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Agricultural Impacts of Biofuels Production

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Analysis of the potential to supply 25% of projected 2025 U.S. transportation fuels indicates sufficient biomass resources are available to meet increased demand while simultaneously meeting food, feed, and export needs. Corn and soybeans continue to be important feedstocks for ethanol and biodiesel production, but cellulose feedstocks (agricultural crop residues, energy crops such as switchgrass, and forestry residues) will play a major role. Farm income increases, mostly because of higher crop prices. Increased crop prices increase the cost of producing biofuels.

Key Words: biodiesel, biofuels, biomass, cellulose feedstocks, crop residues, ethanol, forest residues, switchgrass

JEL Classifications: O11, Q11, Q41

Recently, a number of proposals have been advanced to use alternative fuels from biomass as a means to "break our addiction to oil." These initiatives propose to replace 20%–30% of U.S. fuel use with biomass-derived fuels within the next quarter century. This is a large task. The United States consumed about 140 billion gallons of gasoline in 2005. The feedstocks needed to produce biofuels will come largely from the agricultural and forestry sectors. Such a large increase raises numerous questions regarding feasibility, approach, impacts of such activities, and, most specifically, whether we can meet new fuel demands and still meet food, feed, and export demands (i.e., fuel versus food). Existing analyses do not fully address these questions, as they typically examine the impact of a single limited change (i.e., increasing ethanol production from corn grain or biodiesel production from soybeans).

The vision of a future biobased industry includes the simultaneous production of biofuels, bioelectricity, and bioproducts that uses not only corn grain and soybean oil, but also a host of cellulose feedstocks. We have developed a framework to rigorously evaluate feedstock-related issues associated with the development of a biobased industry utilizing a dynamic model of the U.S. agricultural sector (POLYSYS) that has been modified to include several cellulose feedstocks (endogenous feedstocks include corn stover, wheat straw, and switchgrass; exogenous feedstocks include forest and mill residues) and several bioenergy and bioproduct technologies (ethanol from corn starch and cellulose; biodiesel from soybeans; 1,3-propanediol, lactic acid,

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levulinic acid, succinic acid, and glycerol from starch, cellulose, and/or oil crops; and electricity from cellulose). This paper presents the results of an analysis that examines the replacement of 25% of the projected 2025 U.S. petroleum-derived transportation fuel use with ethanol derived from corn grain and cellulose feedstocks and biodiesel derived from soybeans.

The POLYSYS Model

POLYSYS includes national demand, regional supply, livestock, and aggregate income modules (De La Torre Ugarte et al.; Ray and Moriak) and is anchored to published baseline projections for all model variables (FAPRI; USDA 2006). Products included in POLYSYS are corn, grain sorghum, oats, barley, wheat, soybeans, cotton, rice, beef, pork, lamb and mutton, broilers, turkeys, eggs, and milk. Exogenous commodities include alfalfa and other hay and edible oils and meals. The model simulates the impacts of changes from the baseline on the national crop and livestock supply and demand variables, such as acres, yields, prices, commodity payments, and income. The crop supply module is composed of 305 independent regional linear programming models, each of which represents the land allocation decision in a specific geographic region with relatively homogeneous production characteristics (Agricultural Statistical Districts). Acres are allowed to enter crop production, shift production to a different crop, or move out of crop production on the basis of maximizing returns above costs. The crop demand module utilizes estimated demand elasticities and price flexibilities and is a function of own price, cross-price shifters, and nonprice shifter variables. Demand includes food, feed, and industrial uses, exports, and carryover stocks. The livestock and crop sectors are linked through feed demand. Each module is self-contained but works interdependently in a recursive framework to perform a multiperiod simulation. Several modifications were made to POLYSYS, including extending the baseline, adding cellulose feedstocks, and adding new demand options.

Extension of POLYSYS Baseline

The baseline was extended to the year 2025 by exogenously estimating export changes (annual % rates of change ranging from 0.0 to 1.78, depending on crop), crop yield increases (annual rates of change ranging from 0.43% to 1.13%, depending on crop), and population changes (296–350 million) from 2005 to 2025. Exports and crop yields were estimated by extending the trend line of the final 3 years of the 2006 U.S. Department of Agriculture (USDA) baseline. The resulting projections were used to shock the model in the first iteration and thereafter until equilibrium was reached.

Crop Residues

The aboveground, nongrain portions of corn and wheat (corn stover and wheat straw) are potential sources of cellulose feedstocks. Other crop residues could also be used as biomass resources, but because of data limitations, only corn stover and wheat straw are included in this analysis. Crop residues play a vital role in controlling erosion and maintaining soil quality, and sustainable use must account for these functions. Removable quantities are a function of grain yield, crop rotation, field management practices (especially tillage), climate, and physical characteristics of the soil (soil type, erosivity, and slope). Residue quantities are estimated by multiplying grain yields by grain to residue ratios (harvest indices) (Brown; Heid). Residue quantities needed to maintain erosion below the tolerable soil loss level (the maximum rate of soil erosion that will not lead to prolonged soil deterioration) are from Nelson, who estimated removable quantities by soil type, topography, tillage practice, and crop rotations while controlling for wind and rain erosion. Other soil quality considerations (e.g., organic matter, moisture, potential crop yield impacts) are not accounted for but could be significant (Sheehan et al.; Wilhelm et al.). The analysis assumes continuous cropping systems and increasing use of conservation tillage practices over time. Estimated crop residue collection

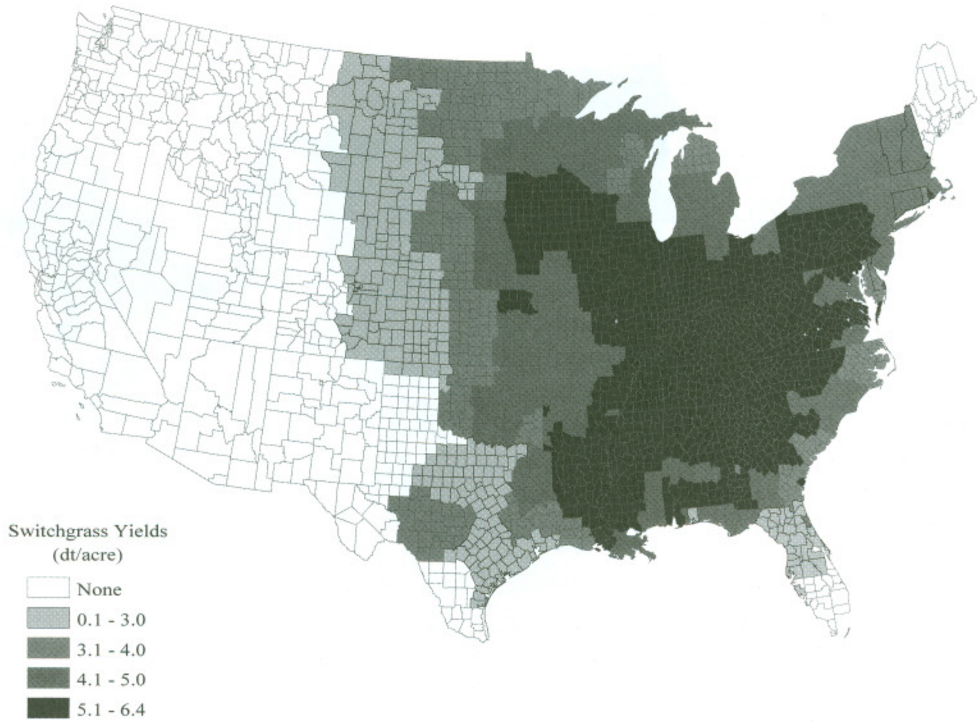

Figure 1. Switchgrass Mature Harvest Yields by Region (dry tons/acre), 2005

costs are based on large, round bales and include chopping and baling costs, in-field transportation costs, and nutrient replacement costs. Costs are in 2002 U.S. dollars.

Dedicated Energy Crops

Switchgrass *(Panicum virgatum)* is a warm-season, native perennial grass being developed as a potential energy crop. Because it is a perennial, decisions to shift cropland acres to its production are based on its net present value (NPV) returns relative to the NPV returns of traditional crops. The extent to which acres can shift is a function of whether the NPV returns of traditional crops are positive, negative, or a mixture for the 3 previous years. Once acres are allocated to switchgrass, they remain in production for its productive life cycle. Cropland pasture acres are allowed to shift to traditional crops and switchgrass under the constraint that the regional loss of forage production from pasture acres must be replaced by new regional hay production. This analysis limits the land base available for switchgrass production to cropland acres only. There may be some potential to produce switchgrass on select noncropland pasture acres, but this possibility is not included in this analysis. Switchgrass production is limited to the eastern two thirds of the United States because of the assumptions that all production is rainfed and a lack of data for western states. The assumed production cycle is 10 years, planting is by no-till practices, and herbicides, but not fertilizer, are applied in the establishment year. Fertilizers are applied in subsequent years at recommended rates by region (McLaughlin and Kszos; Ocumpaugh et al.; Parrish et al.; Taliaferro; Taliaferro, Vogel, and Bouton; Vogel and Jung). The expected harvest yields (dry tons/acre) and production costs ($2002/dry ton) for 2005 are shown in Figures 1 and 2. Assumed yield increases range from 1.0% to 3.0% annum, depending on region. Switchgrass is harvested once per year by large, round baling, and costs include mowing, raking, baling, and in-field transport of bales.

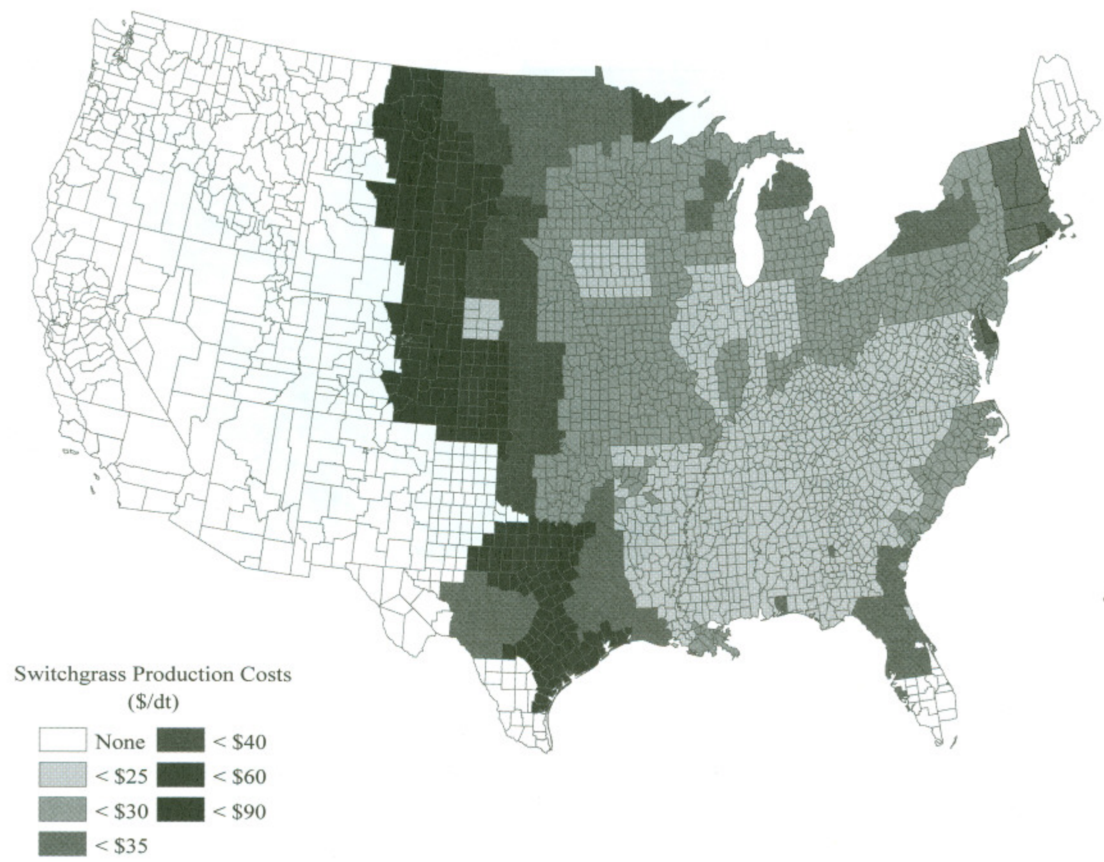

Figure 2. Switchgrass Production Costs by Region ($2002/dry ton), 2005

Bioenergy Technology Assumptions

The analysis examines the impacts of large increases in the production of ethanol from corn grain and cellulose feedstocks and biodiesel from soybeans. Key technical assumptions (conversion efficiencies and costs) are shown in Table 1.

Forest Sector Residues

In addition to agricultural crop residues and dedicated energy crops, the forest sector can serve as a source of cellulose feedstocks. These resources include logging residues, other forest removals, and mill residues. Logging residues are the unused portion of growing stock trees

Table 1. Bioenergy Technology Assumptions[a]

	Year 2005	Year 2015	Year 2025
Ethanol from corn	2.7 gal./bu $0.55/gal.	2.7 gal./bu $0.55/gal.	3.0 gal./bu $0.55/gal.
Ethanol from cellulose	67–70 gal./dt $1.47/gal.	74–80 gal./dt $0.73/gal.	83–90 gal./dt $0.43/gal.
Biodiesel from soybeans	1.4 gal./bu $0.436/gal.	1.4 gal./bu $0.436/gal.	1.4 gal./bu $0.436/gal.

Sources: Aden et al.; BBI International; English, Jensen, and Menard; McAloon et al.

[a] Costs include only the cost of converting the feedstock and exclude feedstock costs and coproduct values.

Table 2. Estimated Forest Sector Supplies by Price and Year (million dry tons)

	\$20/dt	\$25/dt	\$30/dt	\$40/dt	\$50/dt	\$60/dt
2005	2.81	24.27	26.24	76.36	85.57	98.08
2010	2.83	24.85	26.63	77.64	87.07	99.71
2015	2.92	25.47	27.41	79.51	89.15	102.13
2020	3.00	26.24	28.23	81.98	91.92	105.31
2025	3.12	27.01	28.99	84.16	94.40	108.15

cut by logging and left behind. Other removals are the unutilized wood volume from cut or otherwise killed growing stock, from cultural operations such as precommercial thinning, or from timberland diversion to other uses. Primary mill residues are those generated in the conversion of roundwood (logs) into other wood products and include lumber sawmills, pulp mills, and veneer mills.

Supply curves for forest industry resources were estimated and incorporated into the analysis as fixed supplies, exogenous to the POLYSYS model. Logging residue, other removal, and primary mill waste generation data are from the USDA Forest Service. Data are for the survey year 2002. In-forest resources are converted from cubic feet to dry tons using factors in Smith. Projected future logging residue quantities are based on the USDA Forest Service Resource Policy Act assessment (Haynes), which provides regional projections of softwood and hardwood harvest. Other removals consist largely of land clearing operations (urban development), and their projected future quantities are based on projected population and housing growth. Other forest sector materials that could potentially serve as biomass resources include fuel treatment residues that are removed for fire suppression and forest health reasons, but these materials are not included in this analysis.

The cost of collecting logging residues and other removals utilizes a model developed by McQuillan et al., which uses forest inventory data, logging and chipping costs, hauling distances and costs, stocking densities, wood types, and slope and equipment operability constraints to estimate nine regional supply schedules for softwood and hardwood chips for the base year of their study (1983) with projections for future years. This analysis updates the forest inventory, adds a stumpage fee (\$2.00/dry ton), factors out the transportation component, and updates prices to \$2002. The model is used to estimate regional cost distributions, which are then applied to the projected future quantities. A key limitation of the analysis is the inability to fully update the model and to change some technology and structural assumptions.

An estimated 92 million tons of primary mill residues were produced in 2002, but only 1.86 million tons were not used for fuel, fiber, or other uses (e.g., bedding, mulch). Unlike most analyses that assume mill residues currently used are unavailable for bioenergy use, this analysis assumes that if a sufficiently high price is offered, some mill residues could be attracted away from their existing uses. The minimum prices needed (in \$2002) are estimated as the value of the wood in each end product (estimated as a % of the market price), additional processing costs (chipping, handling costs), and a disposal cost for unusable materials (tipping fees). Future quantities are estimated using Haynes and are similar to the logging residue analysis. Table 2 contains the estimated forest sector supplies (combined logging residues, other removals, and primary mill residues) for select prices.

Scenario Examined

The analysis examines the potential to meet 25% of the projected 2025 transportation needs on an energy equivalent basis. Ethanol contains about two thirds of the energy of gasoline, and the required quantities are significantly higher than on a volume basis. Additional ethanol demand (above current production levels) increases from 3.97 billion

Table 3. Feedstock Quantities Needed to Meet Demand, by Type

	Year 2006	Year 2015	Year 2025
Ethanol from corn (billion bushel)	1.85	3.83	4.78
Ethanol from cellulose (million dry ton)		Total = 224	Total = 670
Crop residues		95	245
Switchgrass		76	312
Forest residues		53	113
Biodiesel from soybeans (million bushel)	58	426	835
Residues not used (million dry ton)		Total = 227.7	Total = 1.5
Crop residues		97.1	0.5
Switchgrass		76.9	0.7
Forest residues		53.7	0.3

gallons in 2006 to 68.24 billion gallons in 2025. Biodiesel demand increases from 0.11 billion gallons in 2006 to 1.7 billion gallons in 2025. The analysis requires the demand quantity to be met, regardless of the cost of doing so. Additionally, projected food, feed, and export needs over the time period of analysis must be met.

Results

The analysis found that sufficient feedstocks are available to meet the demand (Table 3). Corn grain and soybean oil continue to play a significant role throughout the time period of the analysis, but to fully meet the 2025 demand, 670 million dry tons of cellulose feedstocks were needed, with switchgrass being the single largest source. In 2015, about 228 million dry tons of cellulose residues were available, but not used, but by 2025, nearly all of the projected quantities of cellulose feedstocks were needed for biofuel production. Despite improvements in conversion costs and efficiencies, the overall cost of producing biofuels increased (Table 4).

Table 4. Bioenergy Production Costs[a]

	Year 2006	Year 2015	Year 2025
Ethanol (corn and cellulose) ($/gal)	1.08	1.32	1.52
Biodiesel ($/gal)	0.69	1.80	2.50

[a] Feedstock cost and coproduct credits included. Feedstock transportation costs not included.

This is due, in part, to the increasing % of ethanol production from cellulose, which is more expensive than from corn grain, but this was also due to increasing crop prices (Table 5).

Net farm income increases for crop producers by an estimated $35 billion by 2025. Changes in livestock income are still being evaluated but will likely be negative. The extent of the impact will depend largely on the degree by which biofuel coproducts (e.g., distillers' dried grains) can be substituted in feed rations. Underlying the changes in crop prices are shifts in crop acres, including the production of switchgrass on 48.8 million acres. Changes in land use patterns and management practices will have substantial environmental implications, which have not been evaluated in detail.

Table 5. Crop Prices, Select Crops[a]

	Year 2006	Year 2015	Year 2025
Corn ($/bu)	2.28	2.56	3.01
	+(0.13)	+(0.14)	+(0.75)
Soybeans ($/bu)	4.67	6.52	7.48
	+(0.07)	+(0.90)	+(2.25)
Wheat ($/bu)	3.06	3.86	4.22
	+(0.01)	+(0.29)	+(0.78)
Switchgrass/other cellulose ($/dt)	20.00	48.68	65.07
	+(20.00)	+(48.68)	+(65.07)

[a] Values in parentheses are deviations from the baseline.

Conclusions and Summary

Given the assumed feedstock and technology parameters used in the analysis, sufficient biomass resources exist to supply 25% of the projected 2025 U.S. transportation fuels while simultaneously meeting food, feed, and export needs. Corn and soybeans continue to be important feedstocks for ethanol and biodiesel production, but to meet the high demand level, cellulose feedstocks (agricultural crop residues, energy crops such as switchgrass, and forestry residues) will need to play a major role. Estimated net farm income increases substantially, mostly because of higher crop prices. But increased crop prices also increase the cost of producing biofuels. Substantial shifts in land use patterns will result and may have significant environmental implications. On a regional basis, the Midwest will continue to be a major feedstock supplier (corn grain, soybean oil, and corn stover), and the southeastern United States could become a major supplier of cellulose feedstocks because of the availability of forest industry residues and the economic competitiveness of switchgrass production in that region.

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