evidenced by the willingness-to-grow data which shows 0% participation will result at current returns for switchgrass due to low non-irrigated yields, risk of growing switchgrass, and high opportunity cost of crop production or keeping land in CRP. The initial switchgrass scenario was evaluated by allowing farmers to maintain the average of $40 per acre CRP payments while allowing switchgrass to be produced and harvested and is referred to as CRPS7. A 75% cost share was included as an option in this scenario in conjunction with the $40 per acre CRP payment to evaluate how a company or government cost share would impact adoption. Similarly in the final switchgrass scenario, this 75% cost share payment was included in conjunction with a theoretical Biomass Crop Assistance Program Payment of $45 per ton of switchgrass (see CRS and USDA, 2010) to determine the impact each had on farm production levels. The additional revenue per ton was evaluated with and without this establishment cost sharing to determine outcomes. This theoretical BCAP scenario was referred to as BCAPS8. These scenarios were evaluated using varied farm-gate price levels and a plant-gate price level of the maximum $80 per dry ton given by ICM. Table 3.8 defines each of these scenarios and their respective code.

Figure 3.1 202 County Study Region

Table 3.1 Locations of Existing Ethanol Plants

Owner	Town	Capacity
Plant 1: Kansas Ethanol LLC	Lyons	15 MGY
Plant 2: NESIKA Energy LLC	Scandia	15 MGY
Plant 3: East Kansas Agri Energy	Garnett	5 MGY
Plant 4: Abengoa Bio-Energy	Colwich	50 MGY
Plant 5: Abengoa Bio-Energy #2	Colwich	50 MGY
Plant 6: Everton Energy LLC	Concordia	15 MGY
Plant 7: MGP Ingredients	Atchison	5 MGY

Table 3.2 Kansas Average Residue Prices

	2012 Minimum	2012 Maximum	2013 Minimum	2013 Maximum	Calculated 2012 Avg. Breakeven Price
Corn Stover	$54.47	$70.12	$54.36	$70.00	$67.05
Wheat Straw	$65.25	$76.00	$68.75	$85.42	$46.81
Sorghum Silage	$55.23	$72.44	$51.67	$70.24	$69.78

(Source: USDA, 2013) (Source: KFMA, 2012)

Table 3.3 Corn Stover Enterprise Budget

Region in Kansas	Grain Yield Bu./acre	Grain Cost $/acre	Grain Cost $/Bu.	Residue Available DT/acre	Residue Less Consv. DT/acre	Harvest Cost $/ton	Fertilizer Replacement Cost $/DT	Biomass Cost $/DT
NE	110	$350.39	$3.19	2.48	1.94	$26.33	$34.91	$61.24
SE	110	$384.76	$3.50	2.48	1.94	$25.84	$34.91	$60.75
NC	90	$302.81	$3.36	2.03	1.44	$26.04	$34.91	$60.95
SC	90	$308.11	$3.42	2.03	1.44	$25.95	$34.91	$60.86
W	80	$313.39	$3.92	1.80	1.19	$25.31	$34.91	$60.22

(Source: KFMA, 2012)

Table 3.4 Wheat Straw Enterprise Budget

Region in Kansas	Grain Yield Bu./acre	Grain Cost $/acre	Grain Cost $/Bu.	Residue Available DT/acre	Residue Less Consv. DT/acre	Harvest Cost $/ton	Fertilizer Replacement Cost $/DT	Biomass Cost $/DT
NE	43	$235.31	$5.47	1.94	1.34	$33.76	$14.11	$47.87
SE	45	$196.77	$4.37	2.03	1.44	$24.85	$14.11	$38.96
NC	50	$224.50	$4.49	2.25	1.69	$24.75	$14.11	$38.86
SC	45	$200.56	$4.46	2.03	1.44	$24.78	$14.11	$38.89
W	45	$247.76	$5.51	2.03	1.44	$24.04	$14.11	$38.15

(Source: KFMA, 2012)

Table 3.5 Sorghum Stover Enterprise Budget

Region in KS	Grain Yield Bu./acre	Grain Cost $/acre	Grain Cost $/Bu.	Residue Available DT/acre	Residue Less Consv. DT/acre	Harvest Cost $/ton	Fertilizer Replacement Cost $/DT	Biomass Cost $/DT
NE	76	$222.33	$2.93	1.71	1.09	$36.72	$34.91	$71.63
SE	85	$281.08	$3.31	1.91	1.32	$26.13	$34.91	$61.04
NC	90	$244.70	$2.72	2.03	1.44	$27.25	$34.91	$62.16
SC	80	$230.41	$2.88	1.80	1.19	$26.90	$34.91	$61.81
W	80	$249.16	$3.11	1.80	1.19	$26.45	$34.91	$61.36

(Source: KFMA, 2012)

Table 3.6 Fertilizer Replacement lbs/ton of Biomass Removed

Nutrient	Per Ton Sorghum	Per Ton Corn	Per Ton Wheat
Nitrogen (N)	17	17	11
Phosphorus (P)	4	4	3
Potassium (K)	50	50	15

(Source: O'Brien, Dumler, and Jones, 2010)

Table 3.7 County KFMA Regional Assignments

1	Adams, IA	NE	*22*	Cloud, KS	NC	*43*	Jefferson, KS	NE
2	Cass, IA	NE	*23*	Coffey, KS	SE	*44*	Jewell, KS	NC
3	Fremont, IA	NE	*24*	Comanche, KS	SW	*45*	Johnson, KS	NE
4	Mills, IA	NE	*25*	Cowley, KS	SE	*46*	Kingman, KS	SC
5	Montgomery, IA	NE	*26*	Crawford, KS	SE	*47*	Kiowa, KS	SW
6	Page, IA	NE	*27*	Dickinson, KS	NC	*48*	Labette, KS	SE
7	Pottawattomie, IA	NE	*28*	Doniphan, KS	NE	*49*	Leavenworth, KS	NE
8	Taylor, IA	NE	*29*	Douglas, KS	NE	*50*	Lincoln, KS	NC
9	Allen, KS	SE	*30*	Edwards, KS	SW	*51*	Linn, KS	SE
10	Anderson, KS	SE	*31*	Elk, KS	SE	*52*	Lyon, KS	NE
11	Atchinson, KS	NE	*32*	Ellis, KS	NW	*53*	Marion, KS	NC
12	Barber, KS	SW	*33*	Ellsworth, KS	NC	*54*	Marshall, KS	NC
13	Barton, KS	SC	*34*	Ford, KS	SW	*55*	McPherson, KS	SC
14	Bourbon, KS	SE	*35*	Franklin, KS	SE	*56*	Miami, KS	SE
15	Brown, KS	NE	*36*	Geary, KS	NC	*57*	Mitchell, KS	NC
16	Butler, KS	SE	*37*	Graham, KS	NW	*58*	Montgomery, KS	SE
17	Chase, KS	NE	*38*	Greenwood, KS	SE	*59*	Morris, KS	NE
18	Chautauqua, KS	SE	*39*	Harper, KS	SC	*60*	Nemaha, KS	NE
19	Cherokee, KS	SE	*40*	Harvey, KS	SC	*61*	Neosho, KS	SE
20	Clark, KS	SW	*41*	Hodgeman, KS	SW	*62*	Ness, KS	NW
21	Clay, KS	NC	*42*	Jackson, KS	NE	*63*	Norton, KS	NW

64	Osage, KS	SE	*85*	Wabaunsee, KS	NE	*106*	DeKalb, MO	NE
65	Osborne, KS	NC	*86*	Washington, KS	NC	*107*	Gentry, MO	NE
66	Ottawa, KS	NC	*87*	Wilson, KS	SE	*108*	Greene, MO	SE
67	Pawnee, KS	SW	*88*	Woodson, KS	SE	*109*	Grundy, MO	NE
68	Phillips, KS	NW	*89*	Wyandotte, KS	NE	*110*	Harrison, MO	NE
69	Pottawatomie, KS	NE	*90*	Andrew, MO	NE	*111*	Henry, MO	SE
70	Pratt, KS	SC	*91*	Atchison, MO	NE	*112*	Hickory, MO	SE
71	Reno, KS	SC	*92*	Barry, MO	SE	*113*	Holt, MO	NE
72	Republic, KS	NC	*93*	Barton, MO	SE	*114*	Jackson, MO	NE
73	Rice, KS	SC	*94*	Bates, MO	SE	*115*	Jasper, MO	SE
74	Riley, KS	NC	*95*	Benton, MO	SE	*116*	Johnson, MO	SE
75	Rooks, KS	NW	*96*	Buchanan, MO	NE	*117*	Lafayette, MO	NE
76	Rush, KS	NW	*97*	Caldwell, MO	NE	*118*	Lawrence, MO	SE
77	Russell, KS	NC	*98*	Carroll, MO	NE	*119*	Livingston, MO	NE
78	Saline, KS	NC	*99*	Cass, MO	SE	*120*	McDonald, MO	SE
79	Sedgwick, KS	SC	*100*	Cedar, MO	SE	*121*	Mercer, MO	NE
80	Shawnee, KS	NE	*101*	Christian, MO	SE	*122*	Newton, MO	SE
81	Smith, KS	NC	*102*	Clay, MO	NE	*123*	Nodaway, MO	NE
82	Stafford, KS	SC	*103*	Clinton, MO	NE	*124*	Pettis, MO	SE
83	Sumner, KS	SC	*104*	Dade, MO	SE	*125*	Platte, MO	NE
84	Trego, KS	NW	*105*	Daviess, MO	NE	*126*	Polk, MO	SE

127	Ray, MO	NE	*148*	Harlan, NE	NW	*169*	York, NE	NC
128	Saint Clair, MO	SE	*149*	Howard, NE	NC	*170*	Adair, OK	SW
129	Saline, MO	NE	*150*	Jefferson, NE	NC	*171*	Alfalfa, OK	SC
130	Stone, MO	SE	*151*	Johnson, NE	NE	*172*	Beaver, OK	SW
131	Vernon, MO	SE	*152*	Kearney, NE	NC	*173*	Blaine, OK	SW
132	Worth, MO	NE	*153*	Lancaster, NE	NC	*174*	Cherokee, OK	SW
133	Adams, NE	NC	*154*	Merrick, NE	NC	*175*	Craig, OK	SW
134	Buffalo, NE	NC	*155*	Nemaha, NE	NE	*176*	Creek, OK	SW
135	Butler, NE	NC	*156*	Nuckolls, NE	NC	*177*	Custer, OK	SW
136	Cass, NE	NE	*157*	Otoe, NE	NE	*178*	Delaware, OK	SW
137	Clay, NE	NC	*158*	Pawnee, NE	NE	*179*	Dewey, OK	SW
138	Custer, NE	NW	*159*	Phelps, NE	NW	*180*	Ellis, OK	SW
139	Dawson, NE	NW	*160*	Polk, NE	NC	*181*	Garfield, OK	SC
140	Douglas, NE	NE	*161*	Richardson, NE	NE	*182*	Grant, OK	SC
141	Fillmore, NE	NC	*162*	Saline, NE	NC	*183*	Harper, OK	SW
142	Franklin, NE	NC	*163*	Sarpy, NE	NE	*184*	Kay, OK	SE
143	Furnas, NE	NW	*164*	Saunders, NE	NC	*185*	Kingfisher, OK	SC
144	Gage, NE	NC	*165*	Seward, NE	NC	*186*	Lincoln, OK	SW
145	Gosper, NE	NW	*166*	Sherman, NE	NC	*187*	Logan, OK	SC
146	Hall, NE	NC	*167*	Thayer, NE	NC	*188*	Major, OK	SW
147	Hamilton, NE	NC	*168*	Webster, NE	NC	*189*	Mayes, OK	SW

190	Noble, OK	SE
191	Nowata, OK	SW
192	Osage, OK	SW
193	Ottawa, OK	SW
194	Pawnee, OK	SW
195	Payne, OK	SW
196	Roger Mills, OK	SW
197	Rogers, OK	SW
198	Tulsa, OK	SW
199	Wagoner, OK	SW
200	Washington, OK	SW
201	Woods, OK	SW
202	Woodward, OK	SW

Table 3.8 Scenario Key

Code	Scenario Name	Brief Scenario Description
BCS1	Base Case	Farm-gate price set equal to farmers' break-even price
MSS2	Matching Scale	Cellulosic ethanol plant scales equal to existing starch ethanol plant scale
PGP80S3	Plant-gate Price $80	Maximum demand and plant sizing with varied farm-gate price and a plant-gate price of $80 per dry ton
PGP100S4	Plant-gate Price $100	Maximum demand and plant sizing with varied farm-gate price and a plant-gate price of $100 per dry ton
PGP120S5	Plant-gate Price $120	Maximum demand and plant sizing with varied farm-gate price and a plant-gate price of $120 per dry ton
NNRS6	No Nutrient Replacement	Where Nutr representing nutrient replacement option in adoption equations equals -1 instead of 1
CRPS7	CRP	$40 per acre CRP payments are kept with a 75% cost share option
BCAPS8	BCAP	Government payment of $45 per ton is received with a 75% cost share option

Chapter 4- Results

This chapter discusses in detail the scenarios and various results that were found. Tables are included to illustrate the main findings from the model and derived conceptual implications.

Base Cases (BCS1 and MSS2)

The model was initially run utilizing the actual farm-gate breakeven costs calculated through enterprise budgets in the base case scenario (BCS1). This was a test to use actual data and pricing to evaluate whether or not the minimum economies of scale of 25 MGY per plant could be achieved under the $60 to 80 range given by the industry. Results indicated the seven plants would not have sufficient feedstock available from farmers to achieve this benchmark with the given minimum plant-gate price of $60 per dry ton and would actually need a minimum of $75 per dry ton for all seven plants to meet the minimum capacity determined by economies of scale. This indicates that until the plant-gate price is reached, there is not enough acreage within the acceptable harvest radius for each plant in the model to support all plants at 25 MGY. The total transportation cost to farmers including loading under this scenario would be $13,746,500, the majority of which would be paid to custom hay operations.

With this minimum plant-gate price of $75 and all plants sized at 25 MGY, the portfolio of feedstocks would consist of 66.9% corn stover, 11.8% wheat straw, 21.3% sorghum stover, and 0% switchgrass. The Biomass Research and Development Initiative (2008) projected that crop residues would account for 64% of the 20 billion gallons of cellulosic ethanol called for by 2022. Of this portion, 70% would be corn stover and 16 to 19 million acres of land would be needed for biomass that wasn't derived from residue (BRDI, 2008).

In MSS2, all current starch plant sizes could be achieved with equivalent cellulosic ethanol add-on plants. It is unrealistic to assume this existing plant size would be exceeded by a market that currently is not in existence. This upper limit under current market conditions of 50 MGY is only feasible with a plant-gate price of $80 per dry ton and results in a total transportation cost of $33,933,460. This indicates that total transportation cost nearly tripled when plant size is doubled from 25MGY to 50MGY. It is interesting to note that under the initial assumptions, corn stover, wheat straw, and sorghum stover comprise essentially all the biomass delivered to the plants. No switchgrass is delivered by the model and even with a theoretical plant-gate price of $120 and exclusion of all wheat tonnage which is the cheapest residue to produce, only a few tons of switchgrass are delivered to the plants due to high costs, low yields, and low adoption rates.

With a plant-gate price of $80 and all plants sized at 25 MGY in BCS1, savings to the plant were found by subtracting transportation and loading costs from the difference between plant-gate price and farm-gate price essentially representing a quasi-consumer surplus. This base case scenario would result in a net savings to cellulosic ethanol plants of a weighted average of: $8.28 per dry ton of corn stover, $28.79 per dry ton of wheat straw, and $6.08 per dry ton of sorghum stover. No switchgrass is delivered under this base case scenario which is likely the most realistic model with the maximum feasible plant-gate price and meeting the minimum economies of scale. The largest plants out of the seven are currently 50 MGY within the established starch ethanol industry, which is double the capacity of the plants in this scenario.

Maximum Plant Size and Demand Scenarios (PGP80S3, PGP100S4, and PGP120S5)

For the second set of scenarios, maximum plant sizes and plant biomass demands were determined using uniform farm-gate prices for all tons of biomass and nutrient replacement costs assumed. The first plant-gate price considered was $80 for PGP80S3 since it was the maximum allowable price dictated by the industry and most of the break-even costs were around $70 per dry ton. Farm-gate prices were increased in $5 increments starting at $50 per dry ton whereas the three plant-gate prices increased by $20. The plant-gate prices were $80 (PGP80S3), $100 (PGP80S4), and $120 (PGP80S5) since expenses are on an upward trend and to evaluate how higher prices paid under possible government subsidies or programs might influence plant size. With varying farm-gate prices, participation rates fluctuate. When plant-gate prices are increased or decreased, the radius plants can pull biomass from increase or decrease.

Figure 4.2 shows the input demand given a perfectly elastic demand of the plant at $80 per dry ton paid by the seven plants up until maximum capacity. Using uniform prices, economies of scale (25MGY) cannot be reached at a farm-gate price of $75 due to the smaller radius from which the plants are pulling and are not met until the farm-gate price drops to $70. Table 4.2 was calculated using equation 5 and shows the maximum cut-off distances for each of the plants under various farm-gate and plant-gate prices used . An additional run found that the maximum farm-gate price where economies of scale could be achieved between these two points was $71. As shown in Figure 4.1, an inflection point exists at a farm-gate price of $60 indicating where participation multiplied by the amount of biomass available at the given plant radius begins decreasing at an increasing rate, whereas before farm-gate price reached $60, this product value was increasing at a decreasing rate. Figure 4.2 indicates the quantity of biomass demanded by the ethanol plants at the maximum capacities.

As shown in Figure 4.3, a plant-gate price of $100 is offered which is well beyond what the current industry is able to sustain, however massive plant capacities are able to be achieved under this scenario. It was not until after a capacity of 405 MGY was reached at a farm-gate price of $65 that plant size goes to zero. Figure 4.4 depicts the quantity demanded at maximum capacities for a $100 plant-gate price.

For a plant-gate price of $120 as shown in Figure 4.5, it is not until a capacity of almost 450 MGY and farm-gate price of $85 that plant size starts to decrease. This indicates that up until this point, maximum participation rates are being achieved for the feedstocks, however the model is limiting out on feedstock delivered under the expected participation rates. Figure 4.6 depicts the input demand curve with a plant-gate price of $120 per dry ton for PGP120S5.

No Nutrient Replacement Scenario (NNRS6)

The willingness-to-participate equations 1, 2, and 3 can be easily altered to remove nutrient replacement by changing the variable Nutr from positive 1 to -1. This drastically reduces farmer participation rates and if the farmer was receiving a farm-gate price lower than $34.91 (for corn stover or sorghum silage) or $14.11 (for wheat straw) above the breakeven cost, this would essentially be the same as having no nutrient replacement, so a plant-gate price of $60 was used. This was dropped by $5 until maximum plant size went to zero which occurred after the farm-gate price reached $35 (see Figure 4.7). This makes sense due to the fact that when the average break-even costs for the enterprise budgets have the nutrient replacement costs of $34.91 removed, the farm production cost is equivalent to approximately $35. Beyond this threshold, it is intuitive that participation would quickly approach zero for corn stover and sorghum silage, due to the farmer not being able to cover the harvest and baling costs. Figure 4.8 shows the biomass demanded at maximum capacity with no nutrient replacement and a plant-gate price of $60 per dry ton.

Edge of Field Supply

Through utilizing break-even costs as the total variable cost to the farmer at the edge of field, a supply estimate for all three residues and switchgrass was found. The same willingness-to-participate equations were used from farm-gate prices ranging from $50 to $120 per dry ton, ceteris paribus. This evaluates how farm-gate price affects producer supply without regard to loading cost, transportation cost, or plant-gate price levels as a conservative estimate of what might be available in biomass markets. The same acreages and yield estimates with 30% left on the field for conservation were used, as with the other scenarios. Figures 4.9 to 4.13 show edge of field supply curves for corn stover, wheat straw, sorghum silage, switchgrass, and total biomass respectively. Corn stover has the largest available supply followed by wheat straw, sorghum silage, and switchgrass. Corn yields the most residue therefore more residue can be removed from the field to maintain conservation. Many farmers are in general unable to harvest wheat straw and sorghum stover due to negative implications on soil moisture content.

Switchgrass Scenarios (CRPS7 and BCAPS8)

Numerous papers have cited CRP land as a way to produce perennial bioenergy crops while maintaining most of the intended purposes of CRP and not taking traditional crop land out of production. Huang, Khanna, and Yang (2011) found that if the soil rental rate paid to landowners with expiring CRP land does not catch up with crop price increases, 69.9% will opt out of the CRP program under their medium land quality scenario. This figure drops to 45.1% when the low land quality scenario is evaluated. According to Petrolia and Ibendahl (2008), their study region, which also included Missouri and Oklahoma, consisted of 73% grassland, which is the most prevalent of CRP land. This study was completed at the beginning of the rapid agricultural price increases following ethanol mandates. It was found that counties with a greater amount of grass land are more likely to opt out of the conservation program if their crop choices were soybeans and corn, but less likely if they were cotton or wheat (Petrolia and Ibendahl, 2008). This net income change was considered causation for beginning switchgrass production on CRP land if CRP payments could be maintained in CRPS7.

In order to simulate keeping CRP payments for land that was no longer enrolled in the program and could potentially be planted to switchgrass, the fixed cost of $40 per acre was removed from the willingness-to-participate equation (4) for switchgrass. This was intended to act as the average CRP subsidy received by farmers in Kansas. Rod Winkler, conservation specialist with Kansas FSA, reported CRP payments in Kansas averaged about $44 per acre in the spring of 2012 (Jorgensen, 2013). A 75% establishment cost-share was added in with the CRP payment in a second trial as a theoretical subsidy from the BCAP program to find whether this greatly boosted participation rates and tonnage pulled. Table 4.3 shows how in the base case with plants sized at 25 MGY, zero tons of switchgrass are pulled with a plant-gate price of $80 and a farm-gate price of $50. This amount increased to 54 tons with the theoretical CRP payment, however the quantity only increased by approximately one ton when a 75% cost share is added into the model run. At this point, most plants still demand no switchgrass. This is most likely due to uncertainty and risk in the market. To farmers it most likely would not make much difference if there is cost sharing or not if they were not guaranteed a market for their biomass yield and had to allocate land and lost opportunity costs for a perennial crop.

Table 4.4 shows that at the same prices but a doubling of plant size, there are enough crop residues within the radius of the plant to achieve this doubling in size. There is relatively no increase in switchgrass necessary to meet this demand under the base case scenario. Even under these additional switchgrass subsidy scenarios, switchgrass is a more costly option and therefore the lower-cost residues are used to fill plant demand.

At a farm-gate price of $70 per dry ton and no additional subsidies, 2,262 dry tons of switchgrass are utilized to meet plant demand. This indicates that under these subsidy conditions it became cheaper to ship switchgrass from a closer county centroid than to supply residues which have a lower production cost located at a further distance from the plant. When the CRP payment is included, this increases to 2,434 dry tons. This amount remains the same with a 75% establishment cost share as shown in Table 4.5.

The Biomass Crop Assistance Program (BCAP) was started in an attempt to jump start the cellulosic industry. Currently the program is limited and offers either a 75% payment for the cost to establish energy crops and annual payments or a matching payment where up to $45 is paid for the collection, harvest, storage and transportation of material deemed eligible (Stubbs,

2011) and this can include residues. However, the program allows biomass utilized for electricity to receive matching payments which have consisted of the bulk of the program funding and this source of funding has recently been cut (Rivers, 2012). The impacts of this program BCAPS8 are the focus of the runs shown in Tables 4.5 through 4.8. Equation (31) was adapted from equation (4) and adds a $45 per ton payment from the government into the willingness to participate equation.

$$(31)\ \text{BCAPAdoptG}_j = \frac{2^{-6.96+1.94*\text{West}_j+3.74*\text{Central}_j+0.16*\left([\text{FGPG}_j+45]*\text{YieldG}_j-\text{VG}-40\right)-0.16*7+0.33+0.23+0.025*\text{CSH}}}{1+2^{-6.96+1.94*\text{West}_j+3.74*\text{Central}_j+0.16*\left([\text{FGPG}_j+45]*\text{YieldG}_j-\text{VG}-40\right)-0.16*7+0.33+0.23+0.025*\text{CSH}}}$$

As with the previous switchgrass scenario, no tons are delivered at a plant-gate price of $80 and farm-gate price of $50 with no switchgrass subsidies in Table 4.6. Once the matching payment is added however, switchgrass production increases dramatically to 4,268 dry tons but this is still a small amount relative to other sources in this study. As was evidenced before, the 75% cost share has little impact on production. Plant size does not have a significant impact on how much switchgrass is delivered.

When farm-gate price is increased to $65 per dry ton, the amount of switchgrass delivered increases by about 61.7% as shown in Table 4.7. Cost share is still negligible. When plant size doubles to the maximum out of the seven locations to 50 MGY, the amount of feedstock demanded practically doubles, however this increase is not evident in switchgrass. This indicates plant size has relatively little effect on switchgrass demand and distance from the plant and subsidy amounts are the main factors affecting demand for this perennial crop.

With a $15 increase in farm-gate price as shown from Table 4.7 to 4.8, the amount of switchgrass biomass increases by approximately 29.7%. With a farm-gate price of $50 (Table 4.6) , switchgrass is delivered from numerous bordering counties from other states including: Clay, MO; Thayer, NE; Alfalfa, OK; Grant, OK; Osage, OK; and Woods, OK. When farm-gate price increases to $65, Thayer, NE; Alfalfa, OK; and Grant, OK are the only out-of-state counties from which switchgrass is delivered. In the final BCAP scenario run where farm-gate price is $70, no counties outside of Kansas delivered switchgrass.

When the shipping limits are altered to include a prepayment by the BCAP program, thereby assuring the farmer they will get the subsidy before delivery, more counties will deliver feedstock. For the same farm-gate and plant-gate prices, 13,960 dry tons will be delivered. This is an increase of 55.4% from the scenario where the $45 matching payment is not added to the limit portion of the transportation model and is shown in Table 4.8.

It is evident that the additional subsidies either through the government or plant are necessary if switchgrass is to be a viable feedstock and compete with crop residues. The BCAP program was very limited and funding has been cut, however after viewing the results of the model, it is clearly the most effective option for drastically increasing participation. It is somewhat surprising that a 75% establishment cost share has little effect on increasing participation rate. This could indicate that farmers are much more concerned about a lack of market for their switchgrass than the hefty price tag of establishment.

Objective 1 was achieved through the model and the amounts available by county can be found in the thesis spreadsheet Optimization of Cellulosic Biomass Analysis on worksheets Corn DT, Wheat DT, Sorghum DT, and Switchgrass DT. Objective 2 was accomplished by multiplying the total biomass amounts from Objective 1 by equations 1 through 4 to endogenously and incorporate participation rates at various farm-gate price levels. The completed model yielded the results to Objective 3 whenever the model was run which reported optimal amounts of feedstock to be shipped. The base case scenario BCS1 solved for Objective 4. Scenarios PGP80S3, PGP100S4, and PGP120S5 evaluated the impacts on input demand curves for Objective 5. Finally for Objective 6, scenarios CRPS7 and BCAPS8 showed what was necessary for switchgrass to be shipped by the model.

Figure 4.1 Max Capacity with a Minimum Plant-gate Price of $80 Per Dry Ton (PGP80S3)

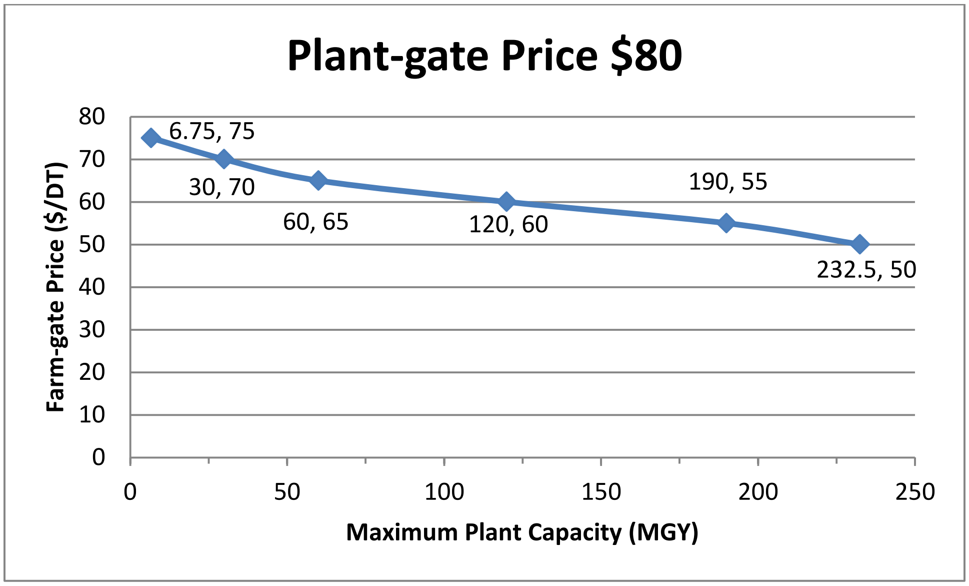


Figure 4.2 Biomass Demanded with a Minimum Plant-gate Price of $80 Per Dry Ton (PGP80S3)

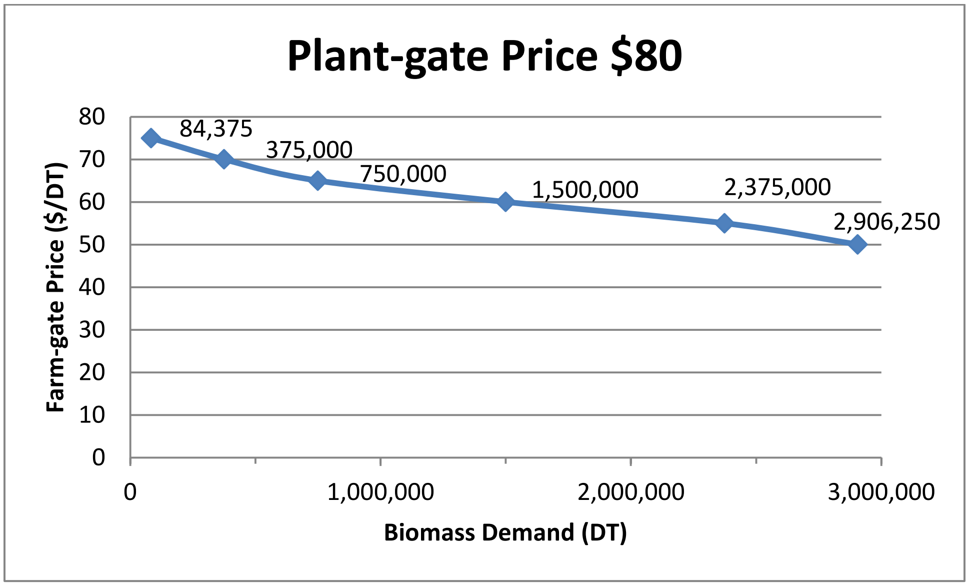


Figure 4.3 Maximum Capacity with a Plant-gate Price of $100 Per Dry Ton (PGP100S4)

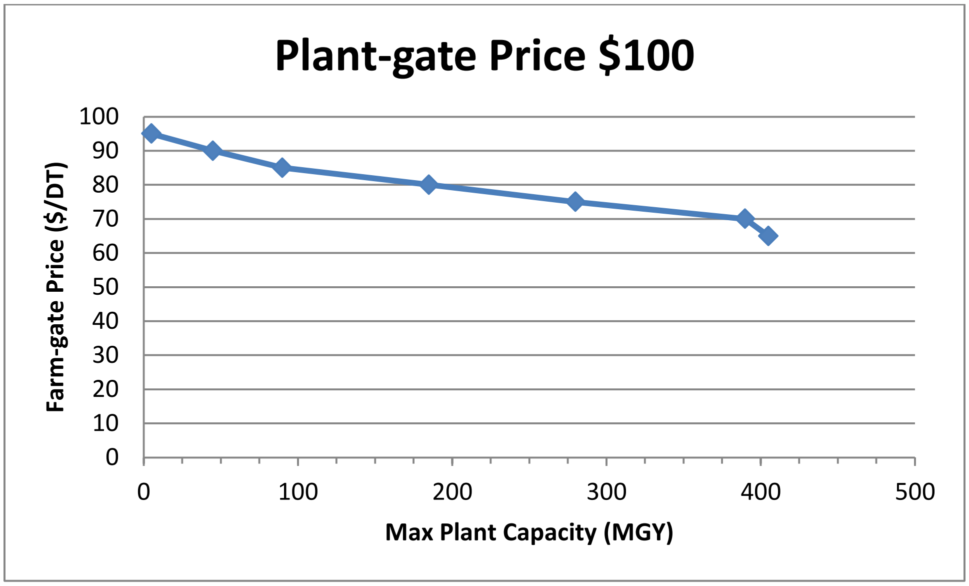


Figure 4.4 Biomass Demanded with a Plant-gate Price of $100 Per Dry Ton (PGP100S4)

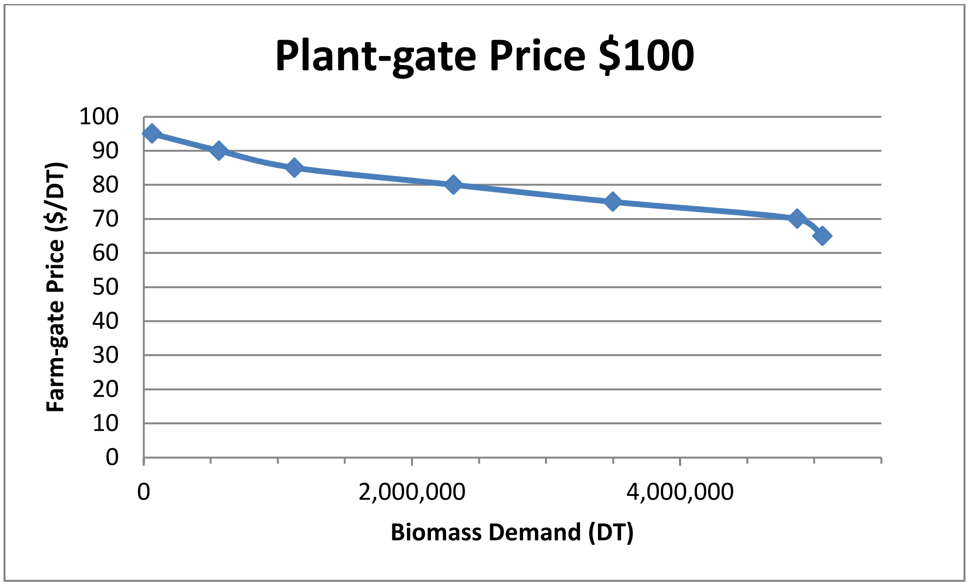


Figure 4.5 Maximum Capacity with a Plant-gate Price of $120 Per Dry Ton (PGP120S5)

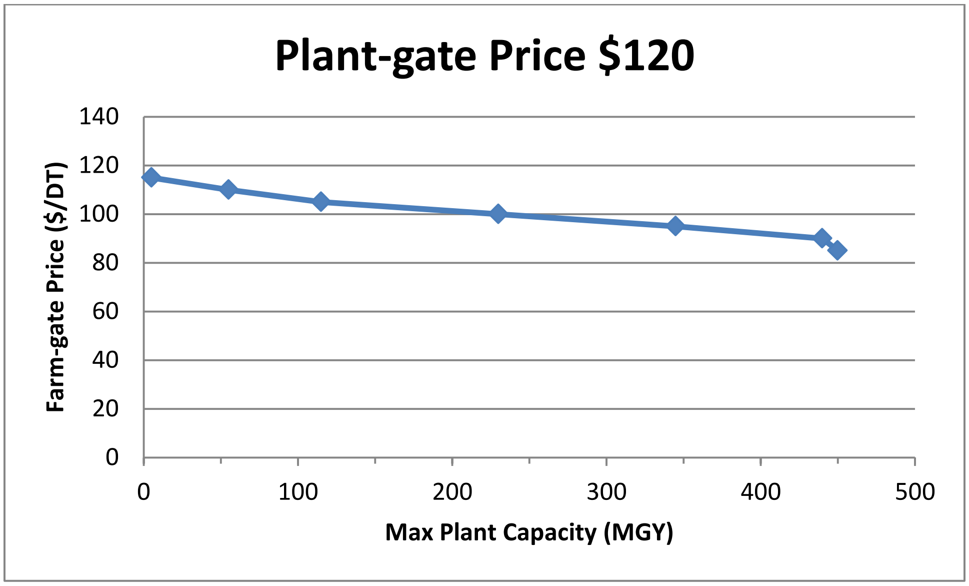


Figure 4.6 Biomass Demanded with a Maximum Plant-gate Price of $120 Per Dry Ton (PGP120S5)

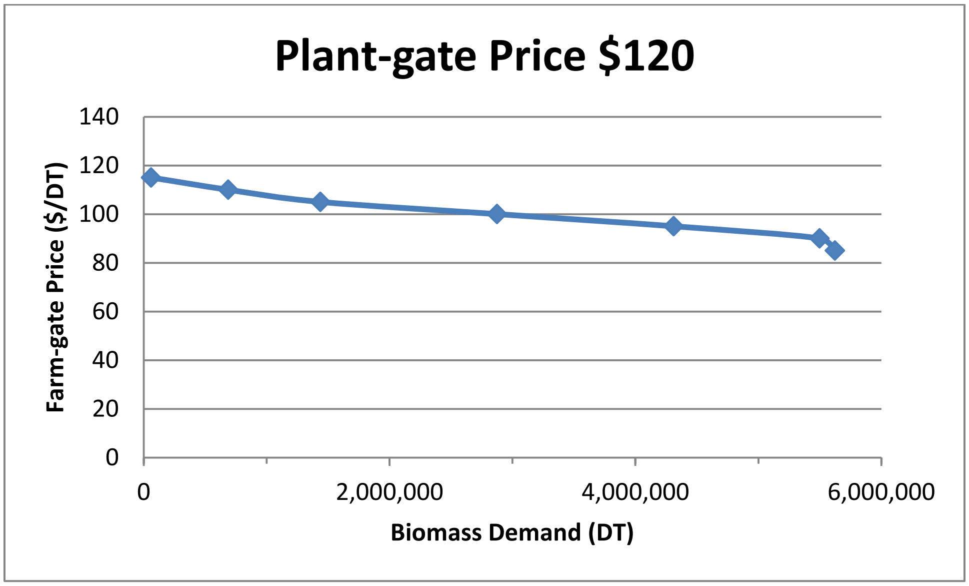


Figure 4.7 Maximum Capacity with a Plant-gate Price of $60 Per Dry Ton and No Nutrient Replacement (NNRS6)

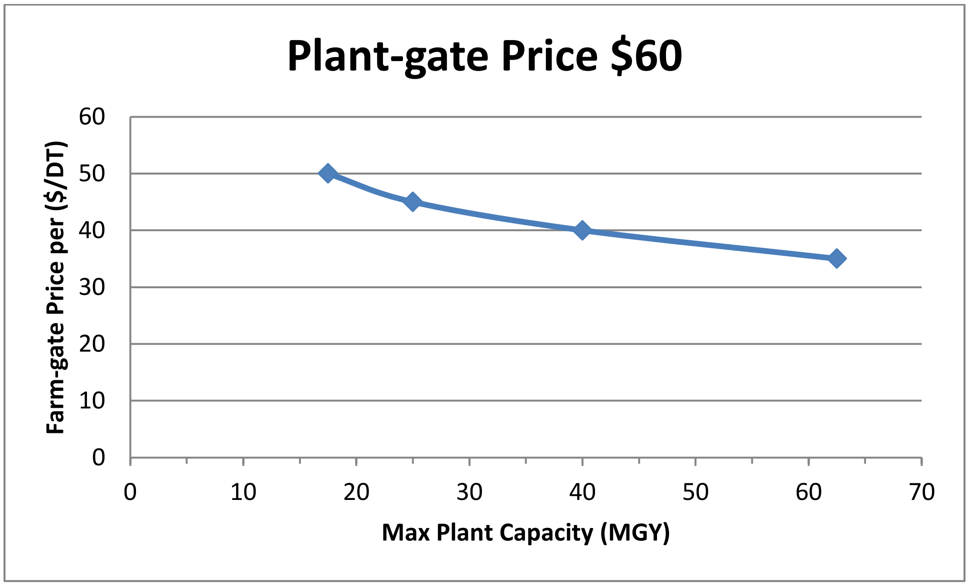


Figure 4.8 Biomass Demanded at a Plant-gate Price of $60/DT with No Nutrient Replacement (NNRS6)

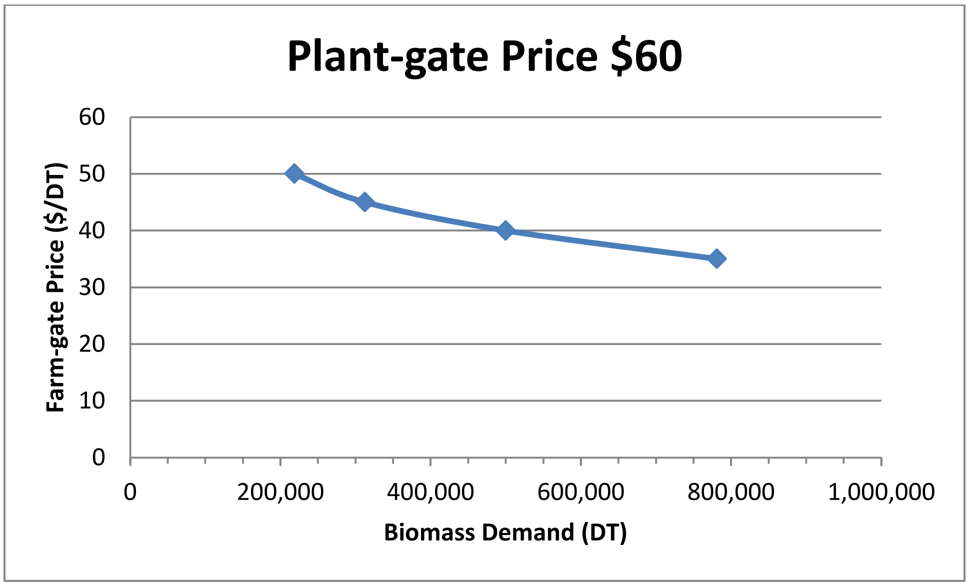


Figure 4.9 Farm-gate Price Ranging from $50 to $120 Per Dry Ton for Corn Stover

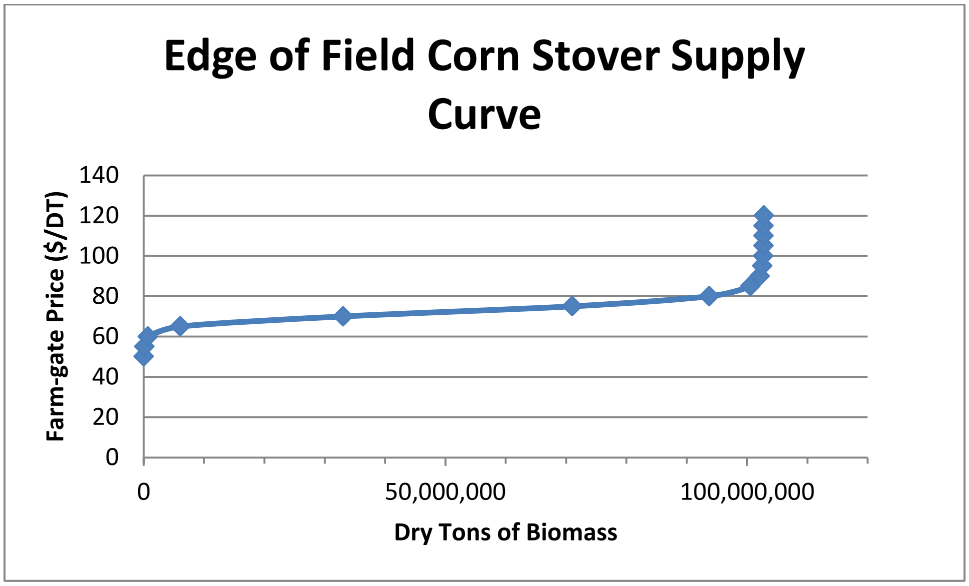


Figure 4.10 Farm-gate Price Ranging from $50 to $120 Per Dry Ton for Wheat Straw

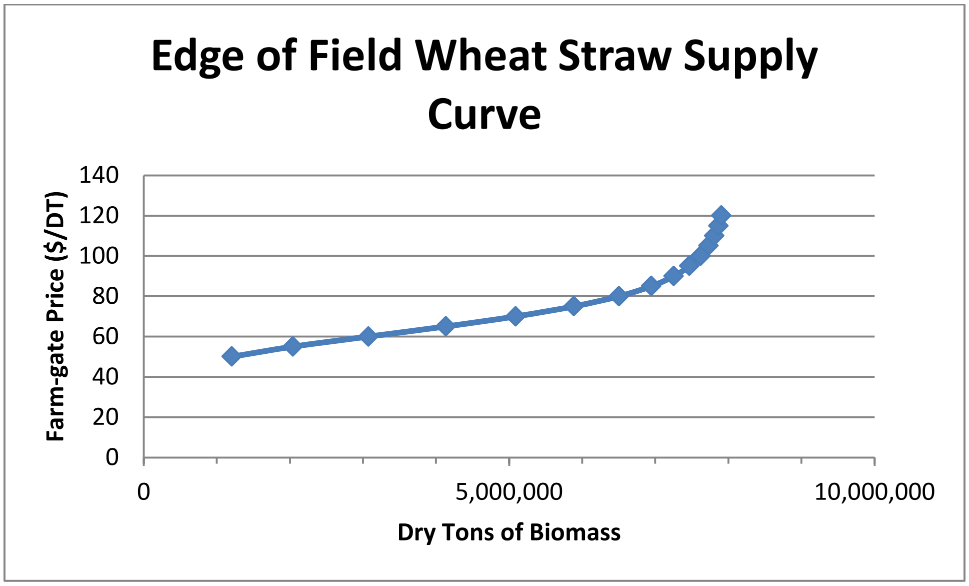


Figure 4.11 Farm-gate Price Ranging from $50 to $120 Per Dry Ton for Sorghum Silage

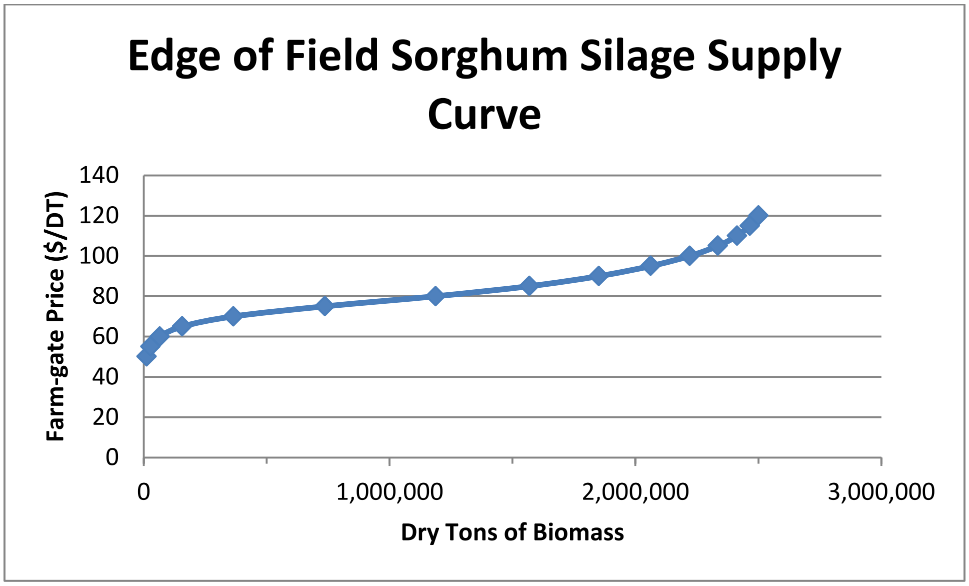


Figure 4.12 Farm-gate Price Ranging from $50 to $120 Per Dry Ton for Switchgrass

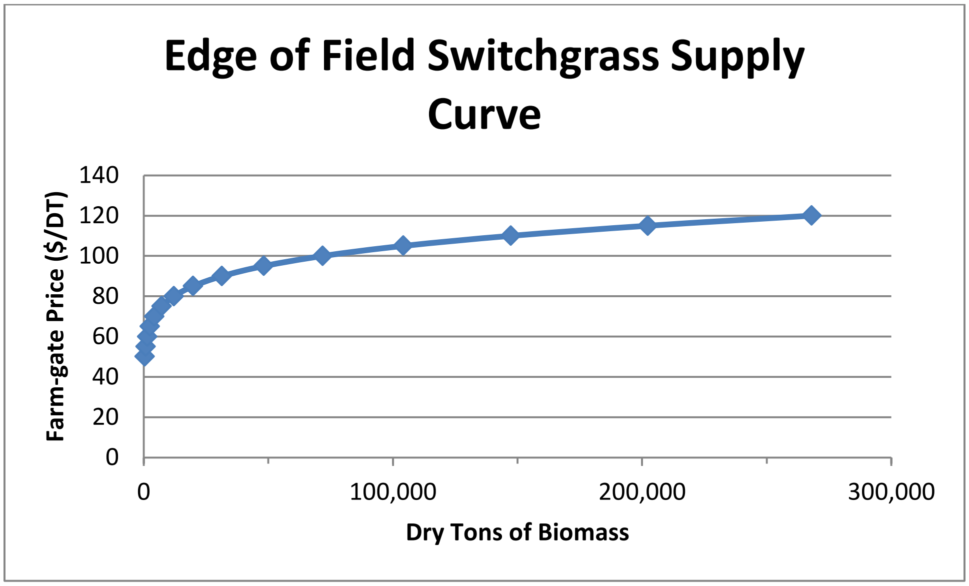


Figure 4.13 Farm-gate Price Ranging from $50 to $120 Per Dry Ton for Total Biomass

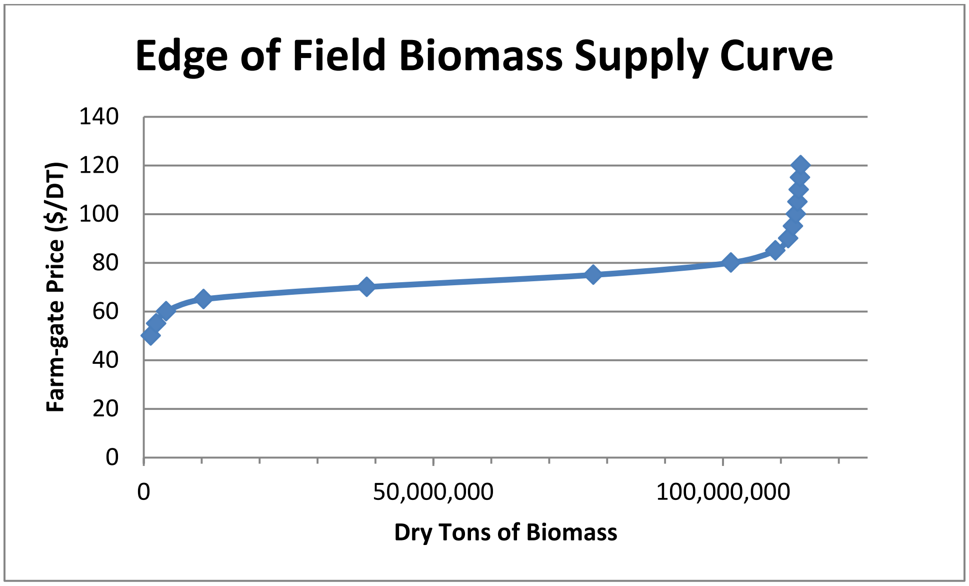


Table 4.1 Locations of Existing Ethanol Plants

Owner	Town	Capacity
Plant 1: Kansas Ethanol LLC	Lyons	15 MGY
Plant 2: NESIKA Energy LLC	Scandia	15 MGY
Plant 3: East Kansas Agri Energy	Garnett	5 MGY
Plant 4: Abengoa Bio-Energy	Colwich	50 MGY
Plant 5: Abengoa Bio-Energy #2	Colwich	50 MGY
Plant 6: Everton Energy LLC	Concordia	15 MGY
Plant 7: MGP Ingredients	Atchison	5 MGY

Table 4.2 Maximum Distances Traveled for Positive Net Returns

Farm-gate Cost ($/Dry Ton)	Plant-gate Price ($/Dry Ton)						
	60	70	80	90	100	110	120
50	71.4	142.9	214.3	285.7	357.1	428.6	500.0
55	35.7	107.1	178.6	250.0	321.4	392.9	464.3
60	0.0	71.4	142.9	214.3	285.7	357.1	428.6
65	0.0	35.7	107.1	178.6	250.0	321.4	392.9
70	0.0	0.0	71.4	142.9	214.3	285.7	357.1
75	0.0	0.0	35.7	107.1	178.6	250.0	321.4
80	0.0	0.0	0.0	71.4	142.9	214.3	285.7
85	0.0	0.0	0.0	35.7	107.1	178.6	250.0
90	0.0	0.0	0.0	0.0	71.4	142.9	214.3
95	0.0	0.0	0.0	0.0	35.7	107.1	178.6
100	0.0	0.0	0.0	0.0	0.0	71.4	142.9
105	0.0	0.0	0.0	0.0	0.0	35.7	107.1
110	0.0	0.0	0.0	0.0	0.0	0.0	71.4
115	0.0	0.0	0.0	0.0	0.0	0.0	35.7
120	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.3 Dry Tons shipped for 25 MGY Plants with a Plant-gate Price of $80 and Farm-gate Price of $50 CRPS7

	25 MGY Plant-gate Price $80 Farm-gate Price $50 Base Case No subsidies	25 MGY Plant-gate Price $80 Farm-gate Price $50 $40 CRP Payment No Cost Share	25 MGY Plant-gate Price $80 Farm-gate Price $50 $40 CRP Payment 75% Cost Share
Plant1	0	1	1
Plant2	0	0	0
Plant3	0	0	0
Plant4	0	0	0
Plant5	0	0	0
Plant6	0	54	55
Plant7	0	0	0
	0	55	56

Table 4.4 Dry Tons shipped for 50 MGY Plants with a Plant-gate Price of $80 and Farm-gate Price of $50 CRPS7

	50 MGY Plant-gate Price $80 Farm-gate Price $50 Base Case No subsidies	50 MGY Plant-gate Price $80 Farm-gate Price $50 $40 CRP Payment No Cost Share	50 MGY Plant-gate Price $80 Farm-gate Price $50 $40 CRP Payment 75% Cost Share
Plant1	0	1	1
Plant2	0	0	0
Plant3	0	0	0
Plant4	0	0	0
Plant5	0	0	0
Plant6	0	54	55
Plant7	0	0	0
	0	55	56

Table 4.5 Dry Tons shipped for 25 MGY Plants with a Plant-gate Price of $80 and Farm-gate Price of $70 CRPS7

	25 MGY Plant-gate Price $80 Farm-gate Price $70 Base Case No subsidies	25 MGY Plant-gate Price $80 Farm-gate Price $70 $40 CRP Payment No Cost Share	25 MGY Plant-gate Price $80 Farm-gate Price $70 $40 CRP Payment 75% Cost Share
Plant1	0	1	1
Plant2	0	3	3
Plant3	0	0	0
Plant4	0	0	0
Plant5	0	2	2
Plant6	2,263	2,428	2,429
Plant7	0	0	0
	2,263	2,434	2,435

Table 4.6 Dry Tons shipped with Plant-gate Price of $80 and Farm-gate Price of $50 BCAPS8

	25MGY/50MGY Plant-gate Price $80 Farm-gate Price $50 Base Case No Subsidies	25MGY Plant-gate Price $80 Farm-gate Price $50 $45 BCAP Payment No Cost Share	25MGY Plant-gate Price $80 Farm-gate Price $50 $45 BCAP Payment 75% Cost Share	50MGY Plant-gate Price $80 Farm-gate Price $50 $45 BCAP Payment No Cost Share	50MGY Plant-gate Price $80 Farm-gate Price $50 $45 BCAP Payment 75% Cost Share
Plant1	0	1,527	1,531	1,546	1,550
Plant2	0	275	280	171	174
Plant3	0	35	36	35	36
Plant4	0	0	0	0	0
Plant5	0	0	0	105	106
Plant6	0	2,429	2,429	2,429	2,429
Plant7	0	1	1	1	1
Totals	0	4,268	4,277	4,287	4,296

Table 4.7 Dry Tons shipped with Plant-gate Price of $80 and Farm-gate Price of $65 BCAPS8

	25MGY/50MGY Plant-gate Price $80 Farm-gate Price $65 Base Case No Subsidies	25MGY Plant-gate Price $80 Farm-gate Price $65 $45 BCAP Payment No Cost Share	25MGY Plant-gate Price $80 Farm-gate Price $65 $45 BCAP Payment 75% Cost Share	50MGY Plant-gate Price $80 Farm-gate Price $65 $45 BCAP Payment No Cost Share	50MGY Plant-gate Price $80 Farm-gate Price $65 $45 BCAP Payment 75% Cost Share
Plant1	0	2,129	2,137	5,264	5,279
Plant2	0	1,340	1,341	2,310	2,318
Plant3	0	351	357	3,445	3,466
Plant4	0	14	14	15	15
Plant5	0	485	485	0	0
Plant6	0	2,432	2,432	2,432	2,432
Plant7	0	151	154	162	165
Totals	0	6,901	6,920	13,629	13,675

Table 4.8 Dry Tons shipped with Plant-gate Price of $80 and Farm-gate Price of $70 BCAPS8

	25MGY/50MGY Plant-gate Price $80 Farm-gate Price $70 Base Case No Subsidies	25MGY Plant-gate Price $80 Farm-gate Price $70 $45 BCAP Payment No Cost Share	25MGY Plant-gate Price $80 Farm-gate Price $70 $45 BCAP Payment 75% Cost Share	25MGY Plant-gate Price $80 Farm-gate Price $70 $45 BCAP Payment Prepayment
Plant1	0	2,653	2,656	6,435
Plant2	0	1,526	1,530	3,239
Plant3	0	1,144	1,153	1,144
Plant4	0	73	75	73
Plant5	0	487	487	0
Plant6	0	2,442	2,443	2,442
Plant7	0	626	635	627
Totals	0	8,954	8,981	13,960

Chapter 5- Conclusion

Utilizing enterprise budget break-even prices in the model indicates that out of the delivered plant-gate price range of $60 to $80 given by the industry, a farm-gate price under $75 would not allow for the 25 MGY economies of scale to be achieved with current production costs. The results indicate that there would be sufficient feedstock supplied at the maximum price level range of $75 through $80 when enterprise budgets are used to calculate break-even cost per district. When using uniform farm-gate prices, $70-80 is feasible.

When uniform farm-gate price scenarios are utilized, this range lowers an additional $5 to make $70 through $80 feasible. These feasible price ranges are essential in determining what an achievable price benchmark for the current industry is as well as indicating what farmers require to deliver a substantial amount of crop residue with large nutrient replacement costs. Switchgrass is never delivered in the model where enterprise budgets are used for pricing, signifying crop residue is an optimal feedstock when farmers receive zero subsidies to grow switchgrass. When uniform prices are used for all feedstocks, around 5 tons of switchgrass are delivered across all seven 25 MGY plants when farm-gate price is equal to $55 and increasing amounts are shipped as price level increases. This number increases to 2,262 dry tons with the same plant price of $80 and a farm-gate price of $70, however this is mainly shipped to one plant.

Switchgrass under the base case scenarios is not the optimal source of biomass and is therefore not delivered by the model when the 2012 enterprise budgets are considered. When the model is run with uniform pricing, switchgrass is delivered, however the proportion of switchgrass biomass compared to residue biomass is not very substantial and could be replaced with crop residues if switchgrass were completely excluded. Research has indicated many plants wish to contract with farmers for switchgrass to ensure a guaranteed source of biomass for part of the year. The model shows that under the assumptions (BCS1), participation would not be an issue if local biomass markets were set up by ethanol plants. Contracting residues would therefore be the least costly and most efficient biomass source compared to switchgrass. Residues also degrade much less than switchgrass which needs to be harvested and fermented rather quickly to avoid substantial degradation losses. Some studies indicated steady supplies such as that from perennials are necessary for plants to ensure feedstocks from year to year. This would require substantial private or government investment as evidenced by the switchgrass scenarios. If the government allowed plants tax credits or write-offs for switchgrass contract payments, this could be an alternative to a direct government subsidy. Expansion of government programs such as the Biomass Crop Assistance Program must be researched further if switchgrass is to become viable or the government wishes to jump-start the cellulosic ethanol industry as it did in subsidizing the starch industry in its infancy. Further yield estimates must be calculated for this model in bordering states, since the model delivered biomass from surrounding counties that border Kansas. Yield estimates were assumed to be the same average in these bordering counties due to a lack of this information and allowed for the model to identify if these counties required further research. These findings are significant since many believe switchgrass to be an essential product for a well-established ethanol industry, however it is basically disregarded by the model due the high total costs of production.

Improving farmer participation rates could lower costs and substantially increase biomass supplies. Qualls et al. (2011) determined that educational programs for farmers should focus on allocation of farm labor and equipment relative to other crops as well as planting and harvest time production management issues. They state these programs could also emphasize input use changes in comparison to other crops and highlight that farmers are concerned with a lack of correlation between lease length and contract length on leased land for switchgrass and other cellulosic crops.

If cellulosic ethanol plants had been in existence at all the seven locations in 2012, there would have been sufficient biomass to supply all seven to meet the required 25 MGY economies of scale benchmark under competition with neighboring plants. More importantly, the price level range dictated by the industry of a $60 to $80 plant-gate price would invoke enough farmer participation to make this practical and profitable to both the plants and the farmers. The solution to the chicken and egg dilemma therefore hinges on raising capital through feasibility plans to investors and entrepreneurs. If risks could be further mitigated, this would greatly aid in making these plants a reality and accomplishing the RFS. The model utilizes fairly conservative estimates based on current conditions and surveys which indicate the biomass and farmer participation necessary for a competitive industry are present (even during years of severe drought) but the markets and infrastructure are not.

Through this research, it was hypothesized that the savings to the plant could potentially be similar to net returns realized by farmers if they were to load and ship the biomass or custom hire in order to do so. The cellulosic ethanol industry will undoubtedly boost local economies and not just on for farmers and custom haying operations. In 2008, Urbanchuk (2008) estimated that the biofuel industry increased state and local tax revenues by $1.3 billion which is further justification for continuing or expanding subsidies. The results of this research indicate switchgrass is not worth subsidizing and residues and annuals should potentially receive subsidies in order to increase adoption rates.

Further Research

Further research should include actual field trials of switchgrass stands in the non-irrigated soil types for all counties within the study region. While some studies have been completed in certain regions, not enough are available to have the kind of accurate projections many farmers would like to see through accurate field trials. At minimum, the same projections that were utilized for Kansas switchgrass stands must be adapted for the bordering states of Nebraska, Iowa, Missouri, and Oklahoma within the study region. This is the main weakness of the model in that these estimates are just projections.

Another future area of research is various biomass contracting scenarios and insurance policies. There are currently no policies for residues or switchgrass which adds to the risk factors farmers face. This risk could be mitigated through expansion of the crop insurance program. Energy sorghum and *Miscanthus* could also be included in future studies.

Finally, farm-level data would be the main improvement that could be made to the model. Exact road distances and yield amounts could then be quantified, however this would add a great deal of complexity, as well as dramatically increase run-time of the model. All the estimates within this model are made according to real county-level data averages and at the time this study was completed, include the most accurate and recent data available at the time.

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Appendix A - Iogen Contracting Sample

Figure A.1 Main Concepts of Iogen Biomass Contracting

Sections	Key Points
“Supply, Storage, and Coordination”	1. “Defines the minimum annual tons 2. Grants processor option to purchase straw for life of the contract (5-10 years) 3. Farmer must supply storage for up to 12 months after harvest and meet standards for straw quality, storage and access (for delivery) 4. Farmer must estimate crop acres by March 15, provide a forecast of straw production by June 15, and provide notice of all changes to acres farmed, crop rotation, or any other pertinent information for straw volume or yields 5. Processor must exercise option to purchase straw by April 15 and July 15. 6. Farmer is responsible for selecting and working with custom operators. 7. Straw stacks must be accessible to loading and transport equipment 12 months a year, 24 hours a day, 7 days a week. 8. Performance may be excused because of acts of God. 9. The risk of crop loss remains with the producer until delivery”
“Pricing and Payment”	1. “Pricing options include 3 choices:

	a. Fixed price, 5 years at $8/ton b. Variable price based on crude oil prices, 20 years at approximately $5-15/ton c. A combination of (a.) and (b.) 2. Payments are made in three installments a. One-third order value will be paid within 30 days of the processor's receipt of the producer's Farm Service Agency report verifying acreage b. A second payment will occur after storage at an appropriate site and processor inspector has verified the estimated tonnage c. Final payment will be made on delivery and certified measurement of the tons delivered"
"Quality"	1. "Acceptance straw quality to be harvested gold without rot or weathering, maximum of 18% moisture content, segregated as the type of straw as agreed, and free of any preventable toxins as identified by the processor in advance of harvest"
"Change in Terms"	1. "Processor has the right to develop and modify standards as it requires so long as changes apply to all producers 2. Producers can be compensated for this change in standards"

"Assignment, Termination, Transfer, and Extension"	1. "Processor has the right to transfer the claims for the straw and straw procurement services to another processor 2. Producer has the right to terminate the agreement if the commencement of construction of a facility has not occurred within 4 years of the date of this option. 3. Processor has the right to offer to extend the agreement 2-4 years, if the producer does not reject the extension within 60 days the extension will be deemed accepted. 4. If the producer sells his land or does not renew leased land, the producer shall make their best effort to transfer the obligations under this agreement 5. Neither the producer nor successor operators can sell straw to competing firms without meeting the obligation of this agreement first."

(Source: Altman, Boessen, and Sanders, 2006 pg. 11)

Appendix B - GAMS CODE

```
SETS
I   ethanol plant locations   / Plant1, Plant2, Plant3, Plant4, Plant5,Plant6, Plant7 /
J   county centroids         / C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11,C12,C13,C14,
C15,C16,C17,C18,C19,C20,C21,C22,C23,C24,C25,C26,C27,C28,C29,C30,C31,C32,

C33,C34,C35,C36,C37,C38,C39,C40,C41,C42,C43,C44,C45,C46,C47,C48,C49,C50,

C51,C52,C53,C54,C55,C56,C57,C58,C59,C60,C61,C62,C63,C64,C65,C66,C67,C68,

C69,C70,C71,C72,C73,C74,C75,C76,C77,C78,C79,C80,C81,C82,C83,C84,C85,C86,

C87,C88,C89,C90,C91,C92,C93,C94,C95,C96,C97,C98,C99,C100,C101,C102,C103,

C104,C105,C106,C107,C108,C109,C110,C111,C112,C113,C114,C115,C116,C117,

C118,C119,C120,C121,C122,C123,C124,C125,C126,C127,C128,C129,C130,C131,

C132,C133,C134,C135,C136,C137,C138,C139,C140,C141,C142,C143,C144,C145,

C146,C147,C148,C149,C150,C151,C152,C153,C154,C155,C156,C157,C158,C159,

C160,C161,C162,C163,C164,C165,C166,C167,C168,C169,C170,C171,C172,C173,

C174,C175,C176,C177,C178,C179,C180,C181,C182,C183,C184,C185,C186,C187,

C188,C189,C190,C191,C192,C193,C194,C195,C196,C197,C198,

C199,C200,C201,C202/ ;
Parameter  A(J)  amount of corn stover available per county j in tons
```

```
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\Corn.txt
/
Parameter B(J)  amount of wheat straw available per county j in tons
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\Wheat.txt
/
Parameter C(J)  amount of sorghum stover available per county j in tons
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\Wheat.txt
/
Parameter E(J)  amount of switchgrass available per county j in tons
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\Switchgrass.txt
/;

TABLE   D(I,J)  'distance_to_ethanol_plant_from_county_centroid_in_miles'
$ondelim
$INCLUDE
C:\Users\Dustin\Documents\Thesis\COUNTYCENTROIDDISTANCES.csv
$offdelim
display d;

PARAMETER   FGPC(J) 'Farm gate price corn per county'
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\CPrice.txt
/
PARAMETER   FGPW(J) 'Farm gate price wheat per county'
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\WPrice.txt
/
```

```
PARAMETER   FGPS(J) 'Farm gate price sorghum per county'
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\S Price.txt
/
PARAMETER   FGPG(J) 'Farm gate price switchgrass per county'
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\GPrice.txt
/
PARAMETER   CW(j)  Designation as a county in central or western region
/
$INCLUDE    C:\Users\Dustin\Documents\cntydesig.txt
/;
PARAMETER YieldC(j)   Yield of Corn Stover per Acre
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\YieldC.txt
/
        YieldW(j)   Yield of Wheat Straw per Acre
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\YieldW.txt
/
        YieldS(j)   Yield of Sorghum Stover per Acre
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\YieldS.txt
/
        YieldG(j)   Yield of Switchgrass per Acre
/
$INCLUDE    C:\Users\Dustin\Documents\Thesis\YieldG.txt
/;

PARAMETER  TC(I,J)      Transport cost in dollars
```

SupplyC(i,j) Total svailable supply of corn stover in county j for plant i

SupplyW(i,j) Total svailable supply of wheat straw in county j for plant i

SupplyS(i,j) Total svailable supply of sorghum stover in county j for plant i

SupplyG(i,j) Total svailable supply of switchgrass in county j for plant i

LimitC(j)   Max distance to transport

LimitW(j)   Max distance to transport

LimitS(j)   Max distance to transport

LimitG(j)   Max distance to transport

AdoptC(j)   Adoption Rate for corn stover in county j

AdoptW(j)   Adoption Rate for wheat straw stover in county j

AdoptS(j)   Adoption Rate for sorghum stover in county j

AdoptG(j)   Adoption Rate for switchgrass in county j

Central(j)   Central Counties

West(j)   Western Counties;

SCALAR   Capadj   Adjustment Factor for Plant Capacity /1/;

SCALAR Trans Transportation cost per loaded mile /.14/;

SCALAR PGP Plant gate price offered /80/;

SCALAR VC Variable Cost of Corn Stover per Acre /60/;

SCALAR VW Variable Cost of Wheat Straw per Acre /60/;

SCALAR VS Variable Cost of Sorghum Stover per Acre /60/;

SCALAR VG Variable Cost of Switchgrass per Acre /181/;

SCALAR Nutr Nutrient replacement option for residues 1 (yes) or -1 (no) /1/;

SCALAR CSH Cost share for switchgrass for seed establishment /0/;

Variables

Z Total cost of shipping feedstock;

Positive Variable

XC(i,j) Amount of corn stover shipped from County Centroid j to Plant i

XW(i,j) Amount of wheat straw shipped from County Centroid j to Plant i

XS(i,j) Amount of sorghum stover shipped from County Centroid j to Plant i

XG(i,j) Amount of switchgrass shipped from County Centroid j to Plant i

P(i) Production at Plant i;

Equations

COST Objective Function

MaxC(j) Max Feedstock Availability of Corn Stover in County j

MaxW(j) Max Feedstock Availability of Wheat Straw in County j

MaxS(j) Max Feedstock Availability of Sorghum Stover in County j

MaxG(j) Max Feedstock Availability of Switchgrass in County j

Cap (i) Capacity at plant i

ShipmentMaxC(i,j) Max quantity that can be shipped for from County j to Plant i of corn stover

ShipmentMaxW(i,j) Max quantity that can be shipped for from County j to Plant i of wheat straw

ShipmentMaxS(i,j) Max quantity that can be shipped for from County j to Plant i of sorghum stover

ShipmentMaxG(i,j) Max quantity that can be shipped for from County j to Plant i of switchgrass

PlantCap1 Plant Capacity for Plant 1

PlantCap2 Plant Capacity for Plant 2

PlantCap3 Plant Capacity for Plant 3

PlantCap4 Plant Capacity for Plant 4

PlantCap5 Plant Capacity for Plant 5

PlantCap6 Plant Capacity for Plant 6

PlantCap7 Plant Capacity for Plant 7;

Central(j) = 0;
West(j) = 0;
Central(j)$(CW(j)=2) = 1;
West(j)$(CW(j)=1) = 1;

AdoptC(j) = 2*exp(-4.49 - 1.26*West(j) + 0.99*Central(j) + 0.13*(FGPC(j)*YieldC(j)-VC)-0.21*2+0.73+0.74*Nutr)/(1+2*exp(-4.49 - 1.26*West(j) + 0.99*Central(j) + 0.13*(FGPC(j)*YieldC(j)-VC)-0.21*2+0.73+0.74*Nutr));

AdoptW(j) = 2*exp(-4.49 - 1.26*West(j) + 0.99*Central(j) + 0.13*(FGPW(j)*YieldW(j)-VW)-0.21*2+0.73+0.74*Nutr)/(1+2*exp(-4.49 - 1.26*West(j) + 0.99*Central(j) + 0.13*(FGPW(j)*YieldW(j)-VW)-0.21*2+0.73+0.74*Nutr));

AdoptS(j) = 2*exp(-4.49 - 1.26*West(j) + 0.99*Central(j) + 0.13*(FGPS(j)*YieldS(j)-VS)-0.21*2+0.73+0.74*Nutr)/(1+2*exp(-4.49 - 1.26*West(j) + 0.99*Central(j) + 0.13*(FGPS(j)*YieldS(j)-VS)-0.21*2+0.73+0.74*Nutr));

AdoptG(j) = 2*exp(-6.96 + 1.94*West(j) + 3.74*Central(j) + 0.16*(FGPG(j)*YieldG(j)-VG-40)-0.16*7+0.33+0.23+0.025*CSH)/(1+2*exp(-6.96 + 1.94*West(j) +3.74*Central(j) + 0.16*(FGPG(j)*YieldG(j)-VG-40)-0.16*7+0.33+0.23+0.025*CSH));

```
TC(i,j)= D(i,j)*Trans+0.78;

LimitC(j) = (PGP-FGPC(j))/Trans;
LimitW(j) = (PGP-FGPW(j))/Trans;
LimitS(j) = (PGP-FGPS(j))/Trans;
LimitG(j) = (PGP-FGPG(j))/Trans;


SupplyC(i,j)$(D(i,j)<= LimitC(j)) = A(j)*AdoptC(j);
SupplyW(i,j)$(D(i,j)<= LimitW(j)) = B(j)*AdoptW(j);
SupplyS(i,j)$(D(i,j)<= LimitS(j)) = C(j)*AdoptS(j);
SupplyG(i,j)$(D(i,j)<= LimitG(j)) = E(j)*AdoptG(j);

SupplyC(i,j)$(D(i,j)> LimitC(j)) = 0;
SupplyW(i,j)$(D(i,j)> LimitW(j)) = 0;
SupplyS(i,j)$(D(i,j)> LimitS(j)) = 0;
SupplyG(i,j)$(D(i,j)> LimitG(j)) = 0;

COST..          Z =E= sum((i,j), TC(i,j)*(XC(i,j)+XW(i,j)+XS(i,j)+XG(i,j)));

MaxC(j)..       sum(i, XC(i,j)) =L= A(j)*AdoptC(j);
MaxW(j)..       sum(i, XW(i,j)) =L= B(j)*AdoptW(j);
MaxS(j)..       sum(i, XS(i,j)) =L= C(j)*AdoptS(j);
MaxG(j)..       sum(i, XG(i,j)) =L= E(j)*AdoptG(j);

Cap(i)..        80*sum(j, XC(i,j) + XW(i,j) + XS(i,j) + XG(i,j)) =E= P(i);

ShipmentMaxC(i,j)..   XC(i,j) =L= SupplyC(i,j);
ShipmentMaxW(i,j)..   XW(i,j) =L= SupplyW(i,j);
ShipmentMaxS(i,j)..   XS(i,j) =L= SupplyS(i,j);
```

```
ShipmentMaxG(i,j)..   XG(i,j) =L= SupplyG(i,j);

PlantCap1..      P("Plant1")=E= 25000000*Capadj;
PlantCap2..      P("Plant2")=E= 25000000*Capadj;
PlantCap3..      P("Plant3")=E= 25000000*Capadj;
PlantCap4..      P("Plant4")=E= 25000000*Capadj;
PlantCap5..      P("Plant5")=E= 25000000*Capadj;
PlantCap6..      P("Plant6")=E= 25000000*Capadj;
PlantCap7..      P("Plant7")=E= 25000000*Capadj;

model project /all/;

solve project using LP minimizing Z;

execute_unload "results80BC.gdx" XC.l

execute 'gdxxrw.exe results80BC.gdx var=XC.l rng=NewSheet!'

execute_unload "results80BC.gdx" XW.l

execute 'gdxxrw.exe results80BC.gdx var=XW.l rng=NewSheet!'

execute_unload "results80BC.gdx" XS.l

execute 'gdxxrw.exe results80BC.gdx var=XS.l rng=NewSheet!'

execute 'gdxxrw.exe results80BC.gdx var=XG.l rng=NewSheet!
```

Appendix C - Spreadsheet Key

Iowa

This worksheet contains the acreage, yield, conversion, and available biomass for all residues and switchgrass for Iowa.

Kansas

This worksheet contains the acreage, yield, conversion, and available biomass for all residues and switchgrass for Kansas.

Missouri

This worksheet contains the acreage, yield, conversion, and available biomass for all residues and switchgrass for Missouri.

Nebraska

This worksheet contains the acreage, yield, conversion, and available biomass for all residues and switchgrass for Nebraska.

Oklahoma

This worksheet contains the acreage, yield, conversion, and available biomass for all residues and switchgrass for Oklahoma.

CRP

This worksheet contains the acreage for expiring CRP land from fiscal year 2011 to fiscal year 2012.

Switchgrass Yields & Costs

This worksheet contains the non-irrigated switchgrass yield estimates and break-even prices from Nelson et al. 2010.

Grain Stover Yields and Costs

This worksheet contains the average acreages for each district, an estimate of the biomass available, and break-even prices for residues with 2012 enterprise budget prices having been obtained from KFMA (2012).

X DT

This worksheet contains the average amount of dry tons per county available of residue assuming enough is left for conservation.

XPrice

This worksheet contains the average price per dry ton based off of the grain stover yields and costs worksheet.

YieldX

This worksheet contains the average residue yield in dry tons for each county.

Cntydesig

This worksheet assigns each county a region based off of KFMA regions.

Edge of Field

This worksheet has the various amounts of residue and switchgrass available at the edge of field under various farm-gate prices.