THE ECONOMICS OF BIOMASS COLLECTION, TRANSPORTATION, AND SUPPLY TO INDIANA CELLULOSIC AND ELECTRIC UTILITY FACILITIES

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Abstract

With cellulosic energy production from various forms of biomass becoming popular in renewable energy research, agricultural producers may be called upon to plant and harvest switchgrass or collect corn stover to supply such energy production to nearby facilities. Determining the entire production and transportation cost to the producer of switchgrass or corn stover and the amount available within a given distance of the plant will result in a per ton cost the plant will need to pay producers in order to be supplied with sufficient quantities of biomass.

This research computes up-to-date biomass production costs using recent prices for all important cost components including seed, fertilizer and herbicide application, mowing/shredding, raking, baling, storage, handling, and transportation. The cost estimates also include nutrient replacement for corn stover. The total per ton cost for either switchgrass or corn stover is a combination of these cost components depending on whether equipment is owned or custom hired, what baling options are used, the size of the farm, and the distance that biomass must be transported. Total per ton costs for transporting biomass 30 miles range between \$39 and \$46 for corn stover and \$57 and \$63 for switchgrass. Using the county quantity data and this cost information, we then estimated biomass supply curves for three Indiana coal-fired electric utility. This supply framework can be applied to plants of any size, location, and type. Finally, we estimated the greenhouse gas emissions reduction from using biomass instead of coal for part of the utility energy and also the carbon tax required to make the biomass cost equivalent to coal.

Keywords: Cellulosic biomass, corn stover, switchgrass, biomass supply, GHG reduction

JEL Codes: Q12, Q42, Q54

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1. Introduction

1.1. Overview

The United States imported over 10 million barrels per day (or nearly 4 billion barrels per year) of crude oil in 2006, and nearly half of those barrels came from OPEC member countries (Energy Information Administration, 2008). OPEC, or the Organization of the Petroleum Exporting Countries, is comprised of eleven member countries, including primary sources of US oil imports such as Saudi Arabia, Nigeria, and Venezuela. The members of OPEC account for about 40 percent of world oil production and hold two-thirds of proven world oil reserves (Energy Information Administration, 2006).

While most of the current efforts to produce biofuels have focused on starch contained in grains such as corn, cellulosic biofuels production is an alternative that is beginning to receive more attention. Cellulose is the primary material of plant cells but is not as easy to covert to ethanol as grains (Renewable Fuels Association, 2007). Because cellulose is a part of all plants including those that do not produce large quantities of starch, the resource potential of making cellulosic biofuels expands greatly. Biofuels production may become possible via corn stover, perennial grasses and trees, wood chips, and manure to name a few potential sources. The development of cellulosic bioenergy production will require finding an economically and environmentally sustainable method for obtaining large quantities of biomass feedstock (Biotechnology Industry Organization, 2006).

Fossil fuel combustion from coal, oil, and natural gas has contributed to more carbon dioxide concentration in the atmosphere (Energy Efficiency and Renewable Energy, 2008). Carbon dioxide emissions from biofuels are balanced by the carbon dioxide absorbed during plant growth. The US Department of Energy estimates that ethanol produced from corn stover can reduce greenhouse gas emissions by as much as 113 percent (Energy Efficiency and Renewable Energy, 2008). Blending ethanol with gasoline fuel used in vehicles serves as an oxygenate that results in more complete combustion.

1.2. Potential for Biomass Energy

Biomass is currently the largest provider of domestic renewable energy (accounting for 47 percent) and supplies over 3 percent of total energy consumption in the United States (Perlack, et al. 2005). With abundant agricultural resources in cereal crops and oilseeds and available idle acres for perennial crops to potentially be planted, the United States is well poised to make biomass a sustainable and significant part of domestic energy production.

Approximately one-half of the 2,263 million acre land base in the United States is capable of producing some amount of biomass (Perlack, et al. 2005). The amount of biomass that can potentially be produced on a given area of land is dependent on crop yields, the percentage of residue that can be collected while still maintaining soil integrity, collection equipment and technology, tillage practices, and acreage allocation. A 2005 study by the United States Department of Agriculture (USDA) and the United States Department of Energy (DOE) estimates that with technology changes that result in a 50 percent increase in crop yields and suitable available acres being converted to perennial crops, 998 million dry tons of biomass annually can be produced from agriculture-based resources (Perlack, et al. 2005). This is a significant increase from the 194 million dry tons currently being produced per year.

Determining what amount of residue must be left on the field in order to maintain soil quality and avoid erosion allows producers to find an environmental and economic equilibrium when faced with the opportunity to sell biomass. Choosing the ideal collection process will determine whether new equipment must be purchased, how much additional labor might be required if residue is collected separately from harvest, and how much soil compaction might occur if multiple passes must be taken in the collection process. Tillage practices affect the amount of residue necessary to protect the soil. No-till practices result in more residue being available for removal, because the soil is less vulnerable to nutrient loss and erosion. Converting from conventional tillage to no-till has upfront capital costs that might make it a less attractive option. Selling crop residue, however, presents producers with an opportunity to recover these capital costs in a reasonable time frame. The allocation of acres between residue producing crops and perennial crops will also affect biomass availability. For example, acreage currently in the Conservation Reserve Program (CRP) or in pasture use may end up being switched into production of perennial crops such as switchgrass or miscanthus.

1.3. <u>Liquid Fuels</u>

Cellulosic biomass potentially could be used to make ethanol via a more efficient production process than from corn. Iogen Corporation, in Ottawa, Canada, is producing just over one million gallons each year of cellulosic ethanol from wheat, oat, and barley straw (Renewable Fuels Association, 2007). In the United States, resources are proposed to be budgeted for the research and development (i.e. 2007 Farm Bill Cellulosic Bioenergy Program) of cellulosic ethanol.

Government legislation and regulation have also mandated increases in cellulosic renewable fuels. The Renewable Fuel Standard was extended and expanded to require 36 billion gallons of renewable fuel use by 2022. Starting in 2010, a portion of that requirement is mandated to come from cellulosic sources that achieve at least a 60 percent greenhouse gas emission reduction (Renewable Fuels Association, 2008).

1.4. <u>Electric Power</u>

Traditional coal-fired electric power plants create one potential market for the use of biomass in domestic energy production. Instead of burning coal, which harms the environment, biomass can serve as an alternative energy source depending upon local availability. The amount power plants could feasibly pay to a producer for biomass will depend upon how much biomass is available within a certain radius of the plant, how much it will cost to transport the biomass from the farm to the plant, and how much capital expenditure is required to outfit the plant with biomass capabilities. Biomass can also serve as an input for cellulosic ethanol production, which with continued research and development could become a more viable and widespread method for producing biofuels.

1.5. Problem

One current problem for biomass resources is a lack of up-to-date cost estimates that are applicable to differing farm capabilities and circumstances. This requires estimating the opportunity costs of not leaving the biomass directly on the field. Since there is no market price for biomass, this estimated cost will vary from plant to plant and from producer to producer within a given plant supply area. This estimation will require quantifying the environmental costs of replacing nutrients that are lost due to less residue on the ground, the collection and harvesting costs, on-farm storage costs, and the transportation costs for each specified plant size with supply coming from various distances. Results from this analysis only consider costs from the field to the plant door and do not consider costs associated with adapting boilers to be able to burn biomass. The costs for the physical biomass and its storage was calculated separately from the transportation cost in order to allow the plant to create a biomass contract and a transportation contract with each individual supplier to avoid overcompensation. The results of this analysis will be of interest to corn producers, those with available marginal cropland or grassland for switchgrass production, and operators of electric power plants. These results, however, are not just limited to electric power plants but also apply to any cellulosic facility using biomass feedstock.

1.6. Objectives

The first objective of this analysis is to determine appropriate activity cost estimates for both corn stover and switchgrass. Rather than creating a single cost estimate for each crop, this analysis attempts to build cost estimates for several situations in an effort to provide cost figures to different operations of different sizes that are located at various distances from an electric power plant looking to purchase biomass.

The second objective of this analysis is to create biomass supply curves for different electric power plants of various capacities and locations throughout the state. For this analysis, three Indiana power plant sizes with nameplate capacities of 43.2, 144.2, and 1184.9 megawatts (MW) are considered. Plant locations are in Tippecanoe, Knox, and Marion counties, respectively.

1.7. Approach

The approach required to meet these objectives includes a spreadsheet model for calculating per ton costs. Once a list of activities and the related parameters were determined, relevant input costs similar to those in Indiana are used to reach a per ton cost for each activity. Summing these activity costs creates a total per ton cost that included production, harvest, collection, handling, storage, and transportation of the biomass.

1.8. Organization

The next section reviews existing literature on corn stover harvesting and collecting, switchgrass production, and transportation of biomass. Parameters and assumptions from these existing studies are used in calculating new cost figures. This includes a review of previously published cost estimates for the various activities of the process.

Following the literature review, we develop current per ton cost estimates for corn stover and switchgrass activities in Indiana that update those already published. These cost estimates address multiple removal scenarios for corn stover as well as custom machinery rates, equipment purchase payments, different farm sizes, and available bale packaging options.

Building on these cost estimates, biomass supply curves are developed for each plant being considered. These are constructed by considering the density of corn stover and switchgrass within the county where the plant is located and within the counties that surround it. Potential offsets in total costs due to less coal consumption and fewer CO_2 emissions are addressed relative to the additional costs incurred from using biomass. Breakeven CO_2 costs are calculated, which represent the level of carbon tax necessary to elicit a market induced switch to cellulose raw material.

The final section summarizes the conclusions on the feasibility of supplying cellulose to Indiana electric utilities. It also points out needs for future research in this area.

2. Literature Review

This literature review serves as an exploration of the current research that exists with respect to biomass collection. With a number of studies arriving at similar aggregate conclusions for the cost of biomass collection, it is important to understand the parameters and assumptions behind these total cost figures and what might make one total cost slightly different from another. These include assumptions regarding yields, harvesting removal rates, nutrient replacement, seeding rates, herbicide application, and storage dry matter loss. This literature review reports the parameters and assumptions of other studies as a way of determining the parameters and assumptions best suited for this analysis. The parameters and assumptions decided on for this analysis will be discussed in the next major section on biomass harvest, collection, and transport costs.

2.1. Corn Stover

2.1.1. Yield Assumptions

The amount of corn stover yield produced from each acre will depend upon corn yields. Lang (2002) assumes grain and stover yields are equal and uses a simple formula to calculate the expected above ground stover yield per acre. A bushel of corn weighs 56 pounds. Dividing this number by 2000 pounds (or a short ton) results in a tons per acre yield of stover.

$$\frac{Corn\ Yield\ (bushels/acre) \times {}^{56\ pounds}/_{bushel}}{{}^{2000\ pounds}/_{ton}} = Stover\ Yield\ (tons/acre)$$

Half of the above ground dry matter is made up of stover and the other half is made up of grain. However, Pordesimo, et al. (2004) found that this 1 to 1 ratio may not be the most realistic. When considering above ground dry matter before and after full grain physiological maturation, they found that a stover to grain ratio of 0.8 to 1 may be more realistic especially when grain moisture is between 18 and 31 percent, despite many studies using the traditional 1 to 1 ratio.

Using the National Agricultural Statistics Service's September 2007 forecast for corn yield of 160 bushels per acre in Lang's formula, corn stover yield per acre is predicted to average 4.48 tons per acre. Consistent with Lang's formula, Quick (2003) assumes a corn yield of 150 bushels per acre to lead to 4.2 tons per acre stover yield. Glassner, et al. (1998) assumes that corn yields between 150 and 200 bushels per acre will result in stover yields of 4 to 5 tons per acre. Other estimates in the literature for corn stover yield with respect to corn yield do not produce such high figures, however. For example, Atchison and Hettenhaus (2003) assume that 170 bushel per acre corn yield will result in 4 tons per acre stover yield, and Sokhansanji and Turhollow (2002) assume that 150 bushel per acre corn yield will result in 3.6 tons per acre stover yield. All of these aforementioned studies have assumed a 1 to 1 ratio between dry matter from stover and dry matter from grain.

2.1.2. Removal Rates

Removal rates or collection efficiency refer to the percentage of available stover that can be collected and removed based on the harvest activities performed. Richey, et al. (1982) estimated that by raking and baling, 29 percent of available stover could be collected. However, machinery improvements since then suggest that removal rates can be much higher. Montross, et al. (2003) have found that only baling stover will result in 38 percent collection, raking and baling will result in 50 to 55 percent collection, and shredding, raking, and baling will result in 64 to 75 percent collection. Lang (2002) estimates that shredding, raking, and baling may result in as much as 80 percent collection. Shinners, et al. (2003a) found that allowing the stover to dry in the field for more time can reduce collection efficiency from 56 percent to 33 percent for baling alone. Sheehan, et al. (2003) assumes that approximately 40 percent of residue can be collected under continuous corn mulch tillage, while 70 percent of residue can be collected under no-till. They suggest that collectable residue rate would be less under a corn-soybean rotation because a smaller amount of residue is produced by soybeans.

Corn stover serves to protect and maintain crop and soil productivity of fields from which corn is harvested. This particularly relates to preserving the organic matter and nutrients of the soil while also avoiding runoff from water erosion and soil loss from wind erosion. Therefore, it is important to determine what effects different degrees of stover removal have on the soil. These agronomic effects must also be balanced with the economic question of how much stover is too little when it comes to ensuring that revenue from stover exceeds the additional costs of collection.

Sheehan, et al. (2003) center a portion of their study on finding the amount of stover that can be collected with erosion loss that can be tolerated. Tolerable soil loss is defined as "the maximum amount of soil loss due to erosion by water or wind that can be allowed without causing adverse effects on soil and water resources" (Miller, et al., 1999). The effects of residue removal on soil erosion are not only difficult to quantify but also difficult to generalize for various soil characteristics (i.e. slope, organic properties, etc.), weather conditions, and management decisions (i.e. residue cover, cover crops, tillage, etc.). Effects are also difficult to measure over the long term, and most existing studies on residue management have focused on the short term (Andrews, 2006). In most cases, though, more residue taken off the field will result in higher water runoff and soil erosion rates (Lindstrom, et al., 1986). With respect to tillage systems, McCool, et al. (1995) found that residue left on the surface (no-till systems) results in lower amounts of soil loss for a given amount of residue left on the field than residue that is incorporated into the soil through tillage. Despite many negative consequences associated with soil erosion, it is also important to remember that roots seem to contribute more to the soil organic matter and carbon accrual than residues (Andrews, 2006).

Figure 2.1 summarizes results found by Lindstrom, et al. (1986) regarding the effects of residue removal on water runoff and soil loss. While this study found increasing amounts of runoff and soil loss as decreasing amounts of residue remained on the field, it also concluded that there was no significant change in runoff or soil loss until at least 30 percent of residue was removed. In other words, runoff and soil loss did not dramatically increase up to the point where 30 percent of residue was removed. On both graphs in Figure 2.1, the lines remain relatively flat from 3000 pounds of residue per acre to 2100 pounds of residue per acre (a 30 percent removal rate). One might also argue that the line does not increase in slope drastically until approximately 1500 pounds of residue remains per acre (a 50 percent removal rate) with about 0.1 inch of runoff and 0.25 inch of soil loss occurred after removing 50 percent relative to 0 percent.

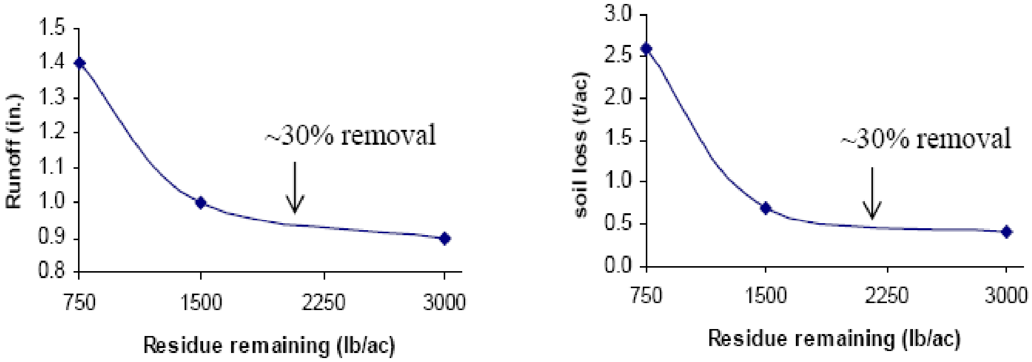

Figure 2.1. Runoff and Soil Loss Relative to Amount of Residue Removed

Karlen, et al. (1997) ran three scenarios for crop residue management for 10 years each. The first was removing crop residue, the second was retaining crop residue, and the third was doubling the original amount of crop residue. Corn fields subject to these regiments had yields of 189 bushels per acre, 194 bushels per acre, and 210 bushels per acre, respectively, four years after each 10 year crop residue management scenario had been completed. While the effects of chosen management practices are still evident, these differences in yield over time for the removal or retention of crop residue do not seem to have a huge impact on corn yields.

Barber (1979) conducted field experiments with various residue treatments for 11 years in Lafayette, Indiana. Residues collected after harvest were removed from the field, returned to the field, or returned to the field at twice the rate collected. Average yields throughout the experiment are reported in Table 2.1. Barber concludes from these results that corn yield was not statistically different due to residue management. He also indicated that after a change in practices (such as residue management), soil organic matter will decrease and then reach a new equilibrium if new practices are left in place for several years.

Table 2.1. Effect of Residue Management on Corn Yield

	0-11 years (bu/acre)	6-11 years (bu/acre)
Residues removed	143.7	150.1
Residues returned	146.2	154.1
Double residues returned	142.6	150.5

Power, et al. (1986) and Linden, et al. (2000) both found that corn yield were higher when residue was left on the field than when it was removed. However, both studies attributed this result primarily to areas with drier soils or below average precipitation. Benoit and Lindstrom (1987) found that Midwestern states with poor drainage and fine-textured soils reported lower yields when there were larger amounts of residue left on the field. Sauer, et al. (1996) reported that thick layers of residue add insulation, which reduces water evaporation and lowers the ground temperature. This could result in poor seed germination, especially in colder areas. On the other hand, if an area is warm and humid, more stover may need to be retained in order to not drive the ground temperature too high.

According the Natural Resource Conservation Service, conservation tillage maintains at least 30 percent of the soil surface residue as a method of reducing soil erosion. This suggests that it will at least be acceptable for the shredding, raking, and baling to occur without damaging the integrity of the soil. This, however, is only a guideline, and different soils and locations will need to be treated differently with respect to how much stover can be safely collected and removed. The effects of residue removal can also be offset with such practices as contour cropping, no-till, and cover crops. This analysis will not assume any one removal rate and will consider three scenarios that allow for different choices to best suit different conditions and characteristics.

2.1.3. Windrows

Windrows can be created by the combine by disconnecting or disabling the spreader that serves to evenly distribute residue behind the combine. This will result in a row of stover that can be easily baled. Throughout the literature, stover harvest that only consists of baling is done by creating a windrow. As noted by Glassner, et al. (1998) and Perlack and Turhollow (2002), baling stover from a windrow will not allow as much available stover to be collected as would raking the stover and then baling. Petrolia (2006) estimates that 30 percent of stover will be collected by harvesting a windrow while 40 percent will be collected when stover is raked and baled. Lang (2002) expected baling a windrow to collect 50 percent of available stover and raking to collect 65 percent. Schechinger and Hettenhaus (2004) found windrow harvest to collect 40 to 50 percent of available stover and raking and baling to collect 70 percent of available stover. While these removal rate estimates are not all the same, they do indicate the difference in collection efficiency between combine-created windrows and rake-created windrows.

Windrows can also reduce the ability for the stover to dry out after it has been harvested. When stover is spread across the field, it will lay on the ground in a thin layer until it is raked and baled. However, windrows will result in stover laying in a narrow and thick row until it is baled.

As noted by Shinners, et al. (2003a), this will slow the natural drying rate, which will decrease the dry matter density and increase the moisture content of bales. This added moisture in the stover bales will likely cause stover quality to decline.

Windrows can be useful for small farms with limited resources (labor, capital, etc.) available for stover harvest. It may also be useful for large farms that have limited flexibility in their harvesting schedule and very little excess labor. Windrows serve to reduce costs and soil compaction as they eliminate an additional pass over the field. However, this will also reduce the amount of stover that is collected and delivered for payment at the power plant.

2.1.4. Nutrient Replacement

According to Petrolia (2006), Lang (2002), and Schechinger and Hettenhaus (2004), nitrogen will not need to be added additionally following stover harvest if it is assumed that fields will be planted in a corn-soybean rotation. However, reduced nitrogen application due to growing soybeans is credited to reduced fertilizer application for soybeans, and attributing it to corn stover as well would be double counting. Therefore, regardless of the rotation used, there will always be a need to add nitrogen to compensate for the removed stover. Nitrogen, phosphorus, and potassium will be added to replace nutrients that would be put into the soil from unharvested stover covering the field.

Table 2.2 outlines the amount of additional nitrogen, phosphorus, and potassium that will need to be added for each ton of stover that is removed as determined by or averaged from existing studies. The average of the nutrient replacement parameters from Lang (2002), Petrolia (2006), and Fixen (2007) results in the assumed additional pounds of fertilizer per ton of harvested stover that will be used in this analysis.

Table 2.2. Suggested Additional Nutrients Per Ton of Stover Harvested

	N (lbs)	P_2O_5 (lbs)	K_2O (lbs)
Schechinger and Hettenhaus (2004)	NA	7.0	35.0
Lang (2002)	15.0	5.9	25.0
Nielsen (1995)	13.6	3.6	19.7
Petrolia (2006)	NA	6.2	33.0
Fixen (2007)	19.0	5.7	32.0

2.2. Switchgrass

2.2.1. Yield Assumptions

Popp and Hogan (2007) assume switchgrass yields to be 3 tons per acre in the first year of harvest (i.e. the year following establishment) and 5 tons per acre in subsequent years. Kszos, et al. (2002) found switchgrass yields in the Corn Belt (including Indiana) to be 5.98 tons per acre, and the production cycle of the stand to be 10 years. Duffy and Nanhou (2001) (in Iowa) and Brummer, et al. (2001) (in Iowa) create several yield scenarios ranging from 1.5 to 6 tons per acre with a 10 year production life for the stand. Tiffany, et al. (2006) (in Minnesota, North

Dakota, and South Dakota) assume a yield of 4 tons per acre, Walsh, et al. (1996) (in mid-Plains states) assume a yield of 4-5 tons per acre, and Perrin, et al. (2003) (in Nebraska, North Dakota, and South Dakota) found yields to be between 2.5 and 3 tons per acre.

2.2.2. Field Preparation and Seeding

Preparation of a switchgrass field that was previously planted to some other variety of grass will first require mowing. After the mowing, the field may be sprayed with glyphosate in order to eliminate the previous grasses and broadleaf weeds to ensure there is no competition for the new switchgrass stand.

Table 2.3 outlines the suggested seeding rates for switchgrass. We assume that Cave-In-Rock switchgrass is planted, because this variety seems to perform well in the Midwest and was originally found in southern Illinois (Missouri NRCS, 1986). Planting should take place anytime between April and June.

Table 2.3. Pure Live Seed Seeding and Planting Date Recommendations

	Pure Live Seed (PLS) (lbs)	Planting Date
Missouri NRCS (1986)	5	Late April to mid-June
Duffy and Nanhou (2001)	5 to 6	Spring
Tiffany, et al. (2006)	10	
Lawrence, et al. (2006)	7 to 9	Before June
Teel, et al. (2003a)	5 to 6	Mid-April to late May
Walsh (2007)	7 to 8	
Rinehart (2006)	4 to 10	

Table 2.4 presents the recommended establishment application rates for fertilizer and herbicide. Some estimates vary largely among sources, and this is likely due to differing soil conditions of the field in which switchgrass is to be planted. Fertilizer and herbicide suggestions may vary from field to field depending upon soil type and quality. Therefore, for the purposes of this analysis, the application rates will be averaged to capture various soil characteristics. Nitrogen should not be applied in the establishment year in order to avoid simulating weeds that may compete with the growth of switchgrass (Missouri NRCS (1986), Duffy and Nanhou (2001), Tiffany, et al. (2006), Lawrence, et al. (2006), Teel, et al. (2003b)).

Table 2.4. Establishment Year Per Acre Fertilizer and Herbicide Regiments

	P_2O_5 (lbs)	K_2O (lbs)	Lime (tons)	Atrazine (qts)	2,4 D (pts)	Glyphosate (qts)
Popp and Hogan (2007)	40	40	1	1	1	1
Duffy and Nanhou (2001)	30	40	3	1.5	1.5	2
Tiffany, et al. (2006)	20	30	NA	NA	NA	3

2.2.3. Production Year

Table 2.5 summarizes the suggested fertilizer and herbicide amounts for the production years following establishment. As with the establishment application, an average will be taken for the purposes of this analysis to address several soil condition cases.

Table 2.5. Production Year Per Acre Fertilizer and Herbicide Regiments

	N (lbs)	P_2O_5 (lbs)	K_2O (lbs)	Atrazine (qts)	2,4 D (pts)
Popp and Hogan (2007)	75	20	60	1	1
Kszoz, et al. (2002)	20 to 25/per dry ton yield	NA	NA	NA	NA
Duffy and Nanhou (2001)	100	1.94/dry ton yield	22.8/dry ton yield	1.5	1.5
Tiffany, et al. (2006)	50	NA	NA	NA	NA
Lawrence, et al. (2006)	50 to 75	NA	NA	NA	NA
Teel, et al. (2003a)	90 to 120	NA	NA	NA	NA
Walsh (2007)	50	15 to 20	25	NA	NA
Gibson and Barnhart (2007)	77 to 150	NA	NA	NA	NA
Rinehart (2006)	50	NA	NA	NA	NA

These suggested application rates will be averaged to determine the fertilizer rates for this analysis. Where existing literature represents the application rate as an amount applied for each ton of switchgrass harvested, a 5 ton per acre yield will be assumed in order to be able to average all rates together, regardless of whether it is given by per ton or per acre.

2.3. Harvesting

An initial question regarding the harvesting of both corn stover and switchgrass is what kind of baler will be used. It is assumed that corn stover and switchgrass harvest will be taking place as a side project for producers predominantly producing other crops. Large round balers have been in use since the 1970s, while large square balers have only become common within the past decade or so (Agrability, 2003). Therefore, considering producers will need to harvest corn stover and switchgrass on a somewhat large basis to make it profitable but may not be able to purchase new or recent equipment immediately, it will be assumed that a large round baler will be used.

The literature seems divided on whether to assume that producers will hire custom operators for harvesting and collecting of both corn stover and switchgrass or use equipment they already own or plan to purchase. For corn stover, Sokhansanj and Turhollow (2002), Atchison and Hettenhaus (2003), Burt (2006), and Nielsen (1995) assumed that custom operators would be hired while Perlack and Turhollow (2002), Petrolia (2006), Shinners, et al. (2003b) and Sokhansanj, et al. (2002) assumed that equipment was purchased by the producer. Glassner, et al. (1998) describe a corn stover collection project that took place in Harlan, IA, in 1996 and

1997, which allowed producers to choose whether they baled their own stover or allowed custom operators to bale. When given the choice, many producers chose the custom operator, which had more specialized equipment and allowed the producer to focus resources on their corn crop harvest.

Switchgrass is much the same as corn stover where Duffy and Nanhou (2001), Tiffany, et al. (2006), and Brummer, et al. (2001) assumed the use of custom operators while Popp and Hogan (2007), Kszos, et al. (2002), and Walsh, et al. (1996) assumed that producers owned the equipment. Since both scenarios are reasonable to assume and some authors have conducted studies using each scenario, this analysis will consider both cases.

2.4. Storage

Dry matter loss of corn stover and switchgrass bales will result in an additional cost that essentially goes unseen. Large round bales will be packaged in twine, net wrap, or plastic wrap and stored at the edge of the field until they are delivered to the power plant. Dry matter loss will be added onto the total product cost per ton as a percentage depending upon the bale packaging used and the amount of time the bale is stored. Table 2.6 breaks down the loss factors from the literature into per month loss factors for each bale packaging type. Loss factors for the analysis will be an average of these per month figures.

Table 2.6. Dry Matter Loss Factors

	Time (months)	Loss for Twine (%)	Per Month Loss for Twine (%)	Loss for Net Wrap (%)	Per Month Loss for Net Wrap (%)	Loss for Plastic Wrap (%)	Per Month Loss for Plastic Wrap (%)
Collins, et al. (1997)	12	25 to 35	2.1 to 2.9	15 to 25	1.25 to 2.1	4 to 7	0. 3 to 0.6
I-FARM (2007)	7	23.4	3.3	8.9	1.25	10.9	1.6
Shinners, et al. (2003a)	8	29.1	3.6	10.7	1.3	NA	NA

2.5. Transportation

Transportation assumptions for the owned equipment scenarios include load capacity of the flatbed trailer, average speed at which the load will travel, and average fuel mileage. Rather than averaging the figures from several studies, the transportation assumptions were taken directly from a few articles in order to ensure consistency and feasibility in the transport load. More detail about the assumptions made in this analysis is discussed in the following section.

2.6. Input Costs

Input costs used in this analysis are as current as possible and as relevant as possible to Indiana. As a reference throughout, Table 2.7 outlines the input costs assumptions used and their sources.

Table 2.7. Input Cost Assumptions

Fertilizer			Source
Anhydrous Ammonia	$536.00	Cost per ton	NASS, Agricultural Prices, April 2007
Liquid Nitrogen	$270.00	Cost per ton	NASS, Agricultural Prices, April 2007
Urea	$450.00	Cost per ton	NASS, Agricultural Prices, April 2007
MAP	$421.00	Cost per ton	NASS, Agricultural Prices, April 2007
Potash	$277.00	Cost per ton	NASS, Agricultural Prices, April 2007
Lime (and application)	$13.76	Cost per ton	Halich, KY Custom Rates, March 2007
Seed			
Cave-In-Rock Switchgrass	$9.50	Cost per lb	Sharp Brothers Seed Company, Clinton, MO
Herbicides			
Glyphosate	$28.90	Cost per gallon	NASS, Agricultural Prices, April 2007
Atrazine	$12.20	Cost per gallon	NASS, Agricultural Prices, April 2007
2,4 D	$15.90	Cost per gallon	NASS, Agricultural Prices, April 2007
Custom			
Stalk Shredder	$8.56	Cost per acre	Halich, KY Custom Rates, March 2007
Rake	$5.40	Cost per acre	Halich, KY Custom Rates, March 2007
Bale	$8.52	Cost per acre	Halich, KY Custom Rates, March 2007
Mower	$10.03	Cost per acre	Halich, KY Custom Rates, March 2007
Fertilizer/Seed Application	$5.13	Cost per acre	Halich, KY Custom Rates, March 2007
Herbicide Application	$5.41	Cost per acre	Halich, KY Custom Rates, March 2007
Packaging			
Twine	$20.75	Cost per roll	Montana Custom Hay
Net Wrap	$200.00	Cost per roll	Montana Custom Hay
Plastic Wrap	$80.00	Cost per roll	Tudor Ag, Avella, PA
Labor			
Field Worker Wage	$9.46	Cost per hour	National Agricultural Statistics Service, Indiana Agriculture Report, September 2006
Ag. Truck Driver Wage	$14.37	Cost per hour	National Agricultural Statistics Service, Indiana Agriculture Report, September 2006
Fuel			
Highway Diesel	$3.93	Cost per gallon	Energy Information Administration, 3/31/2008
On-Farm Diesel	$3.53	Cost per gallon	Energy Information Administration, 3/31/2008

2.7. **Total Dry Ton Costs**

To ensure that the results yielded from this analysis are comparable to what other studies have found, Table 2.8 and Table 2.9 outline the per ton costs from corn stover and switchgrass, respectively. These costs will not be completely comparable to the results of this analysis since they are based on older prices and may include a different set of operations.

Table 2.8. Total Dry Ton Costs, Corn Stover

Author	Publication Year	Cost	Units	Notes
Perlack & Turhollow	2002	$42.70 - $47.10	Per dry ton	Delivered cost
Sokhansanj & Turhollow	2002	$19.70 - $21.40	Per dry ton	Operations up to and including stacking for storage
Glassner, et al.	1998	$31.60 - $35.70	Per dry ton	Delivered cost
Perlack & Turhollow	2003	$43.10 - $51.60	Per dry ton	Delivered cost with producer payment of $10/ton
Sokhansanj, et al.	2002	$21.00 - $41.00	Per dry ton	Delivered cost at distance of 5 miles
Shinners, et al. (2003b)	2003	$30.80 - $41.90	Per dry Mg	Delivered cost

Table 2.9. Total Dry Ton Costs, Switchgrass

Author	Publication Year	Cost	Units	Notes
Popp & Hogan	2007	$52.92 - $60.81	Round bales and modules	½ ton round bales and module building to store chopped forage
Walsh, et al.	2003	$30.00 - $40.00	Per dry ton	Farmgate price
Kszos, et al.	2004	$22.50 - $26.00	Per dry ton	Production cost
Mapemba, et al.	2007	$44.00 - $58.00	Per dry ton	Varies depending on size of biorefinery
Duffy & Nanhou	2001	$49.23 - $116.73	Per dry ton	Yields vary from 1.5 to 6 tons per acre
Tiffany, et al.	2006	$35.00 - $65.00	Per dry ton	Includes storage and transportation
Perrin, et al.	2003	$30.00 - $40.00	Per dry ton	Production cost

3. Biomass Harvest, Collection, and Transportation Cost Analysis

3.1. Corn Stover

Corn stover costs depend greatly on the stover yield per acre, which is related to the grain yield per acre, and the amount of stover that the producer chooses to remove. The per ton cost of corn stover is comprised of several components including nutrient replacement for each ton of stover removed from the field, harvesting or collecting, bale packaging, storage and an associated dry matter loss, handling, and transportation. The corn stover cost is split into two parts: a physical product and the transportation of that product. The plant may create contracts with farms for the physical biomass that will pay the same rate per ton to everyone. Transportation, however, may be taken care of entirely by the plant allowing for a delivery schedule tailored to the demand of the plant or through a separate contract with each producer to pay them only for the miles they travel.

3.1.1. Yield Assumptions

With average corn yields throughout Indiana being 160 bushels per acre in September 2007, it is assumed that per acre stover yields are 4.25 tons per acre. This assumption comes from the existing literature discussed in the literature review. While this stover yield assumption is 0.25 tons less than would be predicted using Lang's formula, it takes into account the studies that found stover yields slightly lower than respective corn yields.

3.1.2. Scenarios and Associated Removal Rates

Depending upon the amount of time available around corn harvest, the weather conditions, and the availability of resources to the producer, stover harvest may take place at different times. The amount of time and labor put into stover harvest will affect the amount of stover that can be collected. This choice will vary from producer to producer and possibly even from field to field. To address this choice, this analysis breaks costs down for the harvest and collection process into three scenarios. Each scenario has an associated removal rate.

If the producer decides to only bale the stover, the corn is harvested and residue collected in a windrow behind the combine. Then an additional pass with a rotary baler bales corn stover into large round bales. This results in removing 38 percent of the available stover on the ground and requires only one additional pass. This removal process is described as "Scenario 1" throughout the rest of this analysis.

If the producer decides to rake and bale the stover, once the corn is harvested, a rake is used to collect the stover into rows. The rake aids in allowing more stover to be picked up by the baler. This results in removing 52.5 percent of the available stover on the ground but requires two additional passes. This removal process is described as "Scenario 2" throughout the rest of this analysis.

If the producer decides to shred, rake, and bale the stover, then a shredder is used after the corn has been harvested in order to cut the stalks even closer to the ground. As a result, more stover will be freely laying on the ground, where it can be raked and baled as before. This results in removing 70 percent of the available stover on the ground but requires three additional passes. As conservation tillage requires at least 30 percent of residue to remain covering the soil, this scenario results in the maximum amount of stover removed while still reducing threats of soil erosion (Illinois NASS, 1998). This removal process is described as "Scenario 3" throughout the rest of this analysis.

It is important to remember that with each additional harvesting activity, an additional pass through the field is necessary. This results in more soil compaction and leaves the field more susceptible to runoff.

3.1.3. Nutrient Replacement

Corn stover left on the field after harvest serves as a way to maintain the nutrient content of the soil for future plantings. Nutrients primarily present in stover include nitrogen, phosphorus, and potassium. For each ton of stover removed, a certain amount of each nutrient must be applied in addition to the traditional annual fertilizer application. This per acre additional application is dependent upon the harvesting and collection scenario that is used. For example, more nutrients need to be added per acre to fields where stover is shredded, raked, and baled relative to fields where stover is only baled. Table 3.1 outlines the added application of nitrogen, phosphorus and potassium and their per ton costs. N is added in either the form of anhydrous ammonia, which contains 82 percent N, or liquid nitrogen, which contains 28 percent N. P_2O_5 is added in the form of monoammonium phosphates (MAP), which contains 52 percent P_2O_5. K_2O is added in the form of potash, which contains 61 percent K_2O. With per ton fertilizer prices from the USDA National Agricultural Statistical Service *April 2007 Agricultural Prices Outlook* and assumed replacement amounts of each nutrient for each ton of stover removed as averaged by assumptions in the existing literature, a per ton nutrient replacement cost for each nutrient can be calculated. N is replaced at a rate of 15.9 pounds per ton of stover removed, P_2O_5 is replaced at a rate of 5.9 pounds per ton of stover removed, and K_2O is replaced at a rate of 30 pounds per ton of stover removed. For the case of nitrogen, the costs are averaged between the application of anhydrous ammonia and liquid nitrogen (which results in a per ton N cost of $6.44).

Table 3.1. Corn Stover Nutrient Replacement

	Fertilizer Used	Fertilizer Composition	Price Per Ton of Fertilizer	Price Per Pound of Nutrient	Pounds to Replace per Ton of Stover Removed	Nutrient Replacement Cost per Ton of Stover Removed
N	Anhydrous Ammonia	82-0-0	$536.00	$0.327	15.9	$5.20
N	Liquid Nitrogen	28-0-0	$270.00	$0.482	15.9	$7.67
N	*Average*					*$6.44*
P_2O_5	MAP	11-52-0	$421.00	$0.404	5.9	$2.39
K_2O	Potash	0-0-61	$277.00	$0.227	30	$6.81
Total						$15.64

Since corn already requires fertilizer application, there will not be an additional application cost required (Petrolia, 2006). Rather, the amount of nutrients per acre will increase depending on the amount of stover that has been removed. The additional nutrient needs add to existing input costs as extra fertilizer is applied along with standard fertilizer amounts.

3.1.4. Harvesting and Collecting

An important consideration in discussing harvesting and collecting is the ownership status of equipment. There is no reasonable way to generalize whether an operation will decide to hire a custom operator or do it themselves with equipment they own or purchase. This decision will rest primarily on what resources the operation already has on hand and how much stover is likely to be harvested. Examples of various situations are as follows:

> A small farm raising corn and soybeans and also managing livestock may not have many tons of stover to harvest but already has the hay baler necessary to bale stover. Because

> they do not have lots of corn and soybean acres to harvest in the small timeframe appropriate in which to do so, they may have sufficient extra labor hours to collect stover with their own equipment.
>
> A large farm raising only corn and soybeans may have a substantial amount of stover available to collect but very little extra labor hours during the fall. Having also decided to specialize in corn and soybeans, the farm does not own any hay equipment. It may be more convenient and a better use of resources to hire a custom operator to collect the stover.
>
> A large corn and soybean farm similar to the one described above may eventually find that harvesting and collecting stover is a lucrative activity that is manageable given their labor schedule. Because they have the necessary labor, they may purchase the equipment needed and operate it themselves. Despite the initial capital cost of new equipment, payments over time on a per ton of stover basis will likely be quite small for a farm with such a substantial amount of acres.
>
> A small farm operating a limited amount of corn, soybeans, and hay will have the equipment necessary to harvest and collect stover. However, with the hay equipment also being used for multiple cuttings throughout the summer and stover harvest in the fall, it will age more rapidly. This may require the farm to purchase new equipment sooner than they expect. Therefore, it may work better to keep the hay equipment only for the purposes of hay and hire a custom operator to collect the small amount of stover.

With so many options on machinery, this analysis will establish two scenarios: custom hired equipment or owned equipment. It will be assumed that if a farm is hiring a custom operator for one activity of the stover process, then it is hiring a custom operator for all activities in the stover process. Similarly, owning one piece of necessary equipment means the farm owns all necessary pieces of equipment.

3.1.4.1. Custom Equipment Rates

All custom rates are taken from survey results from a University of Kentucky Cooperative Extension Service study (Halich, 2007) that collected rates from Ohio, Indiana, Missouri, Iowa, and Kansas to determine an average per acre custom rate for various activities. The per ton custom rate for each activity is calculated by dividing the average custom rate by the amount of stover tons being removed per acre in that particular scenario. Total per ton custom rates for each scenario are done by adding up the appropriate activities for each scenario and are presented in Table 3.2. As the total amount of removed stover from each acre increases with each scenario, the per ton custom rate for that activity decreases.

Table 3.2. Corn Stover Custom Harvest Rates

	Per Acre	Scenario 1 (38% removed) – Per Ton	Scenario 2 (52.5% removed) – Per Ton	Scenario 3 (70% removed) – Per Ton
Shredding	$8.56			$4.08
Raking	$5.40		$3.43	$2.57
Baling	$8.42	$7.47	$5.41	$4.06
Total		$7.47	$8.84	$10.70

3.1.4.2. Owned Equipment

Under the owned equipment condition, an annual per ton payment is calculated for various farm sizes and each scenario. Farm sizes are as follows: 500 acres, 1000 acres, 1500 acres, and 2000 acres. All farm sizes are assumed to be purchasing equipment with the same specifications. Therefore, the type of equipment purchased does not change as farm size changes. The scenario affects the per ton cost as it determines the number of tons per acre to be removed. It is assumed that the tractor used to operate each machine is already owned by the farm. Tthe interest rate for financing the purchase of this equipment is 8 percent.

The stalk shredder is 14 feet wide and purchased for $10,277 with a lifespan of 10 years. The rake is 8.5 feet wide and purchased for $4,105 with a lifespan of 8 years. The large round baler is purchased for $24,579 with a lifespan of 8 years. These equipment specifications are from the Mississippi State Budget Generator parameters for crop implements (Laughlin and Spurlock, 2007).

Each piece of equipment purchased has a corresponding usage rate to indicate how much of total use of the particular piece of equipment is devoted to corn stover harvest and collection. Most likely the stalk shredder will be used 100 percent of the time for stover. A rake and baler, however, may be used for hay production depending upon the characteristics of the farm. While the usage rate may vary, this analysis assumes a 100 percent usage rate for all harvesting equipment.

Annual payments are calculated using a payment function for loan repayment. This annual payment may change if the usage rate is less than 1.0. In these cases, the adjusted annual payment is determined by multiplying the initial annual payment by the usage rate.

This annual payment is then converted into a per ton annual payment based on farm size. The number of acres on which corn is planted determines the total amount of stover that is removed. Each scenario has a per acre removal amount. Multiplying the removal amount by the assumed yield of 4.25 tons per acre and the total number of acres in the farm results in the total number of tons removed by that operation. The annual payment is then divided by the total tons removed to find the per ton cost of the capital equipment. Table 3.3 shows the changes in annual per ton and per acre machinery purchase cost for each farm size and each scenario. The costs included in this table do not include operating costs such as labor or fuel, which are added to the calculations later. This table also includes the purchase cost of equipment associated with transportation (i.e. truck and trailer). This equipment is discussed in further detail later in this section. Within each scenario the per ton equipment cost decreases as farm size increases, and for each farm size, the per ton equipment cost decreases as scenario removal rates increase.

Table 3.3. Capital Costs for Purchased Corn Stover Equipment

Scenario 1				
Number of Acres	500	1000	1500	2000
Tons removed	808	1,615	2,423	3,230
Baler payment/ton	$5.30	$2.65	$1.77	$1.32
Baler payment/acre	$8.55	$4.28	$2.85	$2.14
Rake payment/ton				
Rake payment/acre				
Shredder payment/ton				
Shredder payment/acre				
Product equipment payment/ton	$5.30	$2.65	$1.77	$1.32
Product equipment payment/acre	$8.55	$4.28	$2.85	$2.14
Truck payment/ton	$1.48	$0.74	$0.49	$0.37
Truck payment/acre	$2.38	$1.19	$0.79	$0.60
Trailer payment/ton	$1.85	$0.92	$0.62	$0.46
Trailer payment/acre	$2.98	$1.49	$0.99	$0.75
Transportation equipment payment/ton	$3.32	$1.66	$1.11	$0.83
Transportation equipment payment/acre	$5.37	$2.68	$1.79	$1.34

Scenario 2				
Number of Acres	500	1000	1500	2000
Tons removed	1,116	2,231	3,347	4,463
Baler payment/ton	$3.83	$1.92	$1.28	$0.96
Baler payment/acre	$8.55	$4.28	$2.85	$2.14
Rake payment/ton	$0.64	$0.32	$0.21	$0.16
Rake payment/acre	$1.43	$0.71	$0.48	$0.36
Shredder payment/ton				
Shredder payment/acre				
Product equipment payment/ton	$4.47	$2.24	$1.49	$1.12
Product equipment payment/acre	$9.98	$4.99	$3.33	$2.50
Truck payment/ton	$1.07	$0.53	$0.36	$0.27
Truck payment/acre	$2.38	$1.19	$0.79	$0.60
Trailer payment/ton	$1.34	$0.67	$0.45	$0.33
Trailer payment/acre	$2.98	$1.49	$0.99	$0.75
Transportation equipment payment/ton	$2.40	$1.20	$0.80	$0.60
Transportation equipment payment/acre	$5.37	$2.68	$1.79	$1.34

Table 3.3 continued

Scenario 3				
Number of Acres	500	1000	1500	2000
Tons removed	1,488	2,975	4,463	5,950
Baler payment/ton	$2.88	$1.44	$0.96	$0.72
Baler payment/acre	$8.55	$4.28	$2.85	$2.14
Rake payment/ton	$0.48	$0.24	$0.16	$0.12
Rake payment/acre	$1.43	$0.71	$0.48	$0.36
Shredder payment/ton	$1.03	$0.51	$0.34	$0.26
Shredder payment/acre	$3.06	$1.53	$1.02	$0.77
Product equipment payment/ton	$4.39	$2.19	$1.46	$1.10
Product equipment payment/acre	$13.05	$6.52	$4.35	$3.26
Truck payment/ton	$0.80	$0.40	$0.27	$0.20
Truck payment/acre	$2.38	$1.19	$0.79	$0.60
Trailer payment/ton	$1.00	$0.50	$0.33	$0.25
Trailer payment/acre	$2.98	$1.49	$0.99	$0.75
Transportation equipment payment/ton	$1.80	$0.90	$0.60	$0.45
Transportation equipment payment/acre	$5.37	$2.68	$1.79	$1.34

It is assumed that the stalk shredder is operated with a 150 horsepower, 2 wheel drive tractor. The rake and the baler are operated with 105 horsepower, 2 wheel drive tractors. Operating each machine with the assumed tractor requires a certain amount of fuel as indicated by the Mississippi State Budget Generator (Laughlin and Spurlock, 2007). Total fuel costs are calculated by multiplying the per acre fuel requirement by the price of farm diesel or highway diesel, which is $3.53 and $3.93, respectively, as of March 2008 according to the Energy Information Administration. This is then divided by the tons of stover removed per acre for each given scenario.

As also indicated by the MS State Budget Generator (Laughlin and Spurlock, 2007), there is a per acre labor requirement indicated in hours. This is multiplied by the wage rate of $9.46 per hour for field workers in 2006 according to the National Agricultural Statistics Service to determine total labor costs. This is then divided by the tons of stover removed per acre for each given scenario.

3.2. <u>Switchgrass</u>

Switchgrass costs are incurred in three stages: establishment, production, and transportation. With establishment costs, such as field preparation and seeding, only occurring once every 10 years, this cost is amortized over the life of the switchgrass stand in addition to the annual production costs including fertilizers, herbicides, harvesting, bale packaging, storage and an associated dry matter loss. Transportation, as with corn stover, is treated as a separate cost.

3.2.1. Yield Assumptions

Switchgrass is planted in its establishment year during the spring. During this year, there is no harvest. For the following two or three years, the switchgrass may not yield at its maximum potential. With yield estimates from existing literature ranging from 1.5 to 6 tons per acre, this analysis assumes a constant production year yield of 5 tons per acre with a production cycle life of 10 years.

3.2.2. Land Rent

The choice of growing switchgrass depends upon the economics of biomass collection since biomass is the only result from switchgrass production. If it is not economical for a producer to grow switchgrass for biomass, switchgrass will not be grown at all. This is unlike corn stover, where corn is grown regardless of whether stover is collected or not. Therefore, a per acre cash rent cost is added to account for the opportunity cost of land that could be used to grow some other crop or receive government conservation payments.

Switchgrass likely will be planted on poorer quality cropland or grassland. Cash rents from existing literature include Duffy and Nanhou (2001) estimating $50 per acre for grassland in Iowa and Popp and Hogan (2007) estimating $75 per acre for well-drained, marginal quality land in Arkansas. Dobbins and Cook (2007) estimate poor quality land in Indiana (average yield of 112 bushels per acre) to have a cash rent of $110 per acre in 2007. Pastureland averaged $50 per acre cash rent in Indiana. Based upon the 2007 estimates for Indiana and assuming that grassland or pastureland will be a more likely candidate for switchgrass production than poor cropland, this analysis assumes $70 per acre as cash rent for switchgrass land. With an expected yield of 5 tons per acre, a cash rent cost of $14 per ton is added to the production cost of each year.

3.2.3. Establishment Costs

Establishment costs are only directly incurred during one year. However, since this analysis is intended to result in a per ton annual cost, the establishment costs are spread over the life of the stand and indirectly incurred in each year. These establishment costs greatly depend on the condition and soil type of the specific field in which switchgrass is being planted. For the purposes of this analysis, it is assumed that switchgrass is being planted to a field that was previously planted to some variety of grass.

3.2.3.1. Field Preparation

To remove existing grass from the grassland, fields need to be mowed before seeding can take place in the spring. Following the mowing an application of glyphosate herbicide is added at a rate of 2 quarts per acre to kill the existing grasses and reduce competition with the newly planted switchgrass.

3.2.3.2. Seed

The Cave-in-Rock switchgrass variety is assumed for this study. The variety was originally found in Illinois and reaches maturity by late September. Grasses will grow to between three and five feet in height. Cave-in-Rock grows well in winter weather and adapts well with many soil types.

Each acre is seeded with 7 pounds of pure live seed (PLS). This seeding rate was determined by averaging the suggested pounds per acre of pure live seed as published in the literature. Seeding should take place sometime between April and June.

3.2.3.3. Fertilizer and Herbicide

Establishment year fertilizer application will include both phosphorus and potassium. Unlike in subsequent production years, no nitrogen is applied during the establishment year. This is because added nitrogen might cause other grasses and weeds to grow more rapidly and compete with the newly planted swithgrass. During the establishment year, phosphorus is applied at 30 pounds per acre and potassium at 37 pounds per acre based on averages from the existing literature.

Applying lime adds calcium and magnesium to the soil and increases the pH levels of the soil. Since pH levels vary from field to field, exact amounts of lime to be applied may also vary. This application likely will take place at some point during the life of the switchgrass but not necessarily in the establishment year. However, a fixed cost will be added to the establishment year costs to account for the lime application taking place at least once during the life of the switchgrass. This amount will be 2 tons per acre at a cost of $13.76 per ton for both inputs and application.

A standard herbicide application of Atrazine and 2,4-D, which are both used to control broadleaf weeds, is included. This weed control herbicide regiment will help to ensure that the establishment of the switchgrass will be successful. If extraneous weeds and grasses emerge, they will likely be able to germinate and grow quicker than the switchgrass. Atrazine is applied at a rate of 1.25 quarts per acre, and 2,4-D is applied at a rate of 1.25 pints per acre. Both are averages from the existing literature. This application can take place in the fall before planting, just before planting, or just after planting.

Table 3.4 outlines these establishment year costs for inputs only. This table does not include application costs, which are included in the total per ton costs.

Table 3.4. Switchgrass Establishment Costs, Fertilizer and Herbicide Inputs

Product Used	Product Price	Amount per Acre	Cost per Ton of Switchgrass
MAP (P_2O_5)	$421.00/ton	30 lbs	$2.43
Potash (K_2O)	$277.00/ton	37 lbs	$1.68
Lime	$13.76/ton	2 tons	$5.50
Atrazine	$12.20/gal	1.25 qts	$0.76
2,4 D	$15.90/gal	1.25 pts	$0.50
Glyphosate	$28.90/gal	2 qts	$2.89
			$13.76

3.2.4. Production Year Costs

Production year costs includes those incurred during the maintenance and harvest of switchgrass in every year after establishment throughout the 10 year life of the stand. As with establishment costs, these may differ slightly depending on the condition of the field in which the switchgrass is planted. Fertilizer and herbicide rates are not locked in and can be changed to meet the needs of the specific location and conditions.

3.2.4.1. Fertilizer and Herbicide

Nitrogen is added in production years in order to aid in yield productivity. It is applied at a rate of 80 pounds per acre. Phosphorus and potassium are applied with respect to each ton of switchgrass produced on and removed from one acre. 3.15 pounds of P_2O_5 and 13.25 pounds of K_2O must be reapplied after harvest for each ton of switchgrass removed. These rates are averages of assumptions in the existing literature. It is assumed that the fertilizers Urea, MAP, and potash will be used to apply nitrogen, phosphorus, and potassium, respectively. Urea contains 75 percent N, MAP contains 52 percent P_2O_5, and potash contains 61 percent potassium. Calculating how much of each fertilizer is necessary for each ton of switchgrass is done by taking the per ton fertilizer cost and dividing it by the amount of pounds of the actual nutrient that are in one ton of the fertilizer. This results in per pound costs for each nutrient, and multiplying it by the amount of nutrients that must be reapplied, will result in a per ton fertilizer cost (with respect to each nutrient) for one ton of switchgrass removed.

Herbicide application during the production years follows the same rates per acre and the same input costs as were discussed in the establishment year herbicide plan. Glyphosate is not used in the production years so as to not harm the germinated switchgrass.

Table 3.5 outlines these establishment year costs for inputs only. This table does not include application costs, which are included in the total per ton costs.

Table 3.5. Switchgrass Production Costs, Fertilizer and Herbicide Inputs

Product Used	Product Price	Amount	Cost per Ton of Switchgrass
Urea (N)	$450.00/ton	80 lbs/acre	$8.00
MAP (P_2O_5)	$421.00/ton	30 lbs/per ton harvested	$1.28
Potash (K_2O)	$277.00/ton	37 lbs/per ton harvested	$3.01
Atrazine	$12.20/gal	1.25 qts	$0.76
2,4 D	$15.90/gal	1.25 pts	$0.50
			$13.55

3.2.4.2. Harvesting

As with corn stover, the same question of custom hired machinery or owned equipment also applies to switchgrass. The same assumptions will hold for switchgrass as for corn stover with respect to equipment. This means that all activities are either custom hired, or all activities are done with owned equipment. One difference from the corn stover figures already presented is that there is only one scenario in switchgrass. There is no choice in what fraction of switchgrass can be removed.

The estimates for per acre custom rates are also from the University of Kentucky Cooperative Extension Service survey (Halich, 2007) and are outline in Table 3.6. Per ton costs for switchgrass are lower than those for corn stover despite beginning with the same custom rates due to higher yields for switchgrass than for corn stover.

Table 3.6. Switchgrass Custom Harvest Rates

	Per Acre	Per Ton
Mowing	$10.03	$2.01
Raking	$5.40	$1.08
Baling	$8.42	$1.70
Total	$23.95	$4.79

Owned equipment costs for switchgrass are calculated as with corn stover to make an annual per ton payment for each harvest activity. The rotary mower is 15 feet wide and purchased for $12,547 with a lifespan of 10 years. The rake is 8.5 feet wide and purchased for $4,105 with a lifespan of 8 years. The large round baler is purchased for $24,579 with a lifespan of 8 years. These equipment specifications come from the Mississippi State Budget Generator parameters for crop implements (Laughlin and Spurlock, 2007). The assumed interest rate is 8 percent.

Each piece of equipment purchased has a corresponding usage rate to indicate how much of total usage for the particular piece of equipment is devoted to switchgrass harvest. Should the farm have any level of hay operation, then the usage rate for switchgrass related equipment may be less than 100 percent. However, for the purposes of this analysis, all usage levels will be left at 100 percent.

Annual payments are calculated using a payment function for loan repayment and then be converted into a per ton annual payment based on farm size. The farm size determines the amount of switchgrass that will be harvested. Multiplying the assumed yield of 5 tons per acre by the total number of acres in the farm results in the total number of tons removed. The annual payment is then divided by the total tons removed to find the per ton cost. As expected, annual payments for each piece of machinery decrease as farm size increases. Table 3.7 shows the changes in per ton machinery purchase cost for each farm size and the amount of switchgrass that farm can harvest.

Table 3.7. Capital Costs for Purchased Switchgrass Equipment

Number of Acres	500	1000	1500	2000
Tons removed	2500	5000	7500	10000
Baler payment/ton	$1.71	$0.86	$0.57	$0.43
Baler payment/acre	$8.55	$4.28	$2.85	$2.14
Rake payment/ton	$0.29	$0.14	$0.10	$0.07
Rake payment/acre	$1.43	$0.71	$0.48	$0.36
Mower payment/ton	$0.75	$0.37	$0.25	$0.19
Mower payment/acre	$3.74	$1.87	$1.25	$0.93
Chem Applicator payment/ton	$0.39	$0.19	$0.13	$0.10
Chem Applicator payment/acre	$1.94	$0.97	$0.65	$0.48
Truck payment/ton	$0.48	$0.24	$0.16	$0.12
Truck payment/acre	$2.38	$1.19	$0.79	$0.60
Trailer payment/ton	$0.60	$0.30	$0.20	$0.15
Trailer payment/acre	$2.98	$1.49	$0.99	$0.75
Establishment equipment payment/ton	$1.14	$0.57	$0.38	$0.28
Establishment equipment payment/acre	$5.68	$2.84	$1.89	$1.42
Production equipment payment/ton	$3.13	$1.57	$1.04	$0.78
Production equipment payment/acre	$15.66	$7.83	$5.22	$3.92
Transportation equipment payment/ton	$1.07	$0.54	$0.36	$0.27
Transportation equipment payment/acre	$5.37	$2.68	$1.79	$1.34

It assumes that the rotary mower, rake, and baler are all operated with a 105 horsepower, 2 wheel drive tractor. Operating each machine with the assumed tractor requires a certain amount of fuel as indicated by the Mississippi State Budget Generator (Laughlin and Spurlock, 2007). Total fuel costs are calculated by multiplying the per acre fuel requirement by the piece of farm diesel or highway diesel, which is $3.53 and $3.93, respectively, as of March 2008 according to the Energy Information Administration. This is then divided by the tons of switchgrass harvested per acre.

As also indicated by the Mississippi State Budget Generator (Laughlin and Spurlock, 2007), there is a per acre labor requirement indicated in hours. This is multiplied by the wage rate of $9.46 per hour for field workers in 2006 according to the National Agricultural Statistics Service to determine total labor costs. This is then divided by the tons of switchgrass harvested per acre.

3.3. Baling Options, Handling, and Storage

The choice for the method of baling consists of what a custom operator is able to do with the equipment they use, what type of equipment the producer owns, and how concerned the producer is about dry matter loss while in storage. If a producer owns a baler that only uses twine, then it will be costly to invest in a different type of machine that is compatible with net or plastic wrap. Dry matter loss is highly dependent on the length of time in storage. If bales are being accepted by the power plant in unlimited quantities and can be done so in a timely manner by the custom operator or the producer, then bales will not need to sit at the edge of the field for long. With only a short time in storage, loss may be less of a factor, and costs can be cut by only using twine. However, if bales must be left at the edge of the field for an extended period of time, it may be beneficial to invest in extra protection in order to ensure that the amount of delivered dry matter is maximized. For costs associated with any removal scenario and either the custom hired or owned equipment scenarios, a choice of twine, net wrap, or twine and plastic wrap will be calculated. An associated dry matter loss as a percentage of the total per ton product cost is added onto the final cost to account for an assumed six months of on the ground storage. These loss rates are determined by averages from assumptions used in the existing literature for each type of bale packaging. Based on assumptions by Glassner, et al. (1998) and Popp and Hogan (2007), the moisture content of corn stover and switchgrass after they have been harvested is assumed to be 16 percent.

3.3.1. Twine

Sisal twine is purchased in 20,000 foot rolls for $20.75 per roll. With twine spaced every 4 inches and bales being 5 feet wide, each bale requires 15 revolutions of twine to hold it together. Per ton cost for twine is $0.54. Dry matter loss in a bale stored on the ground and wrapped in twine averages 3.13 percent each month. Assuming a storage time of six months results in a dry matter loss of 18.8 percent. This loss is added as a percentage of the total product cost.

3.3.2. Net Wrap

Net wrap is purchased in 7,000 foot rolls for $200.00 per roll. The wrap is 64 inches wide, which suits 5 foot wide bales. Each bale requires two revolutions of wrap to hold it together and no twine. Per ton cost for net wrap is $1.97. Dry matter loss in a bale stored on the ground and wrapped in net wrap averages 1.4 percent each month. Assuming a storage time of six months results in a dry matter loss of 8.4 percent. This loss is added as a percentage of the total product cost.

3.3.3. Twine and Plastic Wrap

Plastic wrap is purchased in 5,000 foot rolls for $80.00 per roll. The wrap is 30 inches wide and requires two wraps to cover the bale and an additional two wraps to add another layer. Because wrapping takes place after baling, twine is required to hold the bales together initially. Per ton cost for both twine and plastic wrap is $2.75. Dry matter loss in a bale stored on the ground and wrapped in plastic wrap averages 1.025 percent each month. Assuming a storage time of six months results in a dry matter loss of 6.15 percent. This loss is added as a percentage of the total product cost.

3.3.4. Moving to Field Edge

Once baled, the stover is moved to the edge of the field for temporary storage. Cost of moving a ton of stover was found to be $2.00. Bales remain at the edge of the field before being picked up for transport to the power plant. Bales are not taken to a central, on-farm storage facility, since it is assumed that most producers do not have the available space for storing a secondary crop.

3.3.5. Premium for Extended Storage

The power plant needs to maintain a constant supply of biomass throughout the entire year. This results in bales being continuously delivered to the plant and varied lengths of storage time facing each producer. One producer may take their bales immediately to the plant, while another producer may have to keep their bales until the following harvest. Three potential schemes for storage premiums exist. First, the producer could be paid a set per ton per month premium for each month (from one to twelve) that the bales are kept in their possession. Second, the producer could agree to a maximum of six months of storage and be paid for each month beyond six that they still have the bales. Finally, the producer could be paid a flat per ton premium only if they keep the bales for six months or more. This would be payment for the opportunity cost of the land on which the bales are stored. If bales are kept on the edge of the field for more than six months, that land will not be available for planting a crop or producing more switchgrass in the year after harvest.

In calculating this premium, the third scheme will be used. The premium will either be paid or not paid. Therefore, to average this payment, the premium will divided by two under the assumption that half the bales are needed by the plant within six months after harvest and the other half are needed more than six months after harvest. This premium is equal to the estimated value of the product that would have been produced on the land to be used as storage. To calculate this value, the area taken by one ton (or one half ton bale in this analysis because it is assumed that bales are stacked on top of each other to create two rows) will be converted into a fraction of the total area of an acre. With the dimensions of one bales being 5 feet wide and 5.5 feet in diameter and the addition of 1 foot between each bale, the fraction of area in an acre (or 43,560 square feet) taking by one ton is 0.0006. Figure 3.1 shows the storing and stacking method of the bales along with necessary dimensions for calculating the storage premium.

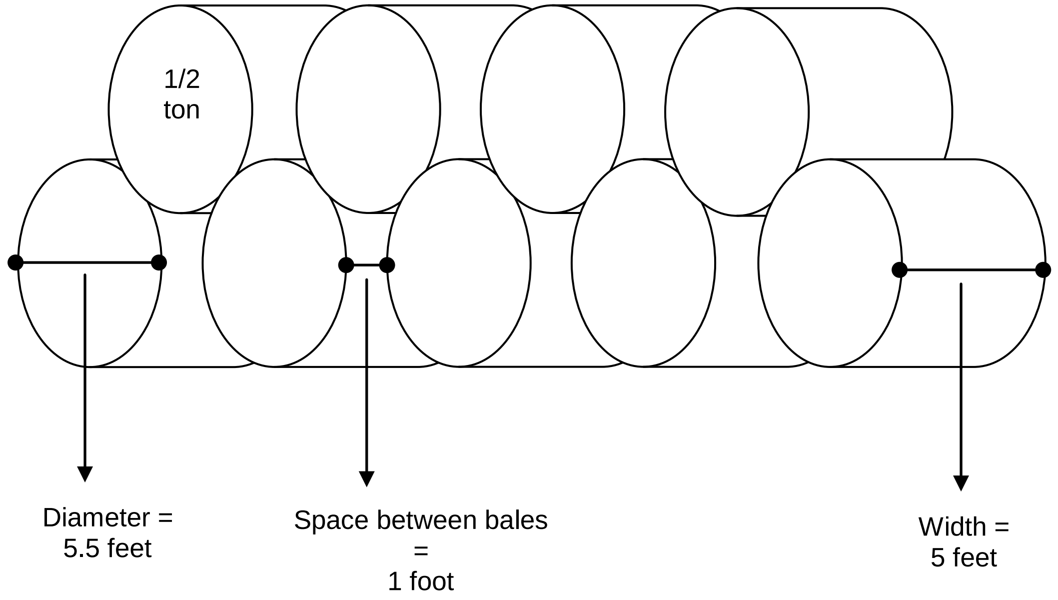

Figure 3.1. Edge of the Field Stacking Method and Dimensions

Net revenue above operating costs from one acre of corn and switchgrass is used to determine the value of this area had it been used to produce the respective crops. The net revenue from corn is as reported in the Economic Research Service Commodity Costs and Returns report from 2006. The net revenue from switchgrass is an average of the per acre product costs as determined in this analysis. Multiplying this net revenue value by the fraction of an acre displaced by the stored bales results in the monetary loss associated with not planting the area to the primary crop. Table 3.8 outlines these calculations to demonstrate how the per ton average storage premium was determined.

Table 3.8. Storage Premium Calculations

	Area displaced by one ton (ft^2)	Area of one acre (ft^2)	Fraction of one acre displaced by one ton	Net revenue after operating expenses per acre	Revenue lost per ton of biomass stored at fields edge beyond six months	Average revenue lost or average storage premium per ton of biomass produced
Corn Stover	32.5	43,560	0.0006	$286.84	$0.21	$0.11
Switchgrass				$250.00	$0.19	$0.09

3.3.6. Profit Premium

The producer also is paid a per ton profit added onto the product cost, dry matter loss, and storage premium discussed above. This profit is intended to compensate for the willingness of the producer to go to any extra trouble to harvest stover or plant switchgrass. This essentially serves to cover the producer's value of time spent producing biomass. As providing biomass for bioenergy production is unlikely to be the primary occupation of any producer, this profit premium is paid to offer producers with an incentive to participate beyond covered costs. This premium rate is assumed to be 15 percent of the product cost and can vary from plant to plant.

3.4. Transportation

Up to this point, all costs that have been discussed are costs for the physical biomass product. This section addresses the costs of transportation, which varies for farms depending upon their distance to the plant. The plant may take care of transportation themselves with their own or custom hired trucks. The plant may also create an individual transportation contract with the producer that discriminates on the basis of distance from the farm to the plant. Loads will be taken on flat bed semi trailers that have a load capacity of 26 round bales that are 5 feet wide, 5.5 feet in diameter, and weigh 0.5 tons (Popp and Hogan, 2007). Carrying a load of 26 round, half ton bales will result in a total load weight of 13 tons. The one way distance to the plant ranges between 5 and 50 miles at intervals of 5 miles. This distance is doubled to account for the return trip.

3.4.1. Custom Transportation Rates

The custom rate for hauling will be assumed to be $3.60 per loaded mile (Popp and Hogan, 2007). This rate is calculated for one-way mileage, as it will be assumed that the hired truck and trailer will not be returning to the field site where it was loaded. Instead, the hauling company will have added a standard return trip cost to the per mile custom rate to cover the cost of traveling from the final destination to the next loading site. To find the total custom per ton hauling cost, this rate is multiplied by the number of miles and divided by the total weight of the load. In addition to the custom hauling rate will be a custom loading rate of $1.15 per ton to account for loading and time spent waiting for unloading to take place at the plant (Popp and Hogan, 2007).

3.4.2. Owned Transportation

Purchase of a semi tractor is assumed to be $20,000 with a lifespan of 10 years. At an 8 percent interest rate, this results in a $2,980.59 annual payment. This figure is then multiplied by a usage rate that indicates what proportion of the life of the machine will be devoted to hauling biomass. This is done to allow the producer to purchase the truck and use it for activities other than just hauling biomass. A per ton cost for the equipment purchase depends on the number of acres harvested and the scenario removal rate in the case of corn stover and is calculated by dividing the annual payment by the total tons removed.

Since semis will make a round trip with one way loaded and one way unloaded, the assumed fuel mileage will be the average of loaded and unloaded mileage estimated. A loaded semi can achieve 5.72 miles per gallon, and an unloaded semi can achieve 7.73 miles per gallon (Berwick and Farooq, 2003). It is, therefore, assumed that semi tractors used to haul stover bales will average 6.73 miles per gallon of diesel fuel used. The current highway diesel price including taxes of $3.93 per gallon will be used for transportation calculations since farm vehicles cannot be driven on the road with tax-exempt farm diesel. To determine the transportation fuel requirements per ton, the total number of miles driven is multiplied by the fuel mileage and then divided by the price of diesel.

It is assumed that semi tractors travel at an average of 50 miles per hour en route to the power plant (Tiffany, et al., 2007). Because a semi driver is a more skilled position than operating machinery, the wage assumption increases to $14.37 per hour according to the Bureau of Labor Statistics in 2006. To determine the transportation labor requirements per ton, the travel time must first be calculated. This is done by dividing the total number of miles driven by the miles per hour speed of the semi tractor. This results in a fraction of an hour that it will take to travel to and from the power plant. Added to this travel time is an assumed 20 minutes, which accounts for both loading in the field and unloading at the plant (Schechinger and Hettenhaus, 2004). This total truck use time is then multiplied by the hourly wage.

3.5. Corn Stover Results

This analysis generates several combinations of operation characteristics and, consequently, many different possibilities for total delivered per ton cost. Therefore, an example breakdown of costs for corn stover is included in Table 3.9 to illustrate the components of the total delivered cost. This particular example is for a 1500 acre farm that owns its own equipment, plans to rake and bale its corn stover, packages bales in net wrap, and is located 25 miles from the power plant to which it is delivering the stover. While the values for each cost component changes, the various items comprising the cost remain the same regardless of farm size or distance to the plant.

Table 3.9. Individual Farm Summary of Per Ton Costs, Corn Stover, Example 1

Corn Stover - Example 1	
Scenario	1
Equipment	Custom
Farm Size (acres)	500
Bale Storage	Twine
One-way Distance from Plant (miles)	40 miles
Load Size (tons)	13
Fertilizer	
Nitrogen	$6.43
Phosphorus	$2.39
Potassium	$6.81
Equipment	
Baler Rate	$5.28
Storage/Handling	
Twine	$0.54
Moving to Field Edge	$2.00
Total Product Cost	$23.44
Dry Matter Loss	
Twine, 6 months (18.8%)	$4.41
Storage Premium (per ton)	$0.11
Plant Premium (per ton)	$4.21
Total plus Premiums	$32.17
Transportation	
Loading	$1.15
Hauling Rate	$11.08
TOTAL COST	$44.40

Components of this table will change if the farm includes more or less harvesting activities or if the farm decides to hire custom equipment. Table 3.10 shows the same expense summary for a 500 acre farm that is 40 miles from the plant and intends to custom hire its equipment for only baling with twine and transporting its corn stover.

Table 3.10. Individual Farm Summary of Per Ton Costs, Corn Stover, Example 2

Corn Stover - Example 2	
Scenario	2
Equipment	Owned
Farm Size (acres)	1500
Bale Storage	Net Wrap
One-way Distance from Plant (miles)	25 miles
Load Size (tons)	13
Fertilizer	
Nitrogen	$6.43
Phosphorus	$2.39
Potassium	$6.81
Equipment	
Rake Purchase	$0.21
Rake Fuel	$1.72
Rake Labor	$0.85
Baler Purchase	$1.28
Baler Fuel	$1.80
Baler Labor	$0.89
Storage/Handling	
Net Wrap	$1.97
Moving to Field Edge	$2.00
Total Product Cost	$26.36
Dry Matter Loss	
Net Wrap, 6 months (8.4%)	$2.21
Storage Premium (per ton)	$0.11
Profit Premium (per ton)	$4.32
Total plus Premiums	$33.00
Transportation	
Loading	$1.15
Trailer Purchase	$0.36
Truck Purchase	$0.45
Truck Fuel	$2.25
Truck Labor	$1.47
TOTAL COST	$38.67

3.6. Switchgrass Results

A breakdown of costs for switchgrass is included in Table 3.11. This particular example is a farm that custom hires its equipment (making farm size irrelevant), packages bales in plastic wrap, and is located 10 miles from the power plant to which it is delivering the switchgrass.

Table 3.11. Individual Farm Summary of Per Ton Costs, Switchgrass, Example 1

Switchgrass - Example 1	
Equipment	Custom
Bale Storage	Plastic Wrap
One-way Distance from Plant (miles)	10 miles
Load Size (tons)	13
ESTABLISHMENT YEAR	
Field Prep	
Mower Rate	$2.01
Seed	
Cave-In-Rock	$13.30
Fertilizer	
Phosphorus	$2.43
Potassium	$1.68
Custom Application	$1.03
Lime (plus application)	$5.50
Herbicides	
Atrazine	$0.76
2,4 D	$0.50
Glyphosate	$2.89
Custom Application	$1.08
Total Establishment Cost	$31.18
Life of Switchgrass Stand (years)	10
Establishment Cost Paid Per Year	$4.65

Table 3.11 continued

PRODUCTION YEAR	
Fertilizer	
Nitrogen	$8.00
Phosphorus	$1.28
Potassium	$3.01
Custom Application	$0.85
Herbicides	
Atrazine	$0.76
2,4 D	$0.50
Custom Application	$1.08
Equipment	
Mower Rate	$2.01
Rake Rate	$1.08
Baler Rate	$1.70
Storage/Handling	
Plastic Wrap	$3.85
Moving to Field Edge	$2.00
Total Establishment and Production Cost	$30.76
Dry Matter Loss	
Plastic Wrap, 6 months (6.15%)	$1.89
Storage Premium (per ton)	$0.09
Land Rent (per ton)	$14.00
Plant Premium (per ton)	$7.03
Total plus Premiums	$53.78
Transportation	
Loading	$1.15
Hauling Rate	$2.77
TOTAL COST	$57.70

Table 3.12 is another example of a switchgrass cost breakdown for a farm that owns its equipment, has 500 acres, uses twine, and is located 50 miles from the power plant.

Table 3.12. Individual Farm Summary of Per Ton Costs, Switchgrass, Example 2

Switchgrass - Example 2	
Equipment	Owned
Farm Size (acres)	500
Bale Storage	Twine
One-way Distance from Plant (miles)	50 miles
Load Size (tons)	13
ESTABLISHMENT YEAR	
Field Prep	
Mower Purchase	$0.75
Mower Fuel	$0.30
Mower Labor	$0.15
Seed	
Cave-In-Rock	$13.30
Fertilizer	
Phosphorus	$2.43
Potassium	$1.68
Custom Application	$1.03
Lime (plus application)	$5.50
Herbicides	
Atrazine	$0.76
2,4 D	$0.50
Glyphosate	$2.89
Chemical Applicator Purchase	$0.39
Chemical Applicator Fuel	$0.16
Chemical Applicator Labor	$0.87
Total Establishment Cost	$30.71
Life of Switchgrass Stand (years)	10
Establishment Cost Paid Per Year	$4.58
PRODUCTION YEAR	
Fertilizer	
Nitrogen	$8.00
Phosphorus	$1.28
Potassium	$3.01
Custom Application	$0.85

Table 3.12 continued

Herbicides	
Atrazine	$0.76
2,4 D	$0.50
Chemical Applicator Purchase	$0.39
Chemical Applicator Fuel	$0.16
Chemical Applicator Labor	$0.87
Equipment	
Mower Purchase	$0.75
Mower Fuel	$0.30
Mower Labor	$0.15
Rake Purchase	$0.29
Rake Fuel	$0.77
Rake Labor	$0.38
Baler Purchase	$1.71
Baler Fuel	$0.80
Baler Labor	$0.40
Storage/Handling	
Twine	$0.54
Moving to Field Edge	$2.00
Total Establishment and Production Cost	$28.48
Dry Matter Loss	
Twine, 6 months (18.8%)	$5.35
Storage Premium (per ton)	$0.09
Land Rent	$14.00
Profit Premium (per ton)	$7.20
Total plus Premiums	$55.13
Transportation	
Loading	$1.15
Trailer Purchase	$0.60
Truck Purchase	$0.48
Truck Fuel	$4.49
Truck Labor	$2.58
TOTAL COST	$64.42

4. Results Analysis

4.1. Overview

Since it is impossible to analyze every possible combination of management decisions that this study considers, the results section examines the results in two ways: product only costs and transportation costs. This addresses situations in which the plant takes care of the transportation of the biomass entirely on its own and situations where the producer is responsible for transporting their biomass to the plant located between 5 and 50 miles away.

A set of final costs averages serves as a preliminary benchmark for comparison. It is unknown for the purposes of this analysis what price the plant will pay for each ton of biomass it contracts, but these averages serve to highlight the differences in cost for various farm sizes and management decisions. Tables 4.1 and 4.2 outline these average costs for both corn stover and switchgrass. These averages include all removal rates and bale packaging options considered in this analysis for each farm size and equipment decision.

Table 4.1. Average Product Only Per Ton Costs by Farm Size/Equipment Decision

CORN STOVER		SWITCHGRASS	
Custom	$33.41	Custom	$53.23
500 acres	$37.48	500 acres	$54.54
1000 acres	$34.47	1000 acres	$52.43
1500 acres	$33.46	1500 acres	$51.73
2000 acres	$32.96	2000 acres	$51.38

Table 4.2. Average Product and Transportation Per Ton Costs
by Farm Size/Equipment Decision

CORN STOVER					
	Custom	500 acres	1000 acres	1500 acres	2000 acres
5 miles	$35.94	$42.18	$37.91	$36.49	$35.78
10 miles	$37.33	$42.85	$38.58	$37.16	$36.45
15 miles	$38.71	$43.52	$39.25	$37.83	$37.12
20 miles	$40.10	$44.19	$39.92	$38.50	$37.79
25 miles	$41.48	$44.86	$40.59	$39.17	$38.46
30 miles	$42.87	$45.53	$41.26	$39.84	$39.13
35 miles	$44.25	$46.20	$41.93	$40.51	$39.80
40 miles	$45.64	$46.87	$42.60	$41.18	$40.47
45 miles	$47.02	$47.55	$43.28	$41.85	$41.14
50 miles	$48.40	$48.22	$43.95	$42.52	$41.81
SWITCHGRASS					
	Custom	500 acres	1000 acres	1500 acres	2000 acres
5 miles	$55.76	$57.80	$55.16	$54.28	$53.84
10 miles	$57.15	$58.48	$55.83	$54.95	$54.51
15 miles	$58.53	$59.15	$56.50	$55.62	$55.18
20 miles	$59.92	$59.82	$57.17	$56.29	$55.85
25 miles	$61.30	$60.49	$57.84	$56.96	$56.52
30 miles	$62.69	$61.16	$58.51	$57.63	$57.19
35 miles	$64.07	$61.83	$59.18	$58.30	$57.86
40 miles	$65.46	$62.50	$59.85	$58.97	$58.53
45 miles	$66.84	$63.17	$60.52	$59.64	$59.20
50 miles	$68.22	$63.84	$61.19	$60.31	$59.87

4.2. Bale Packaging

For both corn stover and switchgrass, packaging bales with net wrap is always the cheapest option for a given farm size, distance to the plant, equipment choice, and removal scenario. This is due to the slightly higher cost of net wrap ($1.97 per ton) being offset by a lower dry matter loss (8.4 percent). Table 4.3 shows the per ton costs of each packaging option and the associated dry matter loss.

Table 4.3. Bale Packaging Costs and Loss Factors

	Cost per ton	Percent dry matter loss (6 months)
Twine only	$0.54	18.8%
Net wrap	$1.97	8.4%
Plastic wrap and twine	$3.85	6.2%

Plastic wrap involves an added cost that is nearly twice as much as net wrap, but the additional dry matter loss savings is only about 2 percent. The increased cost from twine to net wrap is about $1.50 per ton, but the dry matter loss savings is over 10 percent. Therefore, this added cost for net wrap is offset by an added savings.

For corn stover, plastic wrap is always the most expensive option, followed by twine and net wrap. However, for switchgrass, twine is always the most expensive option, followed by plastic wrap and net wrap. This is because of the higher value per ton of switchgrass results in dry matter loss playing a relatively more important role in determining the final per ton product cost. Since stover has a lower value per ton, taking a slightly higher percentage of that value in dry matter loss results in less additional cost.

4.3. Custom Harvesting

For both corn stover and switchgrass, custom per ton costs increase as the distance from the plant increases, and for corn stover, the costs increase as the removal rate increases due to more activities needed in the harvest process. An interesting result from the custom harvesting costs is determining for a particular farm size at what point owning their own equipment becomes cheaper than custom hired equipment.

For corn stover, the larger the farm size and the more stover the farm is looking to remove, the more likely the farm is to own the equipment. However, for smaller sized farms or farms not looking to remove much stover, custom hired equipment is the cheaper choice. Figure 4.1 shows the custom hired equipment costs for all scenarios. The decisions for whether custom or owned equipment will be best for particular producers will be discussed later.

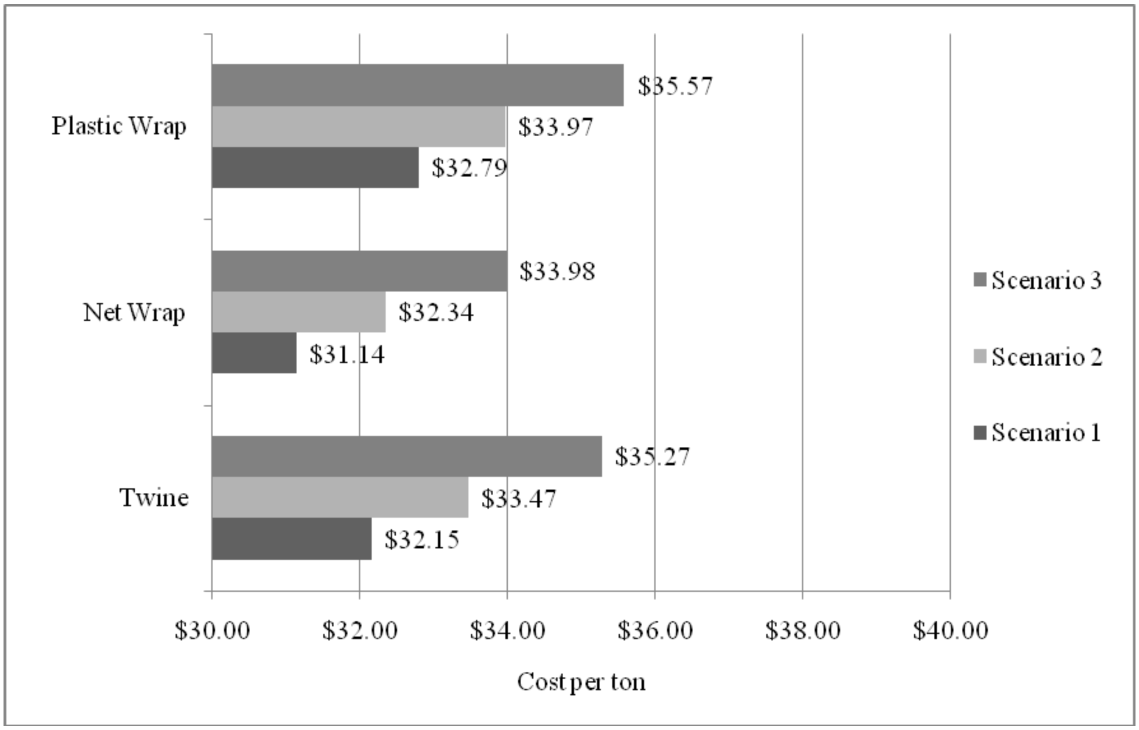

Figure 4.1. Corn Stover Product Only Per Ton Costs, Custom Equipment

For switchgrass, the decision between custom or owned equipment only depends upon the farm size, since a variable removal rate does not exist. Table 4.4 summarizes the custom rates for switchgrass. The decision between custom and owned equipment for switchgrass will be discussed later.

Table 4.4. Switchgrass Product Only Per Ton Costs, Custom Equipment

	Twine	Net Wrap	Plastic Wrap
Product Only	$53.71	$52.22	$53.76

4.4. Corn Stover Specific Results

The corn stover analysis has more possible combinations of management decisions due to the choice of removal rate. The following sections will look at these possibilities to highlight some individual effects. Table 4.5 outlines all the product only costs that will be used in the following analysis, and it can be seen that per ton costs increase as the removal rate increases. Per ton costs across all scenarios decrease as the farm increases. Custom equipment per ton costs tend to be lower than those with owned equipment for smaller farms, while owned equipment per ton costs for larger farms tend to be lower than those with custom equipment.

Table 4.5. Corn Stover Product Only Per Ton Costs

		Custom	500 acres	1000 acres	1500 acres	2000 acres
Scenario 1 (38% removed)	Twine	$32.15	$37.27	$33.65	$32.44	$31.84
	Net Wrap	$31.14	$35.81	$32.50	$31.40	$30.85
	Plastic Wrap	$32.79	$37.36	$34.13	$33.05	$32.51
Scenario 2 (52.5% removed)	Twine	$33.47	$38.25	$35.20	$34.18	$33.67
	Net Wrap	$32.34	$36.70	$33.92	$32.99	$32.52
	Plastic Wrap	$33.97	$38.24	$35.51	$34.60	$34.14
Scenario 3 (70% removed)	Twine	$35.27	$38.44	$35.45	$34.45	$33.95
	Net Wrap	$33.98	$36.88	$34.14	$33.23	$32.78
	Plastic Wrap	$35.57	$38.41	$35.73	$34.84	$34.39

4.4.1. The Effect of Removal Rate Choice

The choice of removal rate will affect cost by changing the number of passes for harvesting that will be needed in the field. Removing more stover increases the fuel, labor, and equipment costs, but it increases the collected stover yield per acre resulting in more tons of stover to be sold. The following graphs show the per ton costs for all farm sizes for product only for each given removal rate choice.

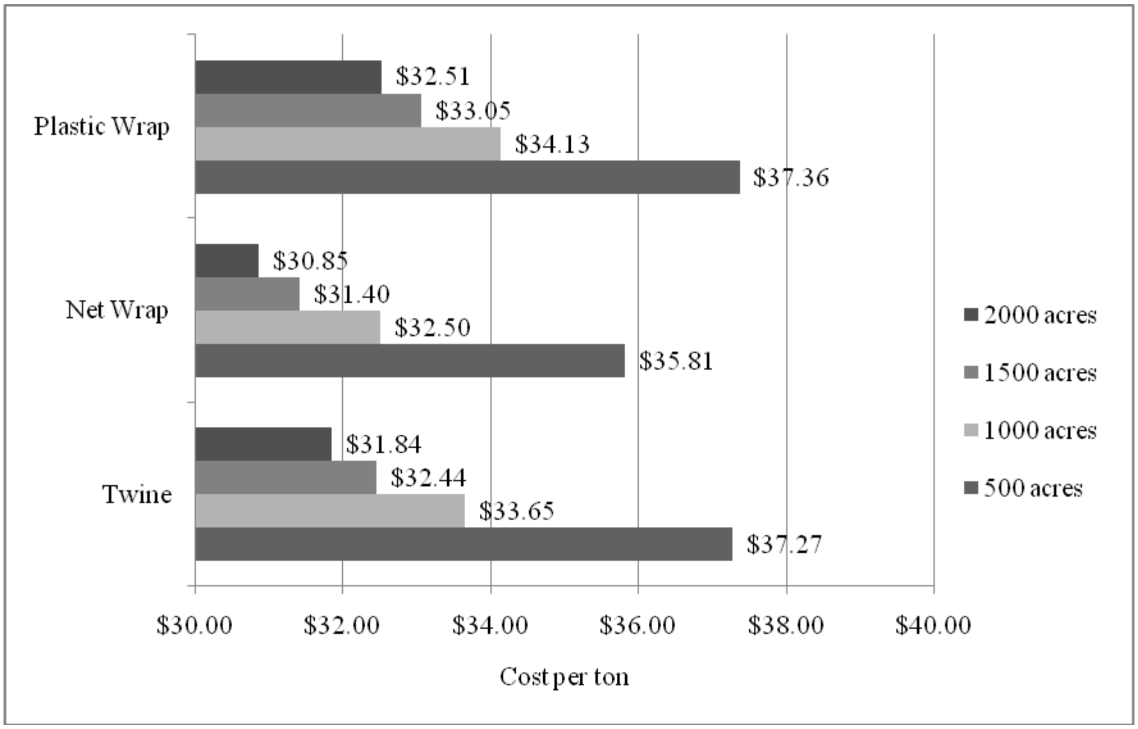

Figure 4.2. Corn Stover Product Only Per Ton Costs, Scenario 1, Owned Equipment

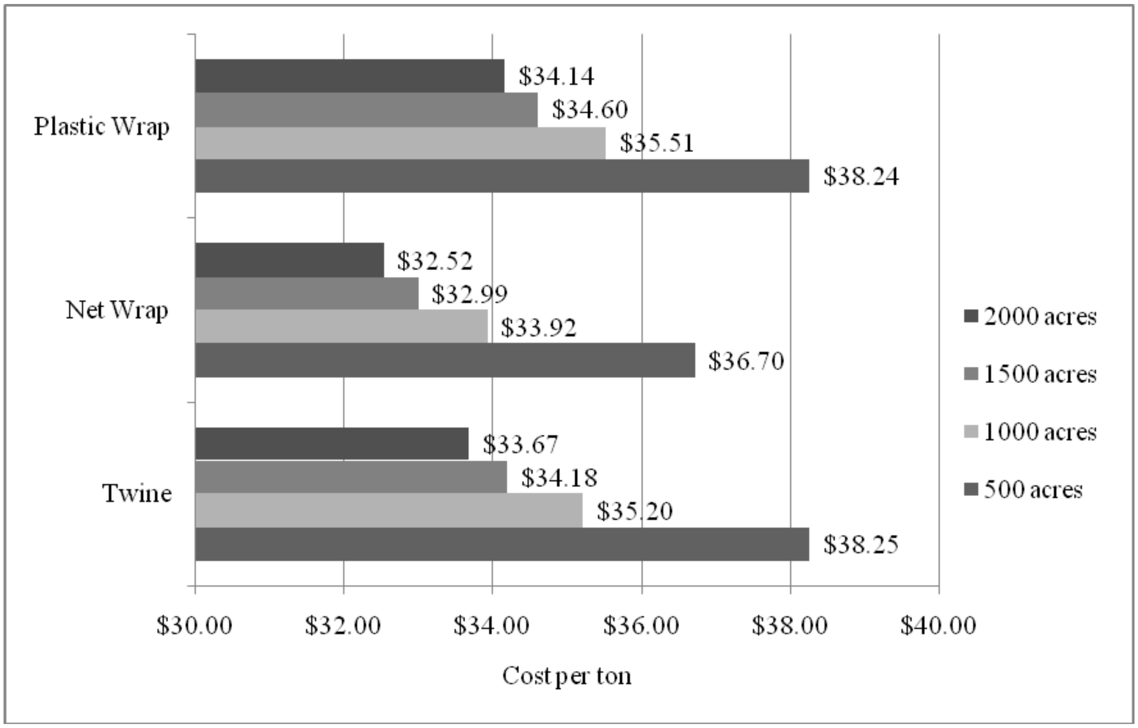

Figure 4.3. Corn Stover Product Only Per Ton Costs, Scenario 2, Owned Equipment

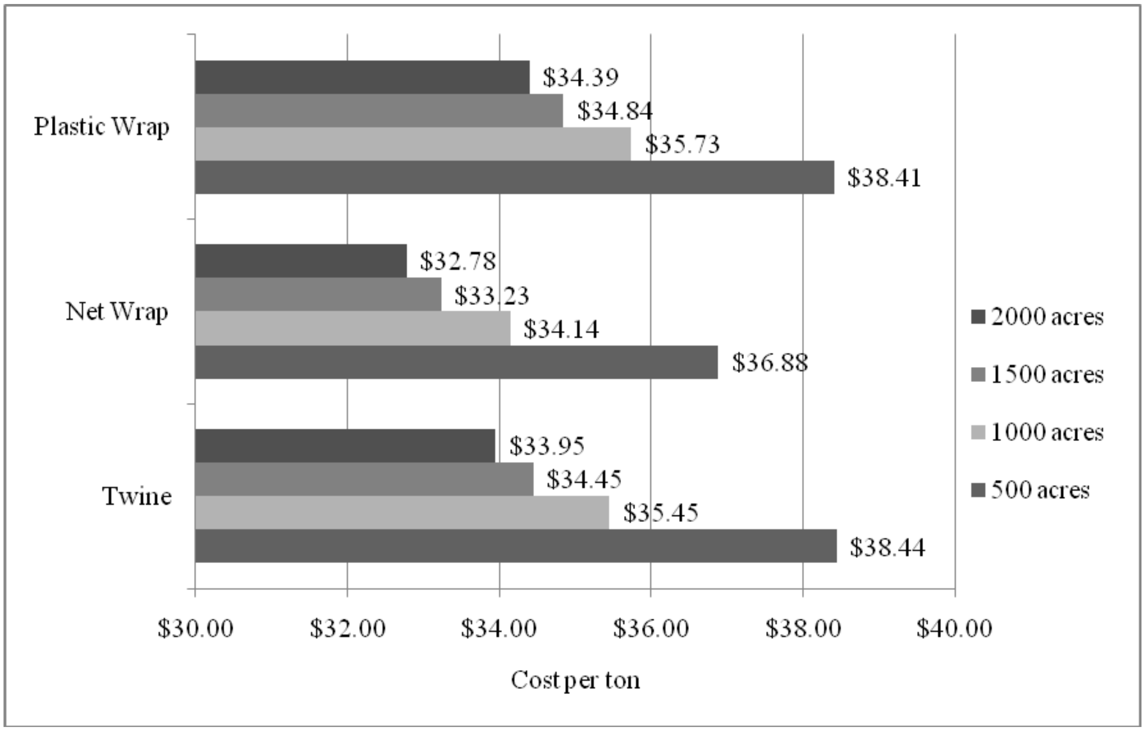

Figure 4.4. Corn Stover Product Only Per Ton Costs, Scenario 3, Owned Equipment

When considering owned equipment, larger farms are able to remove any amount of stover at a less expensive per ton cost than smaller farms. This indicates that incurring a higher cost due to more passes through the field being necessary for a higher removal rate can be paid off by being able to spread the extra cost incurred for each acre over more collected tons of stover.

4.4.2. The Effect of Farm Size

The characteristic of farm size only affects those producers choosing to collect and transport corn stover with their own equipment. If the farm has more acres, it is producing more tons of stover, and the payment for each piece of equipment is lower. Table 4.6 shows how these payments can differ due to farm size by indicating the amount of stover removed by each farm size in all scenarios. The annual payment for equipment is divided by the amount of stover removed (as reported in Table 4.6). With more stover removed on larger farms or on farms employing scenario 3, this gives an indication of which farm size/scenario combinations is able to use owned equipment at the lowest cost.

Table 4.6. Corn Stover Removed by Farm Size and Removal Rate Choice
(assume stover yield of 4.25 tons/acre)

Farm Size (acres)	Total Tons Removed in Scenario 1 (38% removed)	Total Tons Removed in Scenario 2 (52.5% removed)	Total Tons Removed in Scenario 3 (70% removed)
500	808	1116	1488
1000	1615	2231	2975
1500	2423	3347	4463
2000	3230	4463	5950

The following graphs show the per ton costs for all scenarios for product only for each given farm size. As the farm size increases, the product only per ton cost decreases for all scenarios. For all farm sizes, scenario 1 with a removal rate of 38 percent has the lowest product only per ton cost.

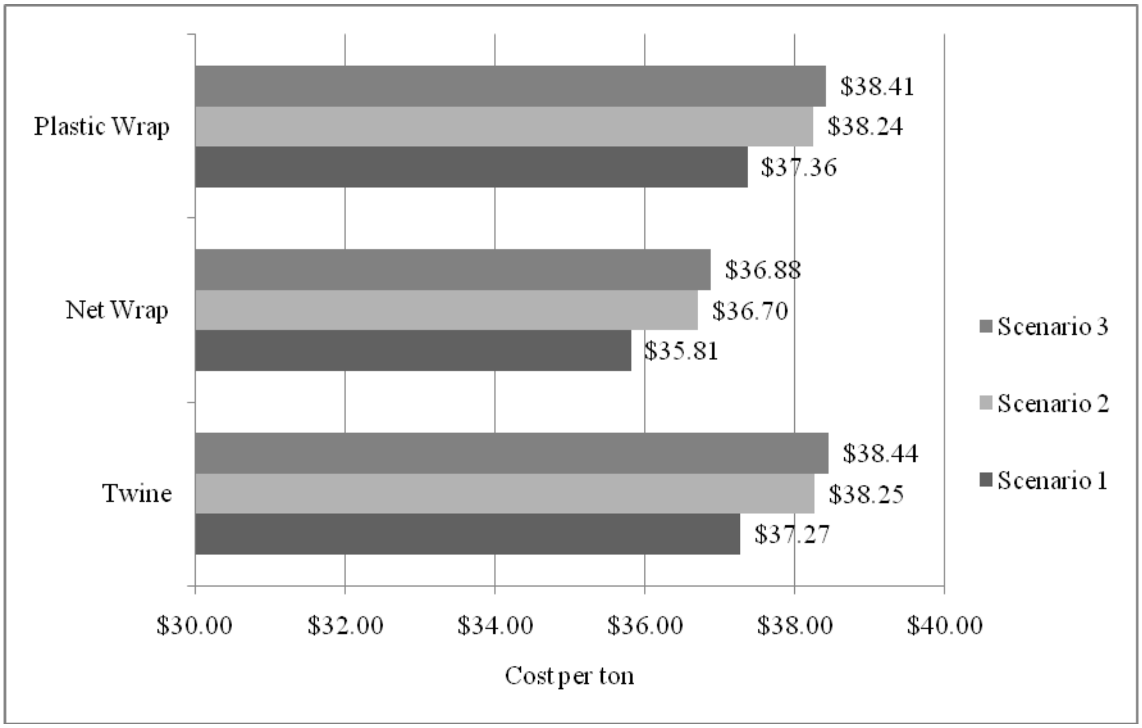

Figure 4.5. Corn Stover Product Only Per Ton Costs, 500 acres, Owned Equipment

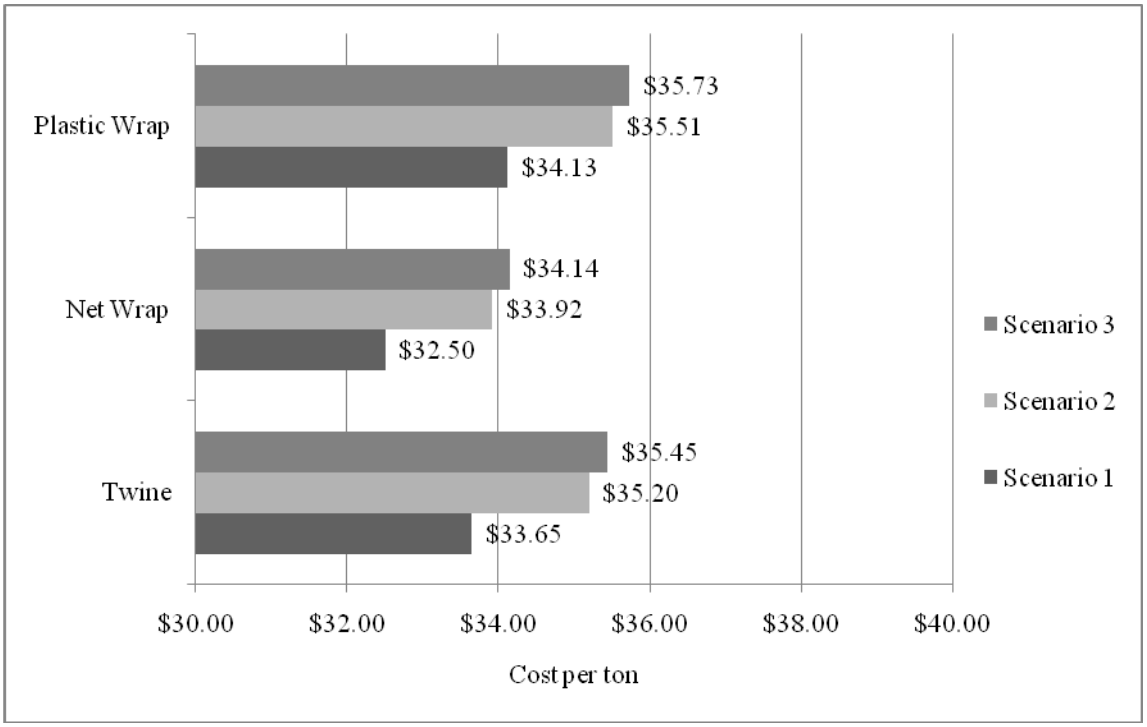

Figure 4.6. Corn Stover Product Only Per Ton Costs, 1000 acres, Owned Equipment

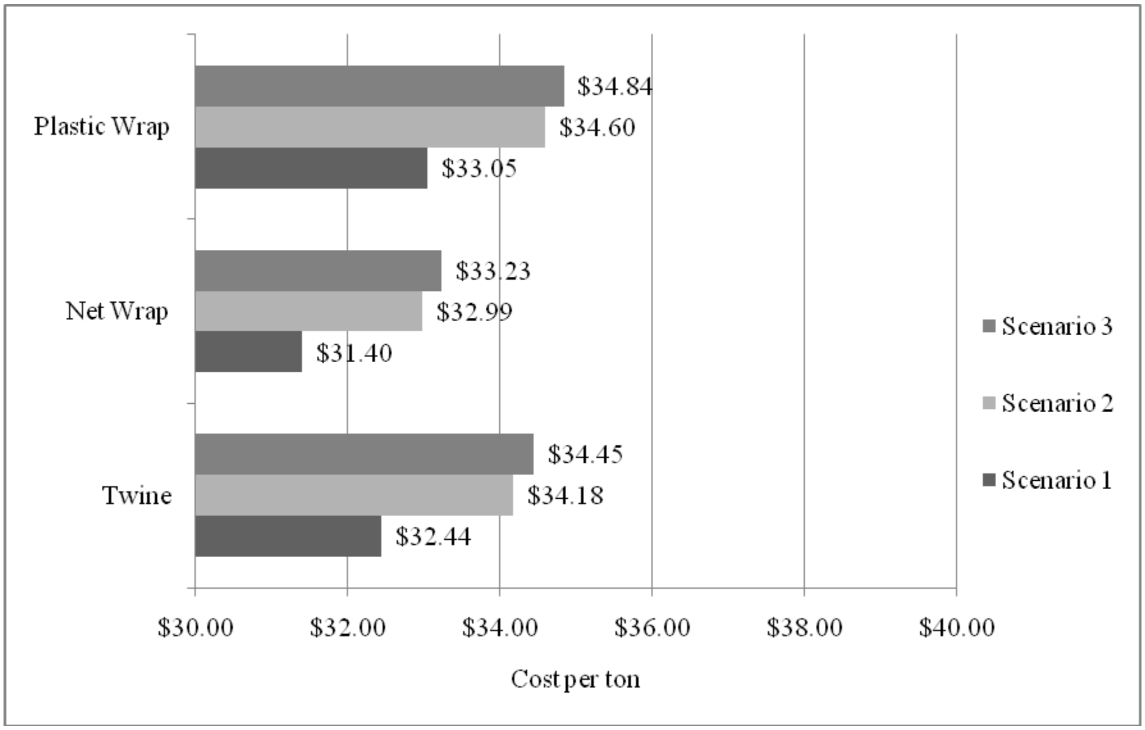

Figure 4.7. Corn Stover Product Only Per Ton Costs, 1500 acres, Owned Equipment

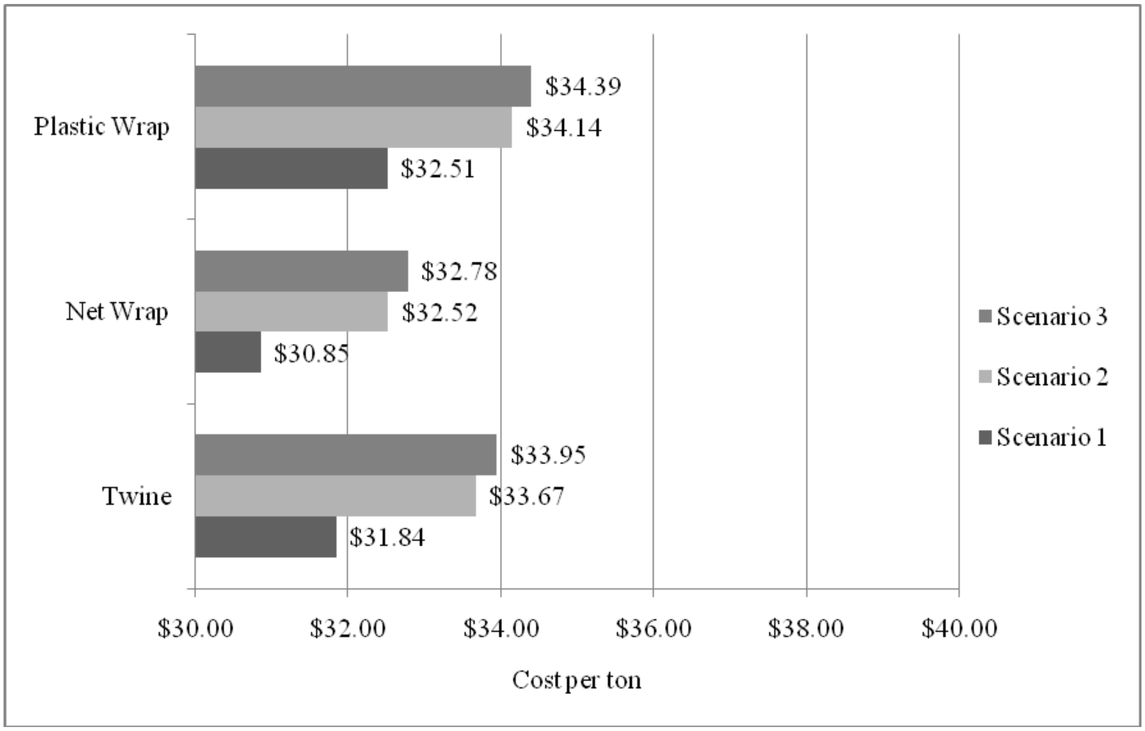

Figure 4.8. Corn Stover Product Only Per Ton Costs, 2000 acres, Owned Equipment

4.4.3. Custom versus Owned Equipment

An important decision for a producer is choosing between custom or owned equipment. As already shown, small farm sizes likely will have higher costs by using owned equipment and will be forced to use custom hired equipment should they choose to harvest stover. Larger farm sizes will likely find owned equipment to be the lower cost option due to the large amount of acres over which to spread their costs.

Figure 4.9 shows all average product only costs for each farm size using custom equipment or owned equipment. These figures are averaged over all baling options. Table 4.7 then shows whether a particular farm size would most likely choose custom equipment or owned equipment. The equipment choice seems to vary largely due to the cost of fuel, since the custom equipment rate is fixed and the owned equipment cost is a function of the cost of fuel. Custom rates that reflect the recent increases in the price of fuel may change these decision results. The scenario of choice will be the scenario that provides that farm size with the lowest per ton product only costs. In every case, Scenario 1 is the scenario of choice because it requires the fewest inputs and activities.

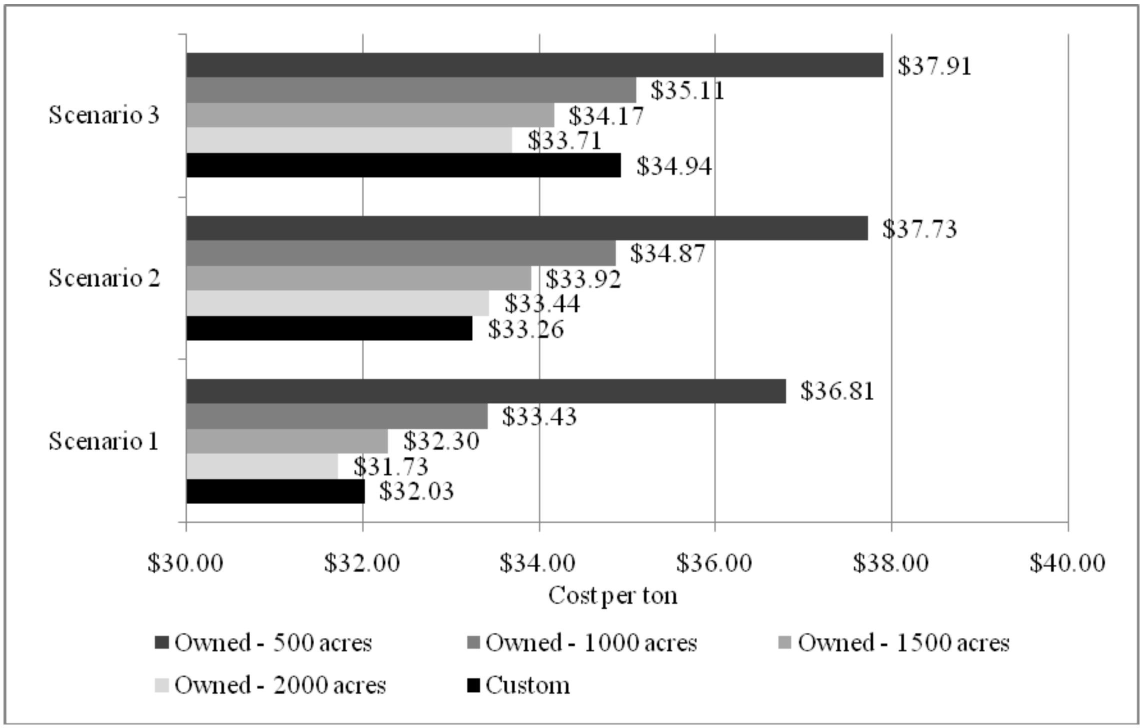

Figure 4.9. Corn Stover Product Only Per Ton Costs, Custom vs. Owned

Table 4.7. Corn Stover Equipment Decisions by Farm Size and Removal Rate Choice

	500 acres	1000 acres	1500 acres	2000 acres
Scenario 1	Custom	Custom	Owned	Owned
Scenario 2	Custom	Custom	Custom	Custom
Scenario 3	Custom	Custom	Custom	Owned
Scenario of Choice	Scenario 1	Scenario 1	Scenario 1	Scenario 1

4.5. Switchgrass Specific Results

The switchgrass analysis does not have the same numerous combinations of possible management decisions as corn stover, because there is not a variable removal rate. The switchgrass must be fully harvested since it is the primary crop rather than the secondary. Table 4.8 outlines all the product only costs that are used in the following switchgrass analysis. As with corn stover, the product only costs decrease as the area planted to switchgrass increases. Custom equipment, however, does not seem to have the same cost advantage for small acreage as it does for corn stover.

Table 4.8. Switchgrass Product Only Per Ton Costs

	Custom	500 acres	1000 acres	1500 acres	2000 acres
Twine	$81.53	$82.52	$79.76	$78.84	$78.38
Net Wrap	$77.60	$78.51	$75.99	$75.15	$74.73
Plastic Wrap	$78.62	$79.51	$77.04	$76.22	$75.81

Figure 4.10 shows the product only costs for each farm size using custom equipment or owned equipment. In Figure 4.10, product prices for all baling options are included. In Table 4.9, these costs are averaged together in order to make a custom and owned comparision. In the case of switchgrass, the equipment decision varies depending on the size of farm. Table 4.9 indicates that only the 500 acre farm size will choose custom equipment while all others will choose to own equipment.

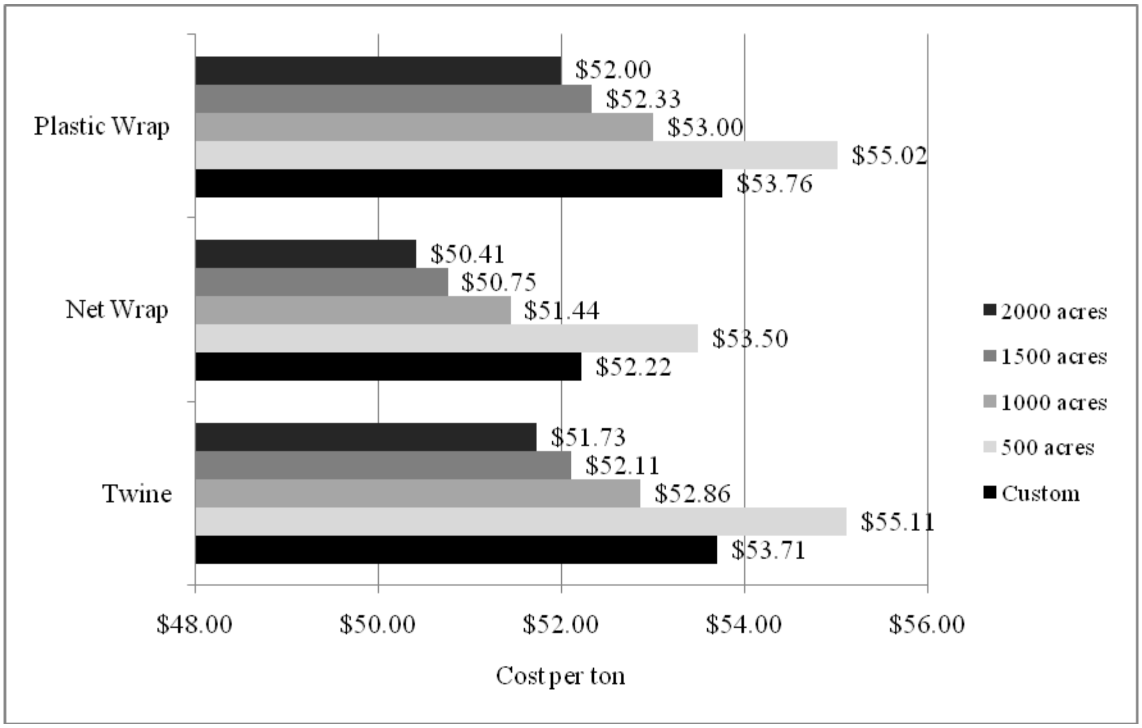

Figure 4.10. Switchgrass Product Only Per Ton Costs, Custom vs. Owned

Table 4.9. Switchgrass Average Product Only Per Ton Costs and Equipment Decisions

	500 acres	1000 acres	1500 acres	2000 acres
Custom	$53.23	$53.23	$53.23	$53.23
Owned	$54.54	$52.43	$51.73	$51.38
Equipment Choice	Custom	Owned	Owned	Owned

It is also important to consider what change in cost may be experienced should the switchgrass yield change. Yields throughout the country are quite different, and technology improvements may lead to higher yields being more widespread. Tables 4.10 and 4.11 include a sensitivity analysis on the per ton costs of switchgrass assuming the yield increases from 5 tons per acre to 7 tons per acre. These costs should be compared to Tables 4.1 and 4.2 to see the decrease in per ton cost due to increased yield.

Table 4.10. Switchgrass Sensitivity on Average Product Only Per Ton Costs

SWITCHGRASS (7 tons per acre)	
Custom	$45.70
500 acres	$46.64
1000 acres	$45.13
1500 acres	$44.63
2000 acres	$44.38

Table 4.11. Switchgrass Sensitivity on Average Product and Transportation Per Ton Costs

SWITCHGRASS (7 tons per acre)					
	Custom	500 acres	1000 acres	1500 acres	2000 acres
5 miles	$48.23	$49.59	$47.70	$47.07	$46.76
10 miles	$49.62	$50.26	$48.37	$47.74	$47.43
15 miles	$51.00	$50.93	$49.04	$48.41	$48.10
20 miles	$52.39	$51.60	$49.71	$49.08	$48.77
25 miles	$53.77	$52.27	$50.38	$49.75	$49.44
30 miles	$55.15	$52.94	$51.05	$50.42	$50.11
35 miles	$56.54	$53.61	$51.72	$51.09	$50.78
40 miles	$57.92	$54.28	$52.39	$51.76	$51.45
45 miles	$59.31	$54.95	$53.06	$52.43	$52.12
50 miles	$60.69	$55.62	$53.73	$53.10	$52.79

4.6. Transportation Results

The transportation results will be presented as a separate set of figures that should be added onto the product only costs already discussed. This separation of results allows for transportation to be taken care of independently by the plant or by an individual producer.

Table 4.12 indicates the additional transportation costs for each ton of biomass to be custom hauled from the field to the plant. For a given distance, this amount is added to the product only costs from Figure 4.1 in the case of corn stover, regardless of the scenario chosen, and Figure 4.10 in the case of switchgrass.

Table 4.12. Transportation Per Ton Cost with Custom Equipment

	Transportation Cost per ton
5 miles	$2.53
10 miles	$3.92
15 miles	$5.30
20 miles	$6.69
25 miles	$8.07
30 miles	$9.46
35 miles	$10.84
40 miles	$12.23
45 miles	$13.61
50 miles	$15.00

Table 4.13 indicates the additional transportation costs for each ton of stover to be hauled with producer owned equipment from the field to the plant. For a given distance and scenario, this amount is added to the product only, owned equipment costs from Table 4.5.

Table 4.13. Corn Stover Transportation Per Ton Cost with Owned Equipment

	Scenario 1 (38% removed)			
	500 acres	1000 acres	1500 acres	2000 acres
5 miles	$5.51	$3.85	$3.30	$3.02
10 miles	$6.18	$4.52	$3.97	$3.69
15 miles	$6.85	$5.19	$4.64	$4.36
20 miles	$7.52	$5.86	$5.31	$5.03
25 miles	$8.19	$6.53	$5.98	$5.70
30 miles	$8.86	$7.20	$6.65	$6.37
35 miles	$9.53	$7.87	$7.32	$7.04
40 miles	$10.20	$8.54	$7.99	$7.71
45 miles	$10.87	$9.21	$8.66	$8.38
50 miles	$11.54	$9.88	$9.33	$9.05
	Scenario 2 (52.5% removed)			
	500 acres	1000 acres	1500 acres	2000 acres
5 miles	$4.59	$3.39	$2.99	$2.79
10 miles	$5.26	$4.06	$3.66	$3.46
15 miles	$5.93	$4.73	$4.33	$4.13
20 miles	$6.60	$5.40	$5.00	$4.80
25 miles	$7.27	$6.07	$5.67	$5.47
30 miles	$7.94	$6.74	$6.34	$6.14
35 miles	$8.61	$7.41	$7.01	$6.81
40 miles	$9.29	$8.08	$7.68	$7.48
45 miles	$9.96	$8.75	$8.35	$8.15
50 miles	$10.63	$9.42	$9.02	$8.82
	Scenario 3 (70% removed)			
	500 acres	1000 acres	1500 acres	2000 acres
5 miles	$3.99	$3.09	$2.79	$2.64
10 miles	$4.66	$3.76	$3.46	$3.31
15 miles	$5.33	$4.43	$4.13	$3.98
20 miles	$6.00	$5.10	$4.80	$4.65
25 miles	$6.67	$5.77	$5.47	$5.32
30 miles	$7.34	$6.44	$6.14	$5.99
35 miles	$8.01	$7.11	$6.81	$6.66
40 miles	$8.68	$7.78	$7.48	$7.33
45 miles	$9.35	$8.45	$8.15	$8.00
50 miles	$10.02	$9.12	$8.82	$8.67

Comparing Tables 4.12 and 4.13 shows that custom transportation costs less per ton than owned transportation for small distances, while owned transportation costs less per ton than custom transportation for large distances. These transportation results are indicative of those incurred by an individual producer operating on an individual level. Were the plants to take care of transportation, these costs likely would be even less and may result in economies of distance that reduce the marginal transportation cost as distance increases.

Table 4.14 indicates the additional transportation costs for each ton of switchgrass to be hauled with producer owned equipment from the field to the plant. For a given distance, this amount is added to the product only, owned equipment costs from Table 4.8.

Table 4.14. Switchgrass Transportation Per Ton Cost with Owned Equipment

	500 acres	1000 acres	1500 acres	2000 acres
5 miles	$3.26	$2.73	$2.55	$2.46
10 miles	$3.93	$3.40	$3.22	$3.13
15 miles	$4.60	$4.07	$3.89	$3.80
20 miles	$5.27	$4.74	$4.56	$4.47
25 miles	$5.94	$5.41	$5.23	$5.14
30 miles	$6.61	$6.08	$5.90	$5.81
35 miles	$7.28	$6.75	$6.57	$6.48
40 miles	$7.95	$7.42	$7.24	$7.15
45 miles	$8.62	$8.09	$7.91	$7.82
50 miles	$9.29	$8.76	$8.58	$8.49

The difference between per ton owned transportation costs for corn stover and switchgrass is due to the capital transportation costs being spread over more tons in the case of switchgrass. This changes the per ton cost among farm sizes as larger farms have more tons to spread the capital costs over, and smaller farms have fewer tons to spread capital costs over. This difference also exists between corn stover and switchgrass due to differences in yields. Farms of the same size with one growing corn stover and the other growing switchgrass face different per ton transportation costs with owned equipment, because the switchgrass farm, which experiences a yield of 5 tons per acre, has more total tons than the corn stover farm, which experiences some fraction of a yield 4.25 tons per acre depending on removal rate choice.

4.6.1. Marginal Transportation Cost

The marginal cost per additional mile that must be traveled can be added onto the transportation cost estimates from Tables 4.12, 4.13, and 4.14 should the one way distance from the field to the plant be different from the mileage possibilities used in this analysis. Table 4.15 outlines the marginal transportation cost per mile for custom and owned equipment as well as the average. This assumes a linear transportation function with no economies of distance.

Table 4.15. Marginal Transportation Costs

Type of Equipment	Marginal Cost per Mile
Custom	$0.28
Owned	$0.12
Average	$0.20

4.7. Biomass Supply and Demand

To apply these costs to the situation of a particular coal power plant, supply curves must be generated based on the location of that plant and the available supply of biomass in the area. The specifications of the three plants that are used in this analysis are in Table 4.16.

Table 4.16. Power Plant Specifications

County	Latitude	Longitude	Capacity (MW)	Heat Production (Btu/hour)
Knox	38° 48’ 25” N	87° 14’ 49” W	144.2	2,023,560,000
Marion	39° 42’ 43” N	86° 11’ 51” W	1184.9	5,405,400,000
Tippecanoe	40° 41’ 70” N	86° 91’ 18” W	43.2	435,489,429

Latitude and longitude measures are used to draw concentric circles around the plant location in order to determine the amount of biomass available within a circle with a particular radius (or one-way distance to the plant ranging from 5 to 50 miles in 5 mile increments).

4.7.1. Biomass Supplied

Data for the biomass supply of both corn stover and switchgrass is available from a recent study by Oak Ridge National Laboratory sponsored by the Department of Energy and the Department of Agriculture that determines the total biomass availability for the United States (Perlack, et al., 2005). Supply for both corn stover and switchgrass are given separately, and it is assumed that supply for both sources can be produced and used at the same time. That is, land on which corn stover is grown is independent of the land on which switchgrass is grown. This data is the total amount of available biomass by county for only the state of Indiana. Due to these data limitations, supply that might potentially come from a neighboring states was assumed to be similar to the supply from Indiana. For the purposes of corn stover, this data is subject to a sustainable removal rate. It is assumed that corn stover is feasibly and sustainably collected at a rate that is the average of the removal rates used in this analysis (38 percent, 52.5 percent, and 70 percent). This makes 53.5 percent of available corn stover as indicated by the data actually collectable. A land participation rate also is assumed for both corn stover and switchgrass. This will be the expected percentage of land with potential for biomass production that will actually have biomass collected or harvested from it. Based on the existing literature, participation rates can range between 30 percent and 80 percent depending on the area (Perlack and Turhollow, 2002, Petrolia, 2006, and Schechinger and Hettenhaus, 2004. For this analysis, two sets of supply curves are created assuming both a 50 percent participation rate and a 75 percent participation rate.

Applying this supply data to a particular location is done with a GIS software application called ArcMap. To begin, a point corresponding to the latitude and longitude of the plant location is added to a map of Indiana counties. From this point, the multiple ring buffer tool is used to draw buffers around the point from 5 to 50 miles at 5 mile increments. Once these circles are drawn around the point, the intersect tool is used to find the area between each buffer that intersects with each particular county. For example, the area is calculated between the 20 and 25 mile buffer that intersects with county A. The same is then done for all counties that are encompassed by this 5 mile wide ring. Then to find the area of the 25 mile radius circle, the intersection areas with all counties from the 5 mile ring, the 5 to 10 mile ring, the 10 to 15 mile ring, the 15 to 20 mile ring, and the 20 to 25 mile ring are added together. For some counties, this area will be zero as no part of the county may be in close enough proximity to the plant to be within the 25 mile circle. Figure 4.11, 4.12, and 4.13 show the location of each plant and the concentric supply circles drawn around each plant location.

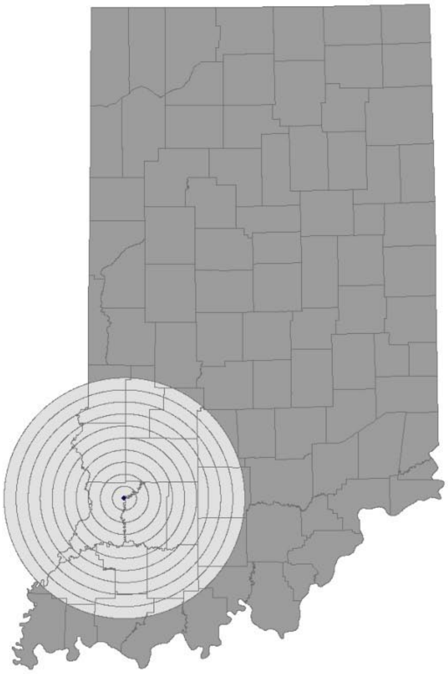

Figure 4.11. Knox County Plant Location

Figure 4.12. Marion County Plant Location

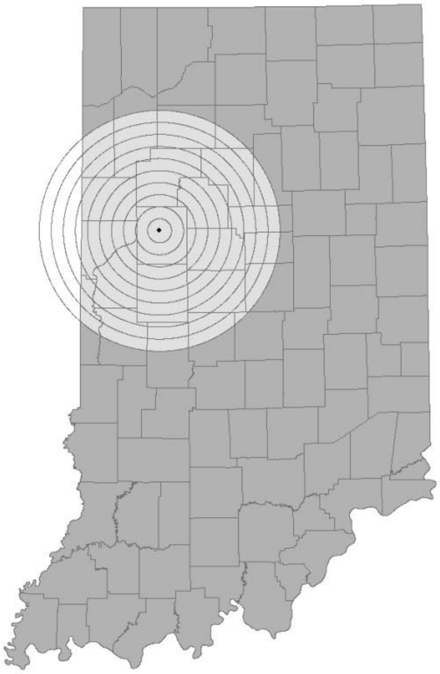

Figure 4.13. Tippecanoe County Plant Location

As can be seen from Figures 4.11 and 4.13, circles with a 50 mile radius from the plant are not fully covered by the state of Indiana. Therefore, this analysis assumes that the supply outside of Indiana is similar to that in Indiana. In the case of the Knox county plant, portions of the circles with a 15 to 50 mile radius are not in Indiana. In the case of the Tippecanoe county plant, portions of the circles with a 35 to 50 mile radius are not in Indiana. Therefore, a fraction is calculated at each distance increment to determine what portion of the area of the circle is accounted for by Indiana. 75 percent of the Knox county plant 50 mile radius circle is in Indiana, and 88 percent of the Tippecanoe county plant 50 mile radius circle is in Indiana. With 25 percent and 12 percent, respectively, of potential supply not being accounted for in each of these cases, these fractions of calculated Indiana supply are added to account for out of state supply.

Once the areas of each county that are in a particular circle with a given radius have been summed, this will serve to find the fraction of the county's area in the circle by dividing the summed area by the total area. Assuming that the biomass in each county is evenly distributed, this fraction is then used to determine the fraction of available biomass from each county that is located within a given circle. The total amount from all counties within a given circle corresponds to the x-axis of the supply curve, which therefore is measured in both miles and tons. Tables 4.17 and 4.18 outline the available annual supply of both corn stover and switchgrass assuming either a 50 percent or 75 percent land participation rate. Those numbers in italics indicate that portions of the supply for that distance are located outside the state of Indiana and were estimated based on the assumption that supply outside of Indiana is similar to supply within in Indiana.

Table 4.17. Area Biomass Supply with 50 Percent Participation Rate

	Knox		Marion		Tippecanoe	
One-Way Distance to Plant	Corn Stover (tons/year)	Switchgrass (tons/year)	Corn Stover (tons/year)	Switchgrass (tons/year)	Corn Stover (tons/year)	Switchgrass (tons/year)
5 miles	1,732	13,558	642	562	6,574	13,076
10 miles	5,906	51,382	4,169	5,793	26,195	52,329
15 miles	*11,304*	*108,615*	13,135	18,444	66,080	98,200
20 miles	*17,162*	*179,782*	38,531	42,294	125,533	147,146
25 miles	*21,427*	*247,531*	76,530	74,139	202,002	207,039
30 miles	*25,730*	*325,911*	123,325	115,635	296,017	278,625
35 miles	*30,391*	*416,979*	174,863	177,998	*402,151*	*360,603*
40 miles	*34,905*	*512,898*	239,525	264,769	*519,562*	*439,839*
45 miles	*39,478*	*613,556*	311,133	371,530	*640,266*	*512,658*
50 miles	*43,642*	*716,975*	384,911	508,913	*765,181*	*586,153*

Table 4.18. Area Biomass Supply with 75 Percent Participation Rate

	Knox		Marion		Tippecanoe	
One-Way Distance to Plant	Corn Stover (tons/year)	Switchgrass (tons/year)	Corn Stover (tons/year)	Switchgrass (tons/year)	Corn Stover (tons/year)	Switchgrass (tons/year)
5 miles	2,599	20,337	963	843	9,861	19,614
10 miles	8,859	77,072	6,254	8,690	39,293	78,494
15 miles	*16,956*	*162,922*	19,702	27,666	99,121	147,300
20 miles	*25,742*	*269,672*	57,797	63,441	188,299	220,719
25 miles	*32,140*	*371,297*	114,795	111,208	303,002	310,558
30 miles	*38,595*	*488,867*	184,988	173,452	444,025	417,937
35 miles	*45,586*	*625,469*	262,294	266,996	*603,226*	*540,904*
40 miles	*52,358*	*769,346*	359,287	397,153	*779,342*	*659,759*
45 miles	*59,216*	*920,334*	466,700	557,295	*960,398*	*768,987*
50 miles	*65,463*	*1,075,462*	577,366	763,370	*1,147,771*	*879,230*

The following graphs depict the supply of both biomass sources under both participation rates. This shows the differences that can be present dependent on geography and the prevalence of certain crops in certain areas. Indiana does not have a uniform supply of biomass throughout the state, which means the plants have to consider the availability of different sources dependent upon their location. In this analysis, these supply differences are present. Figures 4.14 to 4.16 outline the supply in the area of each plant at both land participation rates. The supply is cumulative over the distance, so that the amount indicated at each distance includes all supply within a circle from the plant with a radius of that particular distance. From Figure 4.14, the Knox county plant, which is located in southern Indiana, has a nearly nonexistant supply of corn stover but a large supply of switchgrass. The Marion county plant in Figure 4.15 is located in a metropolitan area, which makes it overall supplies of either biomass sources less than in rural areas. With Marion county being in the central portion of Indiana, supplies of corn stover are more readily available, but switchgrass is still available in more abundance. Figure 4.16 shows the Tippecanoe county plant, which is even further north and located in a highly agricultural area. This location provides larger supplies of both corn stover and switchgrass relative to the other plants, and corn stover is the more available source, especially as distance increases from the plant.

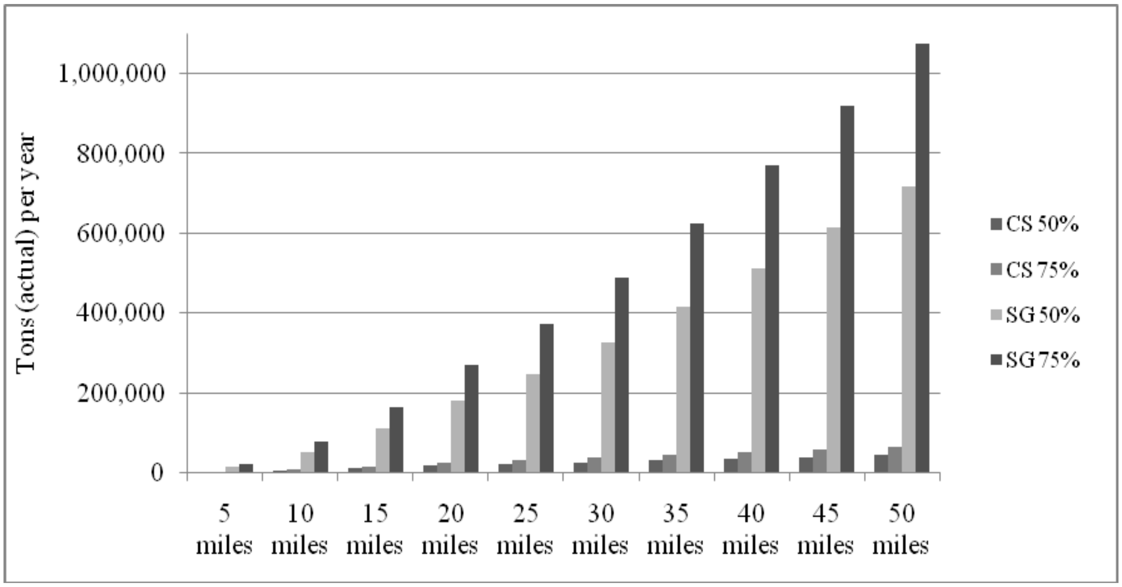

Figure 4.14. Area Biomass Supply, Knox County Plant

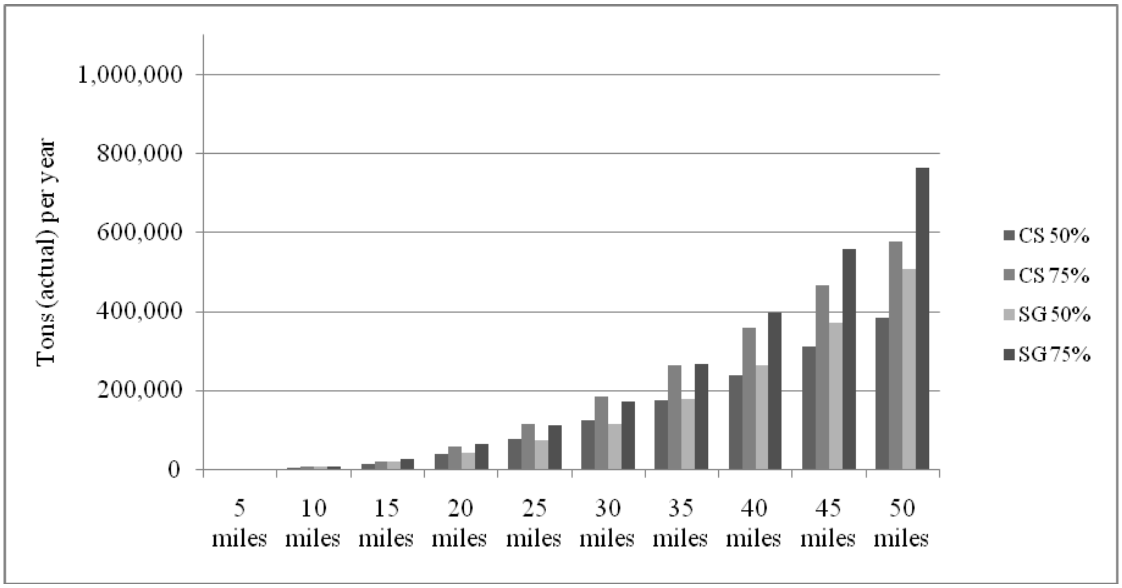

Figure 4.15. Area Biomass Supply, Marion County Plant

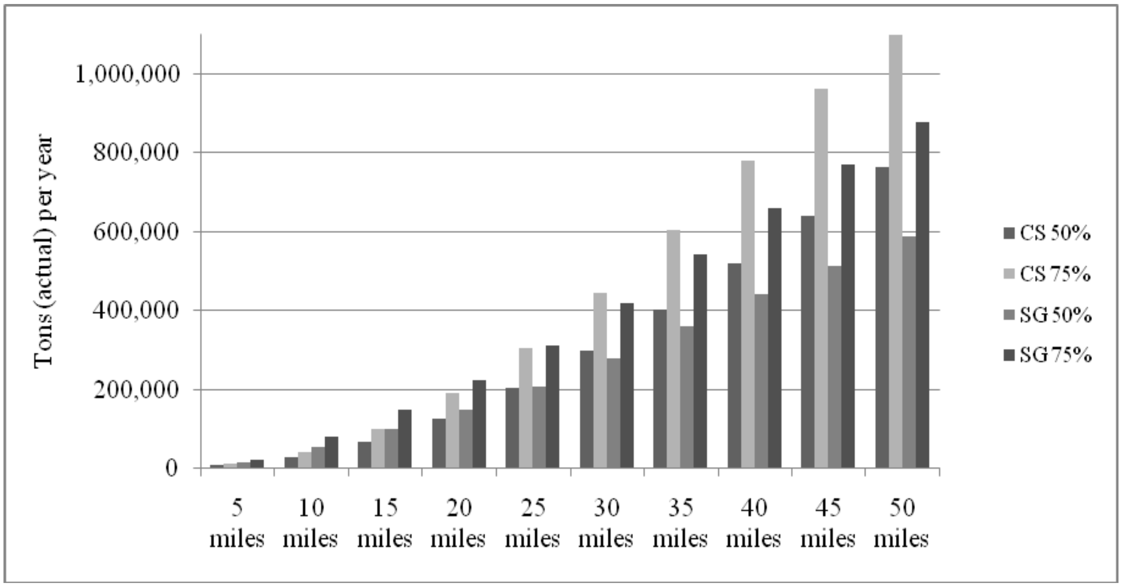

Figure 4.16. Area Biomass Supply, Tippecanoe County Plant

4.7.2. Supply Costs

Since this analysis has addressed several possible scenarios and combinations of management decisions, a set of average costs that are a function of one-way distance to the plant will serve as the costs associated with the available supply. These are simply the delivered cost to the plant from the field, and do not include any handling or processing costs that may be necessary to make the biomass suitable for use in the boiler. In the case of corn stover, these costs are an average of those found in all possible combinations of removal rate, baling options, equipment choices, and farm size. In the case of switchgrass, these costs are an average of those found in all possible combinations of baling options, equipment choices, and farm size. Table 4.19 indicates the costs that this supply analysis will assume in both dry ton units and MMBTU units. These biomass costs per MMBTU can be compared to coal with a cost per MMBTU of $1.56. This is calculated from the assumed price of coal per ton of $34.31 based on EIA market prices as of January 2008 and an average of the high heat values for the plants included in this analysis (see next section).

Table 4.19. Supply Analysis Costs by One-Way Distance

CORN STOVER			SWITCHGRASS		
	Cost per ton	Cost per MMBTU		Cost per ton	Cost per MMBTU
5 miles	$37.66	$2.48	5 miles	$55.37	$3.81
10 miles	$38.47	$2.53	10 miles	$56.18	$3.87
15 miles	$39.29	$2.59	15 miles	$56.99	$3.92
20 miles	$40.10	$2.64	20 miles	$57.81	$3.98
25 miles	$40.91	$2.69	25 miles	$58.62	$4.03
30 miles	$41.73	$2.75	30 miles	$59.43	$4.09
35 miles	$42.54	$2.80	35 miles	$60.25	$4.15
40 miles	$43.35	$2.85	40 miles	$61.06	$4.20
45 miles	$44.17	$2.91	45 miles	$61.87	$4.26
50 miles	$44.98	$2.96	50 miles	$62.69	$4.31

4.7.3. Biomass Demanded

The amount of biomass demanded depends upon the size of each plant and the amount of heat production that is to come from biomass. For this analysis, biomass makes up from 1 to 10 percent of total heat production. Information regarding the demand for fuel inputs from the coal plants comes from the Coal Power Plant Database by National Energy Technology Laboratory and the Environmental Protection Agency (2005 data released in 2007). Total heat production (Btu/hour) with all heat coming from coal is found by the following equation:

$$\left({}^{tons\ of\ coal}\!/_{hour} \times 2000 \right) \times {}^{Btu}\!/_{lb\ of\ coal} = {}^{total\ Btu}\!/_{hour}$$

The heat content of coal (Btu/lb of coal) varies slightly from plant to plant depending on the type of coal that plant uses (ranges from 10,010 and 11,729 Btu/lb of coal). Plants in this analysis are operating with either bituminous or subbituminous coal. Total heat production (Btu/hour) is then multiplied by 1 to 10 percent to determine the heat production per hour from biomass should a certain percentage of heat be required to come from biomass. The gross heat of combustion (or high heat value) of corn stover and switchgrass is assumed to be 7,593 Btu/lb and 7,267 Btu/lb, respectively (Domalski, et al, 1986). This value is the amount of heat that can be produced from burning one dry pound of each type of biomass. This analysis assumes that all plants operate 24 hours per day for 350 days each year. With this, the tons of biomass required per year to produce a given percentage of heat production can be calculated with the following equation:

$$\begin{aligned} & {}^{total\ Btu}\!/_{hour} \times fraction\ of\ heat\ from\ biomass \\ & \times \left({}^{{}^{Btu}\!/_{lb\ of\ biomass}}\!/_{2000} \right) \times {}^{operating\ hours}\!/_{day} \\ & \times {}^{operating\ days}\!/_{year} = {}^{\mathbf{tons\ of\ biomass}}\!/_{\mathbf{year}} \end{aligned}$$

Table 4.20 presents the results from these calculations for all three plants and represents the various demand possibilities from either source of biomass for each fraction of heat factor.

Table 4.20. Plant Biomass Demand by Fraction of Heat to Come from Biomass

	Knox		Marion		Tippecanoe	
Total Heat Production (Btu/hour)	2,023,560,000		5,405,400,000		435,489,429	
Fraction of Heat from Biomass	Corn Stover (tons/year)	Switchgrass (tons/year)	Corn Stover (tons/year)	Switchgrass (tons/year)	Corn Stover (tons/year)	Switchgrass (tons/year)
0.01	11,193	11,695	29,899	31,241	2,409	2,517
0.02	22,386	23,391	59,799	62,482	4,818	5,034
0.03	33,579	35,086	89,698	93,722	7,227	7,551
0.04	44,773	46,781	119,598	124,963	9,635	10,068
0.05	55,966	58,476	149,497	156,204	12,044	12,585
0.06	67,159	70,172	179,397	187,445	14,453	15,102
0.07	78,352	81,867	209,296	218,686	16,862	17,619
0.08	89,545	93,562	239,196	249,926	19,271	20,135
0.09	100,738	105,257	269,095	281,167	21,680	22,652
0.10	111,931	116,953	298,995	312,408	24,089	25,169

These required amounts of biomass corresponding to each fraction of heat from biomass are depicted as vertical lines on the supply curve graphs. Where the supply curve and the vertical line cross indicates the delivered cost of the furthest ton of biomass required in satisfying plant demand.

4.7.4. Supply Curves

Figures 4.17 through 4.28 are supply curves for each plant. For each plant, there are four curves showing both sources of biomass at both land participation rates. The vertical lines represent the possible fractions of total heat production that come from biomass. Where these vertical lines hit the x-axis, the amount of biomass in tons required and the one-way distance from the plant to the furthest ton are indicated. At the point where the vertical line and the supply curve intersect, the associated value on the y-axis indicates the per ton delivered cost for the furthest ton required. The area below the supply curve up to each vertical line indicates the total cost associated with acquiring the amount of biomass needed to generate a particular percentage of total heat. A portion of this cost is for the product and a portion is for the transportation. A horizontal line from the cost at zero miles can be imagined to represent the product only cost. The area under this horizontal line up to the vertical line of interest is the total product cost. The area between the supply curve and the horizontal line up to the vertical line of interest is the total transportation cost. As seen, biomass located further from the plant has higher associated transportation cost. As a result, plants may decide to contract their supply with producers to arrive at a set product cost that is the same for producers at all distances from the plant. The plant would then arrange transportation at its convenience and pay only for the distance traveled from each ton of biomass to the plant.

Reasons for differences in results among plants are likely due to different plant sizes and different availability of each source of biomass around the plant locations. The changes in participation rate simply make more biomass available. An increase in land participation rate makes the same amount of biomass available at a closer distance and therefore at a lower cost. From Figures 4.17 and 4.18, it can be seen that the Knox county plant would be limited in the percentage of heat that can be produced from only corn stover. Figures 4.19 and 4.20, however, show that switchgrass is much more abundant in the area. Therefore, the plant would likely use all the corn stover available in the 50-mile radius and then use the nearby switchgrass because even the cost per ton of corn stover 50 miles away is less than the cost per ton of switchgrass located right next to the plant.

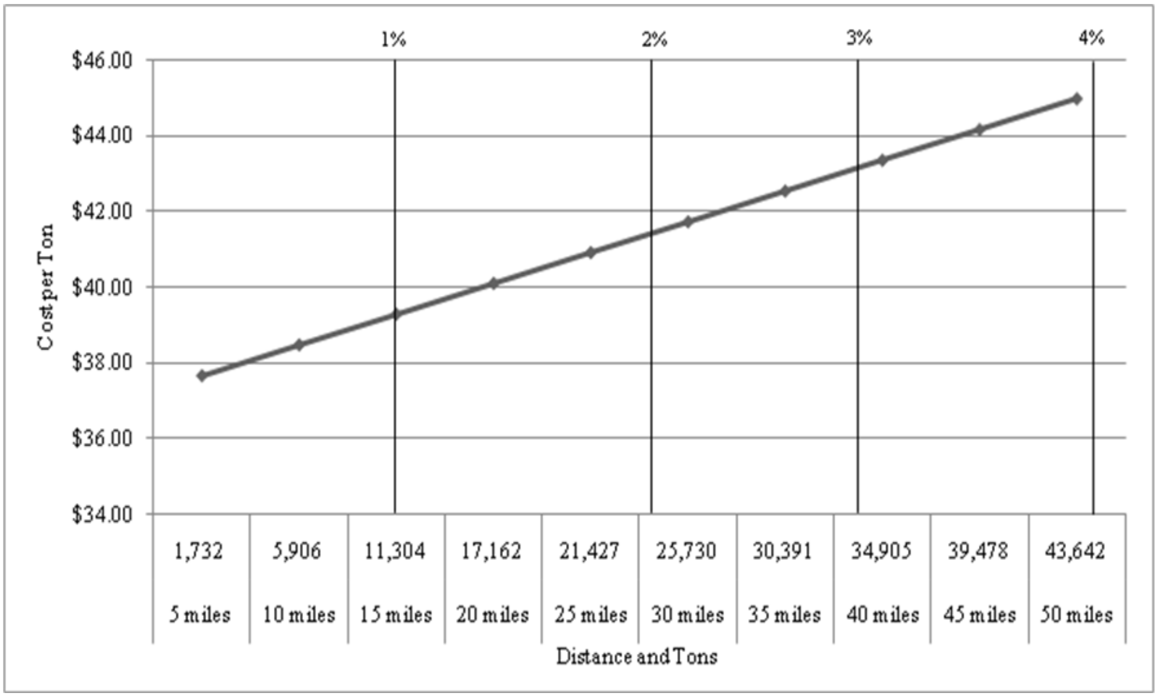

Figure 4.17. Corn Stover Supply, Knox Co. Plant, 50% Participation

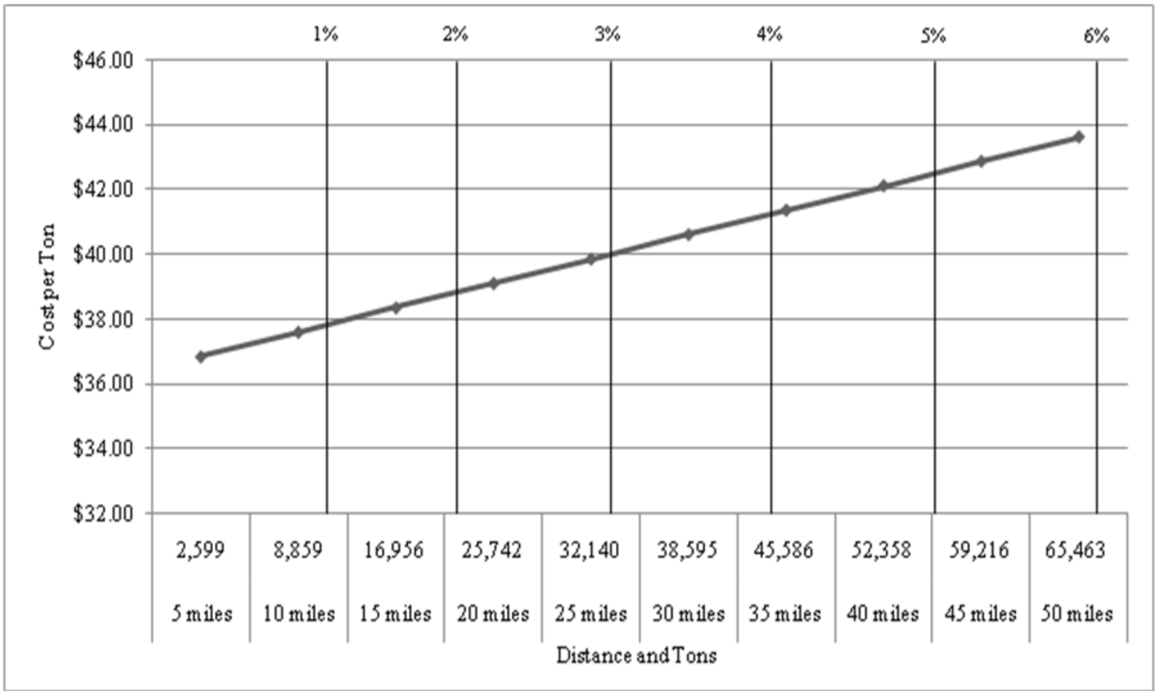

Figure 4.18. Corn Stover Supply, Knox Co. Plant, 75% Participation

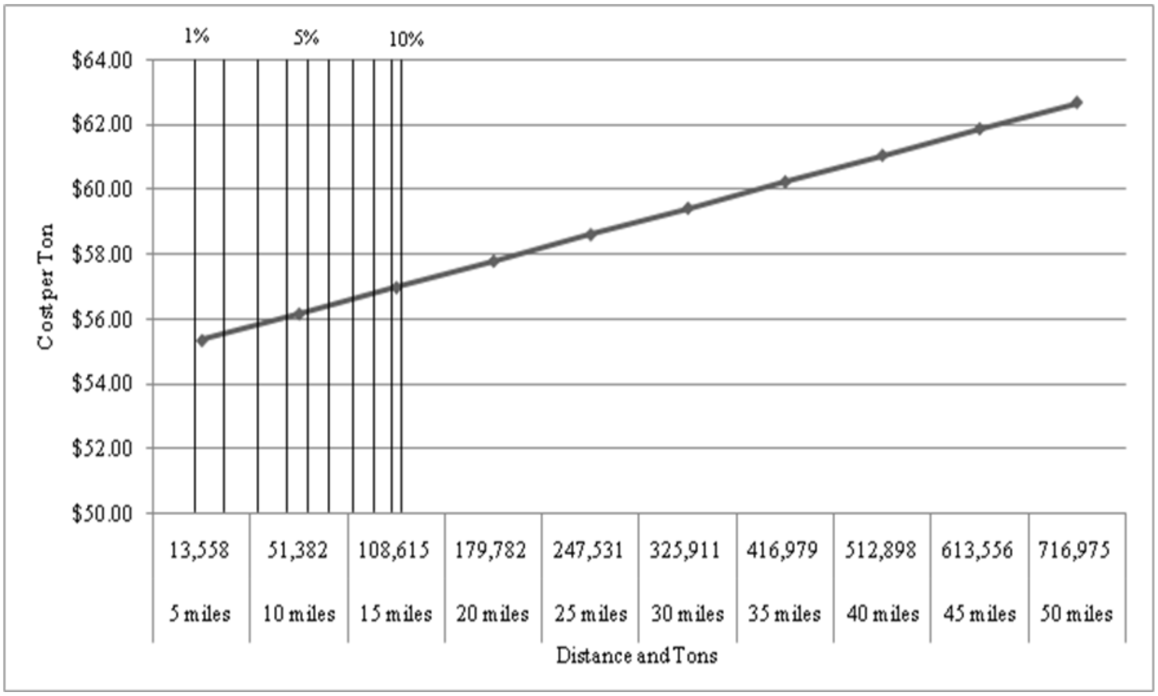

Figure 4.19. Switchgrass Supply, Knox Co. Plant, 50% Participation

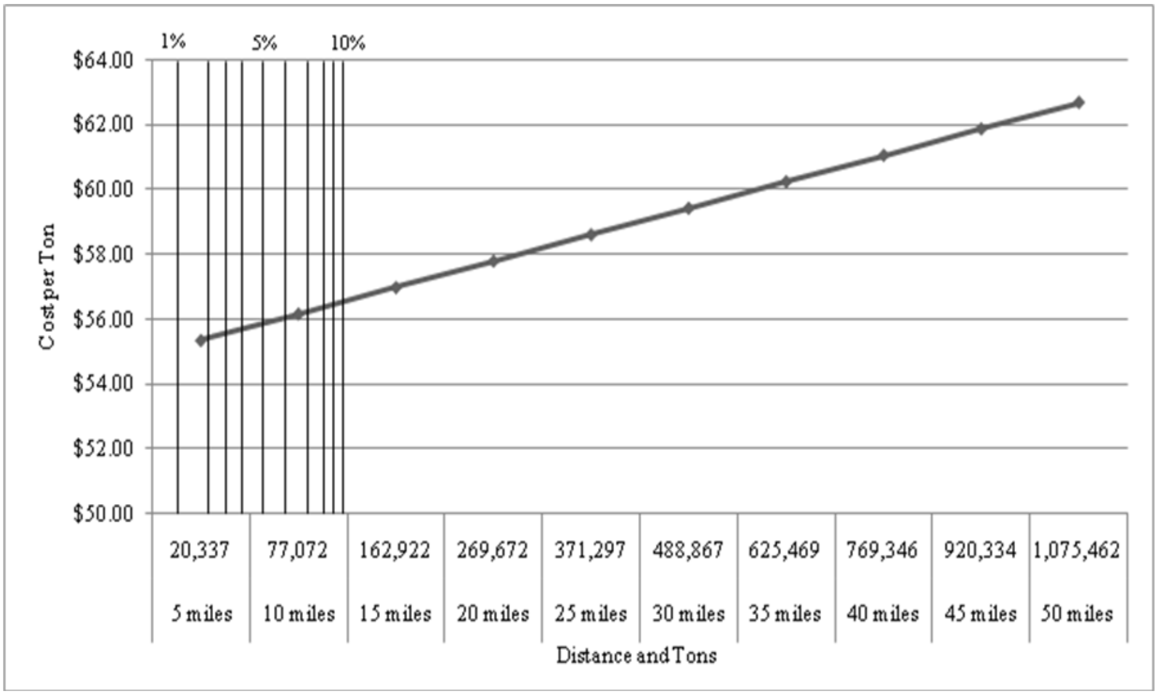

Figure 4.20. Switchgrass Supply, Knox Co. Plant, 75% Participation

The Marion county plant does not encounter the same availability situation as the Knox county plant, and it appears from comparing Figures 4.21 and 4.22 to Figures 4.23 and 4.24 that corn stover and switchgrass are more evenly available in the area than in the prior case. However, the large size of the plant requires more biomass to meet requirements. For example, where the Knox county plant could get switchgrass for 10 percent of heat production at about 13 to 16 miles, the Marion county plant would need to go out about 36 to 42 miles. The same situation occurs with corn stover.

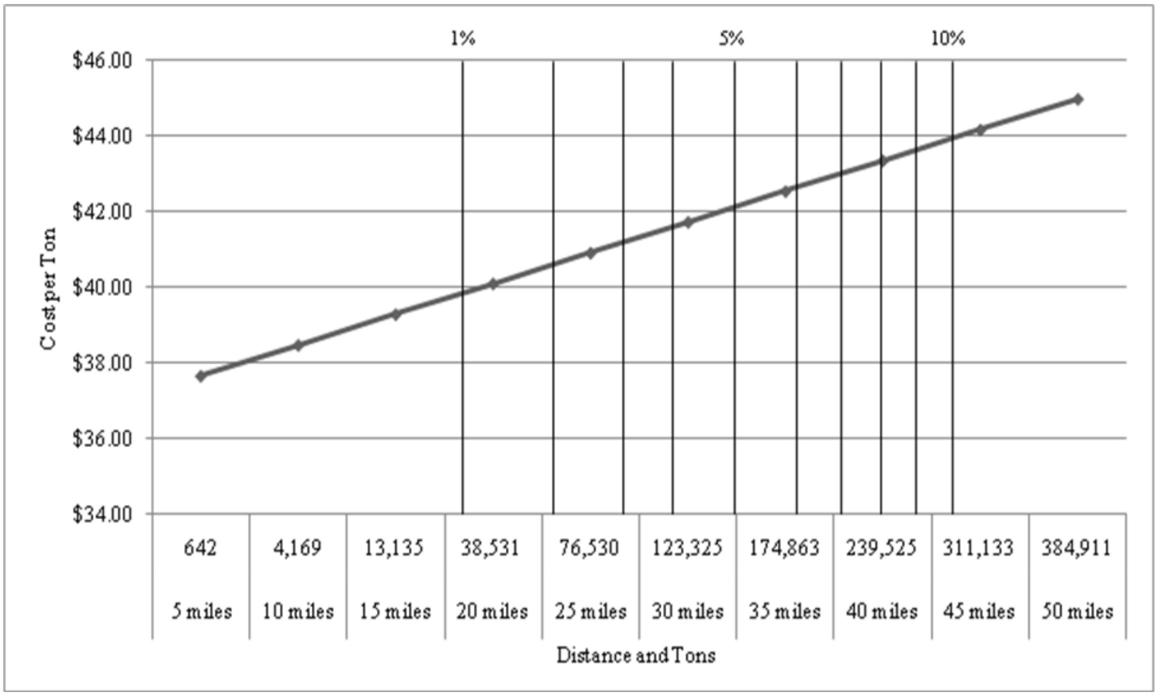

Figure 4.21. Corn Stover Supply, Marion Co. Plant, 50% Participation

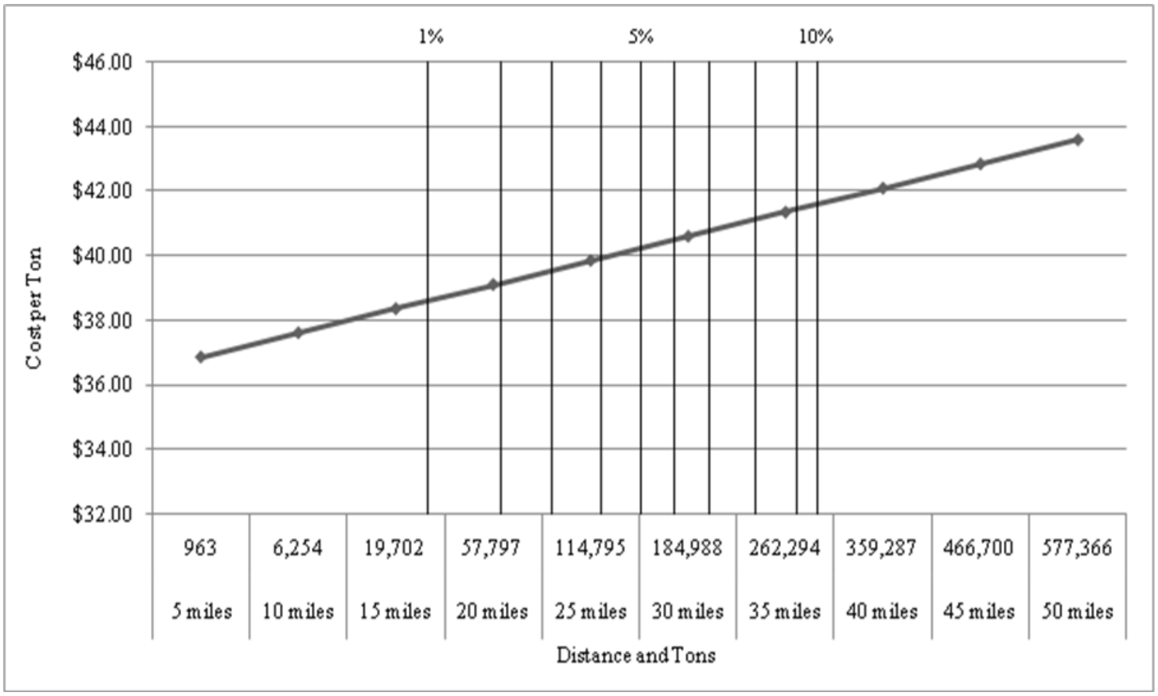

Figure 4.22. Corn Stover Supply, Marion Co. Plant, 75% Participation

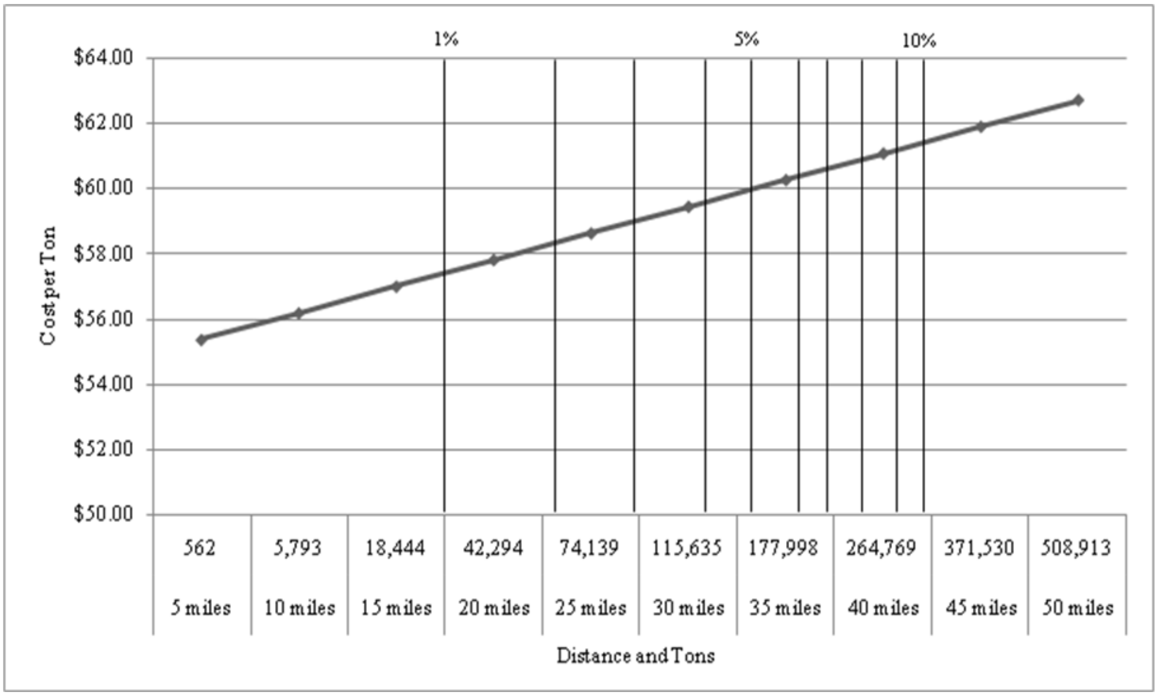

Figure 4.23. Switchgrass Supply, Marion Co. Plant, 50% Participation

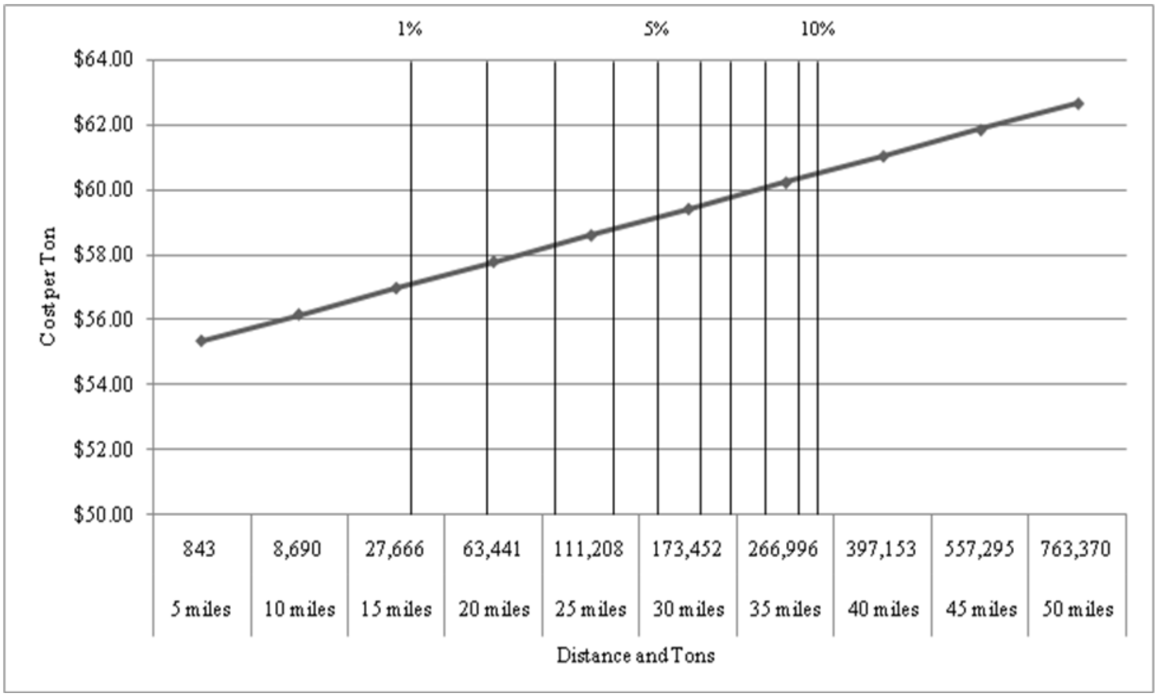

Figure 4.24. Switchgrass Supply, Marion Co. Plant, 75% Participation

The Tippecanoe county plant is a small plant located in an area that is abundant in both corn stover and switchgrass. Regardless of the type of biomass or the land participation rate, 10 percent of heat production could be obtained by going less than 10 miles from the plant. For corn stover, relative to the other plant areas, the Tippecanoe county plant has plenty available, which suggests the area could supply to another larger size plant as well.

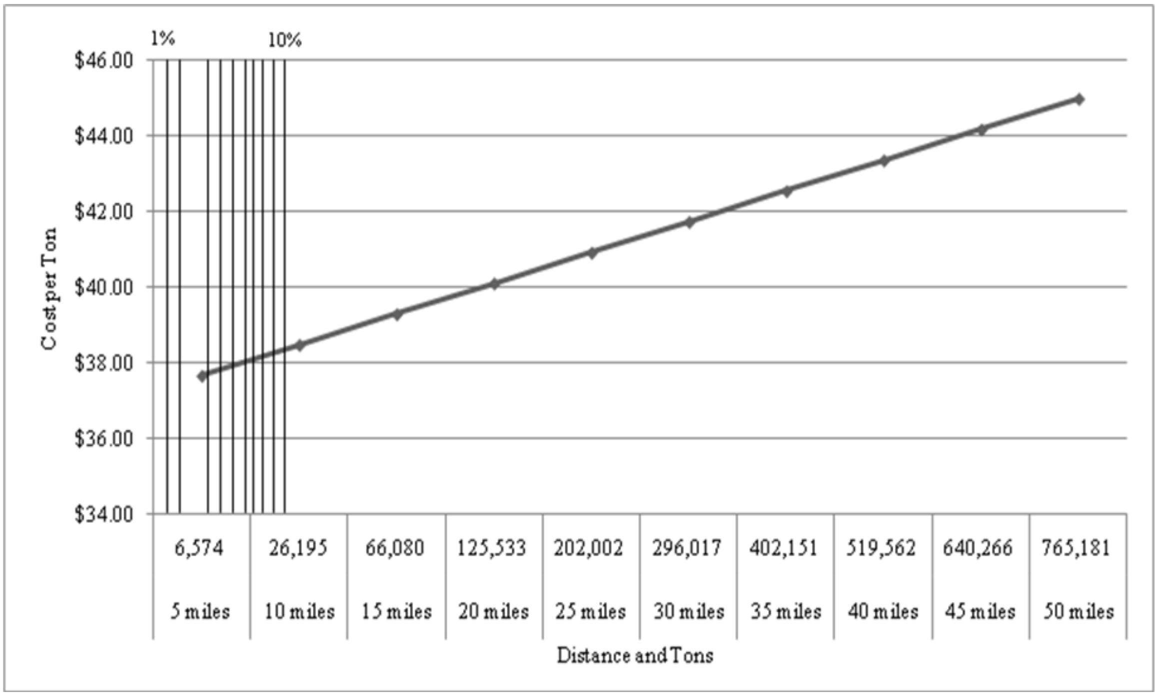

Figure 4.25. Corn Stover Supply, Tippecanoe Co. Plant, 50% Participation

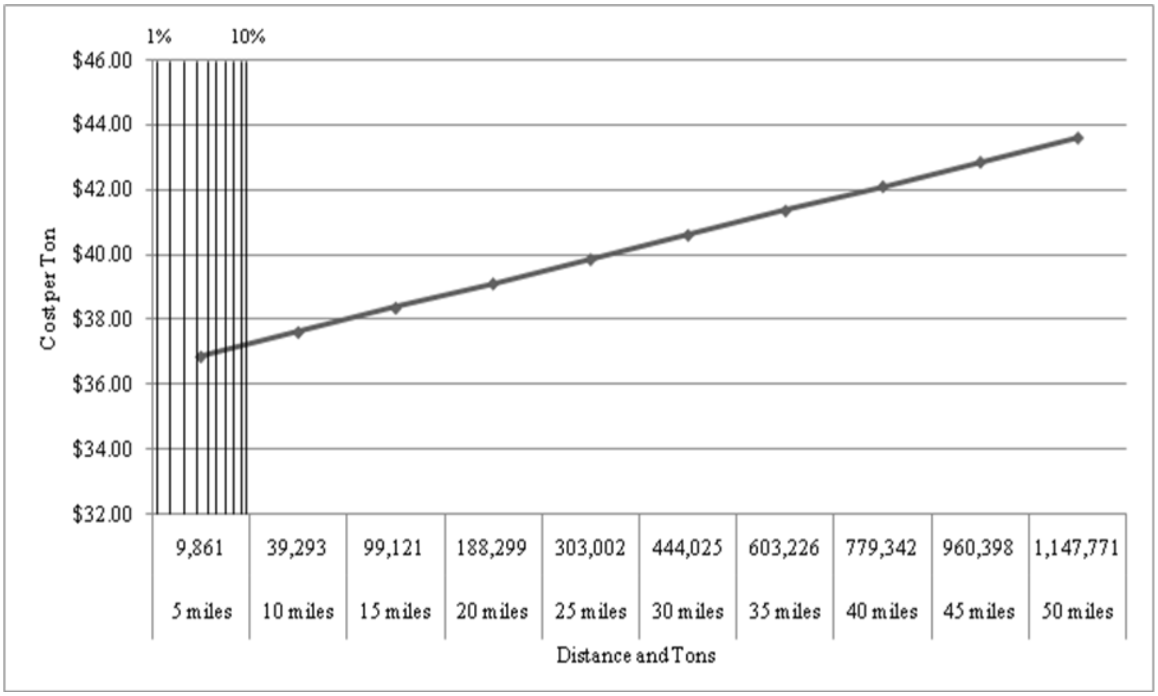

Figure 4.26. Corn Stover Supply, Tippecanoe Co. Plant, 75% Participation

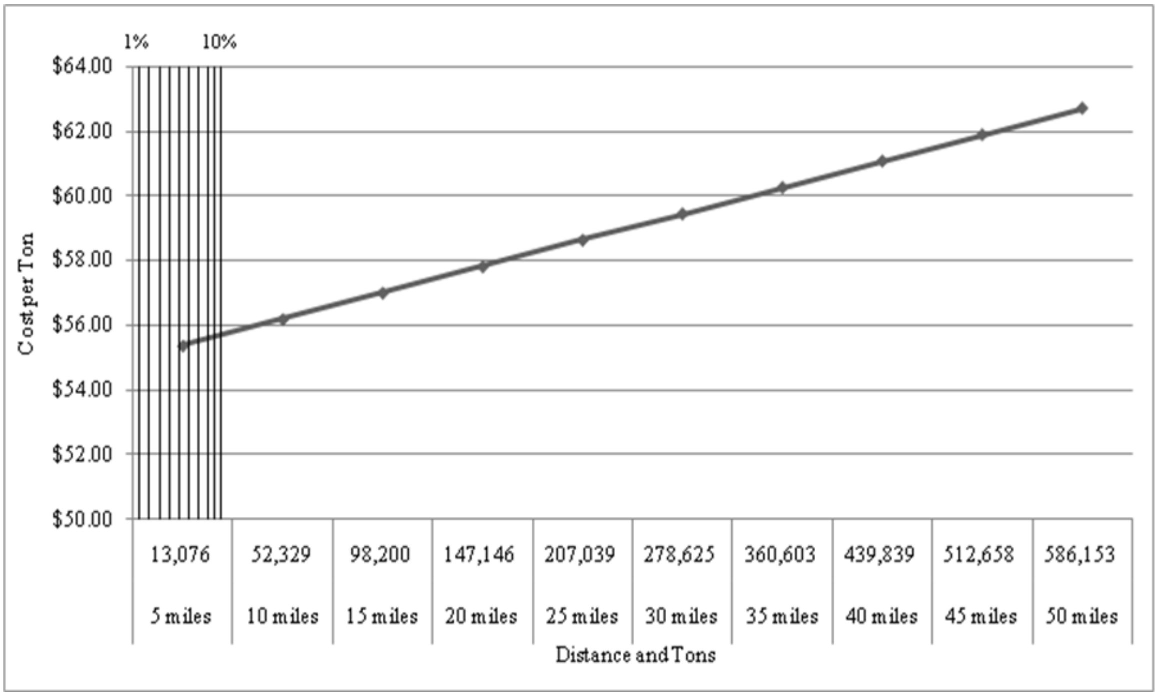

Figure 4.27. Switchgrass Supply, Tippecanoe Co. Plant, 50% Participation

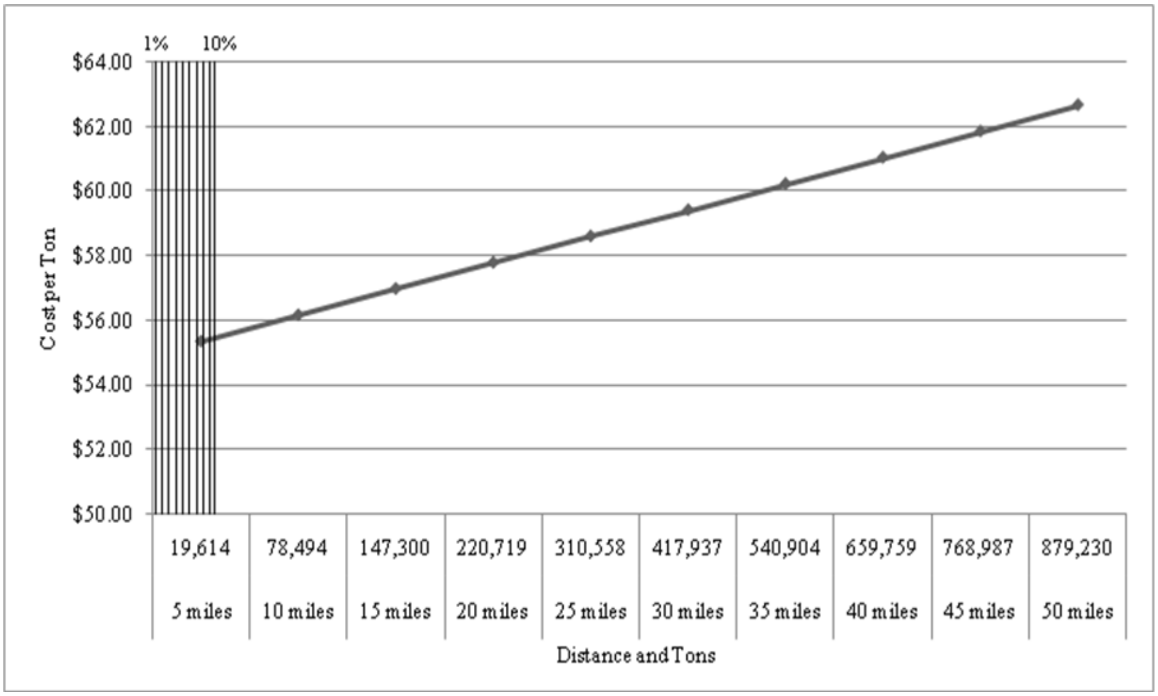

Figure 4.28. Switchgrass Supply, Tippecanoe Co. Plant, 75% Participation

4.8. Emissions Reduction

This use of biomass in place of coal will serve to reduce the greenhouse gas emissions associated with a given amount of heat production. Table 4.21 outlines the anticipated emissions reductions from using corn stover in place of coal. This table has been produced to mirror a similar table for switchgrass (Table 4.23), which comes from the Chariton Valley Biomass Project in south central Iowa (Ney and Schnoor, 2002). The figures for corn stover assume that only inputs from corn stover related activities are included. Therefore, this table does not include any emissions from production and harvest of corn since it is the primary crop and these emissions would occur whether the corn stover was harvested or not. The switchgrass emissions, however, do include all inputs relating to the establishment, production, and harvest of switchgrass, because unlike corn stover, switchgrass is assumed to be the primary crop and would not be grown unless it was used to generate energy.

Table 4.21. CO_2 Equivalent Emissions Reduction, Corn Stover Relative to Coal

Activity	Bioenergy Emission (lb CO_2-eq/MMBtu)	Bioenergy Sequestration (lb CO_2-eq/MMBtu)	Fossil Fuel Emission Avoided (lb CO_2-eq/MMBtu)
Coal Combustion CO2			212.70
Coal Combustion CH4			0.05
Coal Combustion N2O			1.10
Corn Stover Combustion CO2	-143.80		
Corn Stover Combustion CH4	-0.76		
Corn Stover Combustion N2O	-0.30		
Plant Carbon Sequestration		144.18	
Soil Carbon Sequestration		189.12	
Fertilizer Application N2O	-2.78		
Coal Mining CH4			1.78
Post-Mining CH4			0.29
Harvest	-12.19		
Bioenergy On-Site Prep	-8.85		
Coal Mining/Refining			1.95
Coal Transport			1.18
Coal On-Site Prep			0.26
Bioenergy Waste Transport	-0.02		
Fertilizer Production	-3.94		
Fertilizer Transport	-0.11		
Coal Waste Transport			0.01
Total	-172.76	333.30	219.32
Net Emission Reduction (lbs CO2-eq per MMBTU)	379.86		
Net Emission Reduction (tons CO2-eq per ton corn stover)	2.88		

The corn stover calculations are fractions of the switchgrass data from the Chariton Valley report (Ney and Schnoor, 2002). Table 4.22 outlines the ratio calculations used in determining the corn stover emissions as a function of the switchgrass emissions. The combustion ratio is based on the heat value assumed when calculating biomass demand. The sequestration ratio is based on figures from Spatari, et al. (2005). While this study looked at the life cycle assessment of ethanol fuel, the sequestration value does not change. The fertilizer ratio is an average of individual nutrient ratios that are based on the amounts assumed to be applied in this analysis for nutrient replacement in the case of corn stover and establishment and production in the case of switchgrass. These final ratios from Table 4.22 were multiplied by the relevant values from Table 4.23 to find the appropriate emissions reductions for corn stover based on the same assumptions used to calculate the switchgrass figures.

Table 4.22. Emissions Ratios for Calculating Corn Stover Emissions Reduction

	Switchgrass	Corn Stover	Ratio
Combustion (Btu/lb)	7267	7593	1.045
Sequestration (grams of CO2-eq per liter of ethanol)	-4005	-3986	0.995
Fertilizer (average of following components)			0.407
Nitrogen (lbs/acre)	80	0	0.000
Phosphorus (lbs/acre)	33.15	30	0.905
Potassium (lbs/acre)	50.25	15.9	0.316

Table 4.23. CO_2 Equivalent Emissions Reduction, Switchgrass Relative to Coal

Activity	Bioenergy Emission (lb CO_2-eq/MMBtu)	Bioenergy Sequestration (lb CO_2-eq/MMBtu)	Fossil Fuel Emission Avoided (lb CO_2-eq/MMBtu)
Coal Combustion CO2			212.70
Coal Combustion CH4			0.05
Coal Combustion N2O			1.10
Switchgrass Combustion CO2	-137.63		
Switchgrass Combustion CH4	-0.73		
Switchgrass Combustion N2O	-0.29		
Plant Carbon Sequestration		144.87	
Soil Carbon Sequestration		190.02	
Fertilizer Application N2O	-6.82		
Lime Application CO2	-4.17		
Coal Mining CH4			1.78
Post-Mining CH4			0.29
Soil Preparation	-4.28		
Seeding	-0.84		
Herbicide Application	-2.44		
Fertilizer Application	-1.54		
Lime Application	-1.29		
Mechanical Weed Control	-3.95		
Harvest	-12.19		
Bioenergy Transport to Power Plant	0.00		
Bioenergy On-Site Prep	-8.85		
Coal Mining/Refining			1.95
Coal Transport			1.18
Coal On-Site Prep			0.26
Bioenergy Waste Transport	-0.02		
Fertilizer Production	-9.67		
Fertilizer Transport	-0.28		
Herbicide Production	-1.30		
Herbicide Transport	0.00		
Coal Waste Transport			0.01
Total	-196.29	334.89	219.32
Net Emission Reduction (lbs CO2-eq per MMBTU)	357.92		
Net Emission Reduction (tons CO2-eq per ton switchgrass)	2.60		

For both corn stover and switchgrass, a net emission reduction is calculated in terms of tons of CO_2 equivalent reduced per ton of biomass used. Multiplying these reduction rates by the amount demanded by each plant (Table 4.20) results in the net reduction of emissions for each plant for each type of biomass at each fraction of heat from biomass in Table 4.24. Total CO_2 emissions for each plant are calculated by assuming that each ton of coal generates 2.86 tons of CO_2 when completely combusted (Hong and Slatick, 1994) and multiplying this by the total tons of coal used annually by the plant.

Table 4.24. Plant CO_2 Equivalent Emissions Reductions from Biomass Use

	Knox		Marion		Tippecanoe	
Total CO_2 Emissions (tons/year)	2,162,160		6,486,480		445,997	
Fraction of Heat from Biomass	Corn Stover (tons/year)	Switchgrass (tons/year)	Corn Stover (tons/year)	Switchgrass (tons/year)	Corn Stover (tons/year)	Switchgrass (tons/year)
0.01	32,236	30,408	86,111	81,226	6,938	6,544
0.02	64,472	60,815	172,221	162,452	13,875	13,088
0.03	96,709	91,223	258,332	243,678	20,813	19,632
0.04	128,945	121,631	344,442	324,904	27,750	26,176
0.05	161,181	152,038	430,553	406,130	34,688	32,720
0.06	193,417	182,446	516,663	487,356	41,625	39,264
0.07	225,654	212,854	602,774	568,582	48,563	45,808
0.08	257,890	243,262	688,884	649,808	55,500	52,352
0.09	290,126	273,669	774,995	731,034	62,438	58,896
0.10	322,362	304,077	861,105	812,260	69,375	65,440

Assuming an average delivered coal price of \$34.31 per ton (based on EIA market prices as of January 2008) and a CO_2 per metric ton price of \$5.75, the reduced costs from less coal and less CO_2 emissions can be calculated. The carbon credit price is from the market rate for Carbon Financial Instruments (CFIs) on the Chicago Climate Exchange. One CFI contract consists of 100 metric tons of CO_2 equivalent, and the market price as of March 2008 was \$5.75 per metric ton of CO_2 (or \$5.22 per short ton). The Chicago Climate Exchange is a voluntary trading market. The Regional Greenhouse Gas Initiative will be setting up a cap and trade auction system later this year for northeast and mid-Atlantic states, but an auction per ton price and an appropriate permit cap have yet to be determined. The European Union has a well developed system of cap and trade, but its prices are too high to be applicable to the current US situation. Since this analysis assumes two potential land participation rates when determining supply, the per ton costs associated with each fraction of heat production from biomass are averaged between the two land participation rate cases. In other words, the per ton cost when the participation rate is 50 percent of obtaining biomass to satisfy one percent of heat production compared to when the participation rate is 75 percent will typically be higher. This average of costs under the two participation rates at each biomass heat fraction is used to calculate the annual amount spent on biomass.

Table 4.25 estimates the percent difference in total input (coal and biomass) costs relative to the situation where the plant uses only coal. Total input costs when biomass is used are calculated by adding together the savings from coal, the savings from reduced emissions, and the total amount spent on biomass. Only in the case of the Marion county plant using less than 2 percent biomass was this sum less than or equal to zero. The percent difference is then calculated between the total cost using only coal and the total cost using only coal plus the costs associated with using biomass. This indicates that the use of biomass as it offsets some coal costs and CO_2 emissions is not enough to offset the costs incurred from purchasing the biomass.

Table 4.25. Percent Change in Total Input Costs to the Plant When Using Biomass

	Knox		Marion		Tippecanoe	
Total Cost Using Only Coal ($/year)	$25,938,360.00		$77,815,080.00		$5,350,404.78	
Fraction of Heat from Biomass	Corn Stover	Switchgrass	Corn Stover	Switchgrass	Corn Stover	Switchgrass
0.01	0.05%	0.88%	-0.04%	0.78%	0.02%	0.97%
0.02	0.23%	1.84%	-0.01%	1.59%	0.04%	1.93%
0.03	0.56%	2.76%	0.03%	2.48%	0.11%	2.90%
0.04	0.96%	3.69%	0.10%	3.43%	0.15%	3.87%
0.05	1.55%	4.70%	0.21%	4.29%	0.28%	4.83%
0.06	2.18%	5.64%	0.44%	5.34%	0.34%	5.91%
0.07	2.91%	6.71%	0.51%	6.23%	0.39%	6.90%
0.08	3.75%	7.67%	0.58%	7.25%	0.45%	8.04%
0.09	4.69%	8.62%	0.94%	8.31%	0.50%	9.04%
0.10	5.74%	9.76%	1.04%	9.39%	0.56%	10.05%

This is information for plants to determine how much additional cost they are willing to incur in order to incorporate biomass or "go green." These results do not intend to serve as recommendations on whether these plants should use biomass but rather as decision making information. Table 4.26 provides breakeven per ton CO_2 prices for the case of producing 10 percent of total heat production from biomass. These can be compared to the current price from the Chicago Climate Exchange of $5.22 per ton of CO_2. Breakeven prices for the use of corn stover are much lower than those for switchgrass due to the extra feedstock costs that must be covered in the case of switchgrass. These breakeven prices also signal the level of carbon tax that would be necessary to induce firms to use biomass as a substitute for coal under a carbon tax system. Carbon (instead of CO_2) breakeven prices are 3.67 times the values in Table 4.26.

Table 4.26. CO_2 Breakeven Per Ton Prices

	Corn Stover	Switchgrass
Knox	$9.83	$13.54
Marion	$6.16	$14.21
Tippecanoe	$5.65	$13.43

5. Conclusions

5.1. Corn Stover

With corn stover being a secondary crop of field corn and because it is a by-product of the primary crop, many input costs are considered costs associated with corn production rather than corn stover production. Other than nutrient replacement and harvesting activities, there are no additional costs for collecting corn stover. This makes corn stover the less costly option compared to switchgrass without any consideration of transport distance.

Management decisions can also change the costs. Higher removal rates come with more harvesting activities, but these result in more tons removed and lower per ton costs. Lower removal rates have fewer harvesting activities, but less tons removed leads to higher per ton costs. Equipment decisions are also important to consider and vary over farm sizes and removal rate choices.

An unexplored point in this analysis, but one that is important to consider is how removal rate choice might affect the quality of the biomass product. Higher removal rates will result in more soil picked up once the corn stover is baled. Plants accepting the biomass will need a way to ensure that the biomass they receive is of a certain quality or will end up incurring more handling and processing costs to improve the quality.

5.2. Switchgrass

Unlike corn stover, switchgrass is a primary energy crop. The decision to plant switchgrass is accompanied by the input and activity costs that relate to its establishment, production, and harvest. This includes field preparation, seeding, herbicide and fertilizer applications and land rental costs. These additional costs make switchgrass the more expensive option compared to corn stover.

5.3. Supply Situations

Supply of biomass is far from uniform across the state of Indiana and the country as a whole. Variations in supply are affected by the proximity to metropolitan areas and the density of agriculture near the plant. Due to the delivered cost of switchgrass being approximately twice that of corn stover, plants will most likely choose to collect as much corn stover as possible at very far distances before they begin to collect any switchgrass.

Location has proven to be the most important characteristic in determining the biomass patterns of supply. As already shown, each plant considered throughout the state tells a different supply story based largely on it location. Each of these plants ends up using corn stover to meet their feedstock needs, but the distance at which they must travel to obtain sufficient supply changes considerable based on their location. The Knox county plant is located in an area with more switchgrass than corn stover. The Marion county plant is located in a metropolitan area surrounded by rural counties. The Tippecanoe county plant is located in a very agriculturally dense area with slightly more corn stover than switchgrass.

5.4. Limitations

The most apparent limitation to this analysis is that its results apply strictly to the state of Indiana and three specific locations within the state. While many of the cost components may be similar throughout the Midwest, the supply curve stories are closely tied to location. However, results may be similar in other areas of the country where agricultural density and the types of commodities grown are similar to those throughout Indiana. Despite these results being highly specific to Indiana, the framework of the entire analysis could be applied anywhere with available county level biomass data. What may be considered a limitation in the immediate sense creates many opportunities for finding similar results for other areas with only minor modifications of cost parameters and supply data. These results only speak to the situation in Indiana, but this model can be altered to create the same detailed account of supply situations anywhere in the country.

5.5. Overview

The situations of individual farms will likely be extremely telling when it comes to identifying costs. The number of acres to be farmed as it affects the capital costs of equipment is basically set constant in the short term. The type and characteristics of the soil as it might affect the need for fertilizers, herbicides, or preparation activities are unalterable. The distance to a power plant or any other sort of facility looking to purchase biomass is fixed. The farm endowment of labor or the budget available to hire additional labor is also likely to be inflexible and be unable to accommodate the additional time necessary to produce and harvest biomass in a relatively limited timeframe.

With biomass being a mostly secondary activity for those participating, the current resources of the individual producer are likely to dictate whether one decides to pursue biomass production or not. Therefore, from the perspective of the plant, there may be much uncertainty as to how much of the area supply might actually be brought in. Depending on the individual producers in the area, this supply may or may not be abundant. This uncertainty may lead plants to contract their supply of raw material before making any plant investment.

5.6. Future Work

Future work on this topic would most obviously be in finding ways to reduce the cost of producing and transporting biomass. This reduction will not likely come from any one area but rather from many. Since both corn stover and switchgrass involve many inputs and activities for their production and transportation, large reductions in cost will be done by reducing the costs of numerous steps and components. Examples of ways to reduce cost might be further developing efficient corn stover harvesting in one pass rather than have multiple added trips through the field, which leads to more spending on equipment, fuel, and labor, as well as more adverse effects due to soil compaction, or modifying the current Conservation Reserve Program provisions to allow government subsidy for the production of switchgrass on that land. Cost reductions will mostly be a function of further research to make production and transport more efficient and to increase yields.

These results might also be used in exploring the potential for a cellulosic ethanol plant in Indiana and where the optimal plant location might be. Based on the results of this analysis and assuming 60 gallons of ethanol can be produced from one ton of biomass, Indiana corn stover could produce between 100 to 150 million gallons of ethanol annually, and Indiana switchgrass could produce between 160 to 240 million gallons of ethanol annually, depending upon the land participation rate.

List of References

Agrability Project. "Making and Handling Hay Bales Has Gotten Easier." *Agrability Quarterly* 4, no. 1 (2003): 4-5. http://www.agrabilityproject.org/newsletter/october_2003/HayHandling%20Final2.pdf.

Andrews, S.S. "Crop Residue Removal for Biomass Energy Production: Effects on Soils and Recommendations." *White Paper at 2006 Outlook on Agriculture Forum.* 22 February 2006.

Atchison, J.E. and J.R. Hettenhaus. "Innovative Methods for Corn Stover Collecting, Handling, Storing and Transporting." *National Renewable Energy Laboratory.* NREL/SR-510-33893. March 2003.

Barber, S.A. "Corn Residue Management and Soil Organic Matter." *Agronomy Journal* 71 (1979): 625-627.

Benoit, G.R. and M.J. Lindstrom. "Interpreting Tillage-Residue Management Effects." *Journal of Soil and Water Conservation* March-April (1987): 87-90.

Berwick, M. and M. Farooq. "Truck Costing Model for Transportation Managers." *Upper Great Plains Transportation Institute.* North Dakota State University. August 2003.

Biotechnology Industry Organization. "Achieving Sustainable Production of Agricultural Biomass for Biorefinery Feedstock." 21 November 2006.

Brummer, E.C., C.L. Burras, M.D. Duffy, and K.J. Moore. "Switchgrass Production in Iowa: Economic Analysis, Soil Suitability, and Varietal Performance." *Bioenergy Feedstock Development Program.* August 2001.

Burt, A. "Is Corn Stover a Waste? Economic and Agronomic Considerations of Corn Residue Removal." PLNT-6250, Colloquium on Bioproducts, University of Guelph, Fall 2006.

Chicago Climate Exchange. "CFI Contract Specifications." 14 February 2008. http://www.chicagoclimateexchange.com/content.jsf?id=483

Collins, M., D. Ditsch, J.C. Henning, L.W. Turner, S. Isaacs, and G.D. Lacefield. "Round Bale Hay Storage in Kentucky." University of Kentucky, AGR-171. October 1997.

Dobbins, C. and K. Cook. "Indiana Farmland Values and Cash Rents Jump Upward." *Purdue Agricultural Economics Report.* August 2007.

Domalski, E.S., T.L. Jobe, Sr., and T.A. Milne. "Thermodynamic Data for Biomass Conversion and Waste Incineration." *Solar Technical Information Program.* National Bureau of Standards. September 1986.

Duffy, M. and V.Y. Nanhou. “Costs of Producing Switchgrass for Biomass in Southern Iowa.” *Iowa State University Extension PM 1866.* April 2001.

Economic Research Service. US Department of Agriculture. *Commodity Costs and Returns, 2005-2006.* http://www.ers.usda.gov/Data/CostsAndReturns/.

Energy Efficiency and Renewable Energy. US Department of Energy. *ABC’s of Biofuels.* 24 January 2008. http://www1.eere.energy.gov/biomass/abcs_biofuels.html#enviro

Energy Information Administration. *Country Analysis Briefs*, OPEC. 7 March 2006. http://www.eia.doe.gov/cabs/opec.html

Energy Information Administration. *US Imports by Country of Origin*, Crude Oil. 24 January 2008. http://tonto.eia.doe.gov/dnav/pet/pet_move_impcus_a2_nus_epc0_im0_mbblpd_a.htm

Fixen, P. “Potential Biofuels Influence on Nutrient Use and Removal in the US.” *Better Crops* 91, no. 2 (2007): 12-14.

Gibson, L. and S. Barnhart. “Switchgrass.” *Iowa State University Department of Agronomy.* March 2007. http://www.extension.iastate.edu/Publications/AG200.pdf

Glassner, D.A., J.R. Hettenhaus, and T.M. Schechinger. “Corn Stover Collection Project.” *BioEnergy ’98: Expanding BioEnergy Partnerships* (1998): 1100-1110.

Halich, G. “Custom Machinery Rates Applicable to Kentucky.” *University of Kentucky Cooperative Extension Service, Extension No. 07-01.* March 2007.

Hong, B.D. and E.R. Slatick. “Carbon Dioxide Emission Factors for Coal.” *Energy Information Administration Quarterly Coal Report, January – April 1994.* August 1994.

I-FARM. Integrated Crop and Livestock Production and Biomass Planning Tool. Online budget tool. http://i-farmtools.org/i-farm/. Accessed September 2007.

Illinois National Agricultural Statistics Service. US Department of Agriculture. “1998 Illinois Annual Statistics Bulletin.” 1998.

Karlen, D.L., P.G. Hunt, and R.B. Campbell. “Crop Residue Removal Effects on Corn Yield and Fertility of a Norfolk Sandy Loam.” *Soil Science Society of America Journal* 48 (1984): 868-872.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. “Soil Quality: A Concept, Definition, and Framework for Evaluation.” *Soil Science Society of America Journal* 61 (1997): 4-10.

Kszoz, L.A., S.B. McLaughlin, and M. Walsh. “Bioenergy from Switchgrass: Reducing Production Costs By Improving Yield and Optimizing Crop Management.” *Oak Ridge National Laboratory*. 23 May 2002.

Lang, B. “Estimating the Nutrient Value in Corn and Soybean Stover.” *Iowa State University Extension Fact Sheet BL-112.* December 2002.

Lawrence, J., J. Cherney, P. Barney, and Q. Ketterings. “Establishment and Management of Switchgrass.” *Cornell University Cooperative Extension Fact Sheet 20.* 2006.

Laughlin, D. and S. Spurlock. *Mississippi State Budget Generator v 6.0.* Software, User’s Manual, and Crop and Forage Budgets. http://www.agecon.msstate.edu/laughlin/msbg.php. Accessed May 2007.

Linden, D.R., C.E. Clapp, R.H. Dowdy. “Long-Term Corn Grain and Stover Yields as a Function of Tillage and Residue Removal in East Central Minnesota.” *Soil and Tillage Research* 56, no. 3-4 (2000): 167-174.

Lindstrom, L.J. “Effects of Residue Harvesting on Water Runoff, Soil Erosion and Nutrient Loss.” *Agriculture, Ecosystems and Environment* 16 (1986): 103-112.

Mapemba, L.D., F.M. Epplin, C.M. Taliaferro, and R.L. Huhnke. “Biorefinery Feedstock Production on Conservation Reserve Program Land.” *Review of Agricultural Economics* 29, no. 2 (2007): 227-246.

McCool, D.K., Hammel, J.E. and Papendick, R.I. “Surface Residue Management. Crop Residue Management to Reduce Erosion and Improve Soil Quality: Northwest. Papendick, R.I. and Moldenhauer, W.C., U.S. Department of Agriculture Conservation Research Report 40 (1995): 10-16.

Miller, G.A., M. Amemiya, R.W. Jolly, S.W. Melvin, and P.J. Nowak. “Soil Erosion and the Iowa Soil 2000 Program.” *Iowa State University Extension PM 1056.* 1999.

Missouri NRCS. “Cave-In-Rock Switchgrass Fact Sheet.” December 1986.

Montross, M.D., R. Prewitt, S.A. Shearer, T.S. Stombaugh, S.G. McNeil, and S. Sokhansanj. “Economics of Collection and Transportation of Corn Stover.” *American Society of Agricultural Engineers Annual International Meeting*, no. 036081. July 2003.

Ney, R.A. and J.L. Schnoor. “Greenhouse Gas Emission Impacts of Substituting Switchgrass for Coal in Electric Generation: The Chariton Valley Biomass Project.” *Center for Global and Regional Environmental Research.* 20 May 2002.

Nielsen, R.L. “Fertilizer Reckoning for the Mathematically Challenged.” *Purdue University Department of Agronomy*. 26 March 2002.

Nielsen, R.L. "Questions Relative to Harvesting and Storing Corn Stover." *Purdue University Department of Agronomy*. AGRY-95-09. September 1995.

Perlack, R.D. and A.F. Turhollow. "Assessment of Options for the Collection, Handling, and Transport of Corn Stover." *Oak Ridge National Laboratory.* ORNL/TM-2002/44. September 2002.

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply." *Oak Ridge National Laboratory.* ORNL/TM-2006/66. 2005.

Perrin, R., K. Vogel, M. Schmer, and R. Mitchell. "Switchgrass – A Biomass Energy Crop for the Midwest." *North Dakota State University Central Grasslands Research Extension Center.* 2003.

Petrolia, D.R. "The Economics of Harvesting and Transportating Corn Stover for Conversion to Fuel Ethanol: A Case Study for Minnesota." *Staff Paper P06-12.* University of Minnesota, Department of Applied Economics. August 2006.

Popp, M. and R. Hogan, Jr. "Assessment of Two Alternative Switchgrass Harvest Transport Methods." *Farm Foundation Conference Paper.* April 2007.

Pordesimo, L.O., W.C. Edens, and S. Sokhansanj. "Distribution of Aboveground Biomass in Corn Stover." *Biomass and Bioenergy* 26 (2004): 337-343.

Power, J.F., W.W. Wilhelm, and J.W. Doran. "Crop Residue Effects on Soil Environment and Dryland Maize and Soya Bean Production." *Soil and Tillage Research* 8 (1986): 101-111.

Quick, G.R. "Single-Pass Corn and Stover Harvesters: Development and Performance." *Proceedings of the International Conference on Crop Harvesting and Processing.* ASAE Publication Number 701P1103e. 9 February 2003.

Renewable Fuels Association. *Cellulosic Ethanol.* 26 September 2007. http://www.ethanolrfa.org/resource/cellulosic/

Renewable Fuels Association. *Renewable Fuel Standard.* 20 February 2008. http://www.ethanolrfa.org/resource/standard/

Richey, C.B., V.L. Lechtenberg, and J.B. Liljedahl. "Corn Stover Harvest for Energy Production." *Transactions of the ASAE* 25, no. 4 (1982): 834-839, 844.

Rinehart, L. "Switchgrass as a Bioenergy Crop." National Sustainable Agriculture Information Service. 2006. http://attra.ncat.org/attra-pub/PDF/switchgrass.pdf

Sauer, T.J., J.L. Hatfield, and J.H. Prueger. "Corn Residue Age and Placement Effects on Evaporation and Soil Thermal Regime." *Soil Science Society of America Journal* 60 (1996): 1558-1564.

Schechinger, T.M. and J. Hettenhaus. "Corn Stover Harvesting: Grower, Custom Operator, and Processor Issues and Answers: Report on Corn Stover Experiences in Iowa and Wisconsin for the 1997-98 and 1998-99 Crop Years." *Oak Ridge National Laboratory.* ORNL/SUB-04-4500008274-01. April 2004.

Sheehan, J., A. Aden, K. Paustian, K. Killian, J. Brenner, M. Walsh, and R. Nelson. "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol." *Journal of Industrial Ecology* 7, no. 3-4 (2003): 117-146.

Shinners, K.J., B.N. Binversie, and P. Savoie. "Harvest and Storage of Wet and Dry Corn Stover as a Biomass Feedstock." *American Society of Agricultural Engineers Annual International Meeting,* no. 036088. July 2003a.

Shinners, K.J., B.N. Binversie, and P. Savoie. "Whole-Plant Corn Harvesting for Biomass: Comparison of Single-Pass and Multiple-Pass Harvest Systems." *American Society of Agricultural Engineers Annual International Meeting,* no. 036089. July 2003b.

Sokhansanj, S. and A.F. Turhollow. "Baseline Cost for Corn Stover Collection." *Applied Engineering in Agriculture* 18, no. 5 (2002): 525-530.

Sokhansanj, S., A. Turhollow, and R. Perlack. "Stochastic Modeling of Costs of Corn Stover Costs Delivered to an Intermediate Storage Facility." *American Society of Agricultural Engineers Annual International Meeting,* no. 024190. July 2002.

Spatari, S., Y. Zhang, and H.L. Maclean. "Life Cycle Assessment of Switchgrass- and Corn Stover-Derived Ethanol-Fueled Automobiles." *Environmental Science and Technology* 39 (2005): 9750-9758.

Teel, A., S. Barnhart, and G. Miller. "Management Guide for the Production of Switchgrass for Biomass Fuel in Southern Iowa." *Iowa State University Extension PM 1710.* May 2003a.

Teel, A., and S. Barnhart. "Switchgrass Seeding Recommendations for the Production of Biomass Fuel in Southern Iowa." *Iowa State University Extension PM 1773.* May 2003b.

Tiffany, D.G., B. Jordan, E. Dietrich, and B. Vargo-Daggett. "Energy and Chemicals from Native Grasses: Production, Transportation and Processing Technologies Considered in the Northern Great Plains." *Staff Paper P06-11.* University of Minnesota, Department of Applied Economics. June 2006.

Walsh, M.E., D.G. De La Torre Ugarte, H. Shapouri, and S.P. Slinsky. "Bioenergy Crop Production in the United States." *Environmental and Resource Economics* 24 (2003): 313-333.

Walsh, M.E., D. Becker, and R.L. Graham. "The Conservation Reserve Program as a Means to Subsidize Bioenergy Crop Prices." *Proceedings of BIOENERGY '96.* September 1996.

Walsh, M.E. "Switchgrass." *Sun Grant Bio Web.* 25 September 2007.