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Land Use Implications of Expanding Biofuel Demand

Michael R. Dicks, Jody Campiche, Daniel De La Torre Ugarte, Chad Hellwinckel, Henry L. Bryant, and James W. Richardson

The Renewable Fuel Standard mandates in the Energy Independence and Security Act of 2007 will require 36 billion gallons of ethanol to be produced in 2022. The mandates require that 16 of the 36 billion gallons must be produced from cellulosic feedstocks. The potential land use implications resulting from these mandates were examined using two methods, the POLYSYS model and a general equilibrium model. Results of the POLYSYS analysis indicated that 72.1 million tons of corn stover, 23.5 million tons of wheat straw, and 24.7 million acres would be used to produce 109 million tons of switchgrass in 2025 to meet the mandate. Results of the CGE analysis indicated that 10.9 billion bushels of corn grain, 71 million tons of corn stover, and 56,200 tons of switchgrass is needed to meet the mandate.

Key Words: cellulosic ethanol, corn stover, grain ethanol, renewable fuel standard, switchgrass

JEL Classifications: Q15, Q42

Background

In his presidential address at the 2008 Southern Agricultural Economics Association annual meetings, Bill Herndon coined the term "ethanolization" to describe the recent combination of market–induced and policy–induced perfect storm that created the dramatic grain commodity price shocks in early 2008 and the connection of this storm to the recent increase in ethanol production (Herndon, 2008). The market–induced factors, high petroleum prices and low prices associated with chronic excess capacity in crop production, have abated (at least temporarily). The policy–induced factors, the contribution of large expenditures on foreign sources of oil, banning of methyl tertiary butyl ether, and the need for more rural economic development opportunities persist. Herndon points out the wide support from Americans for expansion of the ethanol industry that led to the expanding of the Renewable Fuels Standard (RFS) mandated in the *Energy Independence and Security Act of 2007* (EISA). The mandates provided in the EISA 2007 were made as a result of the optimism associated with achieving energy independence and rural economic development, but were independent of critical assessments of the agricultural impacts of attempting to achieve them. The level of interest and optimism is captured by a 2006 *New York Times* article that stated, "you could turn Oklahoma into an OPEC member by converting all of its farmland into switchgrass" (Pollack, 2006).

Federal and State regulations and incentives have supported the increasing interest in biofuel production and use. These factors have

Authors are Professor and Assistant Professor, Oklahoma State University, Stillwater, OK, Professor and Assistant Professor, University of Tennessee, Knoxville, TN, Assistant Professor, Texas A&M University, College Station, TX, and AFPC Co-Director, Regents Professor, and Sr. TAES Faculty Fellow, Texas A&M University.

created a quick expansion in the production of biofuels (De La Torre Ugarte et al., 2003). The EISA 2007 mandates an expansion in renewable fuels to 36 billion gallons by 2022. The 2007 act also provides that beginning in 2015, a minimum of 3 billion gallons per year of ethanol be produced from cellulosic sources such as corn stover, wheat straw, and switchgrass and a maximum of 15 billion gallons be produced from conventional corn starch. By 2022, the act requires 16 billion gallons of ethanol be produced from cellulosic sources.

The exuberance with the potential for biofuels should be tempered by the reality of the resources available. The United States contains approximately 450 million acres of cropland, and this number has fluctuated only slightly over the last century (Figure 1). The major grain and fiber commodities[1] comprise about 240 million acres, hay and pasture comprise another 110 million acres, idled, failed and fallow acreage accounts for roughly 75 million acres (Conservation Reserve Program (CRP) is roughly 34 million acres) and all other crops (e.g., fruits, vegetables, nuts) comprise the remainder (about 20 million).

While total farmland area is roughly 925 million acres, land not considered cropland has limited capacity for additional crop development. And, contrary to popular belief, there are few farmland acres not already engaged in productive use. Thus, any increase in ethanol production will require some shift in cropland use from current production to "biofuel feedstocks." The exception would be that biofuels could be produced as a joint product of crops already in production. For instance, corn stover can be used to produce ethanol without directly impacting corn production. However, any attempt at the production of biofuels through the use of joint products from a crop will require additional nutrients and may not be biologically, environmentally, or economically feasible over the long run. A final generalization of land use is that the long term excess capacity in cropland has averaged 18% and thus roughly 75 million cropland acres are potentially available for an alternative use. Over 40 million acres have been taken out of production to meet conservation goals. Historically, this excess capacity has been the cause of chronically low prices and its elimination would lead to higher and more unstable prices.

With respect to land use changes between farmland and cropland, Mills et al. (1992) determined that land does shift between major land use categories over long periods as relative prices change. Forage acreage acts as a buffer between crops and timber. As the relative price of these two products change there is a net shift between the land uses. However, as crop prices increase relative to timber prices over the long run, crop production increases through conversion of forage acres while forestlands are converted to forage. These shifts imply the inelastic nature of forage acreage supply, especially in relation to forest and crop acres.

The EISA 2007 mandates that biofuels must be produced from cellulosic materials and the most emphasized crop for this purpose is switchgrass, a perennial grass native to the tall and mix–grass prairies. While according to Epplin (1996), the commercialization of cellulosic–based ethanol could have a greater impact on the agricultural industry than the current starch–based ethanol, technologies that convert cellulosic biomass to ethanol including gasification, pyrolysis, liquefaction, fermentation, and anaerobic digestion are still under development and not commercially available.

The political mandate to obtain energy security through the development of biofuels has created a need to examine how America's 450 million acres of cropland will be reallocated to meet the mandates and what these land use changes will mean for farmers, associated agribusinesses, rural communities, and the environment. Various studies have analyzed specific biofuel related impacts. De La Torre Ugarte et al. (2003) identified the impact of increasing biofuel demand on commodity prices. Tenenbaum (2005) analyzed the relationship between the demand for fuel for vehicles and farm use and the potential use of biofuels. Wilson (2006) addressed the competition between export demand and domestic biofuel

[1] Barley, corn, cotton, oats, rice, sorghum, soybeans, and wheat.

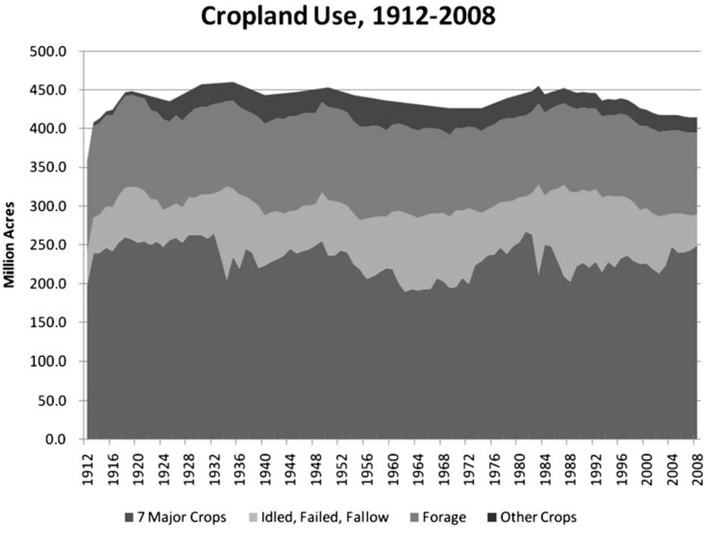

Figure 1. U.S. Cropland Use, 1912–2008

production for U.S. corn supply. Durante and Miltenberger (2004) and Pimental (2006) examine the energy balance of ethanol production. Ragan and Kenkel (2007) and Kenkel et al. (2006) identified the land use changes in Oklahoma to maximize an economic level of biofuel production. And a number of studies have analyzed the indirect impacts on land use changes from increased biofuel production (European Federation for Transportation and the Environment, 2008).

Du, Hennessy, and Edwards (2008) analyzed the impact of biofuel production on cash rents for Iowa farmland under hay and pasture. They found that a higher corn price induces land use conversion from hay and pasture to corn production leading to an increase in cash rental rates for hay and pastureland. They also note that higher rents may induce Conservation Reserve Program acres to return to hay and forage production and that the use of this "low–grade" land on a large scale to produce feedstocks for cellulosic ethanol production would create a more direct demand for nonprime farmland, putting downward pressure on prime farmland rates. Their conclusion was that the long–run equilibrium effect of ethanol policy on lower grade land is unclear.

Elobeid et al. (2006) determined that the total potential production of corn based ethanol would reach over 36 billion gallons at an equilibrium corn price of $4.05 assuming an oil price of $60 per barrel. Reaching this level of production would require 95.6 million corn acres to produce 15.6 billion bushels and reduce corn exports and pork and poultry production. Combining a CGE approach and a land supply model that includes nonmarket goods provided by land, Antoine, Gurgel, and Reilly (2008) demonstrate the changes in land use and commodity prices with increased biofuels production when the value of environmental services is included.

Considering the substitution among farm resources and commodities in a global context, Tweeten and Thompson (2008) found that reaching the 13.2 billion gallon ethanol mandate for 2012 would add $15 billion to U.S. farm receipts assuming a $3.77 price per bushel of corn and a 20% feed recovery rate per bushel. Their study also notes that the U.S. and European Union biofuel mandates will add 0.10 percentage points annually to the global farm output demand. Coupled with the global population increase the demand for farm products world–wide in 2025 will be 143% of the level in 2000.

Using a partial equilibrium and general equilibrium modeling framework, Tyner and Taheripour (2008) determined that at oil prices above $120 the RFS mandates were not binding and the ethanol production would actually exceed the mandate through 2016. However, as with many of the previously mentioned studies, no information is provided on whether the ethanol mandate includes the requirement for cellulosic sources or if the total mandate is met with corn only.

Certainly the literature is rich with studies estimating the impact of increased ethanol production on agricultural markets. But none of these studies provide a comprehensive assessment of the effect of the EISA 2007 mandates through 2025 on commodity supplies given fixed land resources. The first comprehensive attempt to examine the national, regional, and local land use implications were accomplished by the Biomass Research and Development (BRD) Board (2008). The study analyzed the increase in feedstock output required to meet the EISA 2007 mandates through 2016. The models and modeling framework used by the BRD Board are the same that we use except that we extend the analysis to 2025 and include a direct connection to the cattle industry as described in our methods.

The specific purpose of this research is to identify the potential land use changes resulting from the implementation of the mandates found in the *Energy Independence and Security Act of 2007.* We have not restricted the land use to meet environmental standards nor constrained the outcome based on technological limits or the availability of variable inputs. While these issues are certainly important to determine the future biofuel potential, the complexity of the analysis and the constraints on the length of this paper force us to focus on the specific issue of land use changes. We also quickly admit that like the BRD Board's analysis, our analysis remains incomplete as many linkages have yet to be included, especially those of the timber, fuel, and fertilizer markets.

Methods

POLYSYS

The 2015 and 2022 EISA standards are applied in uniform increments over the analysis period as minimum constraints in the POLYSYS modeling system. POLYSYS is a recursive, iterative modeling system that uses a linear programming model to determine planting decisions in year t and an econometric demand system to determine a price in year t + 1 based upon the supplies predicted in year t. The t + 1 year price is then used to determine planting decisions in year t+1. This modeling system uses a baseline and allows specific exogenously imposed changes to induce price and quantity adjustments. The results are presented as changes from the baseline (Ray et al., 1994).

Field–level costs and conversion characteristics of the various feedstock alternatives currently available in the United States were developed for the BRD study and are used here and provided in Table 1. These production costs, yields and yield growth rates, harvest and collection costs, and fuel yields are estimates and in many cases limited to one location specific estimate. A current Sun Grant initiative is underway to assist in developing regionally specific estimates for each of these variables and the first estimates are due late 2009.

Baseline Update and Extension

The USDA baseline projections were for the 2007/2008 through 2016/2017 crop years. Commodity prices and production levels have changed dramatically since USDA published the baseline in February of 2007. To allow the baseline to represent the current situation, we used the November release of the USDA World Agricultural Supply and Demand Estimates (WASDE) to update 2006/2007 data and 2007/2008 projections.

We then allowed POLYSYS to simulate from the 2007/2008 crop year through 2025 with the new WASDE updates to estimate the new baseline. Because USDA baseline projections end in 2016, we extended the USDA baseline to 2025 by exogenously estimating four variables: export changes, yield changes, population changes, and tillage changes. All other variables are solved endogenously from these changes.

Exports beyond 2016 (the final year of USDA baseline) were figured by extending the

Table 1. U.S. Field–Level Cost and Conversion Characteristics of Feedstock Alternatives

Feedstock	Total Feedstock Production Costs (including harvest cost)	Yield Per Acre	Total Output	2016 Baseline Projected Annual Yield Growth Rate	Harvesting and Collection Costs	Fuel Yield
	$/acre	Tons/ac/yr	Mil. Tons/yr	Percent	$/planted acre	Gal/ac
First–generation feedstocks						
Corn	417	4.2	355.2	1.23	101	388–418
Grain sorghum	261	1.8	12.4	0.65	89	168–181
Barley	272	1.5	5.7	0.89	78	138–161
Sugarcane	n/a	32.7	30.1	0.32	n/a	638
Sugarbeets	986	23.8	31.2	0.82	n/a	590
Soybeans	278	1.3	92	1.04	65	64
Second–generation feedstocks						
Corn stover	n/a	3	254	1.23	7–11	240–270
Wheat straw	n/a	1	58	n/a	17	80–90
Switchgrass	133–329	4.2–10.3	n/a	n/a	33–129	336–924
	$dry ton	Dry tons/ac/yr	Mil. dry tons/yr		$/dry tons	Mil. Gal/yr
Short–rotation woody crop	39–58	5–12	n/a	n/a	17–29	393
Forest residues and thinnings	37–92	37–92	n/a	101	n/a	9,040
Conventionally sourced wood	48–71	n/a	15	n/a	32–43	1,335
Primary mill residues	n/a	n/a	1.3	n/a	n/a	116
Municipal solid waste	n/a	n/a	14	n/a	n/a	1,253

Source: Business Research and Development Board

trend in the final 3 years of USDA baseline outward. The resulting export projections were used to 'shock' the model in the first iteration and thereafter solving to an endogenous equilibrium. The baseline exports are listed in Table 2 along with the annual rate of change that was applied to shock the model. The last three years of USDA baseline trend in yields

Table 2. Export Projections for Estimated Baseline

	2007	2010	2015	2020	2025	Rate of Change
Corn (mil bu)	2,350	2,265	2,180	2,371	2,591	1.17%
Grain Sorghum	260	148	150	155	160	0.61%
Oats	2	3	3	3	3	0.00%
Barley	20	20	20	22	24	0.00%
Wheat	1,150	1,150	1,150	1,206	1,272	1.09%
Soybeans	975	782	856	915	980	0.10%
Cotton (mil bales)	16	16	18	19	20	1.52%
Rice (mil cwt)	107	109	116	125	135	1.76%

* Shocked model with USDA baseline trend to all crops accept; Corn and Wheat, where shock factor = 50% of USDA baseline trend.

Table 3. Yield Projections for Estimated Baseline

	2007	2010	2015	2020	2025	Rate of Change
Corn (bu/ac)	153.1	158.8	168.3	178.1	188.5	1.13%
Sorghum	64.8	66.0	68.0	70.0	72.1	0.59%
Oats	62.9	64.1	66.1	68.1	70.2	0.61%
Barley	64.8	66.6	69.6	72.7	75.9	0.86%
Wheat	42.5	43.4	44.9	46.4	48.0	0.67%
Soybeans	41.5	42.9	45.1	47.3	49.4	0.89%
Cotton (lbs/ac)	800.0	830.0	865.0	890.4	916.6	0.58%
Rice (lbs/ac)	6,916.0	7,130.0	7,437.0	7,734.5	8,043.3	0.79%

* USDA baseline trends extended beyond 2016–2025.

are extended beyond 2016–2025. The resulting baseline yields are listed in Table 3 along with the annual rates of change for the individual crops.

Population of the United States was extended out using U.S. Census Bureau 2006 estimates (U.S. Census Bureau, 2006). Population estimates effect food demand and therefore crops prices and production. Table 4 gives the Census Bureau estimates for population in the United States.

Data from the Conservation Technology Information Center (CTIC) indicates that use of no–tillage has been increasing. We assume that the historical rate of increase of no–tillage since 1996 will continue through 2025. By expanding the historical trends, the simulations assume the annual tillage use in Table 5.

Cattle–Hay Linkage

A standard forage requirement is 26 pounds of forage per 1,000 pound cow per day (Redfearn and Bidwell, 2003). During the forage growth season from March to November (period varies depending on location) cattle harvest forage directly from the field. During the forage dormant period, forage must be supplied through forage stocks, in the form of hay or stockpiled forage. While feed grains can substitute for hay in the short run, over the longer term the substitution is not profitable. However, providing high protein feed or feed supplements may reduce the total demand for forage. We determined the tons of hay required per beef cow for each crop reporting district (CRD) using the National Agricultural Statistics Service (NASS) and Census data on beef cow numbers and total hay production. In areas where large hay surpluses are produced we assumed the cow requirement of 2.5 tons of hay per year.

Cropland hay acres are tied to cow/calf profitability and the amount of hay required per cow unit varies by crop reporting district. As land shifts out of hay production the number of cows that can be supported declines and thus beef production declines and price rises. The return per acre to the cow/calf enterprise is based on the number of tons per year of hay required for the cow/calf, the yield per acre of hay, and the value of total beef produced per cow.

Producers shift acreage into alternative crops when the anticipated return from an alternate crop exceeds the anticipated return of their present crop as depicted in the production possibilities curve in Figure 2. The curve illustrates possible output combinations and how relative prices (depicted by the price line) determine the amount of each commodity produced. Changes in the price of biofuel crops

Table 4. Population Projections for Estimated Baseline

	2005	2010	2015	2020	2025
Pop (thousands)	295530.5	308,936	322,302	335,846	349,758

U.S. Bureau of Census

Table 5. Tillage Trends

	Corn			Wheat		
	CT	RT	NT	CT	RT	NT
2006	37.7%	42.6%	19.7%	42.0%	42.6%	15.4%
2007	37.4%	42.6%	20.1%	41.4%	42.6%	16.0%
2008	37.2%	42.6%	20.3%	41.0%	42.6%	16.4%
2009	37.0%	42.6%	20.5%	40.6%	42.6%	16.7%
2010	36.8%	42.6%	20.7%	40.3%	42.6%	17.1%
2011	36.6%	42.6%	20.9%	39.9%	42.6%	17.5%
2012	36.4%	42.6%	21.1%	39.6%	42.6%	17.8%
2013	36.2%	42.6%	21.2%	39.2%	42.6%	18.2%
2014	36.0%	42.6%	21.4%	38.9%	42.6%	18.5%
2015	35.9%	42.6%	21.6%	38.5%	42.6%	18.9%
2016	35.7%	42.6%	21.7%	38.2%	42.6%	19.2%
2017	35.6%	42.6%	21.9%	37.9%	42.6%	19.5%
2018	35.4%	42.6%	22.0%	37.6%	42.6%	19.8%
2019	35.3%	42.6%	22.2%	37.2%	42.6%	20.1%
2020	35.1%	42.6%	22.3%	36.9%	42.6%	20.5%
2021	35.0%	42.6%	22.5%	36.6%	42.6%	20.8%
2022	34.9%	42.6%	22.6%	36.3%	42.6%	21.1%
2023	34.7%	42.6%	22.7%	36.0%	42.8%	21.2%
2024	34.6%	42.6%	22.9%	35.7%	42.7%	21.5%
2025	34.5%	42.5%	23.0%	35.4%	42.7%	21.8%

CT = conservation tillage; RT = reduced tillage; NT = no tillage. Tillage Assumptions from CTIC Projections.

and/or food and fiber crops would change the slope of the line and lead to a different allocation. Changes in technology for biofuels and/or food and fiber crops would change the shape of the curve and also change the amount of biofuel produced. POLYSYS determines this allocation in each crop reporting district, in each state and region in the country. The aggregation of these land allocations within the CRDs determines the national supply. The EISA mandates are increased each year and land resources are reallocated to meet these mandates, subject to existing total number of cropland acres. The new output levels obtained from the land reallocation induces price changes that induce new land use changes. Thus, in each year the net land use changes are a result of both the exogenous mandates and the endogenous price changes.

CGE Model

The 2022 EISA standards were applied as minimum constraints in a computable general equilibrium (CGE) model, consisting of nine regions and 29 sectors. This analysis focuses on land use changes in the United States due to increased biofuel production. The CGE approach allows us to simultaneously analyze the effects of conventional and cellulosic ethanol production on the entire economy. Conventional ethanol is produced from corn grain, while cellulosic ethanol is produced from corn stover and switchgrass. An explicit sector for switchgrass production was incorporated into

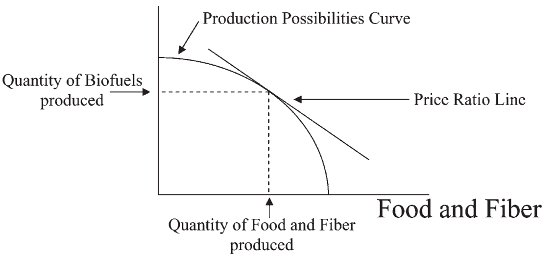

Figure 2. Production Possibilities Curve for Food and Fiber vs. Biofuel

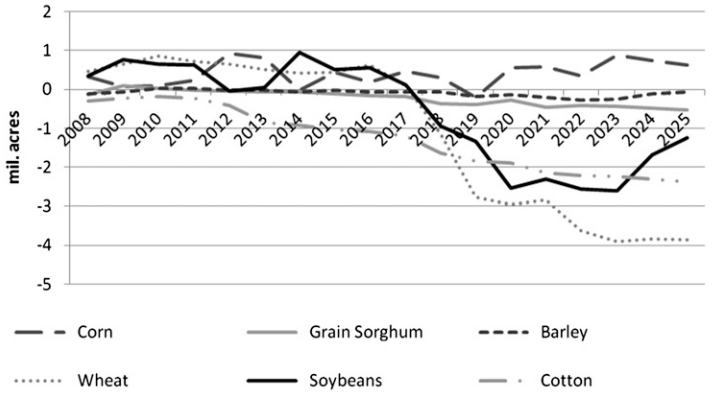

Figure 3. Land Use Changes due to the EISA 2007 Mandates

the model. Corn stover is produced as a joint product of corn production.

The benchmark data used for this analysis is a Social Accounting Matrix (SAM) representation of the Global Trade Analysis Project database version 6.0 (GTAP6) (see Hertel, 2007) and McDonald and Theirfelder (2004), for a detailed description of the database and SAM derivation). The GTAP6 database contains data on the circular flow of funds in the year 2001 among 57 economic sectors in each of 87 regions, as well as trade between regions, taxes, and tariffs. The CGE model used for this analysis is an aggregation of GTAP6. The basis for the aggregation includes importance in agricultural and other trade, consistent treatment under trade policy, and geographical proximity.

This particular analysis focused on U.S. agricultural and biofuel sectors. Renewable fuel sectors were incorporated into the model since they were not originally included in GTAP6. These alternative biofuel technologies entered into the model when they became economically competitive with existing technologies. The top nest in the production technology of these commodities features primary feedstocks and value–added as fixed factors to allow calibration with engineering data and estimates of future conversion efficiency.

Each region is endowed with four primary factors: capital, labor, land, and natural resources. Both producers and consumers can make input substitutions when making production and consumption decisions. Based on the technologies used in production, producers can substitute between labor, capital, land, and natural resources. The tradeoffs made by producers and consumers are captured by the

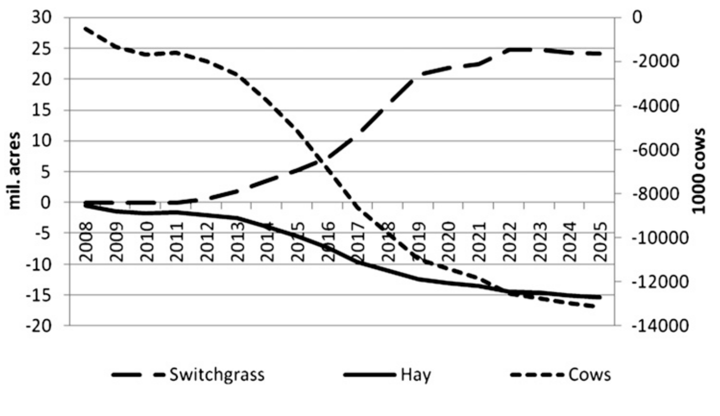

Figure 4. Changes to Hay and Switchgrass Acreage and Numbers of Beef Cows as a Result of the Ethanol Mandates in the EISA 2007

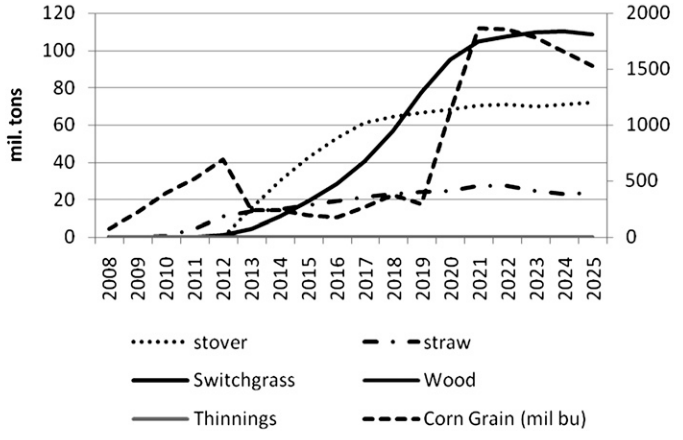

Figure 5. Changes in Quantities of Various Feedstocks as a Result of the Ethanol Mandates in the EISA 2007

elasticities of substitution, which are key parameters in the CGE model. In each period, a Walrasian equilibrium is found that satisfies the three conditions of zero profit, market clearance, and income balance. Nested constant elasticity of substitution (CES) production

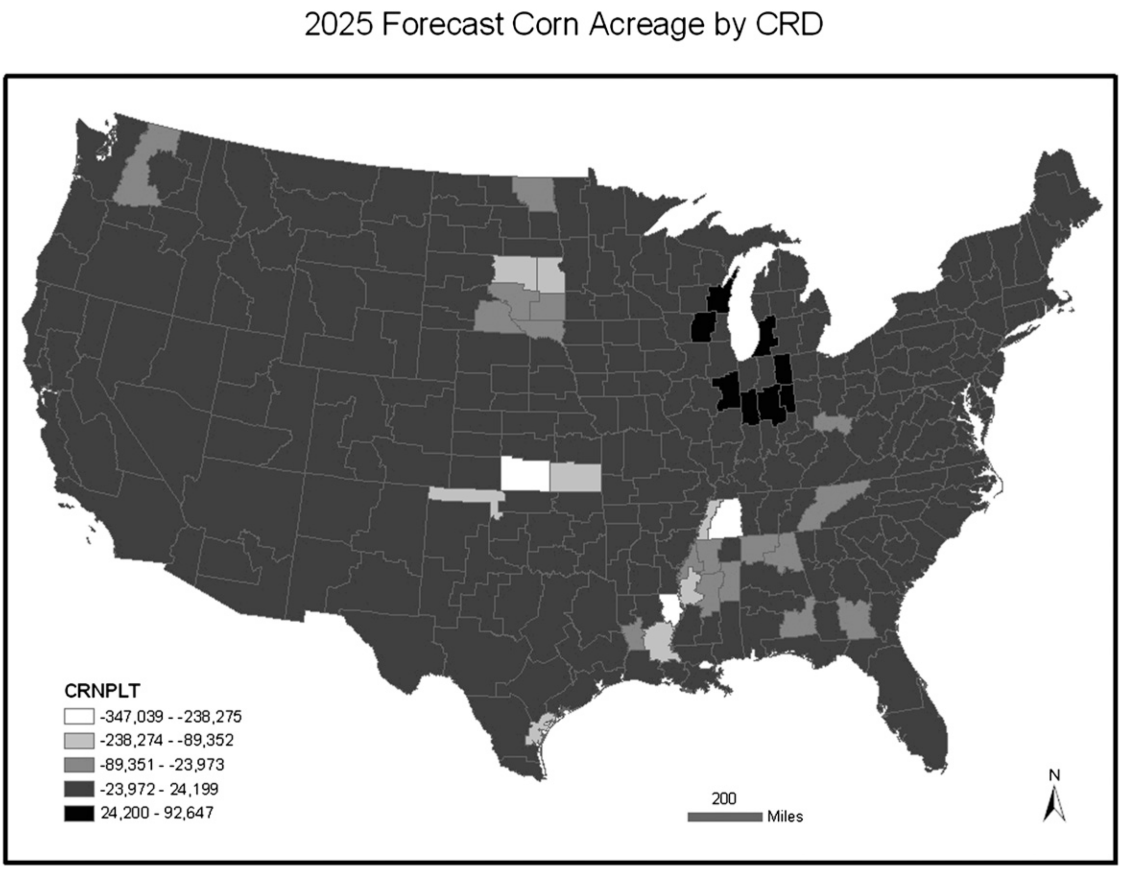

Figure 6. Changes in Corn Acreage by Crop Reporting District as a Result of Meeting the 2025 Ethanol Mandates in the EISA 2007

functions were used to represent constant returns to scale production technologies. The nested structure allowed for greater flexibility in setting elasticities of substitution for fuels. For each sector, the production functions represent the ways in which capital, labor, land, natural resources, and intermediate inputs can be used to produce output. For each region and each sector, a representative firm maximizes profits subject to its production technology constraints by choosing the optimal level of output, quantities of primary factors, and intermediate inputs from other sectors.

To incorporate biofuel sectors into the CGE model, agricultural commodity sectors not currently produced or utilized were added to the model and entered into production under favorable market conditions or technologies. This refers to the production of switchgrass as a dedicated biomass feedstock and the collection of corn stover as a biomass feedstock. Agronomic and engineering data for cellulosic ethanol production from switchgrass were used to calibrate the model parameters. Corn stover collection for biomass was specified as a fixed–proportions joint product of the sector producing other primary commodities (i.e., corn and corn stover). Agronomic data were used to determine the quantities of the joint products produced per unit of primary output. The incorporation of joint products into the CGE model allows for a more realistic depiction of the most likely feedstocks that would be initially employed in cellulosic ethanol production. At this point in time, it may not be practical to assume that cellulosic ethanol production will be fueled by dedicated biomass feedstocks. This approach ensures that dedicated biomass feedstocks do not displace other agricultural commodities to a disproportionate and unrealistic extent.

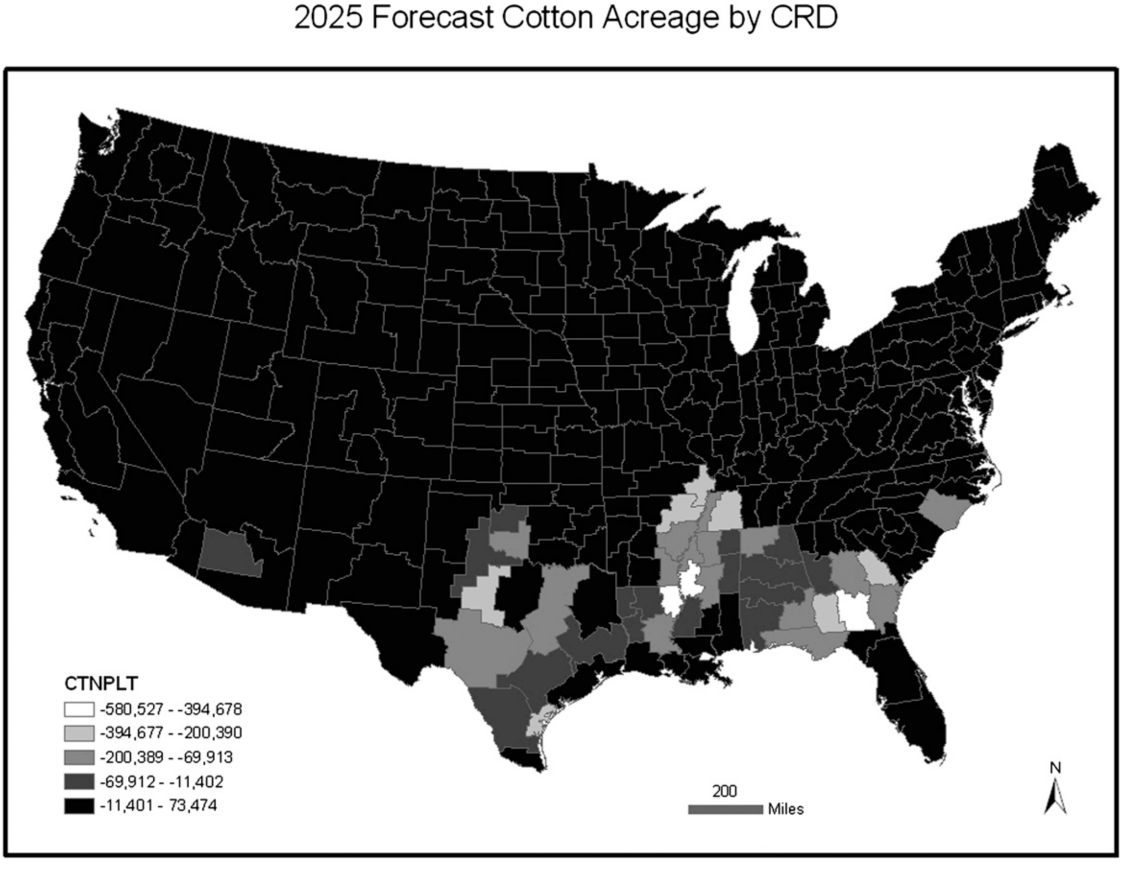

Figure 7. Changes in Cotton Acreage by Crop Reporting District as a Result of Meeting the 2025 Ethanol Mandates in the EISA 2007

The GTAP6 database does not include a separate commodity/activity account for switchgrass, corn stover, corn, or ethanol. Corn is included in the cereal grains sector and switchgrass is included in an aggregated cereals and field crops sector. McDonald, Robinson, and Theirfelder (2006) used the GTAP database to analyze switchgrass production and added a separate switchgrass commodity and activity accounts to the SAM for the U.S. They assumed that switchgrass would not be traded and that switchgrass production would not change in other regions. They assumed that the only interregional linkages will be indirect—an increase in switchgrass production in the United States takes land from other agricultural sectors leading to production changes and trade effects. We have also adopted this assumption and have only added new commodity and activity accounts to the SAM for the United States.

To parameterize the CES production function for the switchgrass sector, McDonald, Robinson, and Theirfelder (2006) assumed that switchgrass production costs were the same as production costs for the other cereals and field crops sector that already exists in the GTAP database. Actual switchgrass production was used to determine total production costs for switchgrass. To parameterize the switchgrass production function, a similar approach to McDonald, Robinson, and Theirfelder (2006) was used. Switchgrass production parameters were assigned similar values to other cereal crops included in GTAP6.

To develop a reasonable cost structure for conventional ethanol, an average estimate of $0.96 per gallon was used based on previous studies (Burnes, Wichelns, and Hagen, 2005; McAloon, Taylor, and Yee, 2000; Shapouri and Gallagher, 2005; Tiffany and Eidman, 2003;

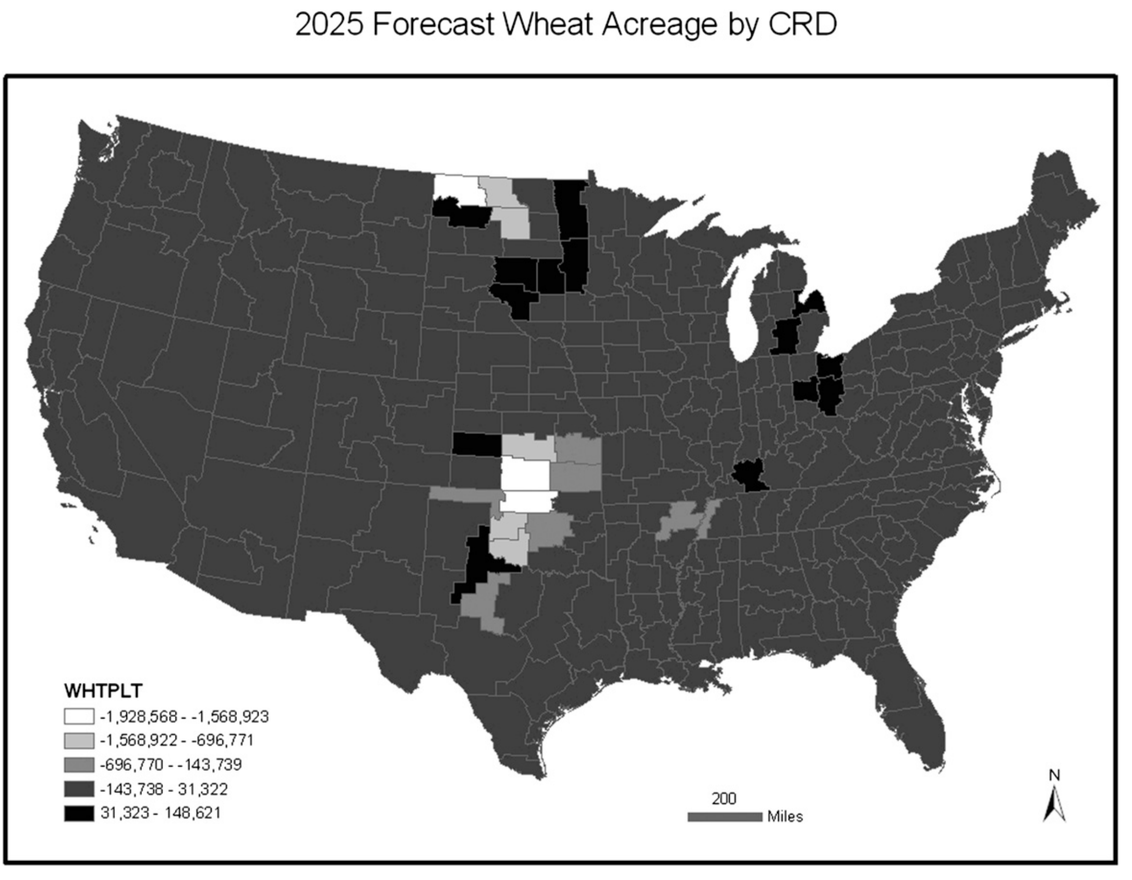

Figure 8. Changes in Wheat Acreage by Crop Reporting District as a Result of Meeting the 2025 Ethanol Mandates in the EISA 2007

Wallace et al., 2005). To develop a reasonable cost structure for the two cellulosic ethanol technologies, an average estimate for all production costs from previous studies was used, with the exception of feedstock costs (Aden et al., 2002; McAloon, Taylor, and Yee, 2000; Wallace et al., 2005; Wooley et al., 1999). Since the production of switchgrass is still not widely practiced, we chose to incorporate the more recent data relating to their production costs and yields into our cost estimates. It was assumed that 85 gallons of ethanol could be produced per ton of switchgrass or corn stover. Following the POLYSYS analysis, switchgrass costs were assumed to be $30/ton which results in cellulosic ethanol costs of $1.47 per gallon. A one–to–one ratio of corn stover to corn grain production was assumed (i.e., one ton of corn grain produces one dry ton of corn stover). For the base scenario, a collection efficiency of 30% was assumed. Corn stover cost data were not incorporated into the model. There is not a separate production function for corn stover, so the model assumes the same costs for corn stover and corn production/collection. Since there is not an actual market price for corn stover, the price of corn stover is determined by market interactions in the model solution.

While many studies have examined the effects of increased biofuel production, few studies have analyzed land use changes resulting from new cellulosic technologies in a general equilibrium framework. McDonald, Robinson, and Theirfelder (2006) analyzed the general equilibrium effects of substituting switchgrass for crude oil in U.S. petroleum production. They found that as more switchgrass is produced, less cereals are produced

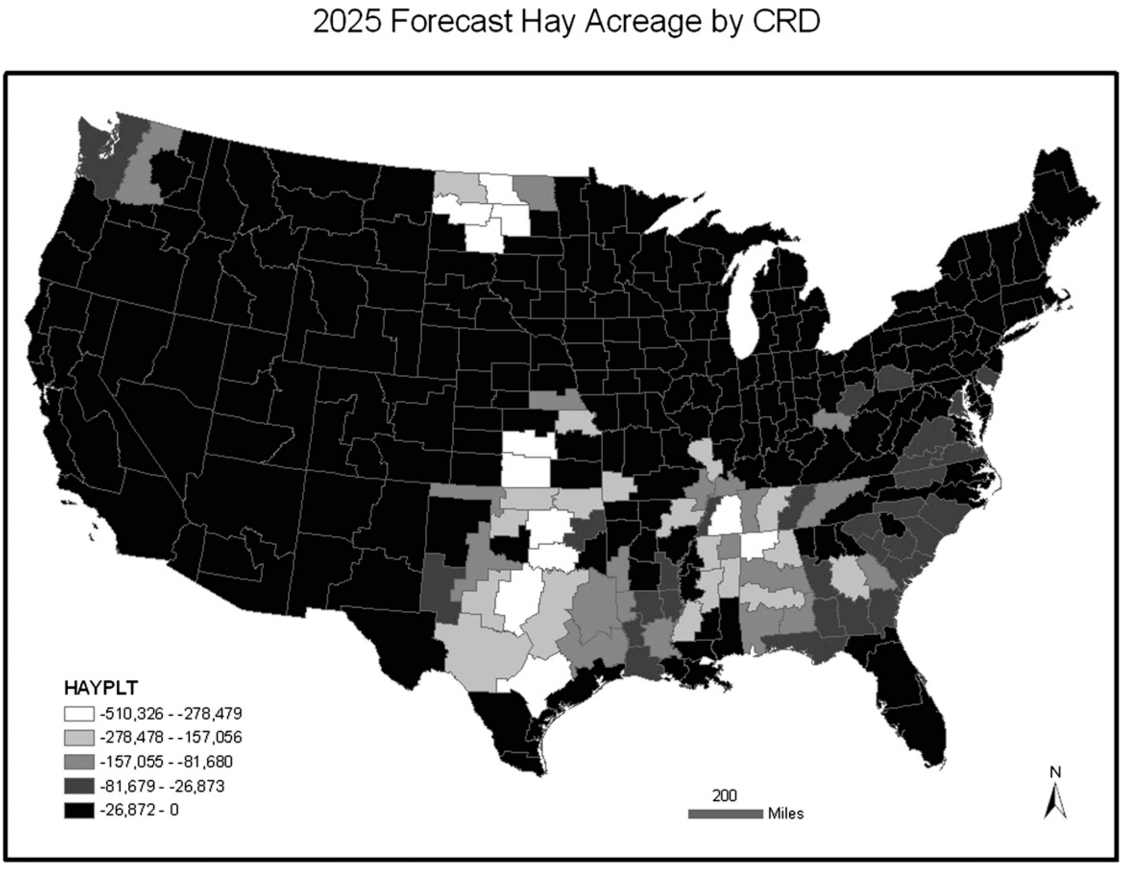

Figure 9. Changes in Hay Acreage by Crop Reporting District as a Result of Meeting the 2025 Ethanol Mandates in the EISA 2007

leading to a slight increase in the world price of cereals.

Results

POLYSYS

The BRD study showed limited land use changes in meeting the EISA mandates, but the study did not constrain land use changes to the currently available cropland acres, did not provide for minimum forage requirements for beef production, and did not extend the forecast past 2016. Our results indicate that meeting the EISA mandates through 2016 can be achieved with only minor changes in land use, but to achieve the mandates of 36 billion gallons of ethanol (16 billion from cellulosic sources) would force significant change in cropland use (Figure 3).

To meet the 2016 mandates, the cellulosic material will be produced mostly from wheat straw (19 million tons) and corn stover (53 million tons). The use of the wheat and corn plant materials increases the returns per acre of these two crops and increases their acreage (644 thousand and 161 thousand acres respectfully) but reduces the acreage of cotton. In addition, roughly 7.4 million acres of hay is moved into switchgrass production for 28 million tons of cellulosic feed stock (Figure 4). This reduction in hay production reduces the cow herd by over 6 million head, an 18% reduction.

The land use shifts required to meet the EISA demands for 2022 are more dramatic. By 2016 all of the cellulosic material that can be supplied from joint products is nearly complete and further production of cellulosic material must be achieved through the increased production of a crop (switchgrass) specific to that

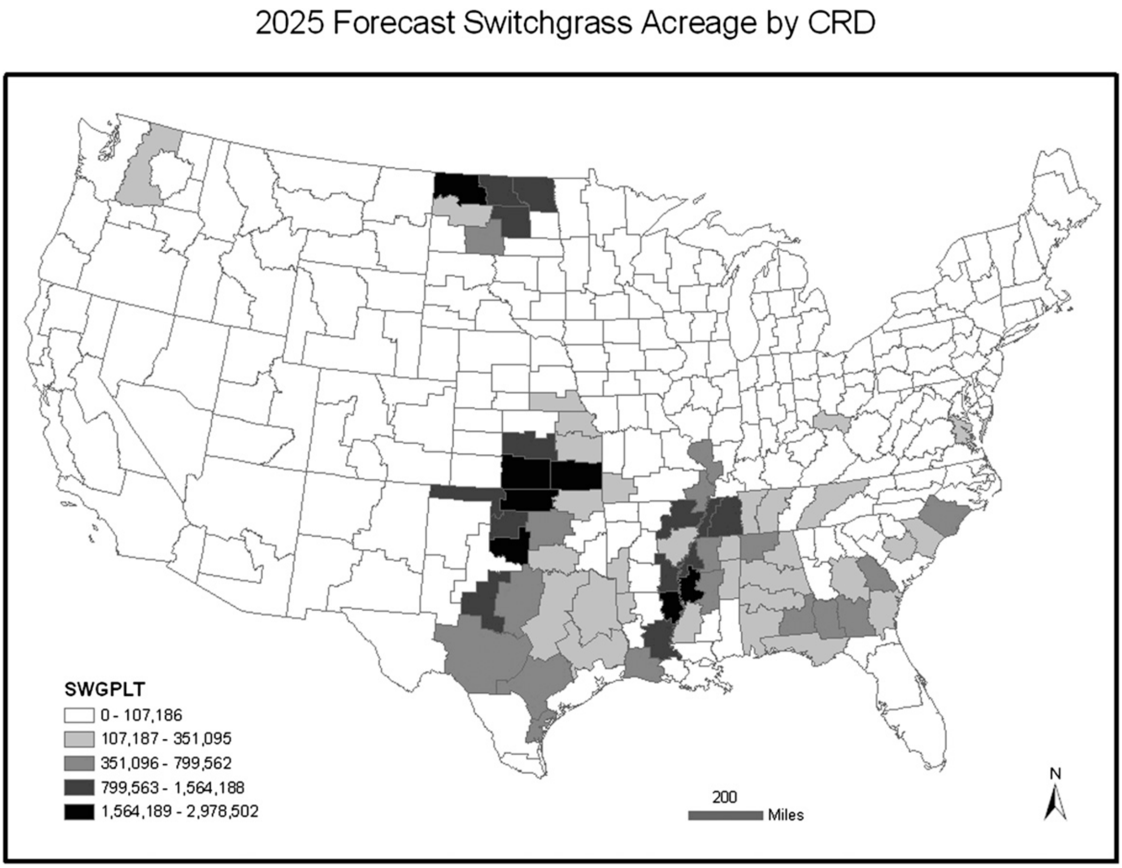

Figure 10. Changes in Switchgrass Acreage by Crop Reporting District as a Result of Meeting the 2025 Ethanol Mandates in the EISA 2007

purpose. The use of the wheat and corn plant materials increases to 23 million tons and 72 million tons respectfully (Figure 5), while the production of switchgrass increases to nearly 109 million tons and requires over 24 million acres. In addition, roughly 15.4 million acres of hay is moved into switchgrass production for 28 million tons of cellulosic feed stock. The increase in switchgrass acreage pulls acreage from all other crops except corn, with wheat yielding nearly 4 million acres and cotton yielding 2.4 million acres. The reduction in the cow herd has doubled to over 13 million head, over 30% of the total beef cow herd.

More important than the total land use changes is the concentrated location of these land use changes. The greatest land use changes occur in the CRDs in the southern United States (Figures 6–11). The loss in hay acreage and cattle occurs in nearly every CRD, but the majority of these reductions occur below the Mason–Dixon line east of the Rocky Mountains, the extended southeastern United States. For the major grain crops and cotton, the reduction in acreage in the southeast is partially offset by increases in acreage in other regions at the expense of hay acreage.

The implications of these land use changes concentrated in the southeastern United States include the need for infrastructure to support the developing cellulosic ethanol industry, to identify optimal size and location of cellulosic ethanol plants, and to determine the net local economy–wide impacts of switching from a cow/calf to cellulosic ethanol industry.

Following the changes in land use, commodity output and price changes are observed. Figure 12 illustrates the changes in output for the crop commodities, with the large increase in switchgrass production that is required to

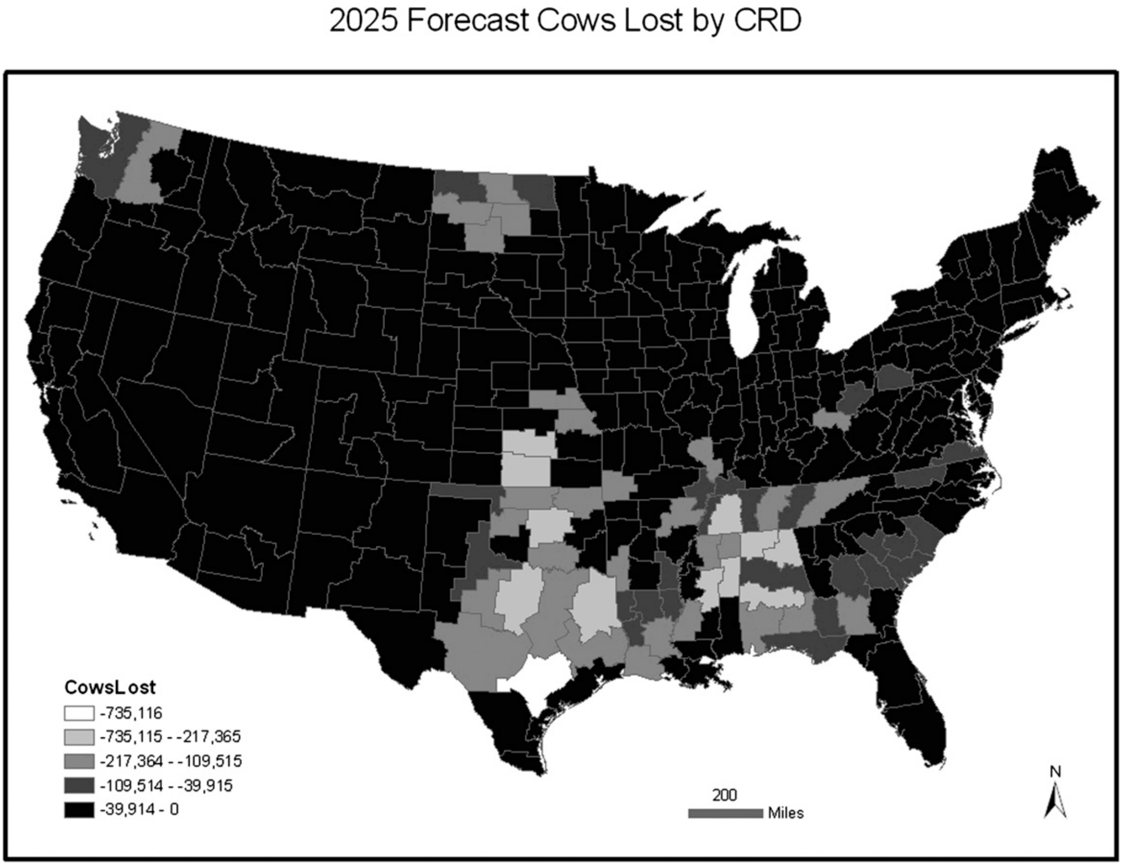

Figure 11. Changes in Number of Beef Cows by Crop Reporting District as a Result of Meeting the 2025 Ethanol Mandates in the EISA 2007

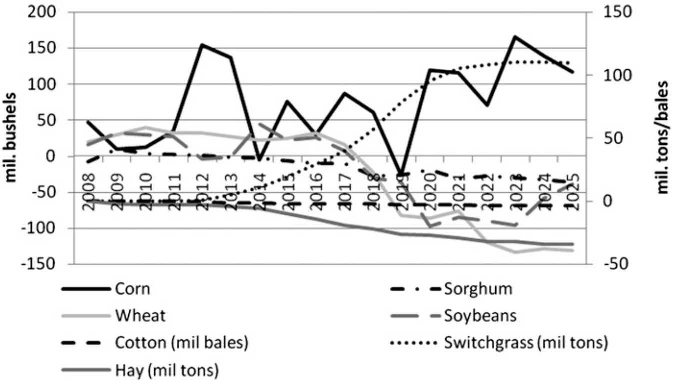

Figure 12. Changes in Output of Major Commodities as a Result of Meeting the 2025 Ethanol Mandates in the EISA 2007

meet the RFS ethanol mandates. However, the changes in output of the other crop commodities are small as a percentage of total output. This is due in part to the tight land constraint.

Figure 13 illustrates the changes in prices that will follow the changes in output levels resulting from the RFS ethanol mandates. All of the prices increase by greater than 15% over the baseline except for hay. Because the number of beef cows is reduced in proportion to the quantity of hay they consume, supply and demand of hay decline such that the hay price change is minimized.

Finally, the increase in prices more than offsets the decline in acreage of most of the grain commodities leading to an increase in net returns as illustrated in Figure 14. The change in net returns for all crops reaches nearly $20 billion with the corn ($10.7 billion in 2022) and switchgrass ($4.3 billion in 2022) comprising most of the increase.

Computable General Equilibrium

Results of the CGE analysis indicated that 31.2 billion gallons of grain ethanol, 6 billion gallons of stover ethanol, and 4.6 million gallons of switchgrass ethanol would be produced to meet the 36 billion RFS mandate (Table 6). Table 7 shows the amount of each feedstock required to meet the 36 billion gallon mandate. To produce 31.2 billion gallons of grain ethanol, 10.9 billion bushels of corn grain must be utilized. The production of 6 billion gallons of stover ethanol requires 71 million tons of corn stover. To produce 4.6 million gallon of

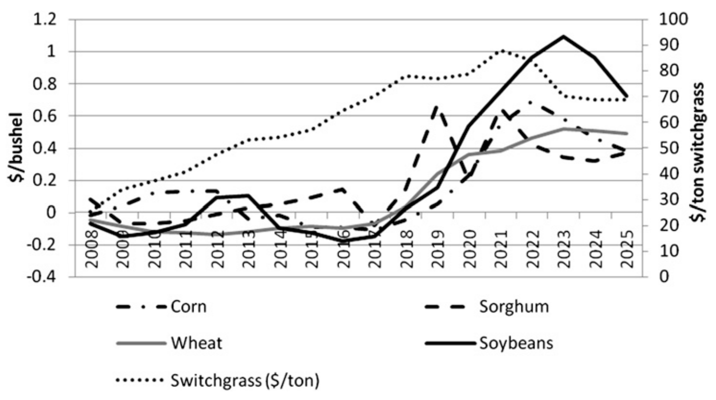

Figure 13. Changes in Prices of Major Commodities as a Result of Meeting the 2025 Ethanol Mandates in the EISA 2007

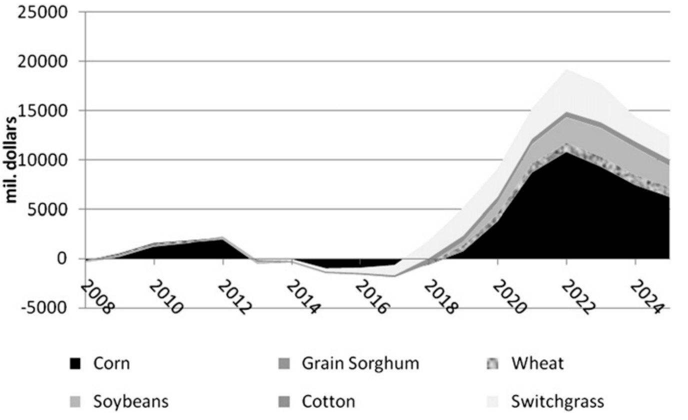

Figure 14. Changes in Net Returns of Major Commodities as a Result of Meeting the 2025 Ethanol Mandates in the EISA 2007

switchgrass ethanol, 56,200 tons of switchgrass is needed. To produce over 30 billion gallons of corn grain ethanol, corn production must increase by a substantial amount. As shown in Table 8, the production of cereal grains increased by 37.4% from the base. The increase in cereal grain (i.e., corn) acreage leads to a decrease in land use in all other crops. The decline in land use is similar for all crops, with wheat experiencing a slightly larger decline.

The RFS mandate leads to an increase in the competition for land, which leads to higher land prices as well as slightly higher crop prices (Table 9). The price of land increased 17.2% from the base. The prices of all crops went up slightly from the base. In the short–run, we might expect larger increases in crop prices. However, since the CGE analysis involves a long–run equilibrium, smaller changes in crop prices were expected.

Conclusions

We have analyzed the impact of attempting to meet the ethanol mandates in the EISA 2007 using only the 450 million acres of currently available cropland. We have not allowed for the reversion of CRP land to crop production but it could be used to provide forage for livestock and thus reduce the decline in beef cow numbers indicated in this study. While the effort to accurately model the potential land use changes associated with increased biofuel production remains far from complete, this study and the others cited earlier begin to provide both a framework and the bounds on impacts for consideration.

The majority of land use changes occur in the southeast and thus the development of a cellulosic industry may not be supported by northern states, the location of the corn based ethanol. In addition, the expansion of the ethanol industry in the south will not be an additive industry but rather one that substitutes for the cow/calf industry and thus may not provide any additional economic activity to the region. This is an analysis that may be important in the discussion of public investment in developing the infrastructure necessary to support the new industry.

Over 30% of the domestic beef cow herd would be eliminated to supply the feedstocks for cellulosic ethanol production and this raises the price of all meats and reduces the price of feed grains ceteris paribus. However, the increased demand for grain ethanol more than offsets the price reduction

Table 6. Ethanol Production with 36 Billion Gallon RFS

Sector	Gallons
Grain ethanol	31.2 billion
Stover ethanol	6 billion
Switchgrass ethanol	4.6 billion

Table 7. Feedstock Needed to Meet 36 Billion Gallon RFS

Sector	Quantity Used
Corn Grain	10.9 billion bu
Stover	71 million tons
Switchgrass	56,200 tons

associated with the reduced livestock feed demand.

Roughly 24 million acres from cropland in existing uses would be required to shift into the production of switchgrass (or some other similar cellulosic feedstock) to meet the cellulosic ethanol production mandates. This assumes the complete use of wheat stubble and corn stover in the development of the cellulosic ethanol. The majority of this acreage would come from hay acreage. The switchgrass yields exceed the current hay production yields and thus an increase demand for soil nutrients is implied. On current hay crops, 50 pounds of actual nitrogen is required to produce an additional ton of forage and roughly 14 pounds of phosphorus (P2O5) is removed for every ton of hay produced. The switchgrass yield is roughly three times that of hay and thus the demand for nutrients should increase substantially.

In the longer–run CGE analysis, small changes in crop prices were observed with the 36 billion gallon RFS mandate. However, there were significant shifts in land use between agricultural commodities. Results of the POLYSYS model suggest larger changes in agricultural prices than the CGE model. However, it is important to note that the results of the CGE analysis represent a long–run equilibrium and primary factors of production were fully mobile across sectors. This leads to long–run adjustments that are not reflected in actual changes over only a few years.

Table 8. Land Use of Major Crops

Sector	% Change from Base
Paddy rice	−10.7%
Wheat	−12.2%
Cereal grains	37.4%
Fruits and vegetables	−10.2%
Oil seeds	−10.9%
Plant–based fibers	−8.9%
Sugar cane/beets	−9.8%
Other crops	−10.0%
Livestock	−9.0%
Other animal products	−8.8%

Table 9. Prices of Land and Major Crops

Sector	% Change from Base
Land	17.2%
Paddy rice	4.2%
Wheat	4.4%
Cereal grains	4.2%
Fruits and vegetables	2.7%
Oil seeds	3.9%
Plant–based fibers	4.0%
Sugar cane/beets	3.2%
Other crops	3.8%
Livestock	2.3%
Other animal products	1.6%

Limitations

As of this writing, no economically competitive commercial size cellulosic ethanol production facility exists in the United States. Cellulosic ethanol conversion rates, processing costs, and infrastructure costs cannot be accurately forecasted. Switchgrass yield data were produced from controlled experiments from a limited area. Switchgrass production methods, fertilizer requirements, and switchgrass yields from on–farm trials on cropland, pasture land, range land, and CRP acres, across climate zones, remain to be established. Currently, we do not have enough data to truly understand the potential of switchgrass as a feedstock.

Unlike grain crops, switchgrass has no alternative commercial uses (locally it may be used for hay) and no federal price support network. Infrastructure (harvest, storage, transportation) is not in place to produce and market switchgrass. Conversely, grain production, harvesting, storage, and transportation are virtually seamless as a result of years of infrastructure development and refinements. For cellulosic biofuel feedstock, the development of the appropriate infrastructure may require many years. While the study projected the biofuel production under mandate, the study did not attempt to model the likelihood of such conversions. The development of an Oklahoma biofuel industry also involves a "chicken and the egg" problem. The lack of a strong local market for biofuel feedstocks may inhibit producers' conversion into biofuel crops. At the same time, the lack of an established raw material base may inhibit the development of biofuel processing infrastructure. Tyner and Taheripour (2008) stated that at an oil price of $120 per barrel biofuel production would exceed the mandates. Elobeid et al. (2006) stated that at a corn price of $4.05 per bushel and oil price of $60 biofuel production would exceed mandates. These findings imply that profit maximizing producers will switch to biofuel crops at specific crop and oil prices. However, no time path is provided for the switch.

Biofuel feedstock production represents an additional alternative for producers. However it should be emphasized that all land in farms is currently in use. The overwhelming majority of range and pasture acres are used to produce forage to feed the roughly 100 million cattle and calves. A biofuels industry would bid resources from current use with possible negative impacts on some agricultural sectors. The majority of the biofuel potential identified in this study related to the conversion of land currently producing hay, cotton, and wheat in the southeast. Converting this land to biofuel feedstocks would have clear implications for the cattle industry.

Conversion into biofuel crops, like any cropping system change, will also impact existing agribusinesses. Existing facilities including farmer–owned grain elevators, and cotton gins could be impacted. In a more general sense, economic activity resulting from a biofuels industry may reduce some of the state's current industries.

Several limitations exist with the CGE approach. The renewable fuel standard is imposed as a total constraint on both grain and cellulosic ethanol production. Currently, there is not a separate "conventional" and "advanced" ethanol constraint. Therefore, the 36 billion gallon requirement is not composed of 16 billion gallons of cellulosic ethanol. In addition, technology improvements in cellulosic ethanol production have not been incorporated into the model.

References

Aden, A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, and B. Wallace. "Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover." Technical Report NRELTP-510-32438. National Renewable Energy Laboratory, Golden, CO, 2002.

Antoine, B., A. Gurgel, and J.M. Reilly. "Will Recreation Demand for Land Limit Biofuels Production." *Journal of Agricultural & Food Industrial Organization*, 6(2008): Article 5.

Biomass Research and Development Board. *Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications, and the Role of Research*. Internet site: http://www.brdisolutions.com/default.aspx.

Burnes, E., D. Wichelns, and J.W. Hagen. "Economic and Policy Implications of Public Support for Ethanol Production in California's San Joaquin Valley." *Energy Policy* 33(2005): 1155–67.

De La Torre Ugarte, D.G., M.E. Walsch, H. Shapouri, and S.P. Slinsky. "The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture." *United States Department of Agriculture*, February 2003:1–41.

Du, X., D. Hennessy, and W.A. Edwards. "Does a Rising Biofuels Tide Raise All Boats? A Study of Cash Rent Determinants for Iowa Farmland under Hay and Pasture." *Journal of Agricultural & Food Industrial Organization,* 6(2008): 1–23.

Durante, D., and M. Miltenberger. "Net Energy Balance of Ethanol Production." *Ethanol Across America* (Fall 2004):1–12.

Elobeid, A., S. Tokgoz, D.J. Hayes, B.A. Babcock, and C.E. Hart. " The Long–Run Impact of Corn–Based Ethanol on the Grain, Oilseed, and Livestock Sectors: A Preliminary Assessment." CARD Briefing Paper 06-BP 49, November 2006.

Epplin, F.M. "Cost to Produce and Deliver Switchgrass Biomass to an Ethanol–Conversion Facility in the Southern Plains of the United States." *Biomass and Bioenergy* 11(1996): 459–67.

European Federation for Transportation and the Environment. *Biofuels and Land Use Change Fact Sheet*. Internet site: http://www.transportenvironment.org/News/2008/11/Biofuels-and-land-use-change-a-debate/ (Accessed November 2008).

Herndon, C.W., Jr. "The Ethanolization of Agriculture and the Roles of Agricultural Economists." *Journal of Agricultural and Applied Economics* 40,2(2008):403–14.

Hertel, T.W. *Global Trade Analysis: Modeling and Applications*. Cambridge: Cambridge University Press, 2007.

Kenkel, P., C. Godsey, F. Epplin, M. Gregory, R. Holcomb, and R. Huhnke. "Potential for Production of Biofuel Feedstocks in Oklahoma." Working Paper. Department of Agricultural Economics, Oklahoma State University, 2006.

McAloon, A., F. Taylor, and W. Yee. "Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks." Technical Report NREL/TP-580-28893. National Renewable Energy Laboratory, 2000.

McDonald, S., S. Robinson, and K. Theirfelder. "Impact of Switching Production to Bioenergy Crops: The Switchgrass Example." *Energy Economics* 28(2006):243–65.

McDonald, S., and K. Theirfelder. "Deriving a Global Social Accounting Matrix from GTAP Version 5 and 6 Data." GTAP Technical Paper, No. 22. 2004.

Mills, K., M.R. Dicks, D. Lewis, and R. Moulton. "Methods for Assessing Agricultural–Forestry Land Use Changes." OAES Research Report P-928, Oklahoma State University, November, 1992.

Pimental, D. *Ethanol Fuel from Corn Faulted as Unsustainable Subsidized Food Burning*. Internet site: http://healthandenergy.com/ethanol.htm (Accessed June 2006).

Pollack, A. "Scientists as Custom Tailors of Genetics." *The New York Times*, September 8, 2006, p. C1.

Ragan, H., and P. Kenkel. "The Potential Impact of Biofuel Production on Crop Production in the Southern Plains." Working Paper. Department of Agricultural Economics, Oklahoma State University, 2007.

Ray, D.E., D.G. De La Torre Ugarte, M.R. Dicks, and K.H. Tiller. "The POLYSYS Modeling System Framework: A Documentation." Agricultural Policy Analysis Center Report, University of Tennessee, 1994.

Redfearn, D.D., and T.G. Bidwell. "Stocking Rate: The Key to Successful Livestock Production." Oklahoma Cooperative Extension Service Report PSS-2871, July 2003.

Shapouri, H., and P. Gallagher. *USDA's 2002 Cost–of–Production Survey*. U.S. Dept of Agriculture, Office of Energy Policy and New Uses, 2005.

Tenenbaum, D.J. "Harvesting the Potential of Biomass." *Environmental Health Perspectives* 113,11(2005):A750–53.

Tiffany, D.G., and V.R. Eidman. "Factors Associated With Success of Fuel Ethanol Producers." Staff Paper P03–07. Department of Applied Economics, University of Minnesota, St. Paul, 2003.

Tweeten, L., and S.R. Thompson. "Long–term Global Agricultural Output Supply– Demand Balance and Real Farm and Food Prices." The Ohio State University Working Paper: AEDE-WP 0044–08. December, 2008.

Tyner, W., and F. Taheripour. "Biofuels, Policy Options, and their Implications: Analysis Using Partial and General Equilibrium Approaches." *Journal of Agricultural & Food Industrial Organization*, 6,9(2008).

USDA. *NASS State Crop Production Statistics*. Washington, DC: United States Department of Agriculture, 2006.

Wallace, R., K. Ibsen, A. McAloon, and W. Yee. "Feasibility Study for Co-Locating and Integrating Ethanol Production Plants from Corn Starch and Lignocellulosic Feedstocks." NREL/TP-510–37092, USDA-ARS 1935-41000-055-00D, A Joint Study Sponsored by the U.S. Department of Agriculture and U.S. Department of Energy, 2005.

Wilson, M. "Runnin' on Empty." *Farm Futures* (July/August 2006):11–16.

Wooley, R., M. Ruth, J. Sheehan, K. Ibsen, H. Majdeski, and A. Galvez. "Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis Current and Futuristic Scenarios." National Renewable Energy Laboratory, NREL/TP-580–26157. 1999.