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A Spatial Equilibrium Model of the Impact of Bio-Fuels Energy Policy on Grain Transportation Flows

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ABSTRACT

Traffic flows in the U.S. have been affected by the substantial increase and, as of January 2009, decrease in biofuel production and use. This paper considers a framework to study the effect on grain transportation flows of the 2005 Energy Act and subsequent legislation, which mandated higher production levels of biofuels, e.g. ethanol and biodiesels. Future research will incorporate changes due to the recent economic slowdown.

Keywords: ethanol, biodiesel, spatial equilibrium, quadratic programming

A Spatial Equilibrium Model of the Impact of Bio-Fuels Energy Policy on Grain Transportation Flows

INTRODUCTION

U.S. ethanol industry has seen a tremendous growth during the last two decades which gained even greater momentum after Energy Policy Act of 2005 and subsequent biofuels related policies. For instance, see Table 1 and Figure 1, U.S. fuel ethanol production capacity increased at an average annual growth rate of 23% between 2000 and 2008, where annual ethanol production capacity of 1.75 billion gallons in 2000 reached 10.57 billion gallons as of January 2009 (RFA 2009a). Similarly, see Table 2, during this period, U.S. fuel ethanol production increased at an average rate of 25% annually from 1.63 billion gallons in 2000 to 9.24 billion gallons in 2008, with the most annual increase of 33% and 42% in 2007 and 2008 respectively (EIA 2009a). This means, approximately 3.4 billion bushels of corn, or 28% of U.S. corn production, was used in ethanol production in 2008. When approximated in terms of bushels, share of ethanol industry’s corn consumption of total U.S. corn production rose from 7% to 28% from 2000 to 2008 respectively. U.S. biodiesel production industry on the other hand, did not grow significantly until the beginning of 2004 and witnessed an explosive growth afterwards with an average annual growth rate of 121% until 2009(see Table 2).

Production of ethanol largely relies on Midwest corn, while biodiesel is often made of soybean byproducts, with both corn and soybeans being the principal commodities transported on the upper Mississippi and Illinois Rivers. Especially, eight Midwestern states – Illinois, Indiana, Iowa, Minnesota, Nebraska, Ohio, South Dakota, and Wisconsin – are the major producers of corn and soybean whose combined production accounts for more than seventy percent of nation's total production of each commodity. For instance, these states produced 9.77 out of 13.07 billion bushels (75%) of nation's corn and 1.84 out of 2.59 billion bushels (71%) of nation's soybeans in 2007 marketing year, see Table 3 (USDA 2008d).

Recently built and planned biofuel facilities are largely located in these eight Midwest regions that ship grain for export via the Mississippi/Illinois Rivers, see Figures 3 and 4 (RFA 2009b and NBB 2008). These states had 6.2 billion gallons, equivalent of 2.3 billion bushels (or 17% of U.S. corn production) of corn, of combined annual ethanol production capacity (or 83% of U.S. ethanol capacity) in 2007. U.S. ethanol industry achieved an annual production capacity of 10.36 billion gallons, where eight Midwestern states production capacity accounted for 80% of U.S. ethanol capacity or 8.3 billion gallons, equivalent of 3.1 billion bushels of corn, as of March 2009, see Table 4, (RFA 2009a). Current and projected ethanol production capacity in proximity to the river is estimated to require about 1.7 billion bushels of corn or 17% of US corn production.

U.S. soybean production declined from 2.9 billion bushels in 2001 to 2.45 billion bushels in 2003. However in 2004, soybean production jumped to 3.1 billion bushels and stayed at that rate fairly stable through 2006 and started declining again (USDA 2008a). Despite the production increase from 2003 to 2006, down-bound shipment of corn and soybeans via Upper Mississippi River declined from 950.5 million bushels to 760 million bushels during this period, see table 5 and Figure 5 (U.S. Army Corps of Engineers 2009). This decline can be partly attributed to the expansion of biofuels production in eight Midwestern states during this period. If this trend continues in the near future, it should be expected that substantial quantities of grain may be directed away from the Mississippi River, which could reduce traffic and congestion at its principal chokepoints, allowing other commodities to enter the River.

Energy Information Agency projects that corn based ethanol production will increase for the projected period of 2005-2030 (EIA 2009b). Along with reference case, EIA makes projections under four alternative scenarios, namely, 1) high economic growth case, 2) low economic growth case, 3) high price case, and 4) low price case. Under all scenarios, most of the growth is projected to occur until 2018. U.S. produced 9.24 billion gallons (which requires about 3.4 billion bushels of corn) of fuel ethanol in 2008 and it is projected to increase to 12.46 and 15.17 billion gallons in 2012 and 2018 respectively (see Table 6). This would translate into additional demand for 2.2 billions of corn in the next decade. a spatial, inter-temporal equilibrium model. The model maximizes the total net welfare and employs quadratic programming approach

Spatial equilibrium models of the grain economy, employs quadratic programming approach, have been used by Fuller, Fellin and Eriksen (2000) to examine the role of the Panama Canal as a grain transport artery and to evaluate the effect of increasing Canal tolls on U.S. agriculture. More recent works on such spatial equilibrium modeling employed by Wilson, DeVuyst, Koo, Dahl and Taylor (2005) which develops a cost-minimizing spatial model of the world grain economy to estimate long-run grain movements on the Mississippi River.

BACKGROUND

Ethanol

RFA defines ethanol as: “Ethanol, or ethyl alcohol, is a renewable alcohol fuel made from abundant agricultural resources. In the U.S. ethanol is primarily produced from the starch contained in grains such as corn, grain sorghum, and wheat through a fermentation and distillation process that converts starch to sugar and then to alcohol.” (RFA 2009c). Currently in the United States, the main feedstock for ethanol production is corn where 97 percent of ethanol is produced from corn. (USDA 2008b).

Ethanol is produced by two production processes: wet milling and dry milling, where dry milling being the most common in the US. In addition to ethanol, the dry milling process yields ethanol byproducts such as condensed distillers solubles (CDS), dried distillers grains (DDGs), and carbon dioxide. Similarly, wet milling process also yields byproducts such as corn oil, corn gluten meal, and carbon dioxide. DDGs and corn gluten meal are used as livestock feed and corn oil and carbon dioxide are used for other industrial purposes. (RFA 2009d).

According to EIA report, In the United States, nearly all ethanol is blended into gasoline at up to 10 percent by volume to produce a fuel called E10 or “gasohol.” All cars that are built after 1970 can run on the ethanol blend E10, however, high level ethanol blends from E60 to E85 requires a “flex-fuel” engine. (EIA 2009c).

Biodiesel

Biodiesel is defined by EIA as: “Biodiesel is a fuel typically made from soybean, canola, or other vegetable oils; animal fats; and recycled grease. It can serve as a substitute for petroleum-derived diesel or distillate fuel.” (EIA 2009d) Glycerin is produced as a biodiesel by-product which is used in soaps and other products. The primary sources of U.S. biodiesel production are soybean oil and yellow grease, most of which come from recycled cooking oil (Radich 2004). According to National Renewable Energy Laboratory, biodiesel blends of B20 (20 percent biodiesel and 80 percent petroleum diesel) or lower can be used in any diesel engine with proper fuel tank maintenance and fuel blending (NREL 2005).

United States Biofuels Policies

By the end of 1990s, several states started banning MTBE use as gasoline oxygenate after discovering its negative effects on health and environment as result of gasoline leakage incidents. In 2000, Environmental Protection Agency (EPA) recommended that the use of MTBE should be banned across all the states. By 2004, 18 states including California, whose share accounted for 31.7% of total U.S. MTBE consumption in 2002 (EIA 2009e), banned the use of MTBE and started switching to ethanol as a gasoline oxygenate. Consequently, as these states began switching to ethanol, demand for fuel ethanol increased steadily.

Subsequent biofuels related policies such as The Energy Policy Act of 2005 (EPAct 2005) and The Energy Independence and Security Act of 2007 (EISA 2007) ensured a secure market for corn based ethanol until 2022 by requiring certain amounts of ethanol be blended into gasoline.

The Energy Policy Act of 2005 includes Renewable Fuel Standard Program (RFS) which mandates the minimum amount of renewable fuels be blended into gasoline. RFS doubles the use of ethanol and biodiesel by 2012, namely it requires that 7.5 billion gallons of national fuel supply be provided by renewable fuels, including ethanol and biodiesel, see Table 7 (EIA 2009f).

The Energy Independence and Security Act of 2007 further expands the EPAct 2005 by requiring 36 billion gallons of renewable fuels blended into gasoline and diesel by 2022. EISA 2007 categorizes production 36 billion gallons of renewable fuels into conventional biofuels (corn ethanol) 15 billion gallons and advanced biofuels (cellulosic ethanol, biodiesel) 21 billion gallons (EIA 2009f). The United States produced 6.5 billion gallons of fuel ethanol (equivalent of 2.4 billion bushels of corn) and 0.49 billion gallons of biodiesel, in 2007.

In addition, above policies provide tax incentives for biofuels producers and blenders. To stimulate the production of ethanol, ethanol and biodiesel producers, who produce less than 60 million gallons a year, are given small producer credit of 10 cents for every gallon produced up to 15 million gallons a year, which is effective until the end of 2010. Registered blender is given a Federal tax credit, Volumetric Ethanol Excise Tax Credit (VEETC), which provides blenders a tax refund of 51 cents per gallon of pure ethanol blended with gasoline. VEETC also gives two types of tax credits, Straight Biodiesel Credit and Biodiesel Mixture Credit, for biodiesel producers. Producers receive Straight Biodiesel credit equaling to $1 per gallon of pure agri-biodiesel and Biodiesel Mixtures credit of 1 cent per percentage point of agri-biodiesel blended with petroleum diesel (Cubert 2006).

OBJECTIVES AND PROCEDURES

The objectives of this study are to (1) estimate the effect of expanded United States ethanol/biodiesel production on domestic and international grain flows and patterns, (2) evaluate the effect of U.S. biofuels energy policy on Mississippi/Illinois Rivers grain traffic and its impact on lock congestion in the lower reaches of these Rivers, and (3) examine the economic potential for reducing U.S. highway and rail congestion with short sea shipping opportunities. The primary objective of this project is an updated and expanded spatial equilibrium model of the world grain economy. The updated model will reflect recent changes in the dynamics of grain production, consumption, and transportation in reaction to the explosive growth of the biofuels market in the U.S. during 2005-2008 and eventually will incorporate the transportation dimension associated with other commodities.

In order to accomplish these objectives, spatial equilibrium models representing the international corn and soybean economies in the 2007-2008 crop year were developed. The spatial models are validated by contrasting actual outcomes in 2007-2008 with solutions obtained using the constructed base models that represent 2007-2008. After validation of the base models, they are modified to include EIA projected demand for corn for ethanol production under five scenarios, along with price responses of different transportation modes.

MODEL DESCRIPTION

To accomplish the research objectives we will use a spatial, inter-temporal equilibrium model. The model maximizes the total net welfare and employs quadratic programming approach by maximizing producer plus consumer surplus minus grain handling, storage and transportation costs. We follow Samuelson (1952), Takayama and Judge (1971) who developed a spatial equilibrium model to deal with this type of problems. In maximizing the objective function several constraints must hold: regional supply and demand balance; transportation mode balance; and storage capacity balance for each region, type of grain, and quarter. The model addresses carefully each of the US regional excess demands and supplies, and transportation, storage and grain handling rates/charges. Other trading countries are treated as an excess supply or excess demand region. Output from the spatial equilibrium models identifies each geographic region's grain production, consumption and price; excess supplies and demands by region; trade flows between all domestic and foreign regions; and the responsible transport mode at each link in the logistics and transportation network that participates in the interregional grain flow. This model updates and improves upon the model developed by Fuller, Fellin and Eriksen (2000).

In the following, S is the quantity supplied, D is the quantity demanded, T is the amount of grain transported, C is the per unit/mile/quarter cost of transportation, I is the amount of grain in storage, k is cost per unit per quarter of storage, i is all possible locations in model, c is type of commodity, q is quarter, m is mode of transportation, s is origin supply/demand/transport location, d is destination supply/demand/transport location, j is all possible locations in the model, and note that $\mathbf{j}, \mathbf{s}, \mathbf{d} \subseteq \mathbf{i}.$

Max

$$-\sum_i \sum_c \sum_q (\alpha_{icq} + 0.5\beta_{icq} * S_{icq}) * S_{icq} + \sum_i \sum_c \sum_q (\alpha_{icq} - 0.5\beta_{icq} * D_{icq}) * D_{icq}$$

$$-\sum_s \sum_d \sum_c \sum_q \sum_m C_{sdcqm} * T_{sdcqm} + \sum_i \sum_c \sum_q k_{icq} * I_{icq}$$

s.t.

$D_{icq} - \sum_j \sum_m T_{icqjm} - I_{i,c,q-1} \leq 0$	$\forall$ i, c, q	demand balance
$S_{icq} - \sum_j \sum_m T_{icqjm} + I_{i,c,q} \leq 0$	$\forall$ i, c, q	supply balance
$Tout_{icqm} - Tin_{icqm} \leq 0$	$\forall$ i, c, q	transport balance
$I_{icq} \leq I_{Tmaxcap}$	$\forall$ i, c, q	storage balance

MODEL DATA

In the construction of the model, we use estimates of international and US excess supply and demand equations; truck, railroad, barge and ship rates; grain storage and handling charges.

Excess Supply and Demand Equations

Regional excess supply equations were obtained with (1) an estimate of the excess supply elasticity, (2) quantity exported from the region and (3) representative price. These data will help us estimate the slope and intercept terms of an inverse excess supply and demand equations. In a similar manner, an inverse excess demand was estimated with the excess demand elasticity, quantity imported into region and a representative price (Shei and Thompson 1977).

Domestic own-price demand and supply elasticities are from econometric models developed by the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri–Columbia (2008). Information on domestic corn and soybean production by crop reporting district is obtained from the USDA (2008c). The USDA (2009a, 2008a) provides national estimates of domestic corn use and soybean crush but no information regarding consumption by crop reporting district or any geographic unit. Therefore, corn consumption and soybean crush by crop reporting district is estimated. With these estimates of regional production and consumption, regional quantities exported and imported are calculated. And, with these data it is possible to determine regional excess supply and demand elasticities. The regional elasticities, in combination with associated exports and imports, and regional prices, facilitated the mathematical derivation of the regional excess supply and demand relationships. See Fuller, Fellin and Eriksen (2000) for an expanded presentation on mathematical derivation of excess supply and demand equations.

The USDA (2009a) estimated domestic corn use in 2007-2008 at 10.3 billion bushels. An estimated 4.34 billion bushels was used for food, alcohol and industrial uses. Another 5.94 billion bushels was used as animal feed and residual. The remaining was used as seed (USDA 2009a) (1 metric ton = 39.4 bushels (bu.) of corn and 37.7 bu. of soybean). To estimate food, alcohol and industrial corn use by crop reporting district, a variety of information sources were utilized.

Domestic corn consumption by livestock, poultry, and dairy is estimated with population data and representative rations from the 2007-2008 crop year. Corn consumption is estimated for beef cows, cattle on feed, broilers, layers, turkeys, milk cows, hogs, pigs, and sheep and lambs. The 2007 Census of Agriculture (USDA 2009b) provides information on county populations, which are subsequently adjusted by state data for 2007-2008. Documents titled *Cattle on Feed*, *Cattle*, *Sheep and Goats*, *Hogs and Pigs*, *Chickens and Eggs* and *Poultry-Production and Value* offered important information on animal populations (USDA 2009c, 2009d, 2009e, 2009f, 2009g, 2009h).

Domestic soybean crush is estimated in 2007-2008 to be 1.83 billion bushels (USDA 2008a). Based on information from the National Oilseed Processors Association (NOPA) (2008) and estimated plant crush capacities, soybean crush is estimated by crop reporting district. Utilizing monthly crush statistics provided by NOPA and a listing of soybean crushers' capacities and location, soybean crush is estimated by crop reporting district. Domestic corn and soybean price by crop reporting district is based on a data set of daily prices paid by elevators, terminals and processors across the United States.

Excess supply and demand elasticities for foreign regions and/or countries will be estimated with own-price demand and supply elasticities that are obtained from models developed by FAPRI (2008). In addition, data from the Production, Supply and Distribution (PS&D) database, which is compiled by the USDA (2008d), was an important source of information for estimation of excess demand and supply parameters. These data includes information on each country's production, beginning stocks, imports, exports, feed, total disappearance and ending stocks by crop year.

The FOB ship grain prices were obtained for many countries with the remainder estimated from available price data and ship rates.

The temporal dimension of U.S. international corn and soybean trade is obtained from the USDA (2008e). The Foreign Agricultural Service’s Attaché Reports (USDA 2008f) offers monthly/quarterly exports and imports of selected corn and soybean exporting and importing countries.

Transportation and Logistics Network

The transportation and logistics network in the U.S. portion of the spatial model links excess supply regions to barge loading facilities, ports and excess demand regions by applicable modes, by quarter. Virtually every excess supply region (crop reporting district) within 200 miles of the upper Mississippi and Illinois Rivers are linked to barge-loading locations on the upper Mississippi and Illinois Rivers by quarterly truck rates. Many of the excess supply regions are linked to the river elevator sites by quarterly rail rates if the rail configuration lends itself to these routings. Similarly, all excess supply regions are linked by truck, and/or rail, to one, and likely two or three, port areas.

Truck rates in the spatial model are estimated with a regression that is based on data included in the USDA's *Grain Transportation Report* (2008g). Railroad rates are estimated using rail rates from USDOT’s 2007 Waybill report USDOT (2008). The waybill is segregated by railroad corridors and then used to estimate rates between excess supply regions and ports, barge loading sites, and excess demand regions.

Grain barge export rates that link the upper Mississippi, mid-Mississippi, lower Mississippi, Illinois and Ohio Rivers to lower Mississippi River ports are collected by the USDA (2008h). This weekly barge rate data is averaged by quarter to obtain export barge rates and, for barge movements to the Tennessee River, the available rates are adjusted in accordance with mileage and tow size.

International grain ship rate data are obtained from the USDA's Agricultural Marketing Service. These data relate originating world region, originating port, destination world region, destination port, date of shipment, shipment terms, size of cargo, and rate.

Grain Handling and Storage Charges

In the U.S. portion of the spatial models, grain-handling charges at country elevators are included as are intermodal transfer charges at barge loading and unloading sites, and ports. In addition, storage charges are included in both the domestic and foreign portions of the model.

EXPECTED RESULTS

An improved and modified spatial equilibrium model will be very useful to address a number of questions with respect to transportation infrastructure, traffic congestion, and international trade issues. In particular, we intend to use the improved model as a platform for future research in order to:

- Gain insight into potential long-term effects of the current energy policy on grain and biofuel related transportation flows along the inland waterways;
- Outline requirements and justifications for targeted development of infrastructure in order to mitigate projected congestion of all transportation modes;
- Examine the potential opportunities for switching rail and truck-transported commerce between the Canada, U.S., and Mexico to the inland and intracoastal waterways.

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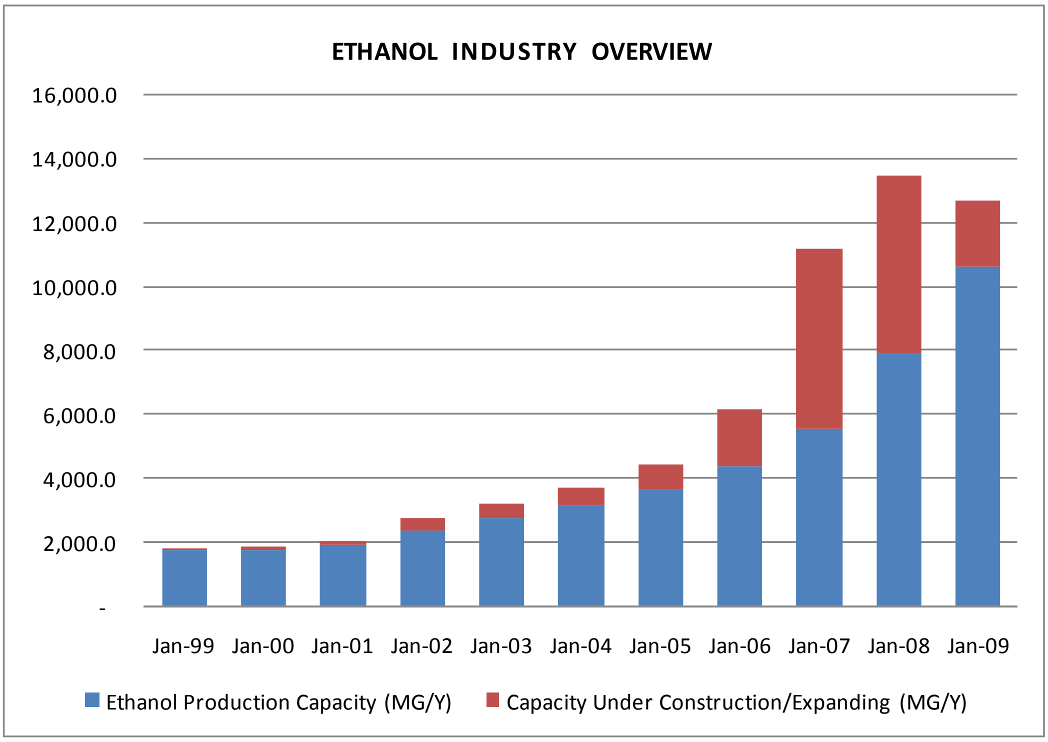

Figure 1: Ethanol Industry Overview

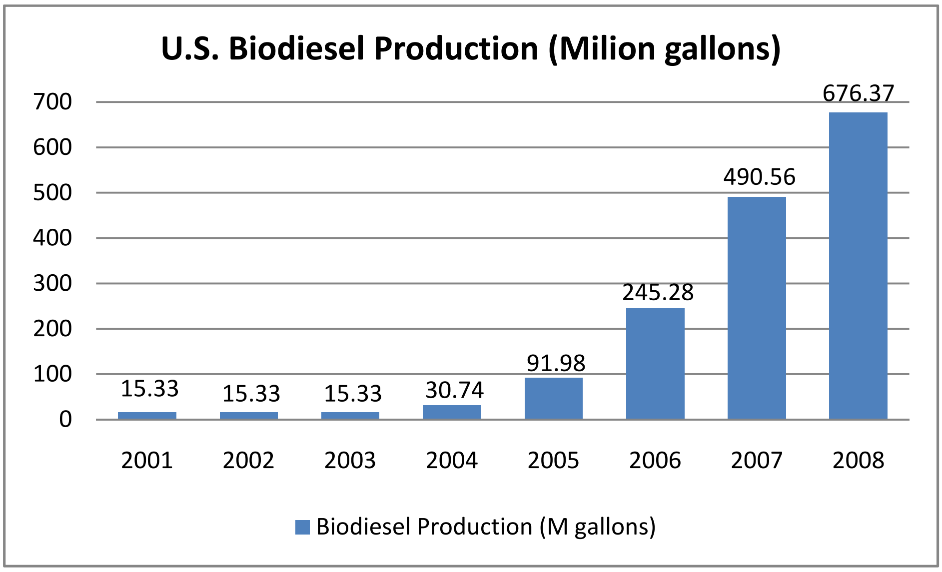

Figure 2: Annual U.S. Biodiesel Production

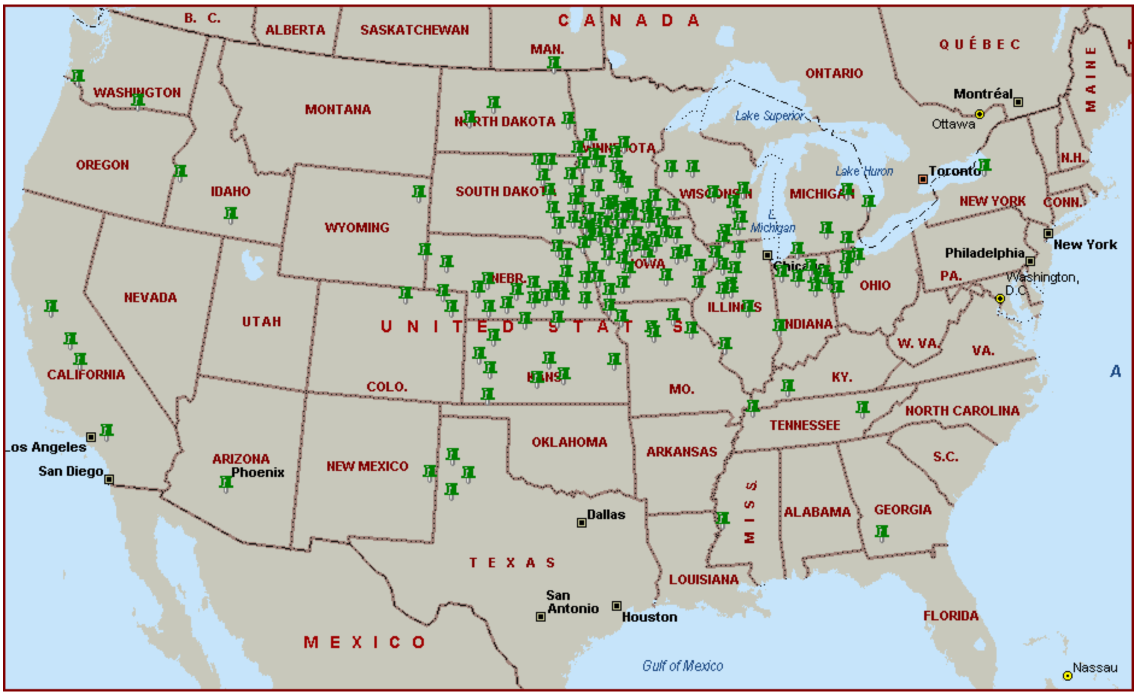

Figure 3: Map of U.S. Ethanol plants (as of April 13, 2009)

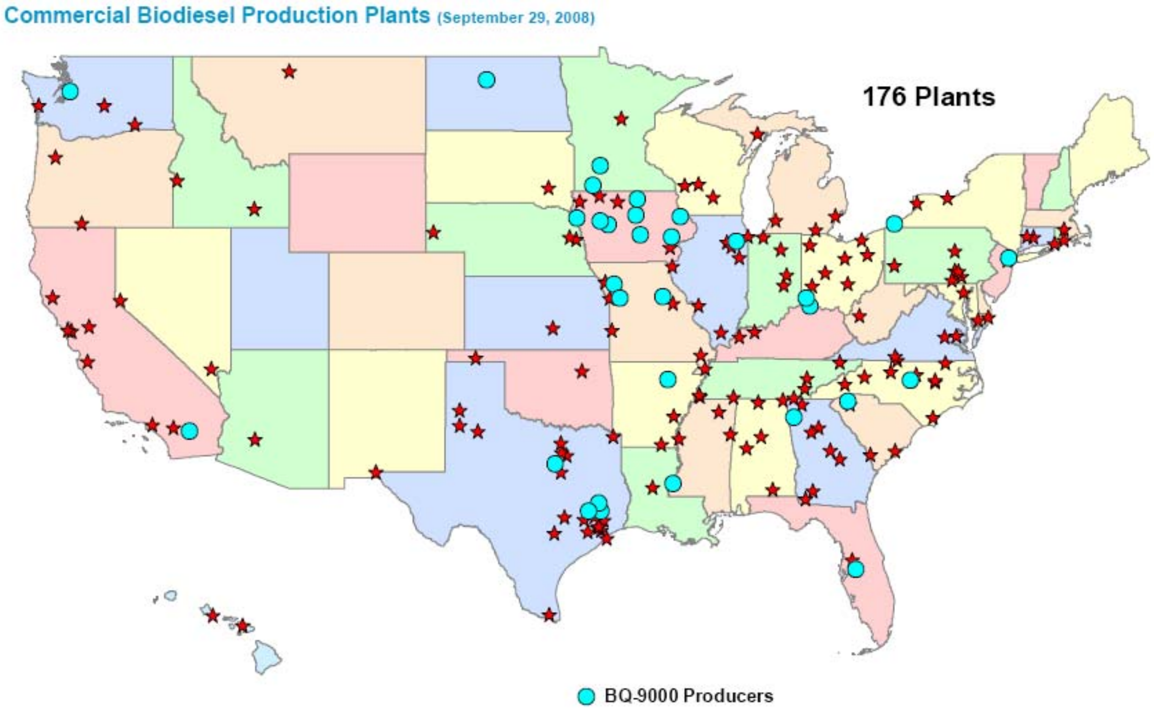

Figure 4: Commercial Biodiesel Plants (as of September 29, 2008)

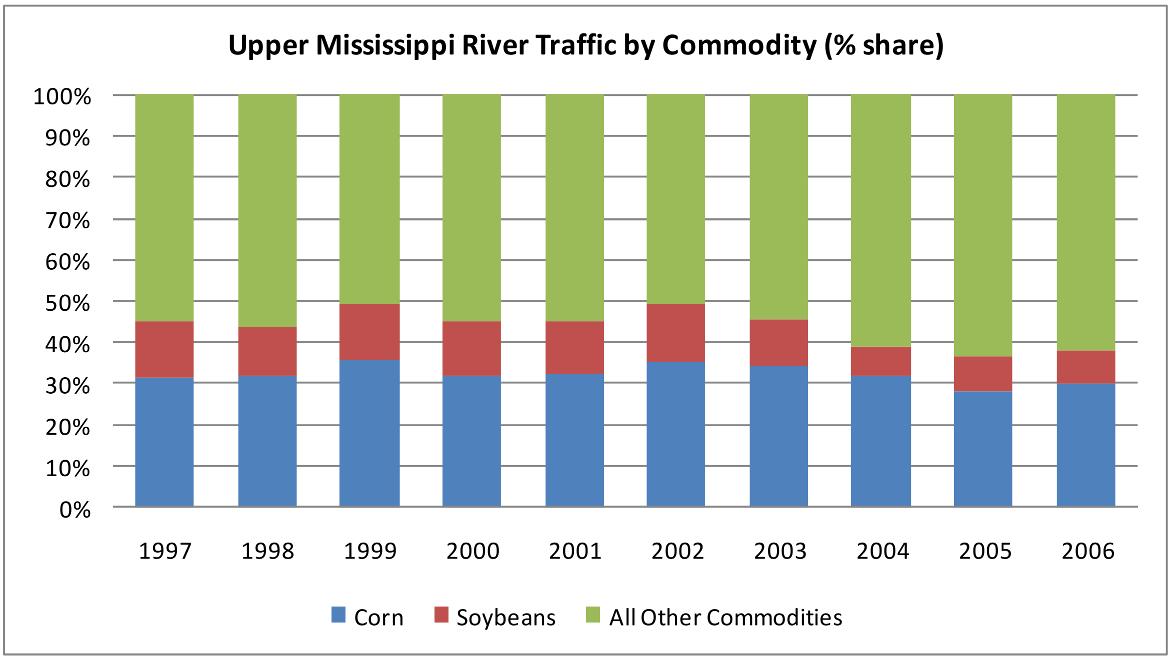

Figure 5: Upper Mississippi River, Minneapolis, MN to Mouth of Missouri River

Table 1: Ethanol Industry Overview

Year	Jan-00	Jan-01	Jan-02	Jan-03	Jan-04	Jan-05	Jan-06	Jan-07	Jan-08	Jan-09
Total Ethanol Plants	54	56	61	68	72	81	95	110	139	170
Ethanol Production Capacity (M G/Y)	1,748.7	1,921.9	2,347.3	2,706.8	3,100.8	3,643.7	4,336.4	5,493.4	7,888.4	10,569.4
Percent Change in Production Capacity	3%	10%	22%	15%	15%	18%	19%	27%	44%	34%
Plants Under Const-ruction/ Expanding	6	5	13	11	15	16	31	76	61	24
Capacity Under Construction (M G/Y)	91.5	64.7	390.7	483.0	598.0	754.0	1,778.0	5,635.5	5,536.0	2,066.0
States with Ethanol Plants	17	18	19	20	19	18	20	21	21	26

Table 2: Annual U.S. Biofuels Production

Year	Unit	2001	2002	2003	2004	2005	2006	2007	2008
Fuel Ethanol Production	M G /Y	1,762.95	2,146.20	2,805.39	3,397.21	3,909.15	4,890.27	6,497.40	9,238.57
Per cent Increase in Ethanol Production	%	8%	22%	31%	21%	15%	25%	33%	42%
Biodiesel Production	M G /Y	15.33	15.33	15.33	30.74	91.98	245.28	490.56	676.37
Per cent Increase in Biodiesel Production	%		0%	0%	101%	199%	167%	100%	38%

Note: The table is modified from its original format at EIA website

Table 3: Corn and Soybean Production in eight Midwestern States, 2007 - 08 MY

	States	Corn Prod M/bushel	Soybean Prod M/bushel
1	Illinois	2,283.8	354.3
2	Indiana	987.4	212.9
3	Iowa	2,368.4	443.6
4	Minnesota	1,136.9	254.9
5	Nebraska	1,472.0	192.5
6	Ohio	541.5	196.2
7	South Dakota	544.5	135.0
8	Wisconsin	442.8	52.4
	Midwest TOTAL	**9,777.1**	**1,841.9**
	Percent of U.S. Total	75%	71%
	U.S. TOTAL	**13,069.0**	**2,585.2**

Table 4: U.S. Fuel Ethanol Production Capacity by State (as of Dec 07 and Mar 09)

	States	Prod cap M G, Dec 07	Prod cap M bu, Dec 07	Prod cap M G, Mar 09	Prod cap M bu, Mar 09
1	Illinois	881.0	325.5	1,233.0	455.5
2	Indiana	467.0	172.5	697.0	257.5
3	Iowa	1,979.0	731.1	2,866.0	1,058.7
4	Minnesota	604.6	223.3	837.6	309.4
5	Nebraska	1,143.5	422.4	1,001.0	369.8
6	Ohio	65.0	24.0	246.0	90.9
7	South Dakota	767.0	283.3	906.0	334.7
8	Wisconsin	278.0	102.7	498.0	184.0
	Midwest TOTAL	**6,185.1**	**2,284.9**	**8,285.0**	**3,060.0**
	Percent of U.S. Total	**83%**	**83%**	**80%**	**80%**
	U.S. TOTAL	**7,415.4**	**2,739.3**	**10,358**	**3,827**

Table 5: Upper Mississippi River, Minneapolis, MN to Mouth of Missouri River

Year	Corn (M s t)	Corn (M bu)	Soybean (M s t)	Soybean (M bu)	All Other Commodities (M s t)	UMR Total (M s t)
1997	24.6	879.4	10.5	348.6	42.8	77.8
1998	25.6	913.4	9.1	304.8	44.9	79.6
1999	30.7	1,096.1	11.4	381.3	43.5	85.7
2000	26.4	943.4	11.2	375.0	45.6	83.3
2001	25.5	912.0	9.9	330.8	43.3	78.8
2002	29.8	1,064.1	11.7	389.1	42.6	84.1
2003	26.6	950.5	8.9	297.3	42.3	77.8
2004	23.3	833.3	5.1	169.5	44.9	73.3
2005	19.3	689.6	5.9	195.4	43.8	68.9
2006	21.3	760.0	5.8	191.7	44.3	71.3

Table 7: The EPAct 2005 RFS Provisions

Year	Applicable Volume of Renewable Fuel (B gal)
2006	4.0
2007	4.7
2008	5.4
2009	6.1
2010	6.8
2011	7.4
2012	7.5

Table 6: Ethanol Cconsumption Projection (B gallons)

Ethanol from corn	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018-26
Reference Case: 2005	8.57	9.34	11.40	11.95	12.46	12.84	13.18	14.11	14.48	15.03	15.17
High Economic Growth Case	8.57	9.34	11.45	11.99	12.48	12.89	13.60	14.16	14.66	15.17	15.17
Low Economic Growth Case	8.57	9.34	11.48	11.99	12.47	12.95	13.65	14.28	14.70	15.17	15.17
High Price Case	8.57	9.32	11.27	11.99	12.49	12.77	13.54	13.84	14.08	14.96	15.17
Low Price Case	8.57	9.35	11.62	11.89	12.52	13.11	13.71	14.70	14.80	15.17	15.17