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Economic Implications to the Agricultural Sector of Increasing the Production of Biomass Feedstocks to Meet Biopower, Biofuels, and Bioproduct Demands

Daniel G. De La Torre Ugarte, Burton C. English, Chad M. Hellwinckel, R. Jamey Menard, and Marie E. Walsh

Authors are Associate Professor, Professor, Research Associate, Research Associate, and Adjunct Professor, respectively, of the Department of Agricultural Economics, Institute of Agriculture, University of Tennessee. De la Torre Ugarte and Hellwinckel are also with the Agricultural Policy Analysis Center. **This study was partially funded through National Research Initiative Program, USDA**

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Department of Agricultural Economics
The University of Tennessee
2621 Morgan Circle
Knoxville, TN 37996-4518
(865) 974-7231

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Executive Summary

The results of this study support the conclusion that the agricultural sector is in the position to supply bioenergy and bioproducts consistent with goals set forward in the Department of Energy's (DOE's) *Vision for Bioenergy and Biobased Products in the U.S,* that biopower can fill 5 percent of U.S. electrical demand in 2020, and that biofuels can fill 10 percent of U.S. fuel demand in 2020 (USDOE, 2002b).

Analysis was conducted for four bioproduct feedstock sources (energy dedicated crop, crop residues, corn grain and soybeans). The use of these four in combination to meet projected bioenergy and bioproduct demands allowed the market to smoothly adjust to the rapid increase in demand. Without the use of all four, the ability of the agricultural sector to meet bioenergy and bioproduct demands would be severely stressed.

In generating biopower, cellulosic biomass (corn stover, wheat straw, and switchgrass) is the only available feedstock included in the model. The projected demand for forest products to generate renewable electricity was determined exogenously. By 2014, corn stover is the largest contributing feedstock with 64.5 million dry tons, followed by switchgrass with 38.9 million dry tons and wheat straw with 2.8 million dry tons to meet 160 billion kWh of demand.

Both corn grain and cellulosic biomass can be used as an ethanol feedstock. By 2011, cellulosic biomass and corn grain are directly competing as feedstocks in the production of ethanol; Approximately 30.5 million dry tons of corn stover, 32.5 million dry tons of switchgrass and 2.32 billion bushels of corn are used to produce 11.24 billion gallons of ethanol. At the end of the period of analysis (year 2014), nearly half of projected ethanol demand is met through the use of biomass feedstocks in producing 16.73 billion gallons of ethanol.

The analysis assumes that soybeans are the only feedstock for biodiesel production. The production of biodiesel demands 98 million bushels of soybeans at the beginning of the period to produce 140 million gallons of biodiesel and by the final year of the analysis, 394 million bushels are used to produce 550 million gallons.

Bioproducts make up a very small portion of total feedstock demand. By 2014, demand from lactic acid, succinic acid and 1,3-Propanediol (PDO) only make up 2 percent of total corn grain feedstock demand. Levulinic acid, which is the only bioproduct using biomass, only accounts for 0.02 percent of total biomass feedstock demand.

Farmers’ net returns increase via directly growing feedstocks such as switchgrass or crop residues, or indirectly through higher crop prices brought about by resource competition. By 2014, crop net returns nearly double increasing from $39.2 million to $72.6 million, a gain of $33.4 million. Realized net income, which includes the livestock sector, follows the same trend as crop net returns. Realized net income in 2014 increases $21.6 million from $54.5 million to $76.1 million.

In summary, the use of agricultural feedstock to produce bioenergy and bioproducts opens an opportunity for agriculture to increase net farm income, reduce government payments, and be an engine for rural economic development. Further research should evaluate the means to achieve the bioenergy and bioproduct goals. Questions regarding feedstocks, conversion, and location need to be addressed. The answers to these three elements will have significant environmental and social consequences.

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Introduction

Use of biomass feedstocks for transportation fuels, bioproducts, and power are increasingly being viewed as opportunities to enhance energy security, provide environmental benefits, and increase economic development particularly in rural areas. Several studies have addressed various aspects of these issues (USDA-OCE, 2002a; Urbanchuk, 2001; Wang, Saricks, and Santini, 1999; House *et al*, 1993; Petrulis, Sommer, and Hines, 1993; USDA-OCE, 2002b; Evans, 1997; CEC, 2001; Shapouri, Duffield, and Wang, 2002; Whitten, 2000; Sheehan, Paustian, and Walsh, 2002a; Sheehan *et al*, 2002b; Walsh *et al*, 2003a and 2003b; De La Torre Ugarte *et al*, 2003; English, Menard, and De La Torre Ugarte, 2000; USDOE-EIA, 2001a and 2001b; Delucchi, 1997; McLaughlin *et al*, 2002; Mann and Spath, 2001a and 2001b; and Sheehan *et al*, 1996).

President Bush has come out with a four point plan that attempts to address our “addiction to oil” and high energy prices. These points are as follows:

- Ensure that American consumers are treated fairly at the gas pump,
- Promote greater fuel efficiency,
- Boost our supplies of crude oil and gasoline, and
- Invest in alternatives to oil so that our demand for gasoline is dramatically reduced.

To achieve item four, the president has called on Congress to increase the use of ethanol, improve hybrid vehicles, and develop hydrogen technology. With regard to transportation fuel, President Bush increased research monies for cellulosic ethanol and signed the first Federal tax credit for biodiesel producers (Bush, 2006).

Recently, several policy initiatives to spur the development and use of bioenergy and bioproducts using starch, cellulose, oil, etc. have been enacted or proposed. The U.S. Congress passed and president signed into law the Biomass Research and Development Act of 2000 (Title III of the Agricultural Risk Protection Act of 2000, H.R. 2559 - Public Law 106-224) on June 20, 2000 (U.S. Congress, 2000). This Act provided the incentive to develop a multi-agency biomass effort to coordinate and accelerate research and development on fuels, powers, chemicals, and other materials from a wide variety of biomass (Biomass research and Development Technical Advisory Committee). The Farm Security and Rural Investment Act of 2002, Title IX establishes, among other provisions, a Federal agency program to purchase bioproducts, provides biorefinery grants to support development of bioproducts and fuels, extends the termination date of the Biomass Research and Development Act of 2000, and expands the feedstocks list for use of the Commodity Credit Corporation payments to eligible producers to purchase biomass feedstocks (U.S. Congress, 2002). The research title continues to recognize bioproducts as a high priority. The long term vision of the U.S. Department of Energy calls for an increase of biomass power from 2.7 quads (1 quadrillion BTUs) to 4.8 quads by 2030, for the use of biobased transportation fuels from 0.5 percent of 2001 fuel consumption to 20 percent by 2030, and the use of biobased products from 5 percent of 2001 production to 25 percent in 2030 (USDOE, 2002a).

Recent policy initiatives provide incentives to triple bioenergy and bioproduct production and use over the next 10-15 years and opportunities exist for a multi-fold increase over these levels in future years. The National Energy Supply Diversification and Disruption Prevention Act (Energy Policy Act of 2005), includes a Renewable Fuel Standard (RFS) for gasoline (7.5 billion gallons by 2012) (U.S. Congress, 2005). Added incentives to use cellulose feedstocks to produce ethanol are provided. Research monies are dedicated to the conversion of cellulose. While not included in the Energy Act of 2005, pressures to adopt Renewable Portfolio Standards[1] continue to increase as 20 individual states have adopted some level of RPS by 2006. In addition to the policy incentives above, the Department of Energy has set long term goals of increasing biomass power from 2.7 quads (1 quadrillion BTUs) to 4.8 quads by 2030, biobased transportation fuels from 0.5 percent of 2001 fuel consumption to 20 percent by 2030, and biobased products from 5 percent of 2001 production to 25 percent in 2030 (USDOE, 2002a).

These developments could stimulate large increases in bioenergy and bioproducts over the next decades. As the industry expands, the relative economic competitiveness of different feedstock-technology-product combinations will change as a result of the interplay between agricultural market dynamics, feedstock choice and supply, and conversion costs. These factors will substantially impact the cost, feedstock, and technology mixes needed to supply expanding bioenergy and bioproduct industries.

Rationale and Significance

An understanding of key issues that determine the cost and structure of expanding bioenergy and bioproduct industries is needed. As these industries expand, competition for the various agricultural feedstocks used in their production will increase, triggering higher feedstock prices and, consequently, higher costs for the bioenergy and bioproducts. The impacts of feedstock competition will significantly affect the expansion pathways needed to meet the combined bioenergy and bioproduct demands.

Recent studies of the RFS and RPS have been conducted, but they examine the potential impacts of an RFS and RPS individually, rather than combined, and none include the potential for additional feedstock competition used to produce bioproducts. The DOE estimates that by the year 2015 under the RFS, 4.87 billion gallons of ethanol (260 million gallons from cellulose feedstocks) and 10 million gallons of biodiesel could be produced (USDOE-EIA, 2001b; DiPardo, 2001). Under the RPS, electricity generated from biomass could reach 168.3 billion kWh by 2020 (USDOE-EIA, 2001a and 2001b; Haq, 2001). Under the reference case, much of this electricity is generated from urban wood wastes, forest residues, and mill residues, but with an RPS and/or potential new emission standards, dedicated energy crops and agricultural

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[1] The Renewables Portfolio Standard (RPS) is a policy that requires a minimum amount of wind, solar, biomass, and geothermal energy is included in the portfolio of electricity resources serving a state or country.

residues become viable feedstock options as well. Studies evaluating agricultural sector economic impacts of the RFS examine ethanol production from corn starch and biodiesel production from soybeans (USDA-OCE, 2002a; Urbanchuk, 2001, FAPRI, 2001). Cellulose ethanol is acknowledged as a commercially viable option within the time frame of the RFS, but is not included in their studies. No study incorporates the potential for bioproducts.

Currently, the agricultural sector is in the midst of decreased farm income caused by stagnant or reduced export demand and increased costs of production coupled with the deficit's pressure to reduce government payments. Nationally, net farm income is forecasted to decrease in 2006 by $16 billion dollars and remain flat through 2015 (USDA-ERS, 2006).

As agricultural incomes decline, public pressure increases toward establishing value-added operations in rural areas. Interest in economic development of rural areas traditionally focuses on manufacturing opportunities and has neglected agricultural value-added prospects. Rural communities export raw commodities or feed them to livestock and export the livestock. Agricultural value-added opportunities are usually classed as minimum wage operations, but attention is now focusing on adding value to the basic commodities themselves (e.g., farmer owned ethanol plants). Converting biomass to energy or products is a means to add value and increase income in rural areas. The additional demands for bioenergy and bioproducts have the potential to generate higher market revenues and replace current levels of government support programs.

What is biomass? Under the Energy Policy Act of 2005, the term biomass is defined as "any lignin waste material that is segregated from other waste materials and is determined to be nonhazardous by the Administrator of the Environmental Protection Agency and any solid, nonhazardous, cellulosic material that is derived from— (A) any of the following forest-related resources: mill residues, precommercial thinnings, slash, and brush, or nonmerchantable material; (B) solid wood waste materials, including waste pallets, crates, dunnage, manufacturing and construction wood wastes (other than pressure-treated, chemically-treated, or painted wood wastes), and landscape or right-of-way tree trimmings, but not including municipal solid waste (garbage), gas derived from the biodegradation of solid waste, or paper that is commonly recycled; (C) agriculture wastes, including orchard tree crops, vineyard, grain, legumes, sugar, and other crop byproducts or residues, and livestock waste nutrients; or (D) a plant that is grown exclusively as a fuel for the production of electricity" (U.S. Congress, 2005).

Numerous starch, oil, and cellulose feedstocks can be used to produce bioenergy and bioproducts; however, this study limits the sources to corn starch, corn stover, soybean oil, wheat straw and switchgrass. Starch from the corn grain is the dominant feedstock in the existing ethanol industry and is the feedstock of choice for most ethanol plants under construction or planned (Renewable Fuels Association, 2002). Soybeans are the second largest crop produced in the United States and are used primarily for food (oil) and feed (meal) uses. Inks produced from soybean oil are used in the printing, lubricants, and surfactants industries (Little, 2001). Increases in industrial uses of soybeans (e.g., biodiesel) and corn starch (ethanol), will not only affect the cost of the corn and soybeans, but will also significantly affect the livestock feed markets through higher crop prices and increased production of livestock feed coproducts. Corn stover and wheat straw, the non-grain portion of the corn and wheat plants, are relatively abundant agricultural residues with the same geographic production regions as corn and wheat (i.e., Midwest for corn and Plains and Northwestern states for wheat). However, removal of corn stover and wheat straw raises many issues about soil quality and long-term productivity. Estimation of corn stover and wheat straw supply curves incorporate residue levels needed for erosion control. Switchgrass is a high yielding native perennial grass with a wide geographical range. Recent analyses indicate that switchgrass can be an economically competitive feedstock alternative (Walsh *et al*, 2003a and 2003b; De La Torre Ugarte *et al*, 2003; McLaughlin *et al*, 2002).

All previously mentioned agricultural feedstocks compete with each other and other crops for agricultural land. The interplay of crop production factors and food, feed, industrial, and export demands largely determine the geographic location, quantity, and price of each crop produced in the United States. As production levels of bioenergy and bioproducts increase, demand for corn, wheat, and soybeans will increase relative to other crops. The potential introduction of a new crop (switchgrass) and developing industrial markets for corn stover and wheat straw, combined with the new uses for corn, wheat, and soybeans, will lead to a new equilibrium in the agricultural markets that will feature different land use patterns, crop quantities, and crop prices than those today. These dynamic market interactions will alter the cost and structure (i.e., feedstock, technology, product mix) of expanding bioenergy and bioproduct industries.

The study provides new information on the extent that the nation can rely on agricultural production as feedstocks for bioenergy and bioproduct industries. National expansion curves for an integrated bioenergy and bioproducts industry are developed. The study provides estimates of key impacts (changes in land allocation, farm prices and income, trade, and government cost) resulting from the expansion pathways. Further, the study provides information on the impacts the bioenergy and bioproduct industries will have on our agricultural sector as measured by price changes, acres in production, changes in net farm income, and location of production.

Methodology

The analysis will incorporate agricultural market dynamics, feedstock supply, conversion technologies, and simultaneously increased bioenergy and bioproduct demand quantities to develop a national industry expansion curve. Figure 1 presents a schematic of the interplay of these factors.

The analysis uses POLYSYS, an agricultural policy simulation model of the U.S. agricultural sector that includes national demand, regional supply, livestock, and aggregate income modules (De La Torre Ugarte, Ray and Tiller, 1998). POLYSYS is anchored to published baseline projections for the agricultural sector and simulates deviations from the baseline. In this study, a 10-year United States Department of Agriculture (USDA) baseline for all crop prices and supplies, except hay, taken from the Food and Agriculture Policy Research Institute (FAPRI) baseline for U.S. agriculture is used. The POLYSYS model includes the eight major crops (corn, grain sorghum, oats, barley, wheat, soybeans, cotton, and rice) as well as switchgrass and hay (alfalfa and other hay included). Corn and wheat residue costs and returns are added to the corresponding crop returns if profitable. POLYSYS is structured as a system of interdependent modules of crop supply, livestock supply, crop demand, livestock demand and agricultural income. The supply modules are solved first, then crop and livestock demand are solved simultaneously, followed by the agricultural income module. This project adds a bioproducts module which fills exogenous demands from the feedstock sources. The bioproducts module captures the dynamics of corn grain, soybean, and cellulosic feedstocks competing to fill bioproduct demands by using a tatonment method to find the optimal allocation of feedstocks to satisfy these demands.

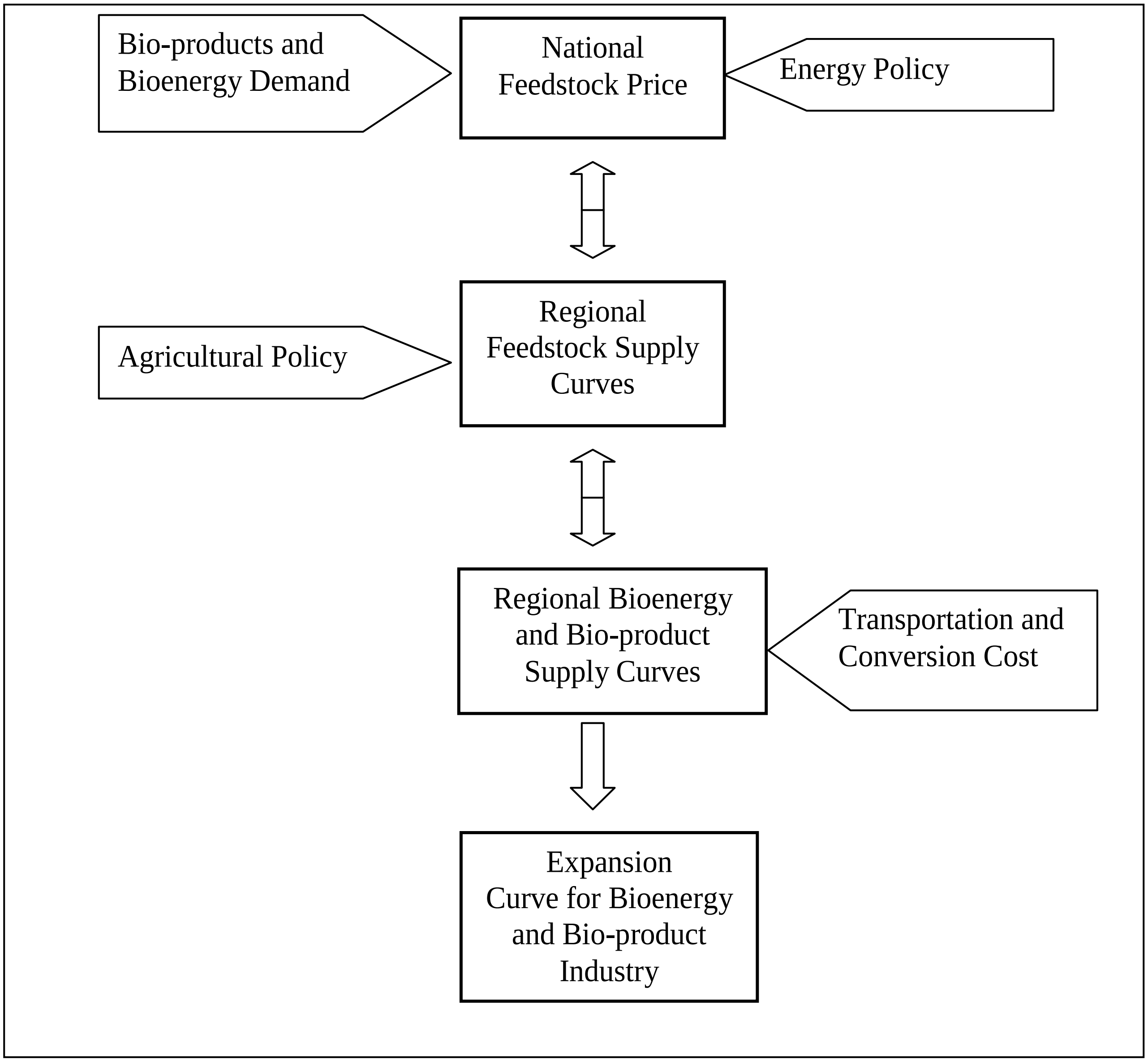

Figure 1. Schematic of key interactions incorporated into the modeling framework

The cropland included in this analysis is the acreage planted to the eight major crops and hay. Additionally, pasture acreage classed as cropland can come into production if the loss of regional pasture can be made up with additional hay production. This analysis does not include the possibility of planting and harvesting switchgrass in acreage enrolled in the Conservation Reserve Program (CRP) nor does it include land currently classed as pasture/rangeland. The objective of the model is to fill projected energy and bioproduct demands from corn grain, soybeans, switchgrass and crop residue supplies and estimate the effects upon production, prices, acreage, government payments and net returns of all model crops and livestock.

Crop Supply Module

The regional crop supply module consists of 305 independent linear programming regional models that correspond to USDA's Agricultural Statistical Districts (ASD). Each ASD is characterized by relatively homogeneous production. The purpose of the crop supply module is to allocate acreage at the regional level to the model crops given baseline information on regional acreage of the model crops, regional enterprise budgets of each crop, lagged prices and a set of allocation rules.

Regional baseline acreage is anchored to a national baseline, which is disaggregated to a regional level based on historical crop production and supply patterns. Once the total acreage available for crop production in each ASD is determined, the supply module allocates acres to competing crops using a linear programming model that maximizes expected returns using one-year-lagged naive price expectations.

Production from each of the 305 ASDs is determined independently and aggregated to obtain national production. Allocation rules are utilized to limit the acreage that can switch from production of one crop to another or removed from production in each ASD. These allocation rules prevent corner solutions and simulate the inelastic nature of agricultural supply. For a full description of the land allocation rules, see the methodology section of The Economic Impacts of Bioenergy Crop Production of U.S. Agriculture (De La Torre Ugarte, *et al*, 2003).

Pasture Acreage

In regions where switchgrass is determined to be profitable, some pasture can be made available to both switchgrass and any other crop. Additionally, in order for pasture acreage to come into production, the loss of regional forge production must be replaced with new regional hay production. The Agricultural Census of 2002 (USDA-NASS, 2002) lists 56 million acres as "crop acreage in pasture". This application makes these lands available to be converted into other crop production. A condition for this to occur is that hay acreage must replace the lost forage productivity regionally of the lost pasture acreage. Regional pasture yields are taken from English, Disney, and Schraufnagel, 1989. For each region annually, the amount of pasture that can potentially switch into other crops is determined by:

$$P_{out} = \%H_{avail} * H_{acres} * H_{yield} / P_{yield}$$
$$H_{in} = P_{out} * P_{yield} / H_{yield}$$
$$NG_{pot} = P_{out} - H_{in}$$

Where, P_{out}	is the amount of pasture that can come out of pasture if available.
$\%H_{avai}$	is the percentage of current hay total acreage that can expand.
H_{acres}	is the current hay total acreage.
H_{yield}	is the yield per acre of hay.
P_{yield}	is the yield per acre of pasture.
H_{in}	is the acres of hay that will come in to replace $P_{out.}$
NG_{pot}	is the potential net gain in acreage.

The actual net gain in land available to other crops from pastureland is constrained through several mechanisms: 1) only pasture classified as historical cropland is available, 2) pasture can only come in at the rate at which hay acreage can grow, 3) hay lands must replace lost forage production at regional hay yield levels, and 4) there must be a crop with positive net expected income to absorb the new land available. Through this filtering process, substantially less than the 56 million acres of “crop acreage in pasture” actually comes into production and less still into production of other crops besides hay.

Crop Demand Module

The crop demand module estimates national level demand quantities and prices using elasticities and changes in baseline prices. Crop utilization is estimated for domestic demand (food, feed, and industrial uses), exports, and stock carryovers. Derivative products such as soybean oil and meal are also included. Demand quantities are estimated as a function of own and cross price elasticities and selected non-price variables such as livestock production. The crop prices are estimated using price flexibilities and stock carryovers are estimated as the residual element. The income module uses information from the crop supply, crop demand, and livestock modules to estimate cash receipts, production expenses, government outlays, net returns, and net realized farm income.

Livestock Module

The livestock module is an integrated version of the Economic Research Service (ERS) econometric livestock model (Weimar and Stillman, 1990) that interacts with the crop supply and demand modules to estimate livestock production, feed use, and market prices. Livestock production levels are a function of lagged livestock and feed own and cross prices, as well as the baseline levels and exogenously determined variables such as livestock exports. The livestock sector is linked to the supply and demand modules principally through the feed grain component. Livestock quantities affect feed grain demand and price, and feed grain prices and supply affect livestock production decisions. Exports and imports of livestock products are exogenous to the model.

Biomass Feedstock Sources

Switchgrass

To evaluate the potential of switchgrass to provide feedstocks to the bioproduct market, potential geographic range, yields, and enterprise budgets of switchgrass are incorporated within POLYSYS.

Switchgrass can grow in all regions of the United States. However, for the purpose of this analysis, the geographic ranges where production can occur are limited to areas where it can be produced with high productivity under rain-fed conditions. Geographic regions and yields are based chiefly on those contained in De La Torre Ugarte (2003). The production of switchgrass included in this analysis is assumed suitable on 368 million of the total 424 million acres included in POLYSYS. Switchgrass yields, by ASD, range from an annual rate of 2 to 6.75 dry tons per acre (dt/ac) depending on location. Switchgrass is not a crop option in western arid regions.

In this application, switchgrass is not available in the first two years of simulation. Currently, in the United States, switchgrass is not produced as a dedicated energy feedstock, although it is grown on some CRP acres and on hay acres as a forage crop. The lack of large-scale commercial production necessitates a lag time before switchgrass can become a feedstock for ethanol or other bioproduct production. A minimum of two years to begin large scale switchgrass production is assumed.

Switchgrass expected prices are a function of one year lagged market prices. Once planted, the expected yields for switchgrass remain fixed for the life of the production rotation. Also, once acres are planted into switchgrass, they remain in switchgrass through the end of the simulation.

Crop Residues

To evaluate the potential of crop residues to provide feedstocks to the bioproduct markets, POLYSYS includes corn stover and wheat straw response curves that estimate stover and straw quantities (dt/ac) as a function of corn and wheat grain yields, and stover and straw production costs as a function of yields of removable residue (dt/ac). The removal of corn stover and wheat straw raises environmental quality issues such as erosion, carbon levels, tilth, moisture, and long-run productivity. The analysis accounts for quantities of stover and straw that must remain on the field to keep erosion at less than or equal to the tolerable soil loss level. The methodology for estimating quantities that must remain takes into account soil types, slope, crop rotations, type and timing of tillage and other management practices, and climate zones among other factors (Nelson, 2002). The estimated response curves incorporated into POLYSYS were obtained from Nelson *et al*. (2003).

The quantities of corn stover and wheat straw that can be removed are the amounts of stover or straw produced minus the highest of the estimated residue quantities needed to control for rain and wind erosion. Corn and wheat grain yields (bushel/acre) are converted to biomass quantities (dt/ac) using standard grain weights (lb/bu) and residue to grain ratios (Heid, 1984; Larson, Gupta, and Onstad, 1979). Corn and wheat yield quantities are those used in POLYSYS. Total quantities of corn stover and wheat that can be collected in each county are estimated for each tillage and dominant crop rotation scenario and weighted by the number of acres using each tillage practice (Conservation Tillage Information Center, 2004).

The costs of collecting corn stover and wheat straw include baling and staging (loading on bale wagon and moving to field edge). Cost of nutrient replacement is included in the estimated collection costs. Costs are estimated as a function of the residue that can be removed (dt/ac).

The choice of whether residues are harvested from a particular county is determined by figuring the difference between the cost of collecting residues to the edge-of-field and the market revenue generated. If positive, the residues are harvested from all county corn or wheat acres. Expected prices are current year residue prices. Current year prices are used because the choice to harvest residues can be made on already planted acres.

Bioenergy Demands

This project's future demand scenario for biopower and biofuels was taken from the DOE's *Vision for Bioenergy and Biobased Products in the U.S* (USDOE, 2002b). The DOE has set goals that biopower can fill 4 percent of U.S. electrical demand in 2010 and 5 percent in 2020, and that biofuels can fill 4 percent of U.S. fuel demand in 2010 and 10 percent in 2020. This is equivalent to 3.2 quads of electricity coming from biomass feedstocks by 2010 and 3.9 quads by 2020, and 1.18 quads of liquid fuels from biological feedstocks by 2010 and 2.98 quads by 2020.

Agricultural feedstocks from residues and/or energy crops are not expected to fill all of biopower demand alone. Quantities of other biological feedstocks projected to help fill total biopower demand and are listed in the DOE's *Energy Outlook, 2005* (USDOE-EIA, 2005). Residential wood, commercial biomass, industrial municipal solid waste, industrial biomass and electrical municipal solid waste are projected to supply 2.83 quads of biopower by 2010 and 2.96 quads by 2015. After subtracting the total contribution of these other sources from total biopower demand, agriculturally based biopower feedstocks must supply an additional 0.37 quads by 2010 and 0.59 quads by 2015 in order to meet the DOE goal. Yearly quantities in kWh are listed in Table 1.

Table 1. Biopower and biofuel demand increases in 2005, 2010, and 2014

		Projected Year of:		
Demand	Units	2005	2010	2014
Bioelectricity	Billion kWh	87.74	108.45	160.03
Ethanol	Billion Gallons	2.31	10.23	18.39
Biodiesel	Billion Gallons	0.14	0.42	0.55

USDA baseline projections already account for a level of corn grain and soybean production for biofuel uses. USDA's 2005 baseline expects corn grain to supply .339 quads of biofuel by 2010 and .361 quads by 2015. Soybeans are expected to supply .005 quads of biofuel by 2010 and .0065 by 2015. These are subtracted from the DOE goals to arrive at the total biofuel demand that must increase above baseline to meet the DOE goal.

DOE's goal for biofuels includes both ethanol and biodiesel. If the increase required to meet the DOE goal required equal increases of both biodiesel and ethanol, then soybean production would need to increase two fold. To avoid this unrealistic scenario, it is assumed that biodiesel will only meet 15 percent of DOE's goal. The other 85 percent of DOE's biofuel's goal not met by biodiesel will be added to ethanol's goal. Therefore, the total DOE biofuel goal is unchanged. For example in 2010, the DOE goal for biodiesel is 4 percent of projected diesel demand, or .396 quads. In the simulation, biodiesel will only meet 15 percent of this, or .059 quads. The other .337 quads are added to ethanol's demand projection to increase it from .78 to 1.117. Therefore, the total biofuels demand goal is unchanged at 1.118 quads. DOE biopower and biofuel demand goals given for the years 2010 and 2020 are annually estimated by linearly connecting the given goals and then converted into millions of kWh and millions of gallons respectively.

Bioproduct Demands

DOE goals also include the production of bioproducts from biomass feedstocks. While thousands of products can be produced, this analysis examines only potential markets for succinic acid, levulinic acid, lactic acid, and 1,3-propanediol. These organic chemicals have been chosen because (1) they have been identified as high priority building block chemicals that can be used to produce a number of additional organic compounds, (2) they have recently begun commercial production or are nearing commercialization status, and (3) sufficient information is available to construct rough supply schedules. A detailed description of the methodology and assumptions used to estimate the conversion costs, conversion rates, and price for the bioproducts is contained in Appendix B.

Optimal Feedstock Allocation

POLYSYS was modified to allow the biomass feedstocks (switchgrass, corn stover, wheat straw) to compete with corn grain feedstock in the production of ethanol. Because ethanol demand is such a large user of agricultural feedstocks, changes in feedstock mix will affect the market price of feedstocks and, therefore, total ethanol costs. An iterative process was used to find the annual feedstock mix where the cost of producing ethanol from corn grain is equal to the cost of producing ethanol from biomass.

Figure 2 shows the process of balancing the feedstock quantities so as to arrive at an equivalent price of ethanol from either corn grain or biomass. First, there are demands that can only be filled with biomass feedstocks; electricity and levulinic acid demand must be met from biomass. Therefore, biomass prices are increased by $1 increments until the model's supply side responds with enough biomass to fill these demands. Next, the demands that can be met with either biomass or corn grain are filled with corn grain in the first iteration. Biodiesel demand is also filled with soybeans. The crop module responds with a high corn price resulting from the increased level of corn demand. At this point, the price of ethanol made from corn grain is used to figure a corresponding price for biomass that would produce ethanol at the equivalent price. The corresponding price of biomass is derived by the following equation:

$$\mathrm{CORPRC}_{\mathrm{biomass}} = (\mathrm{Pcorn} / \mathrm{TECH}_{\mathrm{corn}} + \mathrm{CONV}_{\mathrm{corn}} - \mathrm{CONV}_{\mathrm{biomass})}) / \mathrm{TECH}_{\mathrm{biomass}}$$

Where, $\mathrm{CORPRC}_{\mathrm{biomass}}$	is the corresponding price of biomass
$\mathrm{P}_{\mathrm{corn}}$	is the price of corn grain
$\mathrm{TECH}_{\mathrm{corn}}$	is gallons of ethanol per bushel of corn grain
$\mathrm{CONV}_{\mathrm{corn}}$	is the conversion cost of corn grain to ethanol per gallon
$\mathrm{CONV}_{\mathrm{biomass}}$	is the conversion cost of biomass to ethanol per gallon
$\mathrm{TECH}_{\mathrm{biomass}}$	is the gallons of ethanol per dry ton of biomass

The extra cost of transporting biomass feedstocks from the farm gate to the production facilities is added to all biomass bioproduct conversion costs. The transportation cost is estimated at $8.85 based on 2005 transportation cost estimates provided by Dager (2005) and assuming a maximum distance of 50 mile trip one way. The corresponding price of biomass is compared to the current iteration's price of biomass. If the corresponding price is higher than the iteration price, then it indicates that ethanol made from corn grain is more expensive than ethanol made from biomass. In this situation, the price of biomass is increased and iteration takes place.

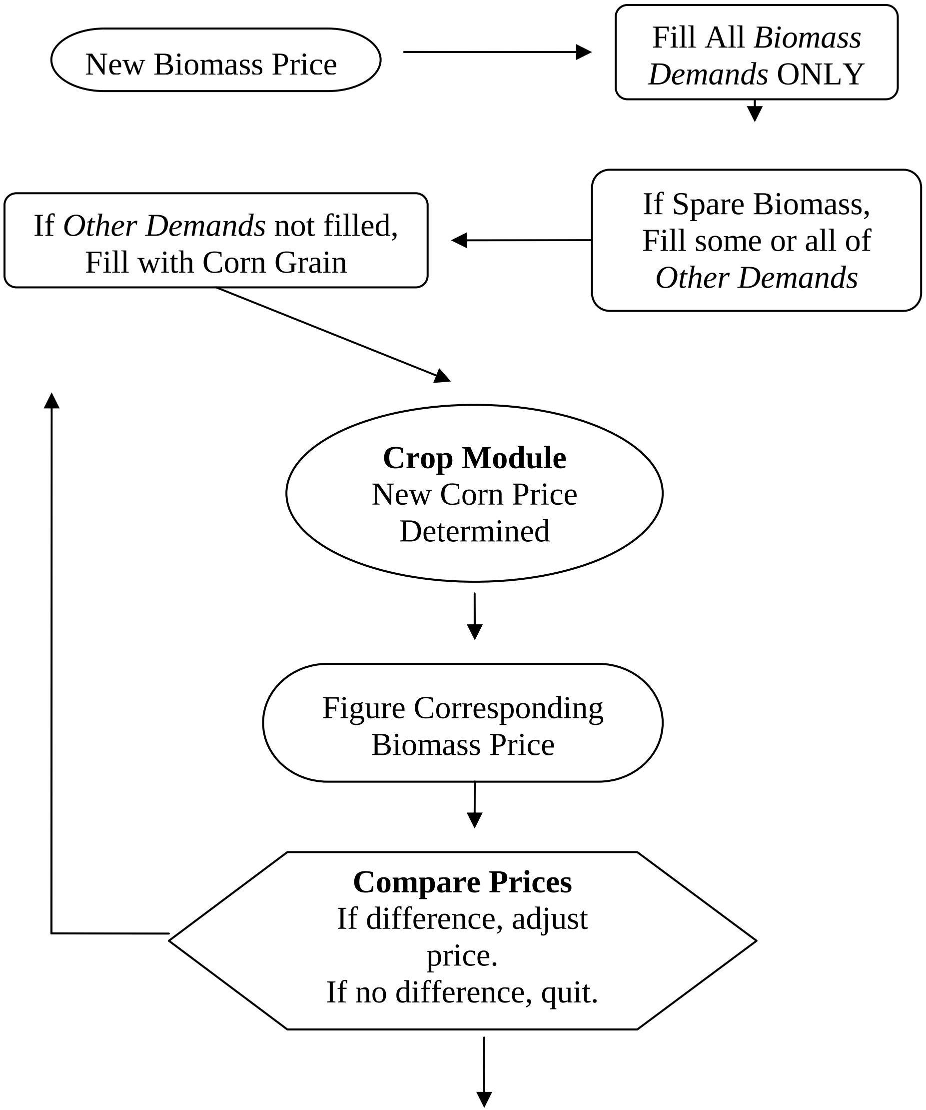

Figure 2. Schematic of the methods employed to determine feedstock price required to meet demands

The higher biomass price will result in a positive supply response in the next iteration, thereby displacing some of the corn grain demand and lowering corn grain price. The iterations continue until the corresponding price of biomass is equal to current iteration biomass price. Once this is achieved and equivalent ethanol costs of production exist, the model has determined the optimal market level of feedstock quantities.

Because ethanol is the dominate bioproduct that can use either biomass or corn grain, its feedstock allocation determines market prices. The iterative corresponding price process described above could be done for every multi-source feedstock bioproduct, but the results would not alter significantly given their rather small portion of total feedstock demand (Bullock, 2006).

Byproducts
Distiller's dry grains from ethanol production and soybean meal from biodiesel production are integrated within the model to evaluate how their quantities and prices affect the final market equilibrium. For every bushel of corn grain used in ethanol production, 18.3 lbs of distiller dry grains are produced. It is assumed that distillers dry grains substitutes for livestock corn grain demand. One ton of distillers dry grain displaces 35.71 bushels of corn feed demand

Credit from the market revenue of distiller's dry grains to the production of ethanol reduced total production costs of ethanol. The market price of distiller's dry grains was estimated by the following equation:

$$DDG_{prc} = 22.7 + 30.80 * (Corn_{prc})$$
$$(R^2 = .96)$$

where, DDG_{prc} is the price per ton of distillers dry grains
$Corn_{prc}$ is the price per bushel of corn grain

For every bushel of soybeans used in biodiesel production, 45.5 lbs of soybean meal are produced. The soybean meal byproduct enters into the POLYSYS soybean product module where price are endogenously determined. The revenue from the sale of soybean meal is credited to the production of biodiesel and acts to reduce the total production costs.

Results

The level presented in Table 1 was attainable within the model simulation. However, this amount of production impacted the agricultural sector of the United States. This section will: 1) analyze the results upon crop acreage, distribution, and prices, 2) evaluate the individual bioenergy and bioproduct sectors, reporting the evolution of their optimal feedstock sources over time and how this effects their total cost of production, 3) report feedstock total quantities and their use over time, and their geographic source, and finally, 4) show the effect of this scenario upon national and regional government payments and farm incomes.

Acreage

Total acreage increases over the simulation period, with most model crops gaining slightly in acreage above the baseline as some pasture acreage converts to crop production. Hay acreage increases to replace lost forage from pasture acreage. Switchgrass is the major benefactor of newly available pasture acreage. Table 2 shows the acreage changes in 2006, 2010, and 2014. In 2010, net acreage grew by 11.4 million acres above baseline. Hay acreage increased by 13 million acres. Corn acreage and soybeans were up by 0.9 million and 1.6 million, respectively. The only model crop to lose acreage was wheat, which declined slightly by 0.1 million acres. The reason for wheat acreage declining is that in most wheat regions, switchgrass is not profitable; therefore, no acreage comes into production from pasture, and in regions where switchgrass is profitable it often takes land from wheat. Figure 3 shows the changes in crop acreage over the entire simulation period.

Table 2. Selected baseline crop acreage and change in acres as a result of biofuel and bioproduct production

Item	2006	2010	2014
		Million Acres	
Change in total acreage	0	11.4	13.6
Corn Baseline	73.6	75.6	76.6
Change in Corn Acreage	*2.4*	*0.8*	*0.8*
Soybean Baseline	72.4	71.7	71.4
Change in Soybean Acreage	*-2.0*	*1.6*	*1.4*
Wheat Baseline	49.7	51.0	52.3
Change in Wheat Acreage	*-1.0*	*-1.1*	*-0.8*
Hay Baseline	62.8	63.1	63.2
Change in Hay Acreage	*-0.3*	*13.0*	*16.4*
Switchgrass	*0.0*	*14.8*	*18.0*

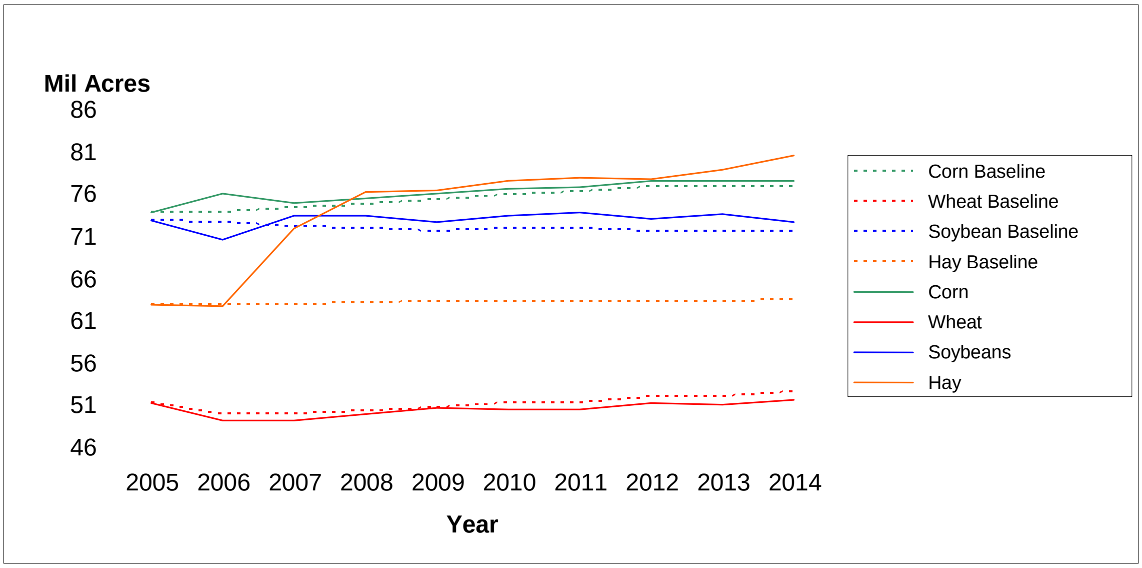

Figure 3. Comparison of baseline with biofuel and bioproduct harvested acres over time for corn, wheat, soybeans, and hay

Net gains are only realized in the eastern United States (Figure 4) since pasture conversion to cropland is restricted to those regions where switchgrass can be grown. In these regions, pasture is further restricted since pasture can only come into production at the rate at which hay can replace pasture. Regions in Missouri, Tennessee, Kentucky and Virginia gain a significant amount of acreage (Figure 4). These are also regions where hay acreage yields well and the production of switchgrass is competitive with other crops. There are also regions, like in Nebraska, that saw large increases in acreage but switchgrass was not produced because it was not competitive with other crops grown.

Prices

Even with the additional acreage relieving some of the supply pressure upon agriculture, the increased demands placed upon the sector resulted in increased market prices. Figure 5 shows the prices of corn and soybeans, both baseline and simulated over the period. In 2010, corn prices increase from $2.45/bu to $3.40/bu, and soybeans jump from $5.55/bu to $6.37/bu. Other non-feedstock prices also increase. Wheat goes from $3.40/bu to $3.81/bu. Cotton and rice prices remain fairly stable with increase in 2010 of only $0.02/lb and $0.77/cwt, respectively. By 2014, the price gains were simulated to be very significant. The price of corn rose from a baseline of $2.45/bu to $4.16/bu, and soybeans increased from $5.70/bu to $6.84. Wheat increased from $3.60/bu to $4.04/bu. Appendix Table A.10 contains the estimated prices of all model crops over the simulation period.

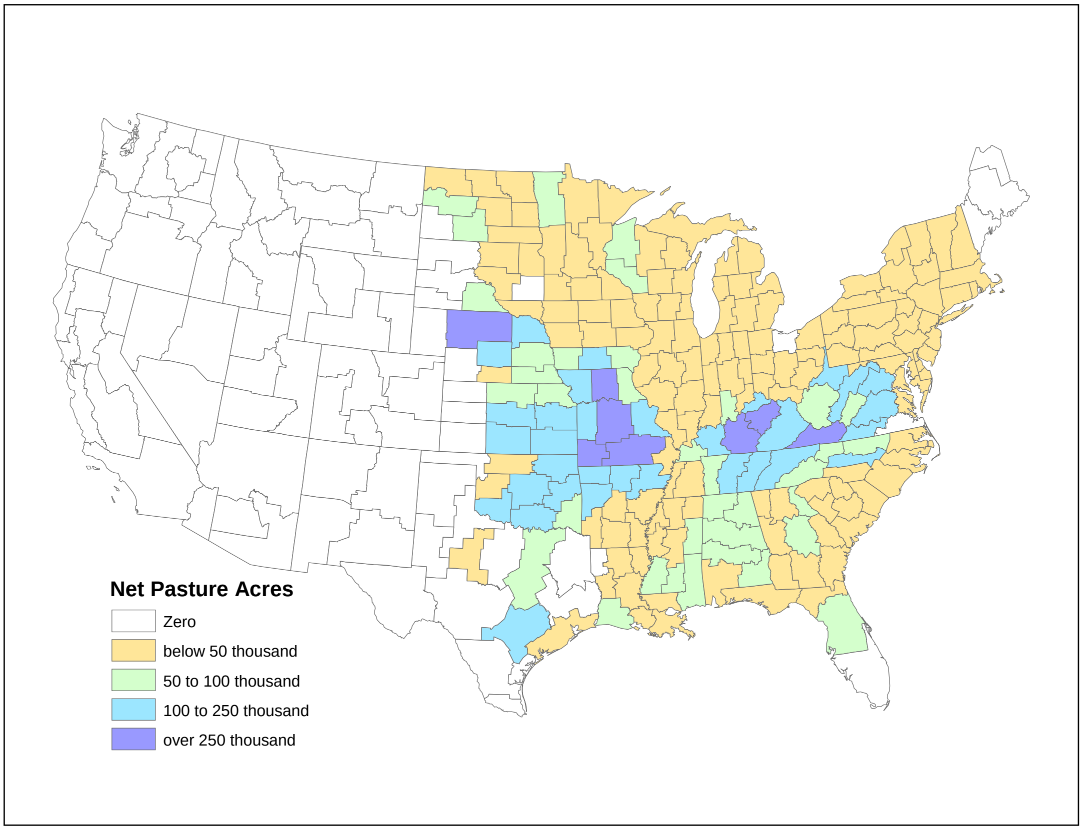

Figure 4. Cumulative pasture acres converted to cropland, 2014

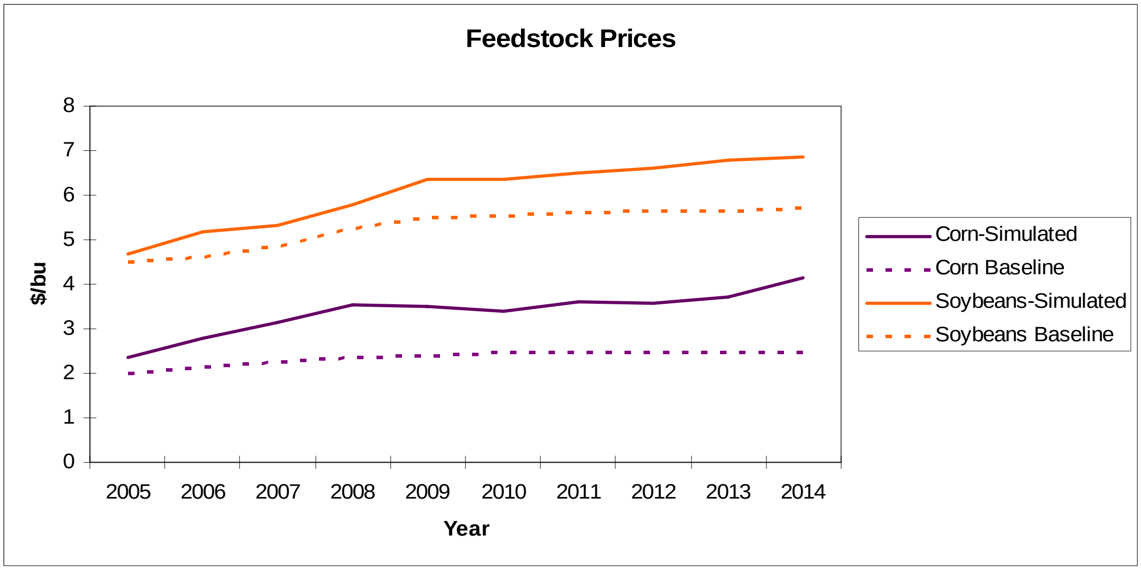

Figure 5. Corn and soybean prices for the baseline and the biofuel and bioproduct scenario.

The price of biomass, on a per Btu basis, is the same for all cellulosic feedstocks in a given year. Biomass prices start at $31/dt in 2005 (Figure 6). This price is the minimal price needed to fill only electricity and levulinic demands since these can not use other feedstocks. In the first two years, switchgrass is not available to be harvested. In the third year, switchgrass is harvested. At $31/dt, annual quantities of biomass slowly increase, sufficient to fill all of the electricity and levulinic demands, and some additional quantities go toward ethanol production.

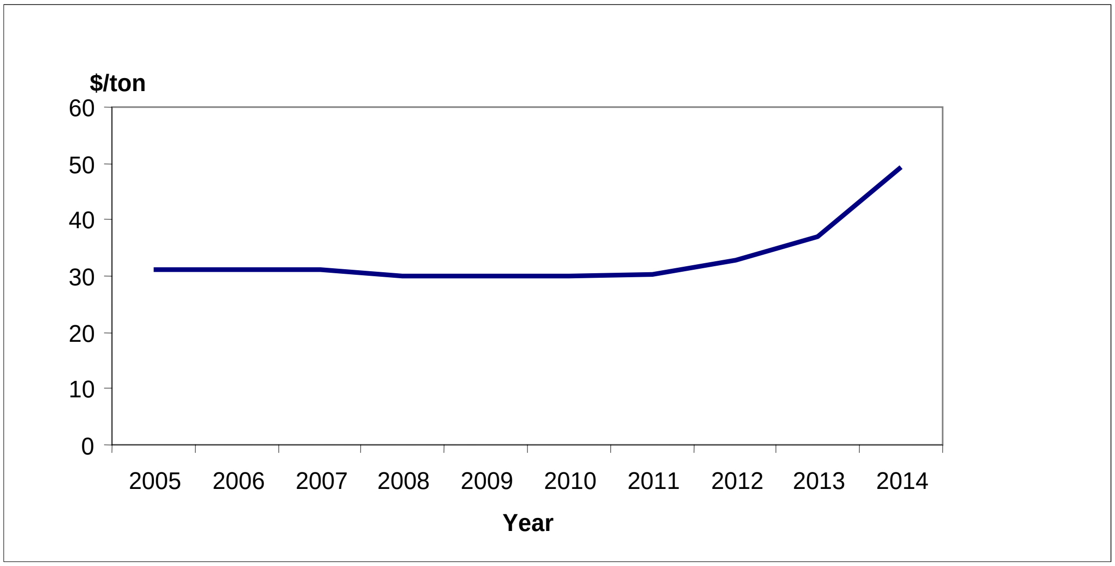

Figure 6. Estimated biomass feedstock supply price (farmgate)

Corn grain's equivalent price stays below the minimum biomass price and is able to fill the rest of the demands. Only in years 2011 and beyond does supply pressure increase corn grain prices, and, therefore, raises the equivalent price above $30/dt. Biomass price rises accordingly and fills more ethanol demand. Biomass price increases to $32.83/dt in 2012 and reaches $49.34/dt by 2014. Appendix Table A.9 contains estimates of the annual price for biomass, corn, soybeans, soybean oil and soybean meal over the simulation period.

Biopower

Biopower only uses cellulosic biomass as a feedstock. In the initial two years, when switchgrass is unavailable, additional demand for biopower is met entirely from corn stover and wheat straw. Simulated demand of 88 billion kWh of electricity is generated through the use of 58.8 million dry tons of crop residues in 2005 (Figure 7). As switchgrass comes into production, it begins to displace crop residues as a feedstock. By 2009, residue feedstocks drop to 32.4 million dry tons as switchgrass increases to 26.8 million dry tons to meet 104 billion kWh of projected biopower demand. After 2009, both crop residues and switchgrass quantities increase to meet increasing biopower demand. By 2014, corn stover is the largest contributing feedstock with 64.5 million dry tons; switchgrass is second with 38.9 million dry tons, followed by wheat straw with 2.8 million dry ton of feedstock to meet 160 billion kWh of demand. Total production cost per kWh hovers around $0.03/kWh until feedstock price increases in the final three years of simulation, when prices are estimated to rise to $0.042/kWh by 2014. Appendix Table A.1 lists the yearly demand levels, feedstock quantities by type, total costs (feedstock and conversion) and per gallon costs.

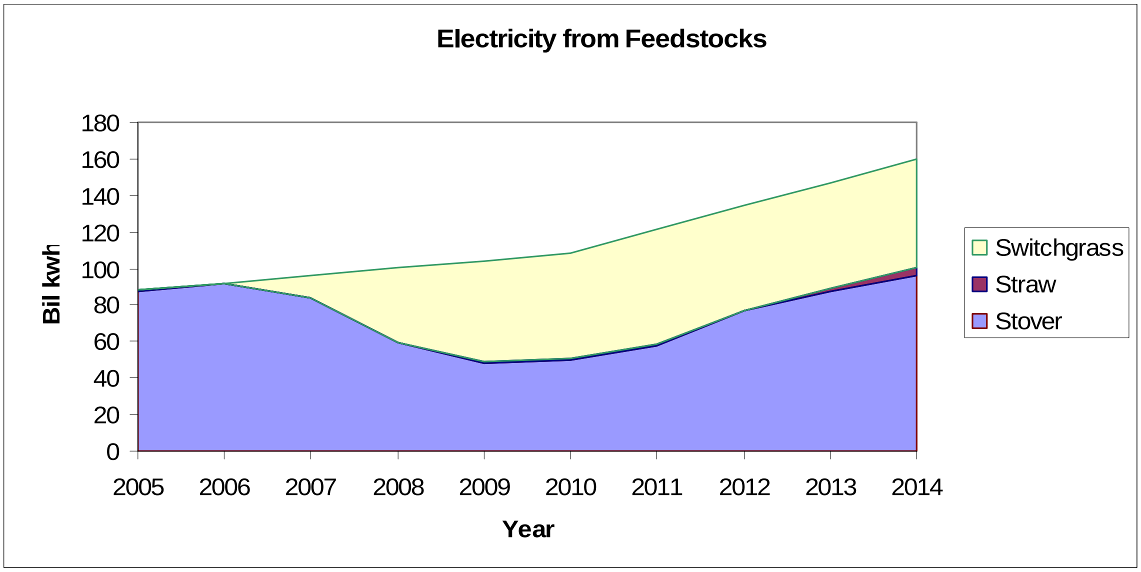

Figure 7. Feedstock quantities used in the production of electricity by type.

Ethanol Production

Ethanol feedstock demand can be met with either biomass or corn grain. Any additional quantities of biomass produced at the minimum price to fill electricity and levulinic are carried over to be used in ethanol production. Beyond this residual quantity, biomass must compete with corn grain, with the lowest cost producer of ethanol filling demand first. In the years before 2011, corn grain is the least cost feedstock in terms of equivalent production cost. Since the production of biomass feedstocks exceed the demand requirements for electricity production and other biomass only demands, ethanol from cellulose increases slowly during the 2006-2011 period. Switchgrass costs and yields are based on a ten year production cycle and on expectations over the ten year period. Acreage once planted to switchgrass is assumed to remain in switchgrass for a ten year period. In addition, switchgrass yields in the initial two years of production are less then the yields in years 3 through 10. Thus, switchgrass feedstocks increase over time and supplies exist even when corn prices decline. Even though biomass is a more expensive feedstock in the early years, using the residual quantities in the production of ethanol allows ethanol production to ease into the use of biomass as a feedstock. Additionally, use of residual biomass relieves price pressure upon corn grain. Without this assumption, a sharp and sudden use of biomass in 2011 as the equivalent price of corn grain rises and biomass becomes competitive as a feedstock in ethanol production.

In 2011, when biomass and corn grain are directly competing, 30.5 million dry tons of corn stover, 32.5 million dry tons of switchgrass and 2.32 billion bushels of corn are used to produce 11.24 billion gallons of ethanol. By 2014, 69.2 million dry tons of stover, 3 million dry tons of straw, 41.8 million dry tons of switchgrass and 2.88 billion bushels of corn are used to produce 16.73 billion gallons of ethanol. Although corn grain feedstocks in ethanol production are increasing in total quantities, its portion in meeting total ethanol demand is decreasing (Figure 8, Appendix Table A.2). By 2014, nearly half of projected ethanol demand is met through the use of biomass feedstocks. Total production costs begin at $1.08 per gallon in 2005, increases to $1.50 per gallon in 2010, and $1.73 per gallon by 2014.

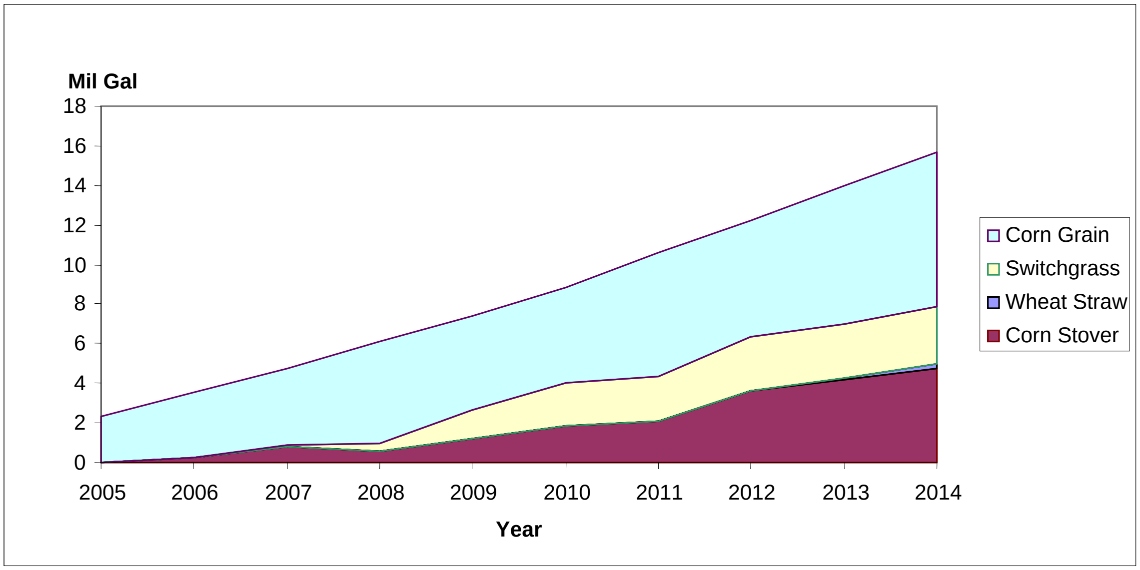

Figure 8. Feedstock quantities used in the production of ethanol by type

Biodiesel

In 2005, 98 million bushels of soybeans are used to produce 140 million gallons of biodiesel at a cost of $1.34 per gallon. Conversion costs are negative due to credit from the sale of soybean meal bioproduct. By 2010, 420 million gallons are produced using 300 million bushels of soybeans at a cost of $2.15 per gallon. By the final year of simulation, 394 million bushels are used to produce 550 million gallons at $2.74 per gallon. Even our relatively conservative projection in biodiesel growth sends soybean prices from $4.68 in 2005 to $6.84 in 2014. Appendix Table A.3 provides estimates on the annual demand levels, feedstock quantities by type, total costs (feedstock and conversion) and per gallon costs.

Bioproducts

Bioproducts make up a very small portion of total feedstock demand. By 2014, demand from lactic acid, succinic acid and PDO only make up 2 percent of total corn grain feedstock demand. Levulinic acid, which is the only bioproduct using biomass, only accounts for 0.02 percent of total biomass feedstock demand. The markets included their size, price per unit and likely penetration are listed in the bioproduct tables in Appendix B. Individual markets only come into the model if the total cost of production from biological sources is less than the current market price.

Levulinic acid demands 0.49 million dry tons of biomass to produce 175 million pounds by 2014 – first pulling from corn stover but then increasing the quantity of switchgrass through the final year. Although feedstock prices increase, total cost of levulinic acid production decrease due to projected drops in conversion costs. Succinic acid is capable of being produced from either corn grain or biomass, but in this simulation only corn grain is used. By the final year, 34 million pounds of succinic acid are produced from 1.23 million bushels of corn grain at a cost of $0.56 per pound. Lactic Acid is one of the largest bioproduct demands, with total demand increasing over the simulation period due to projected growth of polylactic acid, a derivative of lactic acid. By 2014, 60 million bushels of corn are used to produce 1.74 billion pounds of lactic acid at a cost of $0.49 per pound. Propanediol demand increases over the simulation period to 320 million pounds in 2014. To fill this demand, 64 million bushels of corn grain are consumed as feedstock. Total production costs increase as feedstock costs increase to $1.14 per pound in 2014. Appendix Tables A.5, A.6, A.7, and A.8 provide information on the levels of simulated demands, the quantities and types of feedstocks, and total costs (feedstock and conversion) for each bioproduct.

Feedstock Quantities and Use

In the initial year of simulation, biomass makes up slightly more than half of total feedstock volume (Figure 9). As switchgrass comes into production in 2007, biomass's share of total volume increases through 2014. By the final year, biomass makes up two thirds of total feedstock volume. An estimated 134 million tons of stover, 5.9 million tons of wheat straw, 80.9 million tons of switchgrass, and 6.0 billion bushels of corn are used in 2014, to fill biofuel and bioproduct demands.

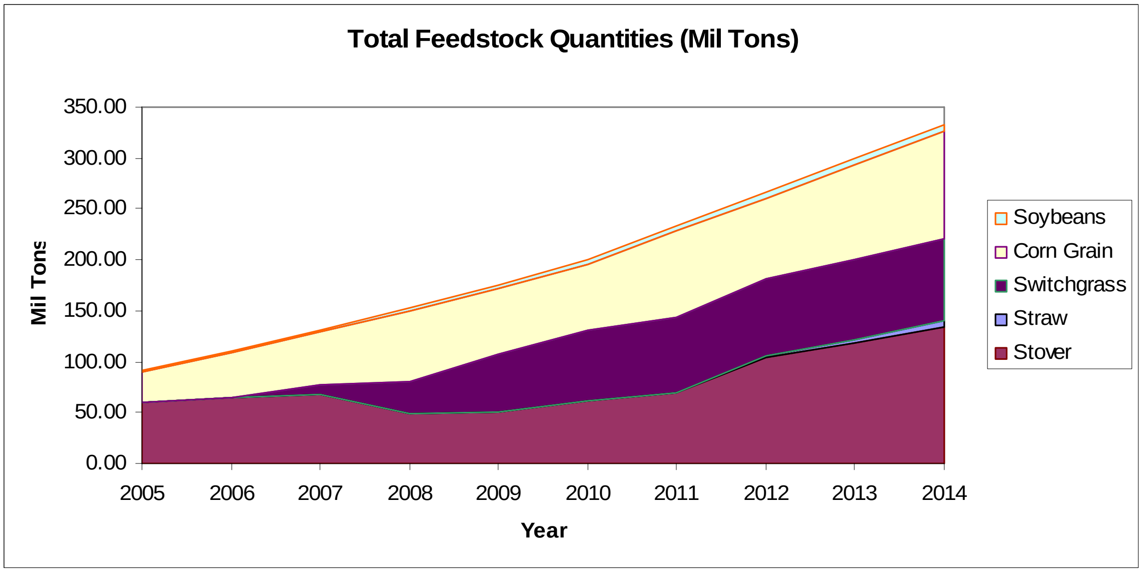

Figure 9. Feedstock quantities used in the production of biofuels and bioproducts

Corn Grain

All but 2 percent of total corn grain use for non-traditional products is used in the production of ethanol. In the initial two years, corn grain demand increases rapidly (Figure 10). After switchgrass comes into production, some of the demand for corn grain is displaced, causing use of corn grain for ethanol and other bioproducts to decline in 2009 and 2010. From 2011 onward, corn grain and biomass have equivalent costs in ethanol production. Corn grain remains competitive with biomass and total use increases annually through 2014. Total use of corn grain for biofuel and bioproduct production is 1.7 billion bushels in 2005, 3.7 billion bushels in 2010 and 6.0 billion bushels in 2014.

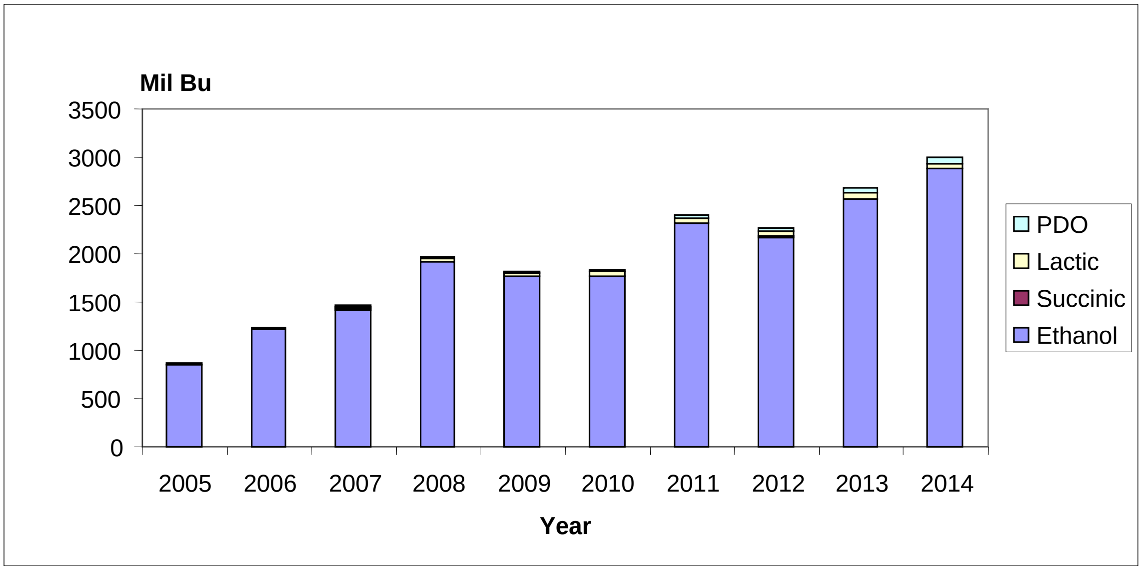

Figure 10. Corn use as a feedstock in the production of biofuels and bioproducts

Switchgrass

Switchgrass is not harvested in the initial two years because of an assumed lag time in beginning large scale commercial production, but once it comes into production its use increases throughout the simulation period (Figure 11). Switchgrass is used in the production of electricity, ethanol and levulinic acid. Initially, the vast majority of switchgrass goes toward the production of electricity, but as switchgrass production increases, more is allocated to ethanol production. From 2011 onward, supply pressure on corn grain ethanol stimulates ethanol production to switch to biomass as a feedstock. By 2014, 41.8 million dry tons of switchgrass are estimated to go toward ethanol production, making up more than half of all switchgrass feedstock.

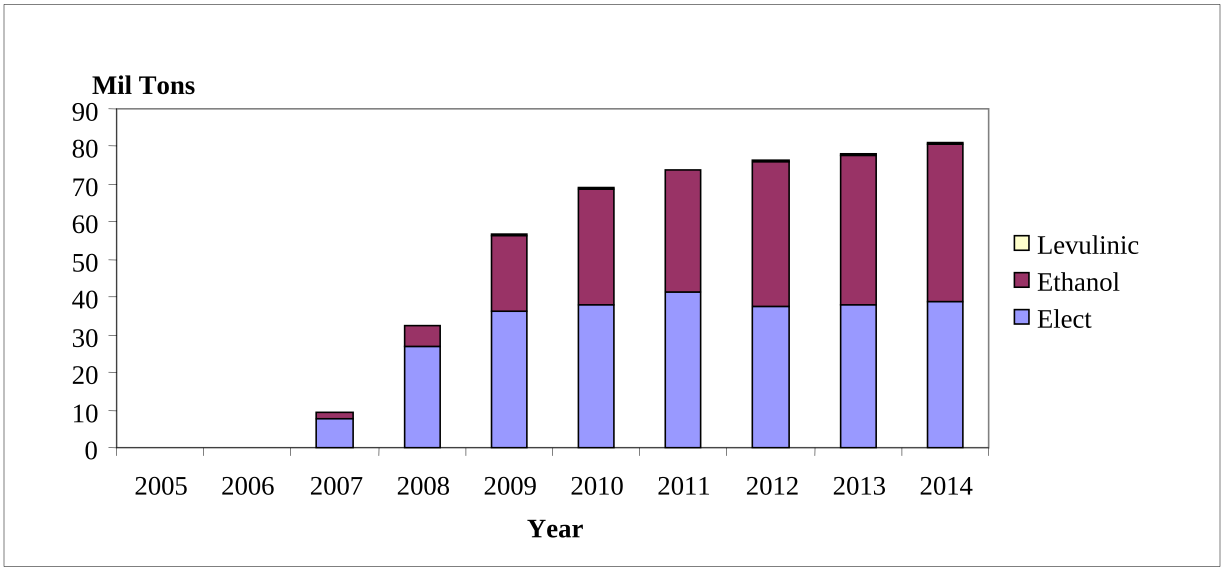

Figure 11. Switchgrass as feedstock in the production of biofuels and bioproducts

In the final year of simulation, the Southeast, Texas and Missouri are the dominant areas of switchgrass production (Figure 12). Higher valued croplands in the northern plains are not converted to switchgrass. Previous studies show the Dakotas being another potential dominant area of switchgrass production. This region does not produce in our current scenario. This is due to the relatively low price paid for biomass throughout the majority of the study period (below $35/dt) and the lower estimated yields for the drier northern and western regions.

Crop Residues

Corn stover and wheat straw are harvested in the initial year of simulation to fill both electricity and ethanol demands. Corn stover makes up 99 percent of the crop residue total quantity. In the initial two years, switchgrass is not in production, therefore biopower and ethanol demands rely heavily upon residues. As switchgrass becomes produce in 2008, total residue quantities fall, but as demands for biopower and ethanol continue to increase through the simulation period, total residue quantities climb again (Figure 13). In the final three years, increasing prices allow for a quick increase in residues economically available to be harvested. In the initial years, when corn grain is relatively cheap and abundant, ethanol production does not use many tons of residues; however, as corn prices increase, crop residues become more competitive and an increased demand for crop residues is projected.

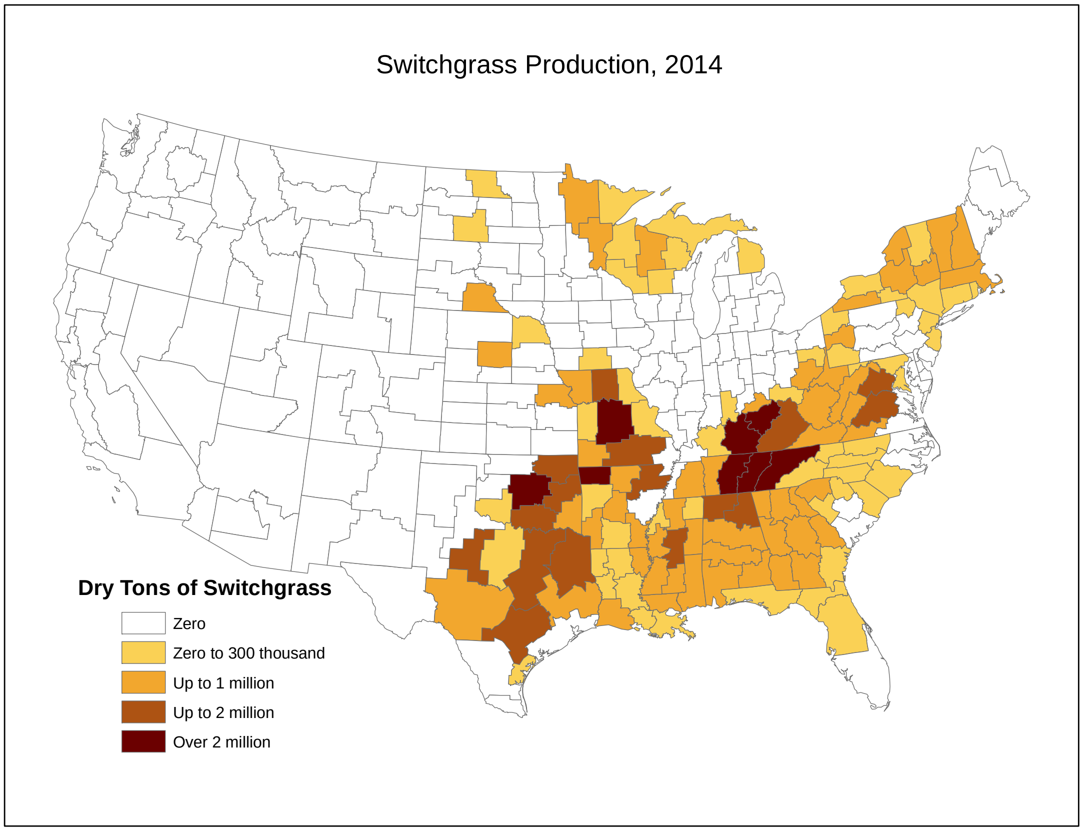

Figure 11. Geographic distribution of switchgrass production, 2014

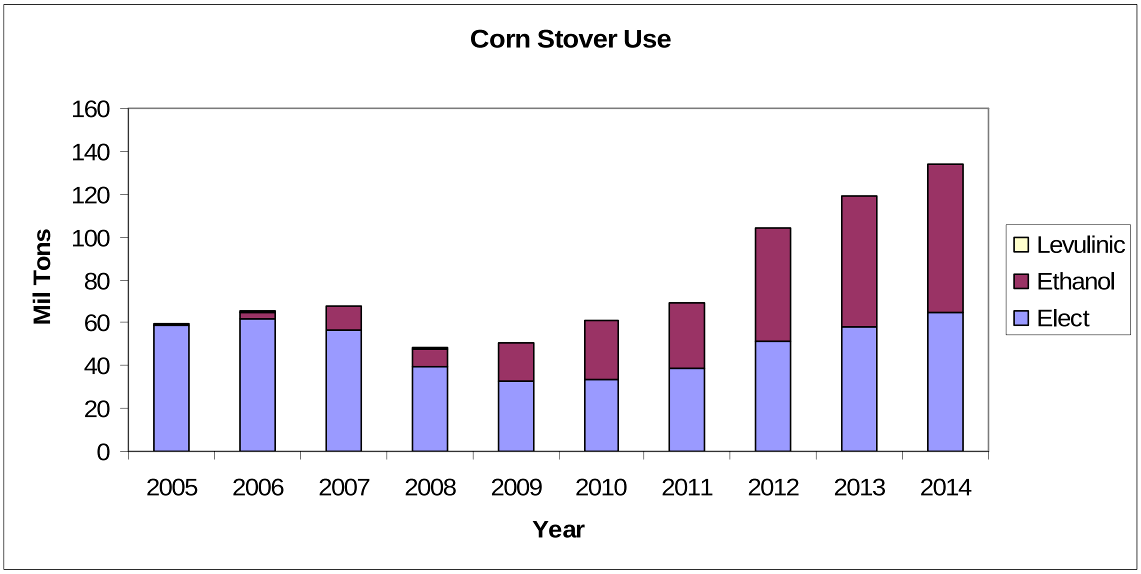

Figure 12. Crop residues as a feedstock in the production of biofuels and bioproducts

Residues are a waste product of grain farming, so naturally residue production mirrors grain production. Use of corn stover is concentrated in the dominant high yielding Corn Belt of Iowa, Minnesota, Illinois, eastern Nebraska, and Indiana (Figure 14).

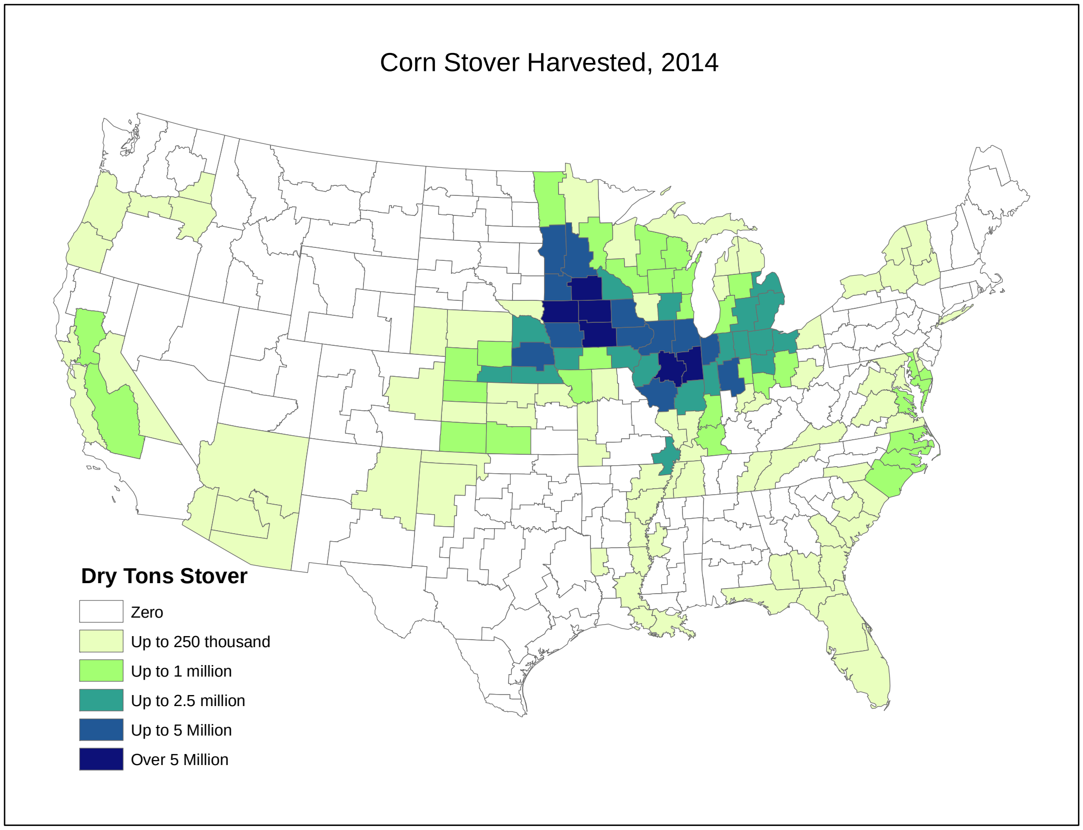

Figure 13. Geographic distribution of harvested corn stover, 2014

Government Payments and Farm Income

USDA baseline projects the current level of loan deficiency payments and counter cyclical payments to decrease rapidly until 2010, when only cotton continues to receive these payments. Because contract payments are not price dependent, they remain constant. The simulation of biopower demands causes government payments to fall even faster than the baseline due to increased market prices. In the initial years, there is a large difference between baseline and simulated government payments; however, later in the simulation the savings are not as great since the baseline government payments have already dropped to zero (Figure 15). The simulation does not affect cotton acreage and prices significantly and, therefore, cotton’s government payments stay relatively stable. One could envision other baseline scenarios where government payments remain high. Under such scenarios, the creation of a biopower sector would lead to greater savings.

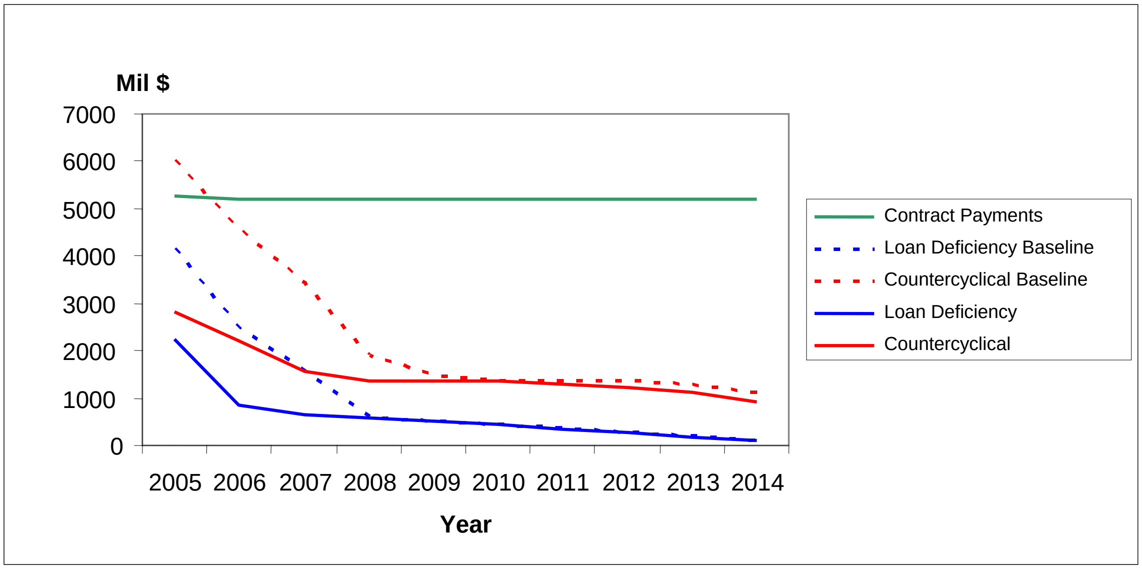

Figure 14. Baseline and simulated government payments to model crops

Farmers gain in net returns through directly growing feedstocks such as switchgrass or crop residues, or indirectly through higher crop prices brought about by resource competition. The greatest gains are captured by the high intensive Corn Belt, both through directly harvesting residues and higher corn prices (Figure 16). Note that some of these high return areas, such as in Missouri, do not produce residues, but they still gain as a result of higher grain prices. The

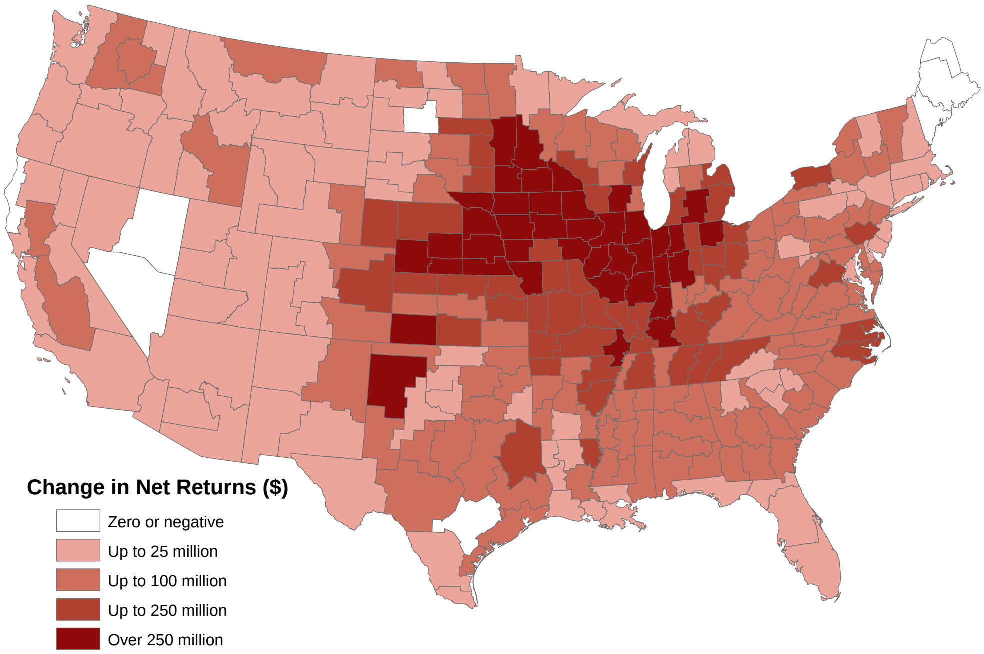

Figure 15. Changes in crop net returns by region, 2014

switchgrass producing areas of Kentucky and Tennessee are also big gainers of net returns. Also, areas throughout the country that are not directly producing feedstocks gain net returns. Nationally, these net returns aggregate to significant gains for the crop sector. Figure 17 shows baseline and simulation model crop net returns. In the initial two years, there is not much difference between the two lines because prices are still relatively low and switchgrass has not begun to compete for land resources. As switchgrass comes into production, net returns rapidly rise through 2014. By 2014, crop net returns nearly double increasing from $39.2 billion to $72.6 billion, a gain of $33.4 billion.

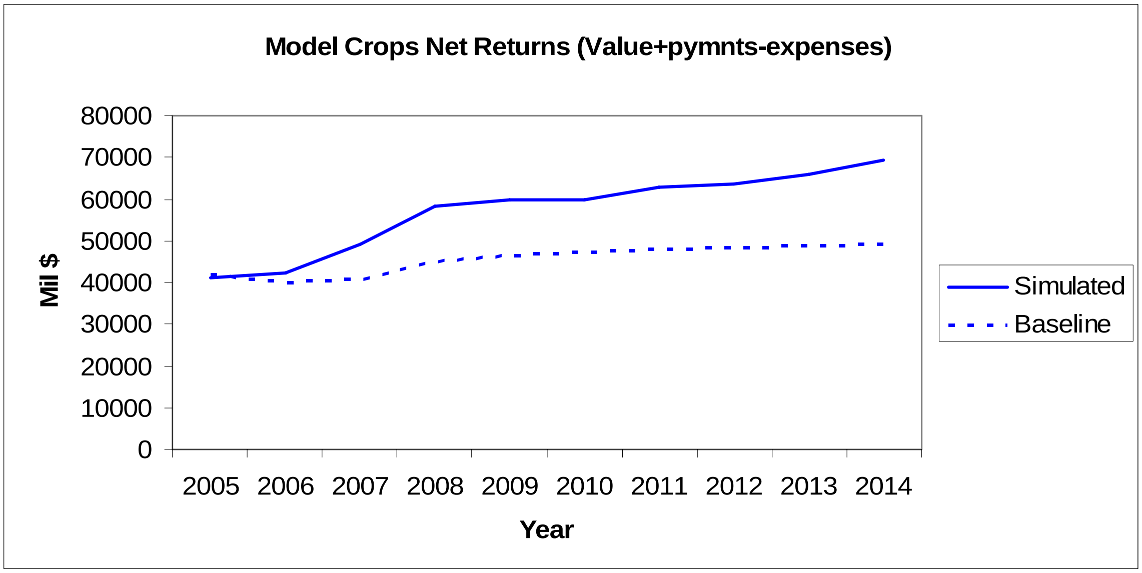

Figure 16. A comparison of the baseline net returns to those net returns projected with biofuel and bioproduct production

Realized net income, which includes the livestock sector, follows the same trend as crop net returns. Realized net income in 2014 increases $21.6 million from $54.5 million to $76.1 million (Figure 18).

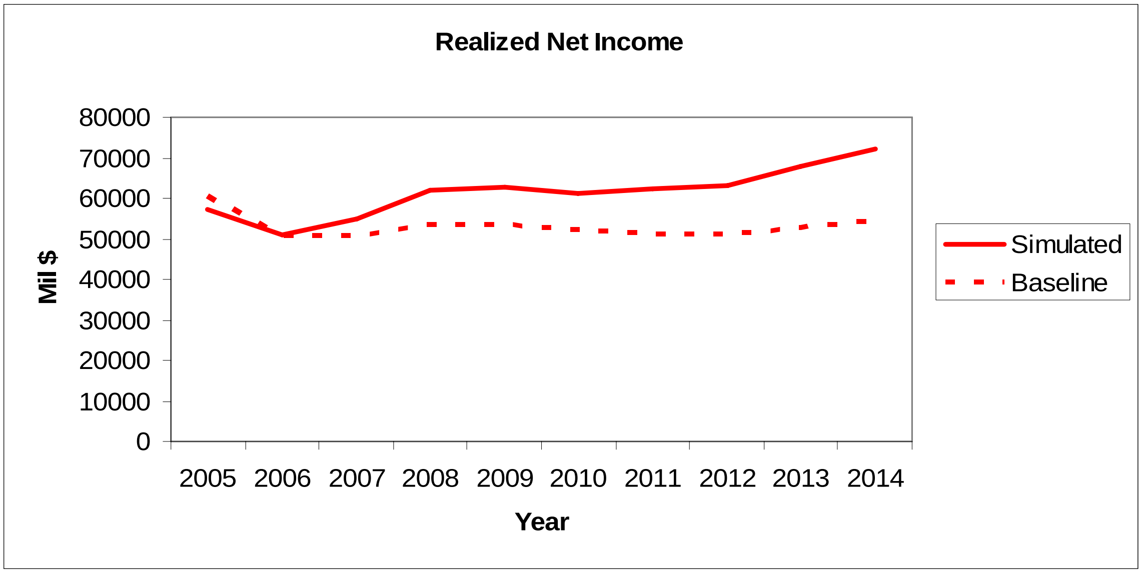

Figure 17. **A comparison of the baseline realized net farm income to realized net farm income projected with biofuel and bioproduct production**

Discussion

The results of this study support the conclusion that the agricultural sector is in the position to supply bioenergy and bioproducts consistent with goals set forward in the *Vision for Bioenergy and Biobased Products in the U*.S (USDOE, 2002b), that biopower can fill 5 percent of U.S. electrical demand in 2020, and that biofuels can fill 10 percent of U.S. fuel demand in 2020.

The use of all three bioproduct feedstock sources (energy dedicated crop, residues and corn grain) allowed the market to smoothly adjust to the rapid increase in demand. Without the use of all three, the ability of the agricultural sector to meet bioenergy and bioproduct demands would be severely stressed. The study showed that crop residue collection can be quickly increased to fill feedstock demand in the initial years while switchgrass production matures. As switchgrass matures, residue collection falls until stresses upon corn grain demand necessitate their increased collection again.

The use of crop residues meets the entire feedstock demand by the electricity sector until switchgrass comes into production. Both crop residues and switchgrass quantities increase to meet increasing biopower demand; by 2014, corn stover is the largest contributing feedstock with 64.5 million dry tons; switchgrass is second with 38.9 million dry tons, followed by wheat straw with 2.8 million dry ton of feedstock to meet 160 billion kWh of demand.

Corn grain and cellulosic biomass can be use as ethanol’s feedstock. In the years before 2011, corn grain is the least cost feedstock in terms of equivalent production cost and ethanol from cellulose increases slowly during the 2006-2011 period. By 2011, cellulosic biomass and corn grain are directly competing as feedstock in the production of ethanol, 30.5 million dry tons of corn stover, 32.5 million dry tons of switchgrass and 2.32 billion bushels of corn are used to produce 11.24 billion gallons of ethanol. At the end of the period of analysis, the year 2014, nearly half of projected ethanol demand is met through the use of biomass feedstocks to produce 16.73 billion gallons of ethanol.

The analysis considers soybeans as the only feedstock for biodiesel production. The production of biodiesel demands 98 million bushels of soybeans at the beginning of the period to produce 140 million gallons of biodiesel and by the final year of the analysis, 394 million bushels are used to produce 550 million gallons. Bioproducts make up a very small portion of total feedstock demand. By 2014, demand from lactic acid, succinic acid and PDO only make up 2 percent of total corn grain feedstock demand. Levulinic acid, which is the only bioproduct using biomass, only accounts for 0.02 percent of total biomass feedstock demand.

The increased demands placed onto agriculture for the production of energy imply a net gain of 14 million acres by 2014. The additional acreage results from the intensification of the pastureland management, which allows some of the cropland planted in hay to shift into both dedicated energy and the eight major crops. Some regions of Missouri, Kentucky and Tennessee can gain more than 250,000 net acres, with a majority of the acres being converted to switchgrass.

Even with the additional acreage relieving some of the supply pressure upon agriculture, the increased demands upon the agricultural production sector resulted in increased market prices. By 2014, the simulated price gains were significant. The price of corn rose from a baseline of $2.45/bu to $4.16/bu, and soybeans increased from $5.70/bu to $6.84. Wheat increased from $3.60/bu to $4.04/bu. The price of biomass, on a per Btu basis, is the same for all cellulosic feedstocks in a given year. Biomass prices start at $31/dt in 2005 and rise accordingly as ethanol demand increases. Biomass price increases to $32.83/dt in 2012 and reaches $49.34/dt by 2014.

USDA baseline projects the current level of loan deficiency payments and counter cyclical payments to decrease rapidly until 2010, when only cotton continues to receive these payments. Because contract payments are not price dependent, they remain constant. The simulation of biopower demands causes government payments to fall even faster than the baseline due to increased market prices and, hence, farm incomes from cash receipts.

Farmers gain in net returns through directly growing feedstocks such as switchgrass or crop residues, or indirectly through higher crop prices brought about by resource competition. The greatest gains are captured by the high intensive Corn Belt, both through directly harvesting residues and higher corn prices. The switchgrass producing areas of Kentucky and Tennessee are also big gainers of net returns. Also, areas throughout the country that are not directly producing feedstocks also gain net returns. Nationally, these net returns represent significant gains for the crop sector. By 2014, crop net returns nearly double increasing from $39.2 million to $72.6 million, a gain of $33.4 million. Realized net income, which includes the livestock sector, follows the same trend as crop net returns. Realized net income in 2014 increases $21.6 million from $54.5 million to $76.1 million.

In summary, the use of agricultural feedstock to produce bioenergy and bioproducts opens an opportunity for agriculture to increase net farm income, reduce government payments, and be an engine for rural economic development. Further research should evaluate the means to achieve the bioenergy and bioproduct goals. Questions regarding feedstocks, conversion, and location need to be addressed. The answers to these three elements will have significant environmental and social consequences.

References

Aden, A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, B. Wallace, L. Montague, A. Slayton, and J Lukas. 2002. *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stove.* National Renewable Energy Laboratory, NREL/TP-510-32438.

Biometics, Inc. 2002. *Commercialization of the BIOFINE Technology for Levulinic Acid From Paper Sludge*. Final Technical Report, Report No. DOE/CE/41178, April 23.

Bozell, J.J., and R. Landucci, eds. 1993. *Thermal/Chemical and Bioprocessing Components*. Alternative Feedstocks Program: Technical and Economic Assessment. Washington, D.C.: U.S. Department of Energy, Office of Industrial Technologies.

Bullock, D. 2006. Cross-Hedging Distillers Dried Grains (DDG) Using U.S. Corn Futures. Internet site: http://www.mda.state.mn.us/riskmgmt/crosshedgingdistillers.pdf (Accessed May 9, 2006).

Bush, G.W. 2006. Fact Sheet: President Bush's Four-Part Plan to Confront High Gasoline Prices. Internet site: http://www.whitehouse.gov/news/releases/2006/04/print/20060425-2.html (Accessed May 17, 2006).

California Energy Commission (CEC). 2001. “Costs and Benefits of a Biomass to Ethanol Production Industry in California.” Internet site: http://www.energy.ca.gov/reports/2001-04-03_500-01-002+002A.PDF (Accessed May 17, 2006).

Cameron, D.C., and J.A. Koutsky. 1994. “Conversion of Glycerol from Soydiesel Production to 1,3-Propanediol”. Final Report to National Biodiesel Development Board. Internet site: http://www.biodiesel.org/resources/reportsdatabase/reports/gen/19941001_gen-243.pdf (Accessed May 17, 2006).

Chen, X., Z. Xiu, J. Wang, D. Zhang, and P. Xu. 2003. “Stoichiometric Analysis and Experimental Investigation of Glycerol Bioconversion to 1,3-Propanediol by Klebsiella Peneumoniae under Microaerobic Conditions.” *Enzymes and Microbial Technology* 33(September 2003):386-394.

Conservation Tillage Information Center (CTIC). 2004. National Crop Residue Management Survey. Internet site: http://www.ctic.purdue.edu/CTIC/CTIC.html (Accessed May 17, 2006).

Dager, C.A. 2005. Personal Communication. River Operations, Navigation and Hydraulic Engineering, Tennessee Valley Authority. November 2005.

Davison, B., M. Donnelly, J. Frye, R. Landucci, and M. Griffin. 1999. "Production of Chemical Derivatives from Renewables." CRADA Final Report, Oak Ridge National Laboratory, C/ORNL/96-0407.

Davison, B., N. Nghiem, M.Donnelly, and M. Peabody. 2003. "Production of Succinic Acid from Lignocellulosic Hydrolysates". CRADA Final Report C/ORNL/99-0552, Oak Ridge National Laboratory.

De La Torre Ugarte, D.G., D.E. Ray, and K.H. Tiller. 1998. "Using the POLYSYS Modeling Framework to Evaluate Environmental Impacts on Agriculture." *Evaluating Natural Resource Use in Agriculture.* T. Robertson, B.C. English, and R.R. Alexander, eds. Ames, Iowa: Iowa State University Press.

De La Torre Ugarte, D.G., M.E. Walsh, H. Shapouri, and S.P. Slinsky. 2003. "The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture". Report Prepared for the U.S. Department of Agriculture and U.S. Department of Energy. Internet site: http://www.usda.gov/oce/reports/energy/AER816Bi.pdf (Accessed May 17, 2006).

Delucchi, M.A. 1997. *A Revised Model of Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity.* UCD-ITS-RR-97-22, Institute of Transportation Studies, University of California, Davis, November (1997). 210 pp.

Dien, B.S., T.R. Whitehead, N.N. Nichols, C.D. Skory, and M. Cotta. 2004. "Recombinant Biocatalysts for Converting Sugar Mixture to Lactic Acid". Great Lakes Regional American Chemical Society Symposium. Paper No. 40. October 17-20.

DiPardo, J. 2001. "Outlook for Biomass Ethanol Production and Demand." U.S. Department of Energy, Energy Information Administration. Internet site: http://www.eia.doe.gov/oiaf/analysispaper/pdf/biomass.pdf (Accessed May 17, 2006).

Electric Power Research Institute (EPRI) and U.S. Department of Energy. 1997. "Renewable Energy Technology Characterizations". DOE, TR-109496. Internet site: http://www1.eere.energy.gov/ba/pdfs/entire_document.pdf (Accessed May 9,2006).

English, B., J. Menard, and D. De La Torre Ugarte. 2000. "Using Corn Stover for Ethanol Production: A Look at the Regional Economic Impacts for Selected Midwestern States". Department of Agricultural Economics, University of Tennessee, Knoxville, TN. Internet site: http://web.utk.edu/~aimag/pubs/cornstover.pdf (Accessed May 9, 2006).

English, B.C., W.T. Disney, and S.A. Schraufnagel. 1989. *A Documentation of the Endogenous and Exogenous Livestock Sectors of the Agricultural Resource Interregional Modeling System.* Ames, Iowa: Center for Agricultural and Rural Development, Iowa State University, Technical Report 89-TR12.

Evans, M. 1997. “Economic Impacts of the Demand for Ethanol”. Kellogg School of Management, Northwestern University. Internet site: http://www.ethanolrfa.org/resource/reports/view.php?id=125 (Accessed May 9, 2006).

Fitzpatrick, S., and J. Jarnefeld. 1996. “BIOFINE’s Voyage from the Lab to the Plant, or Making Neat-Stuff from Biomass”. *Bioenergy ‘96–the Seventh National Bioenergy Conference: Partnerships to Develop and Apply Biomass Technologies Proceedings*, pp. 1083-1090.

Food and Agricultural Policy Research Institute (FAPRI). 2001. “Impacts of Increased Ethanol and Biodiesel Demand.” FAPRI-UMC Report #13-01. Internet site: http://www.fapri.missouri.edu/outreach/publications/2001/FAPRI_UMC_Report_13_01.pdf (Accessed May 9, 2006).

Greene, J.W. 1996. “Incorporation of Pollution Prevention Principles into Chemical Science Education.” MS Thesis, University of Michigan, July.

Haq, Z. 2001. *Biomass for Electricity Generation.* Washington, DC: U.S. Department of Energy, Energy Information Administration. Internet site: http// www.eia.doe.gov/oiaf/analysispaper/pdf/biomass.pdf (Accessed May 9, 2006).

Heid, W.G., Jr. 1984. “Turning Great Plains Crop Residues and Other Products into Energy.” U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 523, Washington, DC, November.

House, R., M. Peters, H. Baumes, and W. Terry Disney. 1993. “Ethanol and Agriculture—Effect of Increased Production on Crop and Livestock Sectors.” U.S. Department of Agriculture, Economic Resource Service, Agricultural Economic Report No. 667, May.

Kelff, S. 2004. “Succinic Acid Production from Biomass,” Presentation at Symposium for Industrial Microbiology, July. Internet site: http://www.mbi.org/simpresnew.pdf (Accessed May 9, 2006).

Larson, W.E., S.C. Gupta and C.A Onstad. 1979. “Predicting the Effects of Tillage and Crop Residue Management on Soil Erosion”. In Effects of Tillage and Crop Residue Removal on Erosion, Runoff, and Plant Nutrients. Journal of Soil and Water Conservation, Special Publication No. 25.

Leaversuch, R. 2004. “Thermoplastic Polyesters: It’s a Good Time to Know Them Better.” Plastics Technology Online Article. Internet site: www.plasticstechnology.com/articles/200406fa1.html (Accessed May 9, 2006).

Little, A.D. 2001. “Aggressive Growth in the Use of Bioderived Energy and Products in the United States by 2010.” Final Report to the U.S. Department of Energy, October.

Mann, M.K. and P.L. Spath. 2001a. "A Life Cycle Assessment of Biomass Cofiring in a Coal Fired Power Plant." *Clean Products and Processes* 3(August 2001):81-91.

Mann, M.K. and P.L. Spath. 2001b. "Life Cycle Assessment of Biomass Cofiring in a Coal Fired Power Plant." Golden, CO: National Renewable Energy Laboratory, NICH Report No. 29457.

McAloon, A., F. Taylor, W. Yee, K. Ibsen, and R. Wooley. 2000. *Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks*. Golden, CO: National Renewable Energy Laboratory, NREL/TP-580-28893.

McLaughlin, S., D.G. De La Torre Ugarte, C.T. Garten, L.R. Lynd, M.A. Sanderson, V.R. Tolbert, M.E. Walsh, and D.D. Wolf. 2002. "High Value Renewable Energy from Prairie Grasses". *Environmental Science and Technology* 36(May):2122-2129.

NatureWorks LLC. "NatureWorks LLC Demonstrates Continued Renewable Resource-Based Innovation". Internet site: http://www.publicaster.com/info/natureworksPLA/ (Accessed May 18, 2006).

Nelson, R.G. 2002. "Resource Assessment and Removal Analysis for Corn Stover and Wheat Straw in the Eastern and Midwestern United States—Rainfall and Wind-Induced Soil Erosion Methodology". *Biomass and Bioenergy* 22(May):349-363.

Nelson, R.G., Walsh, M., Sheehan, J.J., and Graham, R. 2003. "Methodology for Estimating Removable Quantities of Agricultural Residues for Bioenergy and Bioproduct Use, Applied Biochemistry and Biotechnology". Proceedings of the Twenty-Fifth Symposium on Biotechnology for Fuels and Chemicals, May 4-7, Breckenridge, CO, Vol. 113-116, pp. 13-26.

Paster, M., J.L. Pellegrino, and T.M. Carole. 2003. "Industrial Bioproducts: Today and Tomorrow." Internet site: http://www.biomass.govtools.us/pdfs/BioProducts OpportunitiesReportFinal.pdf (Accessed May 9, 2006).

Petrulis, M., J. Sommer, and F. Hines. 1993. "Ethanol Production and Employment." U.S. Department of Agriculture, Economic Resource Service, Agricultural Information Bulletin No. 678.

Renewable Fuels Association. 2002. "Growing Homeland Energy Security, Ethanol Industry Outlook 2002". Internet site: http//www.ethanolrfa.org/outlook2002.html (Accessed May 9, 2006).

Schoenberger, C.R. 2003. "Greenhouse Effect". Internet site: www.forbes.com/forbes/2003/0203/054_print.html (Accessed May 9, 2006).

Shapouri, H., J.A. Duffield, and M. Wang. 2002. "The Energy Balance of Corn Ethanol: An Update." U.S. Department of Agriculture, Office of the Chief Economist, Agricultural Economic Report No. 813.

Sheehan, J. 2002b. *Life Cycle Analysis of Ethanol from Corn Stover*. Golden, CO: National Renewable Energy Laboratory, NICH Report No. PO-510-31792.

Sheehan, J.J., J.A. Duffield, R.B. Coulon, and V.J. Camobreco. 1996. "Life Cycle Assessment of Biodiesel versus Petroleum Diesel Fuel." IECEC 96: 31st Intersociety Energy Conversion Engineering Conference Proceedings, pp. 2140-2143.

Sheehan, J., K. Paustian, and M. Walsh. 2002a. "Is Ethanol from Corn Stover Sustainable—a Case Study in Cyber Farming." Accepted for Presentation at the Annual Meeting of the American Institute of Chemical Engineers, Indianapolis, IN, November 3-8.

Tyson, K. S., J. Bozell, R. Wallace, E. Petersen, and L. Moens. 2004. *Biomass Oil Analysis: Research Needs and Recommendations* Golden, CO: National Renewable Energy Laboratory, NREL/TP-510-34796, June.

U.S. Congress, House of Representatives. 2000. *Agriculture Risk Protection Act of 2000.* Washington, DC: Public Law 106-224, 106th Congress, 20 June. Internet site: http://www. aphis.usda.gov/brs/pdf/AgRiskProtAct2000.pdf (Accessed May 9, 2006).

U.S. Congress, House of Representatives. 2002. *Farm Security and Rural Investment Act of 2002*. Washington, DC: Public Law 107-171, 107th Congress, 13 May 2002. Internet site: http://www.nrcs.usda.gov/about/legislative/pdf/PLaw107171.pdf (Accessed May 9, 2006).

U.S. Congress, House of Representatives and Senate. 2005. *Energy Policy Act of 2005*. Washington, DC: H.R.6, 109th Congress, 4 January 2005. Internet site: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=109_cong_bills&docid =f:h6enr.txt.pdf (Accessed May 9, 2006).

U.S. Department of Agriculture, Economic Research Service. 2006. "USDA Agricultural Baseline Projections to 2015." Office of the Chief Economist, World Agricultural Outlook Board, U.S. Department of Agriculture. Prepared by the Interagency Agricultural Projections Committee. Baseline Report OCE-2006-1, 108 pp. Internet site: http:// www.ers.usda.gov/publications/oce061/oce20061.pdf (Accessed May 16, 2006).

U.S. Department of Agriculture, National Agricultural Statistics Service. 2002. "2002 Census of Agriculture." Internet site: http://www.nass.usda.gov/Census_of_Agriculture/ index.asp (Accessed May 9, 2006).

U.S. Department of Agriculture, Office of the Chief Economist. 2000b. "Economic Analysis of Replacing MTBE with Ethanol in the U.S." Report to Senator Harkin, January 1, 2000. Internet site: http://www.ethanolrfa.org/resource/reports/view.php?id=124 (Accessed May 9, 2006).

U.S. Department of Agriculture, Office of the Chief Economist. 2002a. “Effects on the Farm Economy of a Renewable Fuels Standard for Motor Vehicle Fuel.” Report to Senator Harkin, August 1, 2002. Internet site: http://harkin.senate.gov/specials/20020826-usda-letter.pdf (Accessed May 9, 2006).

U.S. Department of Energy. “Biomass Feedstock Composition and Property Database.” Internet site: http://www1.eere.energy.gov/biomass/feedstock_databases.html (Accessed May 9, 2006).

U.S. Department of Energy. 2002b. “Biomass Research and Development Initiative, Biomass Initiative Timeline.” Internet site: http://www.biomass.govtools.us/about/chronology.asp (Accessed May 17, 2006).

U.S. Department of Energy. “Theoretical Ethanol Yield Calculator.” Internet site: http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html (Accessed May 9, 2006).

U.S. Department of Energy. 2002a. “Vision for Bioenergy and Biobased Products in the United States.” Internet site: http://climatevision.gov/sectors/electricpower/pdfs/bioenergy_vision.pdf (Accessed May 9, 2006).

U.S. Department of Energy, Energy Information Administration. 2001a. *Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants: Sulfur Dioxide, Nitrogen Oxides, Carbon Dioxide and Mercury, and a Renewable Portfolio Standard*. Washington, DC: SR/OIAF/2001-03, July.

U.S. Department of Energy, Energy Information Administration. 2001b. “Annual Energy Outlook 2002.” Washington, DC: DOE/EIA-0383. Internet site: http://www.eia.doe.gov/oiaf/anal_modeling.html (Accessed May 9, 2006).

U.S. Department of Energy, Energy Information Administration. 2005. “Annual Energy Outlook 2005 with Projections to 2025.” Washington, DC: DOE/EIA-0383. Internet site: http://www.eia.doe. gov/oiaf/archive/aeo05/index.html (Accessed May 9, 2006).

Urbanchuk, J.M. 2001. “An Economic Analysis of Legislation for a Renewable Fuels Requirement for Highway Motor Fuels.” Internet site: http://www.ncga.com/ethanol/pdfs/Urbanchuk_Final_Report.pdf (Accessed May 19, 2006).

Walsh, M.E., D. De La Torre Ugarte, H. Shapouri, and S. Slinsky. 2003a. “The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture.” Internet site: http://bioenergy.ornl.gov/papers/wagin/index.html (Accessed May 19, 2006).

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

Wang, M., C. Saricks, and D. Santini. 1999. *Effects of Fuel Ethanol use on Fuel-Cycle Energy and Greenhouse Gas Emissions*. Argonne, IL: Argonne National Laboratory, Center for Transportation Research, ANL/ESD-38, January. Internet site: http://www.transportation.anl.gov/pdfs/TA/58.pdf (Accessed May 16, 2006).

Weimar, M.R. and R.P. Stillman. 1990. "A Long Term Forecasting Model of the Livestock and Poultry Sectors." Proceedings of the NCR-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. Chicago, IL. Internet site: http://www.farmdoc.uiuc.edu/nccc134.

Werpy, T., and G. Petersen eds. 2004. *Top Value Added Chemicals from Biomass; Volume I–Results of Screening for Potential Candidates from Sugars and Synthesis Gas*. Washington, DC: Pacific Northwest National Laboratory, National Renewable Energy Laboratory, Office of Biomass Program, August. Internet site: http://handle.dtic.mil/100.2/ADA436528 (Accessed May 19, 2006).

Werpy, T.A., R.J. Orth, A.J. Schmidt, J.G. Frye, and A.H. Zacher. 2002. "Fuels and Chemicals from Corn." *The 2002 Corn Utilization and Technology Conference Proceedings*.

Whitten, G. 2000. "Air Quality Impacts of Ethanol in California Gasoline." Systems Applications International, Inc., June. Internet site: http://www.ethanolrfa.org/resource/reports/view.php?id=77 (Accessed May 19, 2006).

Appendix A: Biofuels and Bioproduct Scenario Estimates

Table A.1. Biopower demand, feedstock quantities and costs

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Demand (bil kWh)	88	92	96	100	104	108	121	134	147	160
Supply (bil kWh)	88	92	96	100	104	108	121	134	147	160
FEEDSTOCKS										
Corn Stover (mil dt)	58.7	61.4	56.3	39.5	32.4	33.6	38.8	51.2	58.2	64.5
Wheat Straw (mil dt)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	1.3	2.8
Switchgrass (mil dt)	0	0	7.7	26.8	36.4	37.9	41.3	37.4	38.1	38.9
COSTS										
Feedstock Cost (mil $)	1,821	1,907	1,987	1,991	2,067	2,149	2,422	2,922	3,615	5,243
Conversion Cost (mil $)	842	875	908	941	973	1,004	1,119	1,234	1,350	1,463
Total Cost (mil $)	2,662	2,782	2,894	2,932	3,039	3,152	3,541	4,156	4,965	6,706
Cost per kWh	0.03	0.03	0.03	0.029	0.029	0.029	0.029	0.031	0.034	0.042

Table A.2. Ethanol demand, feedstock quantities, and costs

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Demand (bil gal)	2.31	3.53	4.85	6.26	7.77	9.38	11.24	13.09	14.92	16.73
Supply (bil gal)	2.31	3.53	4.85	6.26	7.77	9.38	11.24	13.09	14.92	16.73
FEEDSTOCKS										
Corn Stover (mil dt)	0.3	3.3	11.3	8.3	17.9	27.4	30.5	52.8	60.5	69.2
Wheat Straw (mil dt)	0	0	0	0	0	0	0	0.3	1.4	3
Switchgrass (mil dt)	0	0	1.6	5.6	20.1	30.9	32.4	38.6	39.6	41.8
Corn (mil bu)	847	1,215	1,424	1,913	1,767	1,764	2,322	2,175	2,571	2,880
COSTS										
Feedstock Cost (mil $)	2,008	3,482	4,891	7,196	7,326	7,755	10,310	10,802	13,344	17,610
Conversion Cost (mil $)	486	855	1,808	1,999	4,435	6,329	6,710	9,629	10,470	11,278
Total Cost (mil $)	2,495	4,337	6,700	9,195	11,761	14,085	17,020	20,431	23,814	28,888
Cost per gal	1.08	1.23	1.38	1.47	1.51	1.50	1.51	1.56	1.60	1.73

Table A.3. Biodiesel demand, feedstock quantities and costs

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Demand (bil gal)	0.14	0.18	0.23	0.29	0.35	0.42	0.46	0.50	0.53	0.55
Supply (bil gal)	0.14	0.18	0.23	0.29	0.35	0.42	0.46	0.50	0.53	0.55
FEEDSTOCKS										
Soybeans (mil bu)	98	131	167	207	252	300	330	356	377	394
COSTS										
Feedstock Cost (mil $)	458	680	891	1,200	1,598	1,911	2,147	2,347	2,560	2,696
Conversion Cost (mil $)	-274	-384	-511	-686	-871	-1,007	-1,082	-1,141	-1,156	-1,181
Total Cost (mil $)	185	296	380	514	728	904	1,065	1,205	1,404	1,515
Cost per gal	1.34	1.61	1.62	1.77	2.06	2.15	2.30	2.42	2.66	2.74

Table A.4. Levulinic demand, feedstock quantities and costs

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Demand (mil lb)	175	175	175	175	175	175	175	175	175	175
Supply (mil lb)	175	175	175	175	175	175	175	175	175	175
FEEDSTOCKS										
Corn Stover (mil dt)	0.49	0.49	0.44	0.30	0.24	0.24	0.25	0.29	0.30	0.31
Wheat Straw (mil dt)	0	0	0	0	0	0	0	0	0.01	0.01
Switchgrass (mil dt)	0	0	0.06	0.20	0.27	0.27	0.26	0.21	0.20	0.18
COSTS										
Feedstock Cost (mil $)	15.3	15.3	15.4	15.1	15.2	15.2	15.3	16.6	18.7	24.9
Conversion Cost (mil $)	107.6	100.3	92.9	85.6	78.2	70.9	67	63.2	59.3	55.5
Total Cost (mil $)	122.9	115.5	108.3	100.7	93.4	86.1	82.3	79.7	78.0	80.3
Cost per lb	0.70	0.66	0.62	0.58	0.53	0.49	0.47	0.46	0.45	0.46

Table A.5. Succinic acid demand, feedstock quantities and costs

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Demand (mil lb)	33	33	33	33	33	34	34	34	34	33
Supply (mil lb)	33	33	33	33	33	34	34	34	34	33
FEEDSTOCKS										
Corn Stover (mil dt)	0	0	0	0	0	0	0	0	0	0
Wheat Straw (mil dt)	0	0	0	0	0	0	0	0	0	0
Switchgrass (mil dt)	0	0	0	0	0	0	0	0	0	0
Corn Grain (mil bu)	1.23	1.23	1.23	1.23	1.23	1.26	1.26	1.26	1.26	1.23
COSTS										
Feedstock Cost (mil $)	2.9	3.4	3.9	4.3	4.3	4.3	4.6	4.5	4.7	5.1
Conversion Cost (mil $)	14.0	13.9	13.9	13.8	13.7	14.1	14.1	14.0	14.0	13.5
Total Cost (mil $)	16.9	17.3	17.7	18.2	18.0	18.4	18.6	18.5	18.7	18.6
Cost per lb	0.51	0.53	0.54	0.55	0.55	0.54	0.55	0.55	0.55	0.56

Table A.6. Lactic acid demand, feedstock quantities and costs

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Demand (mil lb)	407.9	592.7	777.5	962.3	1,147.1	1,331.9	1,434.2	1,536.5	1,638.8	1,741.1
Supply (mil lb)	407.9	592.7	777.5	962.3	1,147.1	1,331.9	1,434.2	1,536.5	1,638.8	1,741.1
FEEDSTOCKS										
Corn Stover (mil dt)	0	0	0	0	0	0	0	0	0	0
Wheat Straw (mil dt)	0	0	0	0	0	0	0	0	0	0
Switchgrass (mil dt)	0	0	0	0	0	0	0	0	0	0
Corn Grain (mil bu)	14.07	20.44	26.81	33.18	39.56	45.93	49.46	52.98	56.51	60.04
COSTS										
Feedstock Cost (mil $)	33.2	56.9	84.6	117.6	138.5	156.3	179.1	189.8	210.7	249.8
Conversion Cost (mil $)	139.9	203.3	266.7	330.1	393.5	456.8	491.9	527.0	562.1	597.2
Total Cost (mil $)	173.1	260.2	351.3	447.6	532.0	613.2	671.0	716.8	772.8	847.0
Cost per lb	0.42	0.44	0.45	0.47	0.46	0.46	0.47	0.47	0.47	0.49

Table A.7. 1,3-Propanediol demand, feedstock quantities and costs

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Demand (mil lb)	0.2	20.2	40.2	60.2	80.2	100.2	155.2	210.1	265.1	320.0
Supply (mil lb)	0.2	20.2	40.2	60.2	80.2	100.2	155.2	210.1	265.1	320.0
FEEDSTOCKS										
Corn Grain (mil bu)	0.04	4.04	8.04	12.04	16.04	20.04	31.03	42.02	53.02	64.01
COSTS										
Feedstock Cost (mil $)	0.1	11.2	25.4	42.7	56.2	68.2	112.4	150.5	197.7	266.3
Conversion Cost (mil $)	0.1	6.3	12.5	18.7	24.9	31.1	48.1	65.1	82.2	99.2
Total Cost (mil $)	0.2	17.5	37.8	61.3	81.0	99.3	160.4	215.7	279.8	365.5
Cost per lb	0.78	0.87	0.94	1.02	1.01	0.99	1.03	1.03	1.06	1.14

Table A.8. Total feedstock quantities

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Stover (mil tons)	59.5	65.2	68.1	48.1	50.6	61.3	69.6	104.2	118.9	134.0
Straw (mil tons)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.7	2.7	5.9
Switchgrass (mil tons)	0	0	9.3	32.6	56.7	69.2	73.9	76.2	77.9	80.9
Corn Grain (mil bu)	1,726	2,480	2,920	3,919	3,647	3,662	4,808	4,542	5,364	6,012

Table A.9. Feedstock prices

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Biomass ($/dt)	31.00	31.00	31.00	30.00	30.00	30.00	30.21	32.86	37.05	49.34
Corn ($/bu	2.36	2.78	3.16	3.54	3.50	3.40	3.62	3.58	3.73	4.16
Soybeans ($/bu)	4.68	5.19	5.33	5.80	6.34	6.37	6.51	6.59	6.79	6.84
Soybean Oil ($/lb)	0.23	0.25	0.25	0.27	0.29	0.29	0.31	0.32	0.34	0.36
Soybean Meal ($/ton)	149.85	155.64	161.39	172.49	178.71	174.37	171.02	167.75	161.60	158.67

Table A.10. Model crop prices over simulation period ($/bu unless otherwise specified)

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Corn	2.36	2.78	3.16	3.54	3.5	3.4	3.62	3.58	3.73	4.16
Grain Sorghum	2.18	2.54	2.85	3.16	3.07	2.93	3.11	3.01	3.1	3.18
Oats	1.44	1.59	1.68	1.83	1.86	1.86	1.94	1.92	1.98	2.02
Barley	2.62	3.01	3.21	3.55	3.52	3.45	3.63	3.6	3.72	3.81
Wheat	3.02	3.16	3.33	3.51	3.64	3.81	3.88	3.91	3.99	4.04
Soybeans	4.68	5.19	5.33	5.8	6.34	6.37	6.51	6.59	6.79	6.84
Cotton ($/lb)	0.435	0.458	0.488	0.501	0.509	0.52	0.529	0.535	0.546	0.565
Rice ($/cwt)	7.35	7.61	8.15	8.93	9.3	9.68	9.53	10.37	10.2	10.69
Hay	87.66	88.84	90.26	91.25	92.31	93.24	94.38	95.63	96.58	97.11
Switchgrass	0	31	31	30	30	30	30.21	32.86	37.05	49.34

Appendix B: Bioenergy and Bioproduct Assumptions and Methodology

CHEMICAL COMPOSITION ASSUMPTIONS

The bioenergy conversion rates for cellulose feedstocks depends on their chemical composition—the percent of sugars, percent of lignin, and the energy content per unit (high heating value in btu/dt and kj/dt). Table B.1 presents the assumed chemical composition values for corn stover, wheat straw, and switchgrass used in subsequent analyses. Feedstock composition is the simple average of the observations contained in the U.S. Department of Energy Biomass Feedstock Composition Database (www.eere.energy.gov/biomass).

Table B.1 Chemical Composition of Cellulose Feedstocks

	Arabinan	Xylan	Mannan	Galactan	Glucan	Lignin	Energy Content		Maximum ETOH Yield
	Percent Sugars					percent	HHV btu/dry lb	(million kj/dt)	(gal/dt)
Corn Stover	2.31	19.19	0.47	0.84	35.46	18.69	7844	16.535	
Wheat Straw	2.35	19.22	0.31	0.75	32.64	16.85	7481	15.77	96.36
Switchgrass	2.76	22.11	0.31	0.99	33.58	18.69	8040	16.948	104.27

The costs presented in the following sections represent conversion costs only—the costs of the feedstocks and the values of any coproducts generated are not accounted for. These costs and credits are calculated in the model and then added to the conversion costs to obtain a product cost. All costs are converted to $2002 using the Consumer Price Index. The demand schedules for bioproducts are based on comparisons to competing organic compounds mostly derived from petroleum. The recent large increases in petroleum prices are not reflected in the costs of these products, thus the existing analysis may underestimate the relative economic competitiveness of biologically derived bioproducts.

ETHANOL ASSUMPTIONS

The estimated costs of producing ethanol from corn grain and cellulose feedstocks are based on McAloon *et al*, 2000, which estimates the cost of producing ethanol from corn grain and corn stover using consistent methodologies and assumptions for a facility producing 23.75 million gallons of pure ethanol/year. Cellulose ethanol costs are estimated for an nth stage facility. This analysis assumes these costs can be achieved in year 2015 and adjusts year 2005 and 2010 costs to account for the technology being less mature. Specifically, capital costs are increased to account for over-design in the early facilities by multiplying the capital costs by 1.364 in year 2005 and 1.127 in 2010.

Cellulose to ethanol conversion rates for corn stover for year 2015 are those contained in McAloon (68.55 gallon pure ethanol/dry ton). Ethanol conversion rates for switchgrass and wheat straw are assumed to be 67.5 percent of the theoretical maximum yield which are calculated using the U.S. Department of Energy Theoretical Ethanol Yield Calculator (www.eere.energy.gov/biomass) and the chemical composition contained in Table B.1. The electricity sold (from cellulose ethanol facilities) is the net quantity of electricity produced minus that which is used internally as part of the conversion process. The assumed electricity production rate is 1.142 kWh/lb lignin. Tables B.2 and B.3 summarize the technical and cost assumptions for each ethanol feedstock-technology combination used in the analysis.

Table B.2. Ethanol Production from Corn Starch (dry mill process)

	Year of:		
Products	2005	2010	2015
Ethanol Production (gallon)	2.7	2.7	2.7
DDGS Production (lb/bushel corn)	18.31	18.31	18.31
Conversion Costs ($/gallon pure ethanol)	0.52	0.52	0.52
Denaturant Cost ($/gallon pure ethanol)	0.029	0.029	0.029

Table B.3. Ethanol Production from Cellulose Feedstocks

	Year of:		
Products	2005	2010	2015
Corn Stover			
Ethanol Production (gallon pure ETOH/dt)	68.6	68.6	68.6
Electricity Sold (kWh/gallon pure ETOH)	2.92	2.92	2.92
Conversion Costs ($/gallon pure ETOH)	1.47	1.33	1.25
Denaturant Cost ($/gallon pure ethanol)	0.029	0.029	0.029
Wheat Straw			
Ethanol Production (gallon pure ETOH/dt)	65	65	65
Electricity Sold (kWh/gallon pure ETOH)	2.84	2.84	2.84
Conversion Costs ($/gallon pure ETOH)	1.47	1.33	1.25
Denaturant Cost ($/gallon pure ethanol)	0.029	0.029	0.029
Switchgrass			
Ethanol Production (gallon pure ETOH/dt)	70.4	70.4	70.4
Electricity Sold (kWh/gallon pure ETOH)	2.99	2.99	2.99
Conversion Costs ($/gallon pure ETOH)	0.47	1.33	1.25
Denaturant Cost ($/gallon pure ethanol)	0.029	0.029	0.029

Electricity Assumptions

The analysis examined two cellulose electricity technologies—gasification and biomass cofiring with coal. The principal source of information for conversion costs and efficiencies is Electric Power Research Institute (EPRI) and DOE report – “Renewable Energy Technology Characterizations” (1997).

First-of-a-kind gasification facilities are assumed in year 2005. Costs are based on a 75 MW facility operating 80 percent of the time ($5.256 * 10^8$ kWh/yr capacity). A cellulosic heat rate of 10,000 kj/kWh is assumed. For the years 2010 and 2015, costs are based on a 100 MW facility operating at 80 percent of capacity ($7.008 * 10^8$ kWh/yr capacity) with a cellulosic heat rate of 9,730 kj/kWh. For the purpose of this analysis, the EPRI production cost milestones have been delayed by 5 years (i.e., 2000 costs are achievable in 2005, 2005 costs achievable in 2010, etc.). Capital costs have been adjusted to be consistent with the method used for ethanol (i.e., straight line depreciation over 10 years). The same conversion costs are assumed for all cellulose feedstocks, but electricity production varies slightly as a result of differing energy content for each feedstock.

For the biomass cofiring analysis, facility sizes of 100, 150, and 200 MW are assumed in years 2005, 2010, and 2015 respectively. Plants are assumed to operate at 85 percent capacity and produce $1.1169 * 10^8$ kWh/yr, $1.67535 * 10^8$ kWh/yr, and $2.2338 * 10^8$ kWh/yr respectively. A 15 percent cofire rate is assumed. The assumed heat rate is 11,066 kj/kWh. As with the gasification technology, the EPRI costs for cofiring biomass with coal have been shifted by five years, capital cost estimates adjusted to be consistent with that used for ethanol, and converted to $2002. EPRI included a SOx credit of $100/ton SO_2 in their cost estimates. The estimated costs are the ***incremental cost*** associated with cofiring biomass (e.g., equipment purchases and labor to handle biomass), rather than the total electricity production cost.

Tables B.4 and B.5 summarize the technical and cost assumptions of biomass gasification and cofiring used in the analysis.

Table B.4. Electricity Production by Gasification of Cellulose Feedstocks

	Year of:		
	2005	2010	2015
Corn Stover			
Electricity Production (kWh/dry ton)	1654	1699	1699
Conversion Costs ($/kWh)	0.048	0.042	0.037
Wheat Straw			
Electricity Production (kWh/dry ton)	1577	1621	1621
Conversion Costs ($/kWh)	0.048	0.042	0.037
Switchgrass			
Electricity Production (kWh/dry ton)	1695	1742	1742
Conversion Costs ($/kWh)	0.048	0.042	0.037

Table B.5. Electricity Production by Cofiring Cellulose Feedstocks with Coal

	Year of:		
	2005	2010	2015
Electricity Production from Corn Stover (kWh/dt)	1494	1494	1494
Electricity Production from Wheat Straw (kWh/dt)	1425	1425	1425
Electricity Production from Switchgrass (kWh/dt)	1532	1532	1532
Incremental Conversion Costs ($/kWh)	0.0037	0.0033	0.0032

Bioproduct Methodology

Publicly available bioproduct data is limited, requiring numerous assumptions and simplifications—thus the estimated conversion yields, conversion costs, and demand schedules should be viewed as educated guesses that are hopefully reasonable. While literally thousands of bioproducts could potentially be produced from corn grain and cellulose materials, this analysis has limited the products to (a) glycerol, (b) succinic acid and select derivatives, (c) levulinic acid and select derivatives, (d) lactic acid and select derivatives, and (e) 1,3-propanediol.

Succinic acid, levulinic acid, and glycerol have been identified by the Department of Energy as among the top 12 building block chemicals with numerous potential derivatives. Pilot plants to produce levulinic acid have been constructed in both the U.S. and Italy. Succinic acid has been the focus of substantial research and appears to be nearing commercialization status. Glycerol is a byproduct of biodiesel production and significantly affects the overall economics of the process. Lactic acid is listed among the top 20 building block chemicals, and commercial production from corn starch has recently begun (Natureworks). Market prospects for polylactic acid polymers and for ethyl lactate (solvent) appear robust. Natureworks has indicated the possibility of producing lactic acid from cellulose feedstocks in the future. 1,3-propanediol is a derivative chemical that can be produced in a number of different ways and use in synthetic fiber applications appears robust. DuPont (using a genetically modified *E. coli* that first produces glycerol from glucose and then 1,3-propanediol from glycerol) is currently modifying an existing ethanol facility in TN to produce 1,3-propanediol from corn grain. Other potential products have not been included either due to lack of data and/or they are in early stages of development and not likely to be commercialized in the time frame of this analysis.

A multi-step process is used to estimate potential bioproduct demand schedules. Production of the building block chemical succinic acid and its derivative 1,4 butanediol from corn grain is provided to illustrate the approach.

1. Estimate potential yield of the building block chemical by feedstock source (e.g., 1 bushel of corn yields 29.6 lbs of succinic acid).

2. Estimate the cost of converting the feedstock into the building block chemical (e.g., the cost of converting corn starch into one pound of succinic acid is estimated to be \$0.424).
3. Estimate the potential yield of derivatives that can be obtained from a pound of the building block chemical (e.g., an estimated 0.61 lb of 1,4-butanediol (BDO) can be produced per pound of succinic acid).
4. Estimate the cost of converting the key building block chemical into the derivative chemical (e.g., the estimated cost of converting succinic acid to1,4-butanediol is \$0.22/lb BDO).
5. Estimate the relative competitiveness of biologically derived derivatives with their alternative (generally petroleum derived) sources and use this estimate to determine the maximum price that can be paid for the building block chemical (e.g., the principal source of BDO is from petroleum using the Reppe process and the estimated cost is \$0.66/lb BDO. To be competitive with petroleum derived BDO, biologically derived BDO must be less than \$0.66/lb. Thus the maximum price that can be paid for succinic acid is \$0.44/lb BDO (\$0.66 - \$0.22). With an assumed yield level of 1.64 lb succinic acid/lb BDO, the maximum price that can be paid for succinic acid to produce BDO is \$0.268/lb).
6. Estimate the potential demand schedule for the key building block chemical. (e.g., the existing BDO market is estimated to be 680 million pounds. If succinic acid can be produced at less than \$0.268/lb, then BDO from succinic acid can begin to penetrate the petroleum derived BDO market. At a market penetration rate of 10 percent (68 million pounds BDO), 112 million pounds of succinic acid would be required. Thus, one point in the demand schedule would be a succinic acid quantity of 112 million pounds corresponding to a succinic acid price of \$0.27/lb).
7. Estimate the feedstock demand corresponding to the demand schedule for the key building block chemical (e.g., from step 1, 29.6 pounds of succinic acid are produced per bushel of corn grain. Thus 3.77 million bushels of corn are required to produce 112 million lbs of succinic acid).

Using the above assumptions, biologically derived BDO is not competitive with its petroleum counterpart in that it costs \$0.424/lb to convert corn into succinic acid (not including the cost of the corn) and the maximum price that can be paid for the succinic acid is only \$0.22/lb. However, the framework allows for examination of other cost and technology assumptions both for the bioproduct of interest and its current market counterpart.

Bioproduct yield estimates assume an 80 percent recovery rate over reported and/or theoretical yields reported in the literature.

Glycerol Assumptions

Data Sources: Tyson et al, 2004; Werpy and Petersen, 2004; Bozell and Landucci, 1993; Greene, 1996; Chen et al, 2003; Cameron and Koutsky, 1994.

Table B.6 summarizes the glycerol conversion rate and costs used in the analysis. The U.S. currently imports around 60 million lbs of glycerol and an estimated 25 percent of the domestic production is produced from petroleum (about 80 million lbs). Prices of industrial grade glycerol are less that $0.30/lb. A number of derivative chemicals can be produced from glycerol, but have not been included in this analysis--glycerol is treated only as a byproduct of biodiesel production. Crude glycerin is assumed to be 50 percent glycerol, industrial grade glycerol is assumed to be 85 percent glycerol, and USP quality glycerol is assumed to be 97 percent glycerol.

Table B.6. Glycerol Technology and Cost Assumptions

	Year of:		
	2005	2010	2015
Glycerol Production (lbs/gallon biodiesel)	0.735	0.735	0.735
Purification Cost ($/lb) (Crude glycerin to industrial grade glycerol)	0.10	0.10	0.10
Purification Cost ($/lb) (Industrial grade glycerol to USP grade glycerol)	0.20	0.20	0.20

Succinic Acid Assumptions

Data Sources: Kelff, 2004; Werpy et al, 2002; Paster, Pellegrino, and Carole, 2003; Bozell and Landucci, 1993; Werpy and Petersen, 2004; Aden et al, 2002; Davison et al, 2003; Davison et al, 1999.

The existing succinic acid market is about 33 million pounds. The current market for 1,4-butanediol (BDO) is 680 million pounds produced from petroleum (the Reppe process with an estimated production cost of $0.66/lb BDO; the Davy-Mckee process with an estimated production cost of $0.89/lb BDO; and the Kuroway-Arco process with an estimated production cost of $1.14/lb BDO). The current gamma butyrolactone (GBL), N-methylpyrrolidone (NMP), and 2-pyrrolidone (2-PYR) markets are estimated to be 105, 80, and 65 million pounds respectively. Conversion cost information for GBL, NMP, and 2-PYR was not found, but current production for these compounds uses maleic anhydride as the feedstock and is similar to the Davy-Mckee BDO process. Thus for this analysis, similar conversion costs are used resulting in estimated production costs of petroleum derived GBL, NMP, and 2-PYR of $0.92/lb, $0.85/lb, and $0.93/lb respectively. For this analysis, it is assumed that the cost of converting succinic acid to GBL, NMP, and 2-PYR is the same as converting succinic acid to BDO ($0.22/lb of derivative). The current market for tetrahydrofuran (THF) is about 255 million pounds. Production costs could not be found, but THF is currently produced from petroleum derived BDO. For the purpose of this analysis, we use the same implied succinic acid price as is needed to make biologically derived BDO competitive with the Reppe process. Succinate salts can be used as aviation deicers--typical cost for these uses is $0.60/lb and the market size is 10 million lbs. Tables B.7 and B.8 summarize the technical and cost assumptions for succinic acid and its derivatives.

Table B.7. Succinic Acid Technology and Cost Assumptions

	Year of:		
	2005	2010	2015
Succinic Acid Production (lbs per bushel of corn)	29.9	29.9	29.9
Succinic Acid Production (lbs per dry ton of corn stover)	837	837	837
Succinic Acid Production (lbs per dry ton of wheat straw)	796	796	796
Succinic Acid Production (lbs per dry ton of switchgrass)	859	859	859
Succinic Acid Conversion Cost ($/lb) (from corn grain)	0.424	0.4145	0.409
Succinic Acid Conversion Cost ($/lb) (from cellulose)	0.448	0.416	0.402

Table B. 8. Succinic Acid Derivatives Technology and Cost Assumptions

Succinic Acid Derivatives	Conversion Rate	Conversion Cost	Implied Succinic Acid Cost
	gram derivative/ gram succinic acid	$/lb of derivative	$/lb
1,4-butanediol (BDO)	0.61	0.22	0.27 (Reppe process) 0.41 (Davy-Mckee process) 0.56 (Kuroway-Arco process)
Gamma butyrolactone (GBL)	0.583	0.22	0.41
N-methylpyrrolidone (NMP)	0.672	0.22	0.42
2-pyrrolidone (2-PYR)	0.577	0.22	0.41
Tetrahydrofuran (THF)	0.4885	0.22	0.27
Succinate salts	0.98	0	0.60

Levulinic Acid Assumptions

Data Sources: Biometics, Inc., 2002; Fitzpatrick and Jarnefeld, 1996; Paster, Pellegrino, and Carole, 2003; Bozell and Landucci, 1993; Werpy and Petersen, 2004.

Available information on the costs and efficiency of producing levulinic acid from cellulose are for paper sludge as the feedstock—this analysis has extrapolated this data to other feedstocks, resulting in rough approximations. We assume that 0.5 lb of levulinic acid can be produced per pound of cellulose. Estimated conversion costs are projected to decline over time due largely to economies of size associated with building larger facilities in future years (50 dt/day in 2005, 100 dt/day in 2010, and 500 dt/day in 2015). The existing levulinic acid market is estimated to be 1 million lbs at prices of $4.00 to 6.00/dt. The literature reports the cost of converting levulinic acid into methyl tetrahydrofuran (MTHF) as being $0.05/lb MTHF. MTHF could be used as a fuel oxygenate, a 30.8 billion pound market with existing oxygenate prices of ranging from $0.13 to $0.18/lb. The literature indicates that diphenolic acid (DPA) can be produced for $1.20/lb with a levulinic acid cost of $1.00/lb ($1999)--this implies a conversion cost of $0.76/lb DPA in $2002. DPA will compete with bisphenol A as a polymer additive. The current market size and price for bisphenol A are 1.91 billion pound and $0.94/lb. The literature reports an estimated delta amino levulinate (DALA) cost of $4.40/kg for a levulinic acid price of $3.30/kg ($1996) implying a $2002 conversion cost of $0.40/lb DALA. DALA is being developed as an active ingredient in pesticides and is a relatively new market opportunity with an estimated potential market of 200-400 million pounds. The price that can be paid for DALA is unknown--some reports indicate it could be as high as $10/lb. No conversion costs for tetrahydrofuran (THF) were found. This analysis assumes the same costs as for MTHF. THF is currently used as a solvent with a market of 255 million pounds and a price of $1.55/lb. Tables B.9 and B.10 summarize the levulinic acid and derivative technology and cost assumptions used in the analysis.

Table B.9. Levulinic Acid Technology and Cost Assumptions

	Year of:		
	2005	2010	2015
Levulinic Acid Production (lbs per dry ton of corn stover)	355	355	355
Levulinic Acid Production (lbs per dry ton of wheat straw)	326	326	326
Levulinic Acid Production (lbs per dry ton of switchgrass)	336	336	336
Levulinic Acid Conversion Cost ($/lb) (from cellulose)	0.59	0.379	0.264

Table B.10. Levulinic Acid Derivatives Technology and Cost Assumptions

	Conversion Rate (gram derivative/ gram levulinic acid)	Conversion Cost ($/lb of derivative)	Implied Levulinic Acid Cost ($/lb)
Methyl tetrahydrofuran (MTHF)	0.51	0.047	0.083 to 0.133
Diphenolic acid (DPA)	1.97	0.76	0.78
Delta amino levulinate (DALA)	0.91	0.40	
Tetrahydrofuran (THF)	0.62	0.05	0.75

Lactic Acid Assumptions

Data Sources: Paster, Pellegrino, and Carole, 2003; Bozell and Landucci, 1993; Werpy and Petersen, 2004; Dien et al, 2004.

The existing lactic acid market is about 5 million pounds and price is $0.70/lb. Conversion cost data for corn starch to lactic acid assumes a capital cost based on the reported cost and size of the NatureWorks Blair, NE facility ($300 million, 300 million lbs of polylactic acid/year). Operating costs are assumed to be similar to those of producing ethanol from corn starch. Lactic acid production from cellulose feedstocks is limited. The U.S.D.A-Agricultural Research Service reports achieving lactic acid yields of 0.82 gram/gram glucose and 0.88/gram/gram xylose using genetically modified *Klebsiella oxytoca*. In the absence of available information, this analysis assumes the cost of converting cellulose to lactic acid is the same as converting cellulose to succinic acid. Current production of polylactic acid (PLA) from corn starch is 300 million pounds. NatureWorks estimates the market for their PLA will be 1.1 billion pounds within a decade. Other studies estimate a potential PLA market of around 1.45 billion pounds by 2010. This analysis assumes markets of 300, 875, and 1,450 million pounds of PLA for 2005, 2010, and 2015. Conversion of lactic acid to polylactic acid (PLA) is relatively straightforward and has a high recovery rate (95 percent). PLA will compete with products currently valued at $0.30 to $1.50/lb. Energetics, Inc. estimates a potential market for ethyl lactate of 1 billion pounds by 2020. Argonne National Laboratory (ANL) estimates potential solvent markets for EL of 20, 120, and 1000 to 2000 million pounds at EL prices of $1.60, $1.25, and $1.00 or lower respectively. The cost of converting lactic acid to ethyl lactate (EL) was not found. ANL reports developing a new membrane-based separation and purification process that will reduce the cost of producing ethyl lactate to an estimated $0.85 to $1.00/pound. Using these costs as the price of EL, and assuming that both the lactic acid and the ethanol used to produce EL are derived from corn grain, the cost of producing EL from lactic acid is estimated to range from $0.48 to $0.61/lb EL. The potential acrylic acid (AC) market could be 2 billion pounds and the cost of producing AC from petroleum is reportedly around $0.71/lb AC. Conversion costs are unknown—for the purpose of this analysis, they are assumed to be similar to those for EL (i.e., $0.50/lb AC). Tables B.11 and B.12 summarize the lactic acid and derivative technology and costs assumptions used in the analysis.

Table B.11. Lactic Acid Technology and Cost Assumptions

	Year of:		
	2005	2010	2015
Lactic Acid Production (lbs per bushel of corn)	26.4	26.4	26.4
Lactic Acid Production (lbs per dry ton of corn stover)	661	661	661
Lactic Acid Production (lbs per dry ton of wheat straw)	629	629	629
Lactic Acid Production (lbs per dry ton of switchgrass)	676	676	676
Lactic Acid Conversion Cost ($/lb) (from corn grain)	0.343	0.343	0.343
Lactic Acid Conversion Cost ($/lb) (from cellulose)	0.448	0.416	0.402

Table B.12. Lactic Acid Derivatives Technology and Cost Assumptions

	Conversion Rate (gram derivative/ gram lactic acid)	Conversion Cost ($/lb of derivative)	Implied Lactic Acid Cost ($/lb)
Polylactides (PLA)	1.32	0.05	0.72
Ethyl Lactate (EL)	1.05	0.48 to 0.61	1.16; 0.75; 0.46; 0.28 for EL costs of $1.60, $1.25, and <= $1.00/lb respectively
Acrylic Acid (AC)	0.498	0.50	0.11

1,3-Propanediol Assumptions

Data Sources: Leaversuch, 2004; Schoenberger, 2003

1,3-propanediol (PDO), when combined with terephthalic acid, produces a polymer used as a synthetic fiber. PDO can be made from petroleum-- Shell recently opened a facility in Canada producing around 100 million lbs annually at a reported production cost of about $1.00/lb PDO. PDO can be produced from glycerol derived from biodiesel operations. Estimated costs of this process range from $0.45 to $1.95/lb PDO. DuPont in collaboration with Genencor modified an E.coli strain to ferment sugar (from corn grain) to glycerol to PDO in a one step process. DuPont is currently modifying an ethanol plant in Loudon, TN to produce PDO using this process. The total investment is reportedly $100 million and the facility is expected to produce 100 million pounds of PDO annually. Process specifics are confidential--this analysis has attempted to estimate conversion rates and costs from public information. The analysis assumes a PDO market of 500 million pounds by 2020 with 75 percent of the market captured by the biological process relative to the petroleum process. Table B.13 summarizes the PDO technology and cost assumptions used in the analysis.

Table B.13. 1,3-Propanediol Technology and Cost Assumptions

	Year of:		
	2005	2010	2015
1,3-Propanediol Production (lbs per bushel of corn)	5.38	5.38	5.38
1,3-Propanediol Conversion Cost ($/lb) (from corn grain)	0.457	0.457	0.457