Risk, Infrastructure and Industry Evolution

Proceedings of a conference June 24-25, 2008, in Berkeley, California

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Executive Summary

Burton C. English, Kim Jensen, and Jamey Menard

High crude oil prices and concerns about the environment and energy security have fueled interest in renewable energy sources. With this interest, the U.S. biofuels industry has experienced rapid expansion. This expansion has created both opportunities and challenges for energy producers, agriculture, transporters of agricultural and bioenergy products, and rural communities. As feedstocks for renewable energy are expanded from traditional sources into dedicated energy crops, new sources of risk, changes in infrastructure requirements, and need for new educational programs will likely occur. These rapid and market changes in bioenergy markets have drawn the attention of scientists, energy leaders and policy makers. In June 2008, university, private sector and government researchers were invited to a second in five conference series on the Transition to a Bioeconomy. Risks, infrastructure issues, and the evolution of the industry were the focus of this conference.

The Farm Foundation's Steve Halbrook (now located at the University of Arkansas) and Mary Thompson, along with Peggy Caswell, Jim Duffield, Vernon Eidman, Burton English, Jim Fischer, Janie Hipp, Steve Klose, Suchada Langley, John Miranowski, Joe Outlaw, Laila Racevskis, Felix Spinelli, Wallace Tyner, and David Zilberman, were on the planning team for a series of conferences on the transition to a bioeconomy. The five conferences were to focus on:

1. Integration of Agriculture and Energy Systems
2. Risk, Infrastructure and Industry Evolution
3. Environmental and Rural Development Impacts
4. Implications of a Global Bioeconomy, and
5. Extension Education for a Bioeconomy.

This Executive Summary focuses on the second conference in the series. The conference was held on June 24 and 25, 2008, in Berkeley, California. The conference was a collaborative effort and financially supported by the Farm Foundation, USDA's Office of Energy Policy and New Uses, USDA's Economic Research Service, and the Energy Biosciences Institute. Conference participants examined feedstock volatility and the forces driving it; the impacts of volatility on the biofuels industry, Rural America, and the nation's infrastructure; and biofuels facility site selection and factors determining the location of the biofuel industry. Topics at the conference included the following:

- The Evolving Bioeconomy Industry,
- Risk and Uncertainty,
- Ownership, Site Selection and Economies of Scale,
- Issues of Second Generation Biofuels,
- Infrastructure and Policy Issues in the Bioeconomy, and
- Challenges and Opportunities of the Next Decade.

Those participating in the last two sessions participated in a round table discussion following a brief presentation.

In the opening session, Michael Wetzstein, University of Georgia, provided information on *New Relationships: Ethanol, Corn, and Gasoline Price Volatility*; David Zilberman, University of California – Berkeley presented *The Distributional Effects of Biofuels*; and *Biofuels, the Rural Economy and Farm Structure* was discussed by John Miranowski, Iowa State University. Michael Wetzstein found that ethanol will increase fuel prices, but that increase in the price of transportation fuels will mitigate a shock's persistence. David Zilberman estimated price response as a result of changes in supply and demand. He noted that the future of the biofuel industry is dependent on innovation, with the need for agriculture to attain higher productivity. Emergence of an educational industrial complex, including public/private partnerships in research and development, will be needed. Increased attention to technology transfer issues will be critical. The evolution of the industry will be impacted by intellectual property rights and regulations regarding land use and carbon. John Miranowski in his discussion on the impact of the growth in the ethanol industry on Rural America indicated that the expansion would have a positive impact on the rural economy, however, this impact will decrease at the margin over time. Expansion of corn ethanol over 20 billion gallons could ultimately reverse this trend and have a negative impact to the rural economy.

In the second session, elements of risk within the economy, for the farm, and for the renewable transportation fuel-based industry were discussed. Methods for managing risk were also discussed. Gordon Rausser lead off this session with a presentation, *Managing Risks Associated with Biofuels*, discussing a potential methodological approach to allocating public sector funds for research and development, which incorporates the impact of discovery from those projects, along with the effect those projects would have on the overall research and development portfolio. Jim Larson followed this talk with a discussion on farm risk. In his presentation, *Risk and Uncertainty at the Farm Level*, a number of potential on-farm risks were discussed, including risks during dedicated energy crop establishment years, harvest risks, and storage risks. In a case study, Jim reported that impacts of weather and input price risk differ depending on soil productivity. He further found that the Biomass Crop Assistance Program, recently signed into law, will have a larger impact on marginal soils. Seth Meyer's presentation was titled *Policy Risks and Consequences for the Biofuels Industry.* Seth discussed policy risks and the impact policy might have on the bioeconomy. He indicated that the implementation of current policies in the future was uncertain. Tax credits, tariffs, and mandates and their impacts to the biofuels industry were discussed. Seth concluded with a discussion on how the Renewable Identification Number (RIN) could be used as a market driven policy tool. Paul Willems' presentation, *Managing Risk in the Bioeconomy*, provided three perspectives on risk – society, value chain, and company. He followed this discussion with how the Energy Biosciences Institute, a public/private entity, will approach research in attempts to mitigate risk.

The third and fourth sessions incorporated selected papers on ownership, site selection, scales of economy, and the second generation biofuel industry. Tony Crooks discussed *Bioenergy Ownership and Investment Models for Rural America*. In his presentation, the attributes of four different ownership business models -- Corporate, Farmer-Owned, Engineer/Builder-Owned, and Franchise -- were discussed. This was followed by a discussion on how Rural America might have the capital to invest in the biofuels industry in order to capture additional benefits through the establishment of a close-ended renewable energy fund created for investment by farmers and rural residents. Lance Stewart and Dayton Lambert's presentation was titled *Spatial Heterogeneity of Factors Determining Ethanol Production Site Selection, 2000-2007.* They evaluated the factors influencing ethanol production site selection using data from 2000-2007. They found that extremely rural areas may not be attractive to the ethanol industry. The primary drivers for location were feedstock access, lack of direct competition, and infrastructure availability. Applying their model, they projected potential future areas where corn ethanol plants might locate. David Perkis discussed the location of cellulosic ethanol plants in Indiana in his presentation titled *Spatial Optimization and Economies of Scale for Cellulose to Ethanol Facilities in Indiana*. He found that the northern part of Indiana had sufficient feedstocks and the density required to support larger ethanol plants than in the southern part. Based on feedstock supplies, Indiana could produce between 400 million and one billion gallons of cellulosic ethanol. In Abhishek Goel and Cole Gustafson's presentation, *Economic Feasibility of Supplementing Corn Ethanol Feedstock with Fractioned Dry Peas: A Risk Analysis*, they evaluated the use of fractionated dry peas with corn in the production of ethanol. They found that replacing 10 percent of the corn with dry peas would reduce profits by $0.43 per gallon. Corn prices would have to increase by 20 percent in order to break even. Danielle Carrier's presentation was titled *The Cellulosic Biorefinery: Coproducts and Required Infrastructure.* Carriers suggested that valuable phytochemicals could be extracted with subcritical water prior to the biochemical or thermochemical conversion. This could be done at the refinery, on the farm or anywhere in between. Sarah Brechbill's presentation was titled *The Economies of Biomass Collection and Transportation and its Supply to Indiana Cellulosic and Electric Utility Facilities.* In a companion paper to Perkis', Brechbill evaluated the potential of using Indiana cellulose production capability in electric power generation. Evaluating three power plant locations, she found that due to cost, corn stover was the preferred feedstock over switchgrass. At the Knox electric generating plant, in order to attain a 10 percent cofire, corn stover from 80 miles away would be required. However, the power generated from this cofire would be more expensive than just using coal. If a carbon credit existed for replacing coal with corn stover, the utility would require a $10.03 per ton of CO_2 at the Knox plant to $5.79 per ton of CO_2 at the Tippecanoe plant.

In the fourth session, Thomas Dorr discussed the role USDA Rural Development will have in the transition to a bioeconomy in a presentation titled *Rural Policy for the 21st Century*. He indicated that education regarding the various business models and partnership arrangements are needed. He suggested farmers hold $2.3 trillion in equity, but need a roadmap and technical support, to assist in investments to benefit from the emerging biofuels industry. He concluded that USDA Rural Development will have a significant role in the development of the infrastructure required by a mature biofuels industry and in developing an entrepreneurial spirit in Rural America. Greater resources will be focused on outreach, education, and technical support for the biofuels industry development. Frank Dooley's presentation was titled *Infrastructure for the Bioeconomy*. He examined the demands a rapid expansion of the ethanol industry will have on this nation's infrastructure. Dooley indicated that modal shares of grain traffic will likely change in the near future, with relatively more corn being shipped to local ethanol plants by truck instead of distance markets by rail or barge. Furthermore, he indicated that rail and barge will see growth in DDGS export shipments as the U.S. market for this feed becomes saturated. He noted that, currently, ethanol shipment patterns are characterized by an industry located in the Corn Belt with demand scattered across the country. The industry is reconsidering their investments in transportation equipment and infrastructure, while government adjusts policies to effectively move ethanol to market. In Paul Hammes's presentation, *Transportation Infrastructure for the Bioeconomy*, he discussed rail transportation and the impacts biofuels expansion has had and will have on the ethanol supply chain. Currently, unit trains are sent to California and the northeast with 20 percent of the deliveries done by unit train. Investments are being made to establish both loading and unloading unit train terminals, so that by 2015, 50 percent of the deliveries will be by unit train made to all parts of the United States. Hammes summarized by saying that the biofuels industry development occurred quite quickly placing pressure on the rail network. In particular, it presented challenges at the destination markets for the unloading of ethanol. One of the challenges has been that ethanol is moved in small units and in concentrated areas. Future challenges will be the development of rail infrastructure to meet capacity demands and more development at destination terminals. Mark Hanson presented *Legal Structures and Issues for the Bioeconomy*. Starting from the premise that bioenergy companies will be required to manage for both supply and price risk, the bioenergy companies will require a predictable supply, longer range pricing, greater control over the supply chain, and will focus on components of the plant such as oil content, sugar content, etc. Farmers will likely be faced with fewer open markets, more contract markets, and will seek ways to reduce downward market risk. These will likely lead farmers to selling production rights and the use of component pricing. New opportunities for storage and fractionation will emerge.

In the final session, Challenges and Opportunities of the Next Decade were examined. Gale Buchanan's presentation focused on opportunities for *Research and Education for the Bioeconomy*. He noted that tremendous amounts of research are still needed to foster development of the bioeconomy. Production, harvest, storage, and conversion all beg for additional research and education programs. In Paul Bryan's presentation, *Integrating the BioPetroleum Sector*, he discussed factors that will lead to the integration of biofuels with the current petroleum sector. Paul identified key components as the development of large concentrated supplies of feedstock, second generation technologies, industrial scale infrastructure, and sustainable business models. The products developed needed to be compatible with storage and distribution infrastructure, the existing fleet, broad blending with petroleum fuels, and in addition, must meet consumer expectations for superior performance. Chris Groobey presented *Financing the Bioeconomy* and discussed challenges to the biofuels industry, forecasting that a number of project level restructuring are going to take place along with increased bankruptcy filings. These events will occur, because ethanol margins are below the level required as a result of increased feedstock prices and lower ethanol prices. If we are to transition to a new bioeconomy, Groobley suggests that state support is essential and that the AgBanks need to come back to the market. A combination of making more money from existing plants by co-locating other facilities or finding other sources of income from the same plant is needed, and there is also a need for more and bigger business structures.

Concluding the conference, Peggy Caswell presented *What we Know and What We Need to Know*. Peggy discussed what was learned at the conference and what remains to be learned. Caswell indicated that we need to know how farmers and feedstock providers are going to have modify their business practices to meet the needs of the emerging industry. Different types of contracts and financing will need to be examined, with pros and cons of each weighed. Furthermore, educational programs regarding business structures and arrangements will need to be developed. Ethanol companies are going to need a consistent and reliable source of product, while farming by nature is very variable. In order to secure financing, the companies will need reliable supply and farmers will be taking on risks when contracts are signed. Caswell indicated much more research is needed to address these issues.

The authors and paper titles included in this book are:

- Zibin Zhang and Michael Wetzstein: New Relationships: Ethanol, Corn, and Gasoline Volatility;
- Steven Sexton, Deepak Rajagopal, Gal Hochman, David Roland-Holsts, and David Zilberman: Biofuel: Distributional and Other Implications of Current and the Next Generation Technologies;

- John Miranowski, David Swenson, Liesl Eathington, and Alicia Rosburg: Biofuel, the Rural Economy, and Farm Structure;
- Gordon Rausser and Mary Papineau: Managing R&D Risk in Renewable Energy;
- James Larson: Risk and Uncertainty at the Farm Level;
- Wyatt Thompson, Seth Meyer, and Pat Westhoff: Policy Risk for the Biofuels Industry;
- Anthony Crooks, James Baarda, and David Chesnick: Bioenergy Ownership and Investment Models for Rural America;
- Lance Stewart and Dayton Lambert: Factors Determining Corn-Based Ethanol Plant Site Selection, 2000-2007;
- David Perkis, Wallace Tyner, Paul Preckel, and Sarah Brechbill: Spatial Optimization and Economies of Scale for Cellulose to Ethanol Facilities in Indiana;
- Cole Gustafson, Scott Pryor, Dennis Wiesenborn, Abhisek Goel, Ron Haugen, and Andrew Wilhelmi: Economic Feasibility of Supplementing Corn Ethanol Feedstock with Fractionated Dry Peas: A Risk Perspective;
- Danielle Carrier and Edgar Clausen: The Cellulosic Biorefinery: Coproducts Extraction from Biomass;
- Sarah Brechbill, Wallace Tyner, and Klein Illeleji: The Economics of Biomass Collection and Transportation and its Supply to Indiana Cellulosic and electric Utility Facilities;
- Thomas Dorr: Rural Policy for the 21st Century; and
- Frank Dooley: Infrastructure for the Bioeconomy.

New Relationships: Ethanol, Corn, and Gasoline Volatility

Zibin Zhang and Michael E. Wetzstein[1]

Background

With upward-trending gasoline prices accompanied by heightened price volatility, diversifying into biofuels, made from renewable recently living biological materials, has become a major U.S. policy objective. Vehicle fuel prices are more volatile than prices for 95 percent of products sold by domestic producers (Regnier, 2007). Such price volatility retards the entire macroeconomy and is at least partially responsible for the U.S. economy falling into the 2001 and possibly 2008 recessions. Ferderer (1996) notes fuel-price volatility affects the entire U.S. economy through sectoral shocks and uncertainty. Castillo, Montoro, and Tuesta (2007), demonstrate that fuel-price volatility stimulates inflation and results in Kneller and Young's (2001) conclusion that fuel-price volatility is robustly and negatively correlated with economic growth.

Although biofuels, such as ethanol, are generally more expensive than their petroleum counterparts, portfolio theory suggests diversification can reduce fuel-price volatility and thus may offer a socially preferred trade-off in terms of expected price and variance. This social preference for higher expected price and lower variance is supported when vehicle-fuel externalities (greenhouse gases, fuel security, air quality, road congestion, and vehicle accidents) are price internalized, yielding a better true social cost of burning fuels.

However, food versus fuel security has recently emerged as another major external cost of biofuels. In 2007, the price of corn, the nation's number one crop in total production in terms of yield, doubled. The popular press attributes much of this run-up in corn prices to the swelling demand for ethanol fuel (Etter, Brat, and Gray, 2007). Market economics predicts this high price of corn will be mitigated by a supply response and a softening of demand (Meekhof, Tyner, and Holland, 1980; Webb, 1981). Corn acreage was quite responsive to the sharp price hike with acreage reaching historic highs (USDA-ERS, 2008). The recent boom in ethanol refining capacity has dampened, with the ethanol price in conjunction with high corn prices forcing some ethanol refineries to shutdown and retard the expected entry of others (Hargreaves, 2007). This current fluid ethanol/corn market manifests in both the first and second moments of corn and ethanol prices. Not only does ethanol potentially influence the level of corn prices but it can also impact corn's price volatility.

As an aid in shedding some light on the relations among biofuel and fossil fuel prices with consideration of environmental and food security implications, the results of two recent investigations based on time series analysis are presented (Zhang *et al*., 2008a and 2008b). First, research results indicate if the U.S. develops a comprehensive vehicle fuel policy, gasoline price fluctuations can be mitigated and at the same time reduce harmful vehicle environmental effects. Second, past research on the economics of biofuels has generally adopted a static framework with difficulties in determining causality among the variables and not extending policy analysis to environmental implications. Such shortcomings are particularly acute in the investigation of biofuel's and fossil fuel's price volatilities. A static framework will generally not aid in the investigations of dynamic price relationships and the causality among biofuel and fossil fuel prices. This causality is important when considering the current food versus fuel security issue with food prices increasing faster in developing countries where people living in poverty devote over half of their income to food (Senauer, 2008).

The following section presents observations related to the stochastic biofuels market by two recent reviews of the biofuel economic literature. Based on this foundation, the next section discusses a policy which both mitigates volatile U.S. gasoline prices and internalizes vehicle external costs. However, this policy does not address the food versus fuel issues, so an initial attempt at addressing this issue is then presented.

[1] Zhang is a Graduate Student and Wetzstein is a Professor, all respectively, in the Department of Agricultural and Applied Economics at the University of Georgia, Athens, Georgia.

Current Biofuel Industry Observations

Recent reviews on biofuel economics yield a number of observations on the current state of the biofuels industry (Rajagopal and Zilberman, 2007; Zhang and Wetzstein, 2008). Most notable in terms of stochastic fuel prices and fuel externalities are the following observations. With the automobile and gasoline industries on a long-run gasoline trajectory, some large shock is required for a shift in trajectory toward alternative renewable fuels, otherwise network externalities will prevent such a shift (Dimitri and Effland, 2007). Such a shock can be in the form of government programs designed to support biofuels. However, these programs result in many independent decisions at different levels of government yielding policies that are often poorly coordinated and targeted (Koplow, 2006). For instance, restrictions on world trade, such as ethanol tariffs, can support an emerging industry but distort market prices and discourage ethanol adoption (Kojima and Johnson, 2005). This results in the United States increasingly trading an export in which it has a tremendous comparative advantage (corn) for a product in which it has a comparative disadvantage (ethanol) (Runge and Senauer, 2007). In terms of the environment, recent scientific articles question if biofuels reduce greenhouse gas emissions relative to fossil-based fuels (Rajagopal *et al*., 2007; Searchinger *et al*., 2008) and biofuels may compete for renewable and nonrenewable resources which impact its sustainability and that of food (Rajagopal and Zilberman, 2007). Finally, agricultural markets are in general very responsive to price shocks, which will tend to mitigate food inflation (Webb, 1981). However, at least in the short-run, market gyrations will occur which negatively impact the world's poor (Daschle, 2007).

A Vehicle Fuel Portfolio

Diversifying into renewable fuels has become a major U.S. policy objective. Considering ethanol, which is currently the main U.S. renewable fuel, the United States has two choices in acquiring fuel ethanol: home-grown domestic production or imports, with Brazil as the major source. A vehicle fuel price-efficiency frontier composed of efficient petroleum and ethanol portfolios can be estimated by mating a generalized autoregressive conditional heteroskedasticity (GARCH) model to portfolio-efficiency analysis. This frontier reveals a trade-off between risk (volatile fuel prices) and reward (low fuel prices). Policymakers can then employ their subjective risk preferences, which may consider vehicle-fuel externalities, in selecting an optimal portfolio on the efficiency frontier.

For this approach, the data set consists of monthly wholesale fuel prices for Brazil anhydrous ethanol, U.S. ethanol, and U.S. conventional gasoline from 1998 to 2007. Prices for Brazilian and U.S. ethanol were adjusted to reflect differences in fuel efficiency, transportation costs, and the ethanol fuel subsidy. By diversifying into Brazilian and U.S. ethanol, the United States can achieve the lowest possible price volatility at a given price. Negatively correlated fuels can result in significant reductions in the overall fuel portfolio, and even positive correlations can yield a reduction in portfolio volatility.

Mathematically the expected portfolio price considering Brazilian and U.S. ethanol, along with petroleum fuel is

$$(1)\quad E(p) = \alpha_B E(p_B) + \alpha_E E(p_E) + \alpha_G E(p_G),$$

where $E(p)$, $E(p_B)$, $E(p_E)$, and $E(p_G)$ are the expected portfolio, Brazilian ethanol, U.S. ethanol and petroleum prices, respectively, and α_B, α_E, and α_G are the associated weights for the respective expected prices with their sum equaling unity. The volatility associated with $E(p)$ is represented by the portfolio's variance

$$(2)\quad \sigma^2 = \alpha_B^2 \mathrm{var}(p_B) + \alpha_E^2 \mathrm{var}(p_E) + \alpha_G^2 \mathrm{var}(p_G) + 2\alpha_B\alpha_E \mathrm{cov}(p_B, p_E) + 2\alpha_B\alpha_G \mathrm{cov}(p_B, p_G) + 2\alpha_E\alpha_G \mathrm{cov}(p_E, p_G),$$

where $\mathrm{var}(p_B)$, $\mathrm{var}(p_E)$, and $\mathrm{var}(p_G)$ are the variances of Brazilian and U.S. ethanol and petroleum fuel prices, and cov represents the associated covariance.

The efficient portfolio frontier is the set of all dominant portfolios. Using mathematical programming, a portfolio dominates an alternative portfolio, if the expected portfolio price cannot be decreased holding variance constant and variance cannot be reduced holding price constant. Standard estimation assumes constant volatility over time, which in the current vehicle-fuel market is probably too restrictive. A multivariate GARCH (MGARCH) model solves this problem by allowing the volatility to vary with time. For estimating the volatility, MGARCH weights past variances and covariances with the weights determined by the data with the use of maximum-likelihood estimation. The MGARCH model assumes the best predictors of future volatility is a weighted average of the long-run volatility, the predicted current volatility, and any new information. This is called adaptive or learning behavior and in a statistical sense can be thought of as Bayesian updating.

Results

The efficient portfolio frontier for year 2006, illustrated in Figure 1, was derived based on equations (1) and (2). Selected frontier points are listed in Table 1. The trade-off between volatility and price is observed given the negative sloping convex efficiency frontier. Gasoline alone, not blended with ethanol, is on the frontier with the lowest price and highest volatility. The relative higher prices for Brazilian and U.S. ethanol account for gasoline's frontier minimum price. Reducing fuel volatility is possible by increasing the percentage of Brazilian and U.S. ethanol used in the U.S. fuel market. As indicated in Table 1, such a reduction in volatility is achieved

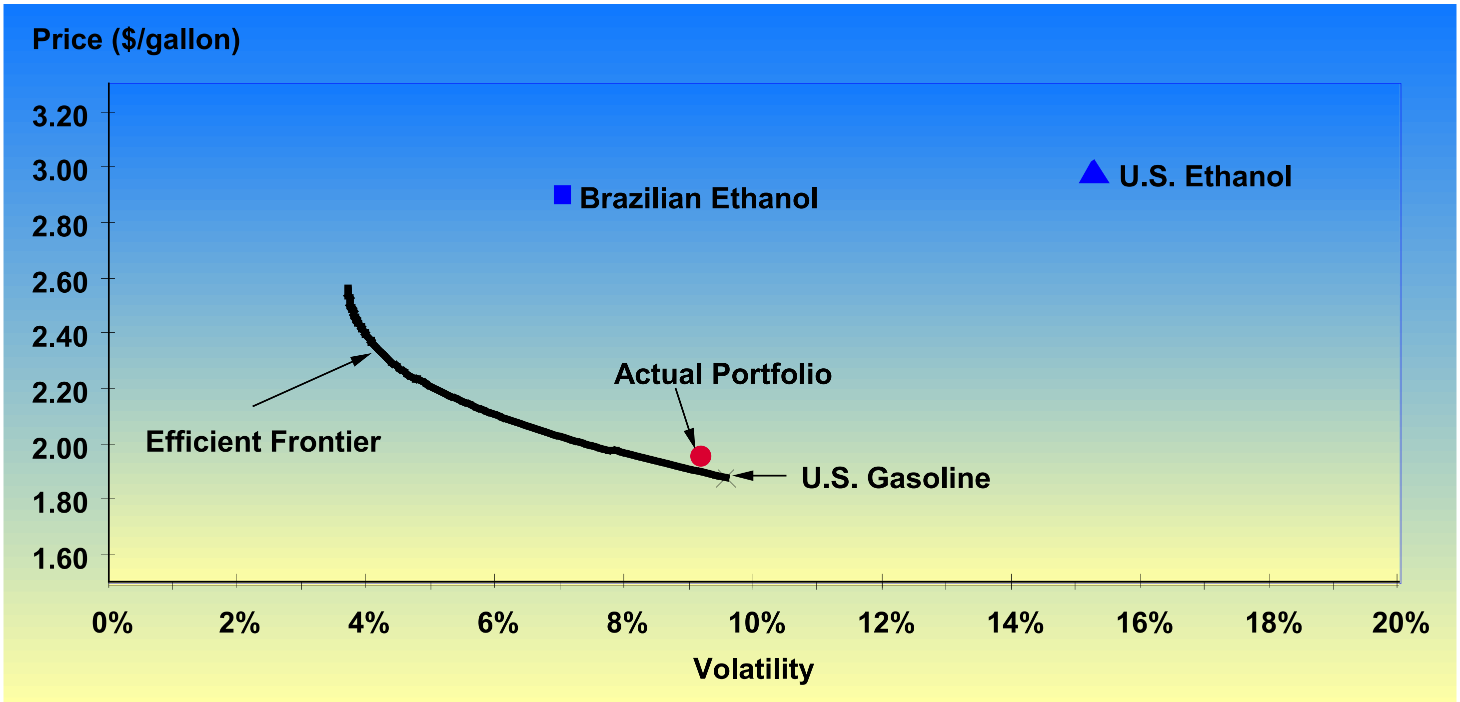

Figure 1. Efficient Portfolio Frontier with Current Subsidy/Tariff Policy, Year 2006

Table 1. Selected Frontier Points for Year 2006

Price ($/gal)	Subsidy/Tariff Volatility	Subsidy/Tariff Weights: Ethanol Brazil	Subsidy/Tariff Weights: Ethanol U.S.	Subsidy/Tariff Weights: Gasoline U.S.	Free-Market Volatility	Free-Market Weights: Ethanol Brazil	Free-Market Weights: Ethanol U.S.	Free-Market Weights: Gasoline U.S.
1.9	0.092	0.02	0	0.98	0.106	0.02	0	0.98
2.0	0.075	0.12	0	0.88	0.086	0.13	0	0.87
2.1	0.061	0.23	0	0.77	0.069	0.24	0	0.76
2.2	0.051	0.33	0	0.67	0.056	0.35	0	0.65
2.3	0.044	0.41	0.02	0.57	0.046	0.46	0	0.54
2.4	0.040	0.47	0.06	0.47	0.040	0.56	0	0.44
2.5	0.038	0.51	0.11	0.38	0.036	0.67	0	0.33

by a greater percentage increase in Brazilian ethanol compared with U.S. ethanol. As an example, from Table 1, at a price of $2.50, the lowest volatility portfolio, with an ethanol subsidy and import tariff, is 51 percent Brazilian ethanol, 11 percent U.S. ethanol, and 38 percent petroleum gasoline.

Policy Analysis I: Considering Free-Market Ethanol

Investigating the removal of the tariff in conjunction with eliminating the federal ethanol subsidy results in the portfolio illustrated for year 2006 in Figure 2, along with selected frontier points listed in Table 1. For the more volatile year 2006, there is not a marked reduction in volatility. Thus, moving toward free-trade does not lead to a marked shift in the efficiency frontier, but does shift the efficient portfolios away from U.S. ethanol toward Brazilian ethanol. This indicates that caution is warranted for advocating a free-trade biofuels market with the objective of shifting the efficient frontier toward lower prices and price volatility. Depending on the current correlations among the fuels, the efficient frontier may or may not exhibit a marked inward shift.

Policy Analysis II: Considering Environmental Costs

The market prices for Brazilian and U.S. ethanol and gasoline do not reflect the true social costs of vehicle fuel consumption. Parry, Walls, and Harrington (2007) summarize these external costs in terms of greenhouse gases, oil dependency, air quality, congestion, and accidents (Table 2). Air quality, congestion, and accident costs do not vary with fuel type. While employing a total lifecycle analysis, EPA has estimated greenhouse gas emissions from ethanol are reduced approximately 20 percent with corn-based ethanol compared with petroleum gasoline emissions. Brazilian eth-

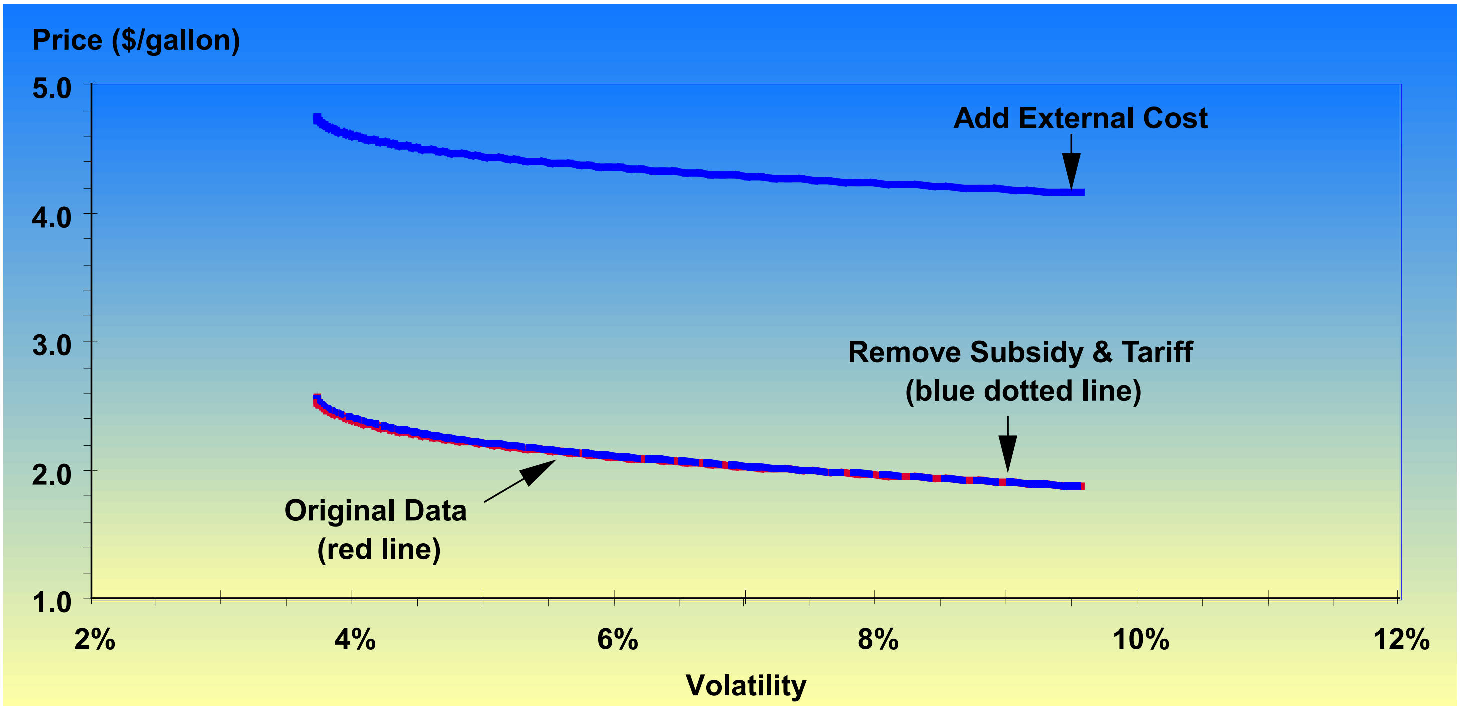

Figure 2. Free-Trade and Added Environmental Cost Efficient Portfolio Frontiers for Year 2006

Table 2. External Costs

External Costs	Ethanol		Gasoline
	Brazil	U.S.	
		(cents/gallon)	
Fuel Related Costs			
Greenhouse Gases	4.8	4.8	6.0
Oil Dependency	0	0	12
Mileasge Related Costs			
Local Air Quality	42	42	42
Congestion	105	105	105
Accidents	63	63	63
Total	214.8	214.8	228.0

anol, chiefly produced with sugarcane, has the potential for a larger emission reduction. However, as indicated from Table 2, and addressed by Parry, Walls, and Harrington (2007), the fuel related externalities are small compared to the mileage related costs. There are no oil dependency externalities for ethanol; however, air quality emissions are not reduced with a larger use of ethanol in the portfolio (Jacobson, 2007). Incorporating these costs into the analysis by augmenting each vehicle fuel with its respective environmental costs, yields a new set of expected prices and associated volatilities. As illustrated in Figure 2, incorporating the environmental costs results in essentially an upward vertically parallel shift in the efficiency frontier. The lack of a marked variation in environmental costs among the three fuel types accounts for this parallel shift.

Implications

Results indicate the current U.S. vehicle-fuel policies yield an efficient portfolio of alternative fuels on the efficiency frontier. However, the policies either implicitly or explicitly are generally minimizing the expected price at the expense of high fuel-price volatility.

By shifting policies, yielding an upward movement along the efficiency frontier, fuel-price volatility is reduced at a cost of higher prices. Depending on social preferences, such a shift, possibly promoting economic stability and growth, may be desirable. In fact, given the major environmental costs of vehicle fuels are not currently accounted in the fuel-market price, the cost of higher fuel prices from reducing volatility may instead be socially desirable. Thus, if the United States is truly interested in developing a comprehensive vehicle-fuel pricing policy, consideration of policies designed to reduce volatility and increase fuel prices would be appropriate. Such policies would take the form of providing incentives for the adoption of alternative flex-fuel vehicles and supply of blended ethanol fuels. Consideration of reducing trade barriers may also be considered. However, as this analysis indicates, care should be taken in developing such policies. In more volatile years, moving toward free-trade may not lead to a marked shift in the efficiency frontier, and may shift the efficient portfolios away from U.S. domestic toward foreign fuel supply.

Food Versus Fuel Issue

An emerging major external cost of fuel-based ethanol is the possible spillover effects of biofuel refining on agricultural commodities. If ethanol is causing upward pressure on commodity prices and/or increasing commodity price volatility, then such costs should be accounted for in developing the above efficient fuel portfolio frontier.

These possible spillover effects are addressed with weekly price series for U.S. ethanol, corn, conventional gasoline, and oil. From the log price changes, volatility is estimated using two procedures. First, a six-week overlapping window for ethanol and corn prices are used to calculate standard deviations as measures of price volatility. This is the classical descriptive tool for forecasting variances. It is the first autoregressive conditional heteroskedascity (ARCH) model given the assumption that the variance of the next period price is a simple average of the past standard deviations (Engle, 2001). As noted by Campbell *et al*. (2001) and Pindyck (2004), this relatively simple procedure for measuring volatility has an advantage of not requiring a parametric model describing the evolution of volatility over time. Second, series for conditional volatility are estimated with an MGARCH model incorporating not only ethanol and corn prices, but also prices of conventional gasoline and oil. The advantage of MGARCH over a fixed-lag standard deviation approach is dropping the restrictive assumptions of constant weights within the lagged period and zero weights prior to the period. MGARCH lets these weights be parameters to be estimated and yields parsimonious parameter estimation which is relatively easier to estimate by assuming adaptive behavior (Bayesian updating) than ARCH models. The technical links among price volatilities of corn, ethanol, gasoline, and oil suggest interactions within these prices. Thus, recognizing this feature through a multivariate modeling framework should lead to more relevant empirical models than working with separate univariate models.

The focus is on prices, with the acknowledgment there are other measures of volatility. Instead volatility associated with consumption, production, or inventories could be addressed. However, interest is in the overall market with the spot prices as the best single statistic for market conditions. As noted by Pindyck (2004), spot price volatility reflects the volatility of current as well as expected future values of production, consumption, and inventory demand.

As discussed by Adrangi *et al*. (2001), for the California oil and diesel fuel markets, microeconomic theory explains the demand for corn as a derived demand, where the price of the final good, ethanol, influences the quantity and thus price of the intermediate good, corn. Based on this theory, the hypothesized direction of dynamic prices would flow from the price of ethanol to the corn price. This provides a theoretical justification for the current food versus fuel debate. The increased demand for ethanol fuel translates into an associated higher price which directly impacts the price of corn. However, if the dynamics do not support this derived demand hypothesis, market power on the part of corn producers' ability to market their production to non-ethanol markets may exist. Corn prices would then tend to dictate ethanol prices.

Data

The data set includes four weekly price series: U.S. ethanol, corn, conventional gasoline, and oil from the last week of March 1989 through the first week of December 2007. Except for U.S. oil prices, all price series are averaged over different locations. Weekly nominal wholesale prices for U.S. ethanol are collected from Ethanol & Biodiesel News (formerly Renewable Fuel News) at three U.S. locations: Los Angeles, Houston, and New York City. U.S. weekly corn prices mated with ethanol prices are collected from USDA Agricultural Marketing Service for three U.S. locations: Nebraska, Kansas, and Texas. The conventional gasoline spot prices for the same three U.S. locations as ethanol prices are collected from the "Weekly Petroleum Status Report" available at the Energy Information Administration website (USDOE-EIA, 2007a), and U.S. FOB weekly West Texas Intermediate oil spot prices are also taken from the Energy Information Administration website (USDOE-EIA, 2007b).

Each series is tested for the presence of a unit root with all the series failing to reject the null hypothesis of a unit root at a 10 percent significant level, except for the ethanol price series. However, all first differencing the logarithm of the price series result in rejecting the null hypothesis at a 1 percent significant level, indicating stationarity.

Measurement of Corn and Ethanol Volatility

Classical Measurement (Sample Standard Deviation)

Employing a six-week overlapping window, the volatilities of ethanol and corn stationary prices, $p_t = 100 ln(P_t/P_{t-1})$, where P_t is the price time-series variable, are estimated by computing separately their respective sample standard deviations (volatility)

$$(3)\ \hat{\rho}_t = \sqrt{\frac{1}{5}\sum_{\tau=0}^{5}(p_{t-\tau} - \bar{p}_t)^2},$$

where $\hat{\rho}_t$ is the standard deviation covering the price window of a series (ethanol or corn prices) and $\bar{p}_t$ is the mean value of the price window.

MGARCH Measurement

As noted by Pindyck (2004), use of overlapping window methods introduces serial correlation and imprecise estimates of the standard deviation. These disadvantages are mitigated by employing an MGARCH model for estimating conditional variances (volatilities), along with a vector autoregressive (VAR) model for estimating the evolution of the ethanol, corn, gasoline, and oil standardized price series.

Sample Standard Deviation Estimation

Figures 3 and 4 illustrate the price series and volatility for ethanol and corn, where volatility is measured as the sample standard deviations of log price changes (3). From Figure 3, ethanol price volatility tends to be volatile at the beginning, less so in the mid to late 90s, followed by a marked increase in volatility at the turn of the 21st century. Ethanol prices have been particularly sensitive to short-run supply and demand shifts in recent years because of the highly inelastic nature of this market. With the ban and liability issues of the fuel oxygenate additive MTBE (methyl-tertiary-butyl ether), in the short-run, fuel blenders are limited in their ability to switch from ethanol as an oxygenate additive. Also, significant lead time is required in order to bring additional domestic ethanol supplies to market and foreign supply is restricted with a 54¢ per gallon import tariff. This has contributed to the recent increase in ethanol price volatility. In contrast, corn volatility does not exhibit this decline in volatility swings in the mid to late 90s. Both price series have a high degree of skewness and kurtosis, but less so for the log price changes. The Jarque-Bera test statistic rejects the hypothesis of normality at the 1 percent level for both price series.

The sample standard deviation regressions were estimated for both ethanol and corn. Own-lagged volatility regressions with and without a time trend were first estimated followed by regressions also considering the cross volatility effects (corn for the ethanol regression and ethanol for the corn regression). In all the regressions with a time trend, the associated time coefficients are significant at the 5 percent level, indicating increased volatility overtime. However, the coefficients are all quite small yielding approximately only a 0.24 percent and 0.60 percent yearly increase in ethanol and corn volatility, respectively. Also, the time coefficients have almost no effect on the other coefficients.

Comparing the restricted and unrestricted regressions, Wald tests for Granger causality are reported in Table 3. At the 5 percent level of significance, the test statistics indicate neither price volatility is "causing" the other price volatility. However, at the weaker 10 percent level ethanol-price volatility is "causing" corn price volatility. This indicates other variables, possibly gasoline and oil prices, may be contributing to the observed changes in both corn and ethanol volatility.

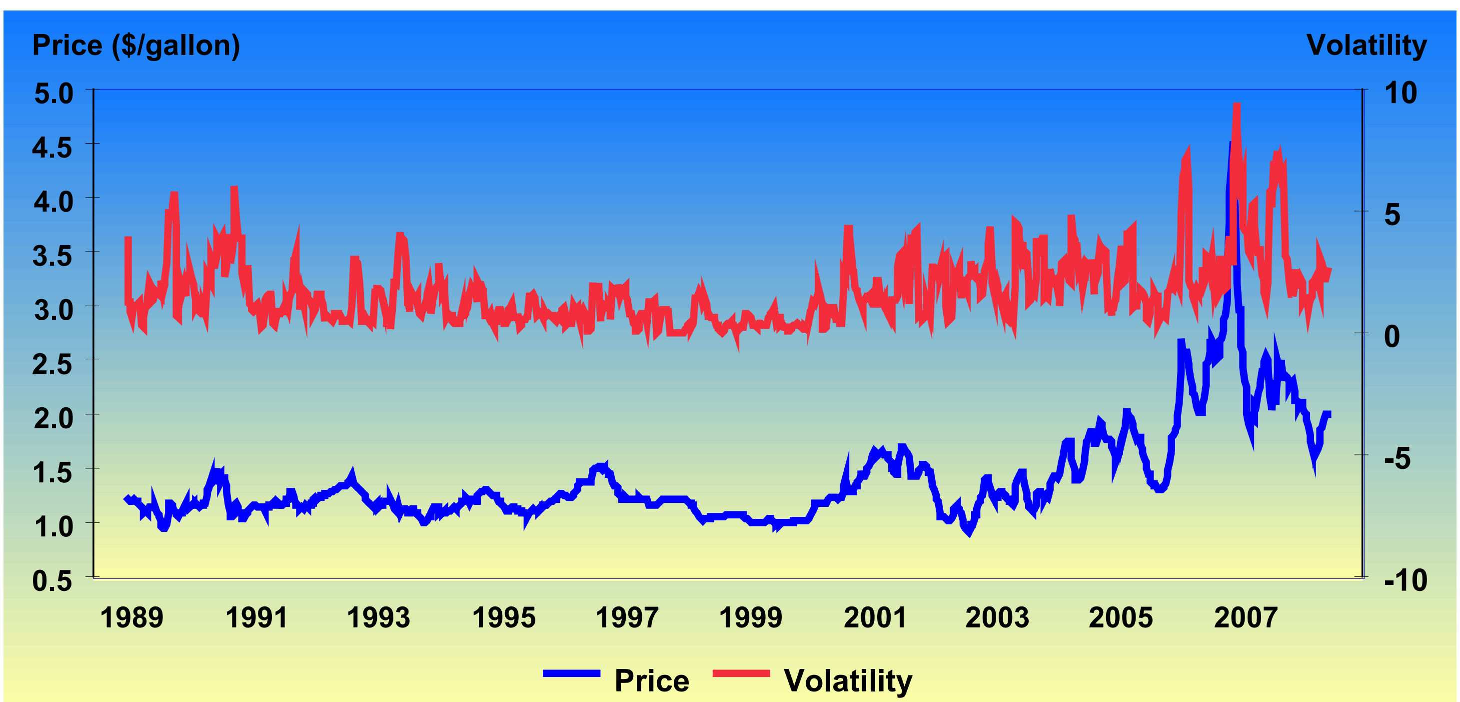

Figure 3. Ethanol Price Series and Price Volatility

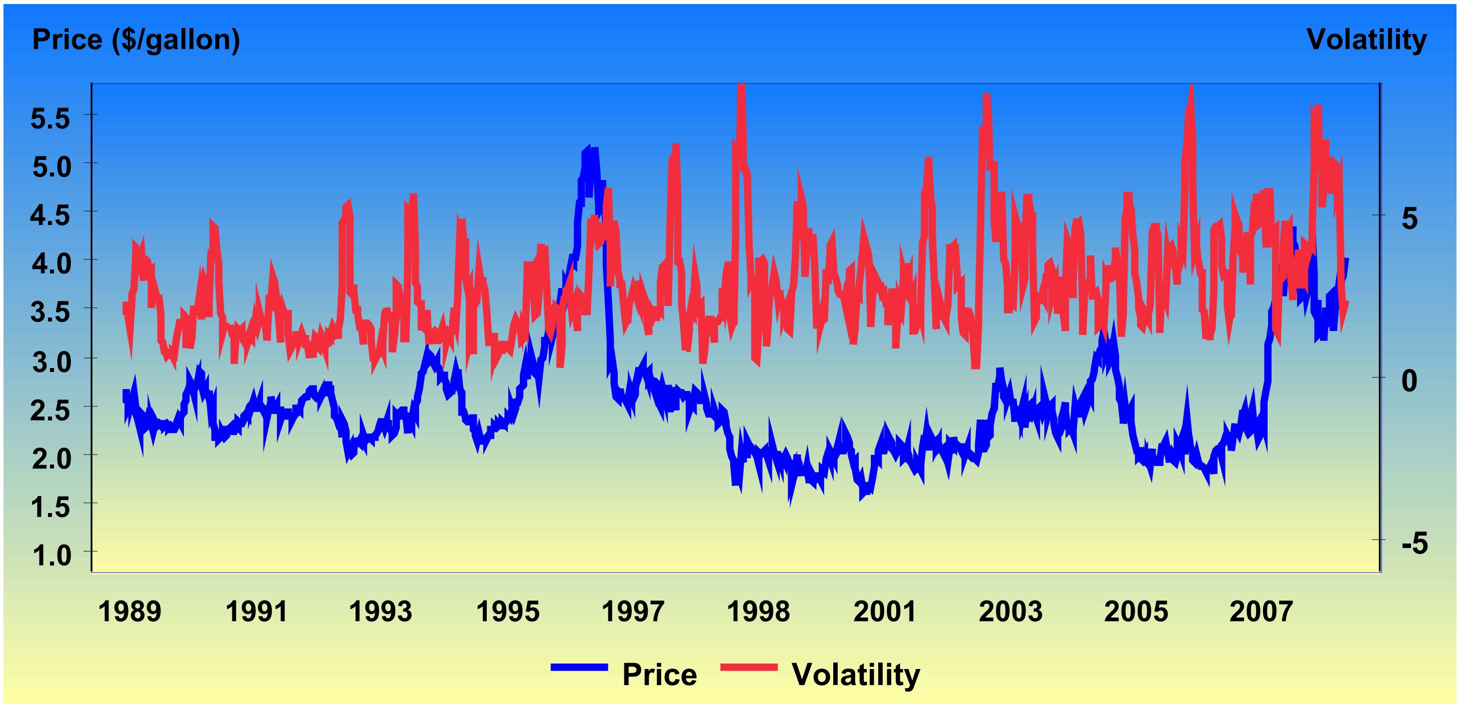

Figure 4. Corn Price Series and Price Volatility

Table 3. Granger Causality Wald Tests for the Null Hypotheses of No Granger Causation

Direction of Price-Volatility Causality[a]	χ^2	Result[b]	Conclusion
$\rho_c \rightarrow \rho_e$	8.54*	Do Not Reject Null	No Causation
$\rho_e \rightarrow \rho_c$	11.23*	Reject Null	Granger Causation

[a]The arrow, $\rightarrow$, indicates the direction of Granger causality. Ethanol, corn, gasoline, and oil price volatility are denoted ρ_e, ρ_c, ρ_g, and ρ_o respectively.
Note: * indicates significance at the 10 percent level.

Although the results may indicate ethanol-price volatility is Granger causing corn-price volatility, the shocks to corn-price volatility appear to be quite transitory as indicated by the estimated half-life. As discussed by Seong, Morshed, and Ahn (2006), half-life, $\hat{\kappa}$, is a measure of the persistence of a deviation in price volatility from its trend, and is measured as

$$\hat{\kappa} = -ln2/ln[\sum AR(i)].$$

The half-life of a corn-price volatility deviation is estimated at less than five weeks indicating a rather transitory effect.

VAR and MGARCH Estimation

VAR and MGARCH models jointly are one method for addressing the restrictive assumptions associated with the sample standard deviation approach. Incorporating gasoline and oil prices into the model, along with corn and ethanol prices, the relationships of these level prices are investigated first with a VAR model.

The Final Prediction Error, Akaike's, and Hannan and Quinn information criterion statistics were computed for determining the lag length in the VAR specification. The Final Prediction Error and Akaike's statistics indicated a lag length of four compared to a lag of two for Hannan and Quinn criteria. The resulting discrepancy is the result of very small changes in the summary statistics for these tests across the lag number. Estimation of the model for alternative lag lengths yielded robust results with nearly identical estimated coefficients. For reporting the results, a four-lag specification was selected.

The VAR model estimated coefficients and associated standard errors indicate both the oil-price and ethanol-price regressions are significantly affected by conventional gasoline-price lags. These relations are further illustrated by the Wald tests for Granger causality (Table 4). The large highly significant (less than 1 percent) and low significant (greater than 15 percent) χ^2s for the ethanol and gasoline tests and gasoline and oil tests, support Granger causation for these prices. Specifically, from Table 4, gasoline prices are Granger causing both ethanol and oil prices. The price of gasoline is driving up ethanol and oil prices. This supports the microeconomic theory hypothesis of a derived demand for ethanol and oil associated with gasoline production. The ever increasing demand for gasoline within the United States and

Table 4. Granger Causality Wald Tests for the Null Hypotheses of No Granger Causation

Direction of Price Causality[a]	χ^2	Decision
Ethanol & Corn Prices		
$\rho_e \rightarrow \rho_c$	6.118	Do Not Reject
$\rho_c \rightarrow \rho_e$	6.273	Do Not Reject
Ethanol & Gasoline Prices		
$\rho_e \rightarrow \rho_g$	6.657	Do Not Reject
$\rho_g \rightarrow \rho_e$	21.961*	Reject
Ethanol & Oil Prices		
$\rho_e \rightarrow \rho_o$	8.562***	Reject
$\rho_o \rightarrow \rho_e$	4.692	Do Not Reject
Gasoline & Oil Prices		
$\rho_g \rightarrow \rho_o$	28.408*	Reject
$\rho_o \rightarrow \rho_g$	3.825	Do Not Reject
Gasoline & Corn Prices		
$\rho_g \rightarrow \rho_c$	8.809***	Reject
$\rho_c \rightarrow \rho_g$	9.923**	Reject
Oil & Corn Prices		
$\rho_o \rightarrow \rho_c$	7.306	Do Not Reject
$\rho_c \rightarrow \rho_o$	9.059***	Reject

[a]The arrow, →, indicates the direction of Granger causality. Prices of ethanol, corn, gasoline, and oil, in terms of percentage change, are ρ_e, ρ_c, ρ_g, and ρ_o respectively.
Note: *, **, *** indicate significance at the 1 percent, 5 percent, and 10 percent level respectively.

the existing tight world oil market underlies this oil-derived demand. With ethanol as a fuel oxygenate, it is a complement with conventional gasoline in vehicle fuel production. As the demand for vehicle fuels increases, the complementary input demand for ethanol and conventional gasoline increases.

In terms of relatively low χ^2s, the other Wald tests in Table 4 are weak. Corn and ethanol prices appear not to be responding to their cross lag prices, while other prices, possibly gasoline and oil, are contributing to ethanol and corn price movements. These results are consistent with gasoline as the major market for oil, consuming approximately 70 percent of U.S. petroleum demand (USDOE-EIA, 2007), ethanol contributing less than 5 percent of vehicle fuel consumption, and corn having alternative food-marketing outlets when ethanol prices are depressed.

In addition to the direction of causation, the influence of one variable on another provides information on the relative magnitude of its causation. Performing variance-decomposition analysis yields this information by measuring the effect of shocks in each variable on the current and future values of the variables. Specifically, decomposition reflects the percentage of forecast variance of each variable in the VAR model caused by shocks to the other variables. Table 5 lists the decomposition matrix after five periods (weeks).

From Table 5, the variability of the ethanol (corn) price contributes only 0.8 percent (1.1 percent) of the forecast variance for the corn (ethanol) price. In contrast, for the gasoline price, the share of forecast variance from the oil and ethanol prices are 29.3 percent and 5.2 percent respectively. This variance-decomposition analysis further supports the influence of gasoline prices on oil and ethanol prices and the general lack of an ethanol/corn price relation.

The persistence of a deviation in price from its trend is revealed in impulse response curves. The response functions measure the effect of a one standard-deviation shock of a given variable on current and future values of the variables. With the exception of an ethanol price shock on its own price, there was little if any persistence to a price shock. In general, within one to two weeks any price shocks where dissipated. The ethanol persistence from its own shock was longer (five weeks). This relatively more persistent effect in the ethanol market may reflect its lack of maturity. In contrast to the oil, gasoline, and corn markets, the expanding nature of ethanol into a national market limits its price responsiveness. This persistence in ethanol prices and lack of any persistence in corn prices from an ethanol price stock are illustrated in Figure 5. Corn has little if any response to an ethanol price shock, while ethanol has a relatively large lag response which is persistent for a number of weeks.

Table 5. Variance-Decompositions after Five Periods (Weeks)

Variable	Percentage of Forecast Error			
Price	ρ_g	ρ_o	ρ_e	ρ_c
Gasoline, ρ_g	0.939	0.004	0.041	0.016
Oil, ρ_o	0.293	0.659	0.039	0.009
Ethanol, ρ_e	0.052	0.004	0.932	0.011
Corn, ρ_c	0.007	0.007	0.008	0.980

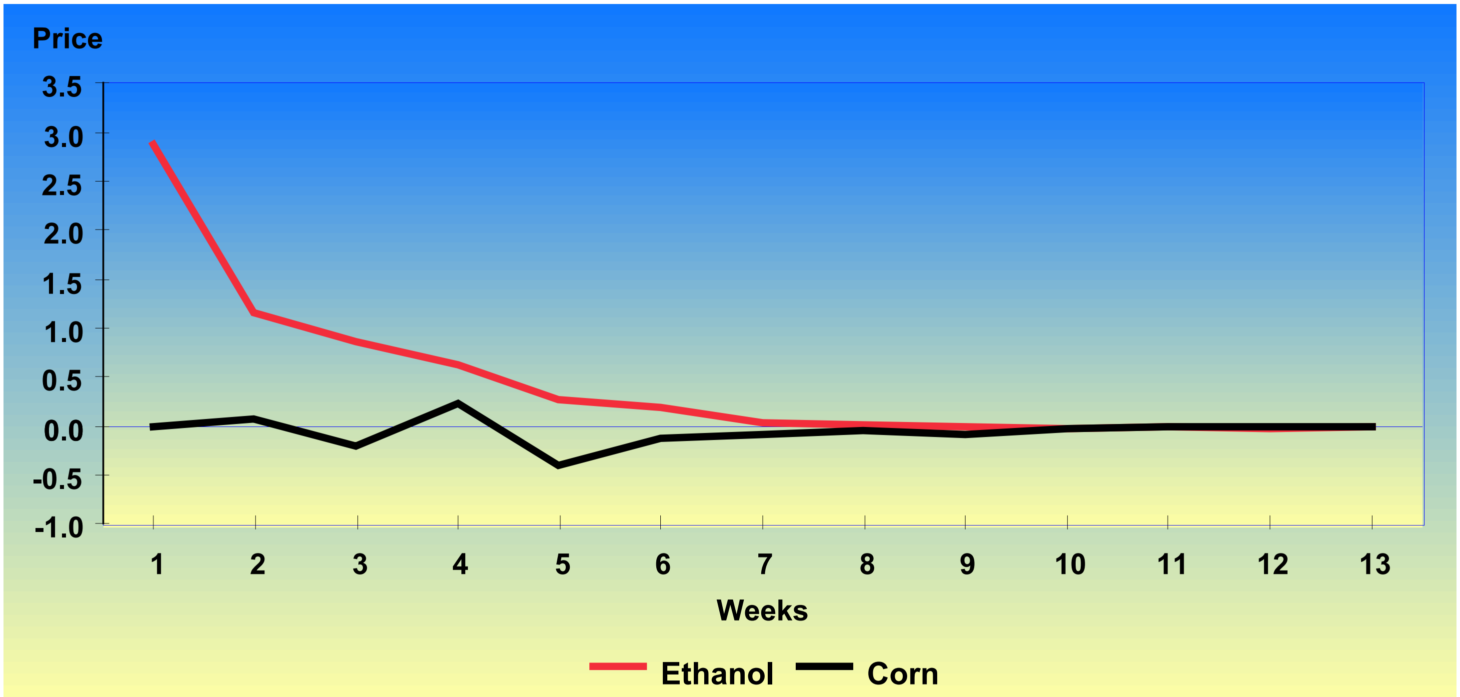

Figure 5. Impulse Response Function from a Shock in the Ethanol Price

A structural shift in the relationships among these prices may have occurred with rapid expansion of fuel ethanol after the implementation of states phasing out MTBE and replacing it with ethanol as a fuel additive. This shift was considered by estimating a VAR model on a sub-sample of the date from mid 2000 to the end of 2007. Results are similar to the whole data sample, indicating again the dominance of gasoline in driving the fuel market.

In contrast to the VAR results, the MGARCH results in modeling price volatility yields both a direct and indirect link between ethanol and corn price volatility. Consistent with the sample standard deviation results, the MGARCH results indicate ethanol-price volatility influences corn-price volatility directly through ethanol's conditional variance while corn-price volatility does not influence ethanol volatility. Considering the indirect relation through the ethanol/corn-price conditional covariance, ethanol-price volatility is positively related to the covariance, while corn-price volatility is negatively related. Recall from Figures 1 and 2, corn prices are generally more volatile than ethanol prices, so an increase in their covariance will tend to curb corn-price volatility and heighten ethanol-price volatility. Such inverse ethanol- and corn-price volatility effects are also revealed in the covariances between oil- and ethanol-price volatility and oil- and corn-price volatility. The oil- and ethanol-price volatility covariance has a positive influence on ethanol-price volatility, while the oil-corn price volatility covariance has a negative influence on corn-price volatility. Oil-price volatility also has a direct effect on gasoline-price volatility with the reverse also being true.

Similar to the VAR model, a possible structural shift was investigated by again considering the data sub-sample from mid 2000 to the end of 2007. In contrast to the VAR model, results do slightly differ for the sub-sample. The GARCH coefficients associated with corn and ethanol for their regressions are no longer significant at even the 15 percent level. This indicates the direct and indirect GARCH conditional variances and covariances do not influence corn and ethanol price volatility. However, the ARCH ethanol term is significant at the 1 percent level in the corn regression and the corn term is 1 percent significant in the ethanol regression. These two terms represent current shocks and indicate that corn-price volatility is influenced by the volatility of ethanol prices and vice versa. Although the nature of the volatility influence may differ between data sets, a link between ethanol- and corn-price volatility exists for both sets. Particularly for ethanol influencing corn, in terms of price volatility, results indicate an interrelation between the two price volatilities.

The sample standard deviation, VAR, and MGARCH results indicate that popular beliefs may be confusing the link of price volatility between ethanol and corn with instead the run-up in corn prices to the swelling demand for ethanol fuel. The sample standard deviation and MGARCH results indicate that ethanol price enhancement, from shifts in its demand, have increased the volatility of ethanol prices and exerted an associated increase in corn volatility. However, VAR results indicate the price level of corn is not impacted by ethanol prices. A positive ethanol price shock does increase corn prices, but the lack of corn-price persistence to an ethanol price shock results in the corn price relatively rapidly mean reverting. The flexibility of corn acreage and yield enhancement abilities mitigates any price shocks. The price of corn reflects this flexibility by integrating the current as well as expected future values of yields, consumption, and inventories.

Implications

These results are consistent with economic theory. In terms of derived demand theory, results support ethanol and oil demands as derived demands from vehicle-fuel production. Gasoline prices directly influence the prices of ethanol and oil. However, of greater significance for the food versus fuel security issues, results support the effect of prices as market signals which restore markets to their equilibriums after a demand or supply event (shock). As the results indicate, such shocks may increase the volatility of markets, but decentralized freely operating markets will mitigate the persistence of these shocks. As specifically addressed, the recent upward direction of corn prices may have been supported by an ethanol demand shift, but the results indicate that such an upward shift is only transitory. Market forces will restore corn prices toward their historical equilibrium levels. Corn-price volatility increases with the initial jump in prices followed by a return to equilibrium.

Conclusions

Based on the results of the analysis from these two investigations, consideration should be given to governmental policies that promote an increasing share of ethanol in our vehicle-fuel portfolio and also provide a buffer in the form of agricultural commodity surpluses. A greater share of ethanol in our vehicle-fuel portfolio has the potential of reducing fuel-price volatility and internalizing some of the external costs of motor vehicles. However, care is warranted in advocating policies of free trade in ethanol. As indicated for the year 2006, such free trade may not result in the desired inward shift of the efficiency frontier, but instead just result in a larger share of ethanol being imported at the expense of domestic refining. As the share of ethanol in our vehicle fuel mix increases, concern of arises with ethanol's impacts on agricultural commodity prices. The initial analysis on ethanol's effect on corn prices indicates, while it does not appear to influence the level of prices, it does potentially increase corn-price volatility. Such volatility may have an effect on U.S. economic growth, but the major impact is on the poor in developing countries. U.S. agricultural policy should be directed toward mitigating such commodity-price volatility with commodity buffers for supplementing supplies in years of insufficient harvests.

Further research is warranted in expanding the analysis by considering other grains, specifically soybeans, and improving on the methodology by considering incorporating cointegration. Work is presently under way in these directions. Further analysis should also be directed toward addressing the food versus fuel issue. Consideration of the causation among world fuel and commodities prices would shed light on the relationship of biofuels with agricultural commodities.

One major caveat to these conclusions is the partial equilibrium nature of the analysis. The analysis does not, in a general equilibrium framework, investigate how biofuels fit into a portfolio with other alternative energy sources. A parallel avenue for decreasing oil in the U.S. fuel portfolio is increasing the share of hybrid vehicles with the ability to tap into the electric power grid (plug-in hybrids). As CEO automobile manufactures have stated, the future of the automobile is in electric power. The question is what place if any will biofuels fit into this future.

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Biofuel: Distributional and Other Implications of Current and the Next Generation Technologies

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Introduction

The emergence of bioenergy offers the prospect of significant climate change mitigation, as well as greater energy independence for many countries. It presents the possibility of substitution between two essential but very different commodities, energy and food. This apparent trade-off, coupled with concerns about environmental protection, has created important controversies in the biofuel policy dialogue. Enthusiasm for biofuel may have reached a pinnacle two years ago when President George W. Bush suggested ethanol could break the U.S.'s addiction to oil and imposed a renewable fuel standard in the Energy Policy Act of 2005. Federal requirements for biofuel production are not just a response to evidence of human-caused global climate change, but also to rising oil prices and to national security concerns that increasingly call for domestic energy production and less reliance on imports from the volatile Middle East.

Though these forces continue to build pressure for oil alternatives, support for biofuel has waned and even become the subject of protest amid growing recognition that biofuel production can adversely affect food supplies and environmental systems (see, for example, Etter, 2007; Sexton *et al.*, 2007). It has also become clear that the current generation of biofuel will not come close to breaking U.S.'s addiction to oil (Rajagopal *et al.*, 2007). Nevertheless, and in spite of doubt about the usefulness of biofuel, it is evident the current technologies have provided short-term benefits in terms of increased gasoline supply and higher farm incomes. The second generation of biofuel promises to score better on the environmental front and to be a more viable substitute to oil (Farrell *et al.*, 2006).

The future of biofuel is being explored in laboratories across the country. In what constitutes the most significant manifestation of the education-industrial complex since biotechnology a decade ago, oil companies are funding alternative energy projects at major research universities (Sexton *et al.*, 2007). Agreements between University of California-Davis and Chevron and University of California-Berkeley and BP, for instance, can make the University of California a leader at the frontier of biofuel research. While it is not yet known whether biofuel will prove to be a viable alternative to oil or remain merely a fuel extender, it is already reshaping agriculture and creating a nexus among policies for agriculture, energy and the environment.

Forces of Change

Global warming weighs more heavily on the public conscience than it did even a few years ago. The American people increasingly view climate change as a threat they can help mitigate. For instance, a 2007 Yale University – Gallup survey found 48 percent of Americans believe global warming is now, or will soon have, dangerous impacts on people—a 20 percentage point increase from 2004. Also, 82 percent of Americans believe they can personally help mitigate global warming (Leiserowitz, 2007).

The evolution of public opinion has led Washington to pursue policies that address climate change and has prompted industry to compete on environmental friendliness and pursue strategies to reduce carbon emissions on their own. Major oil companies tout their use of renewable energy and their exploration of new technology. Car manufacturers compete for the cleanest fleets. Fortune 500 companies plant trees, bury carbon, capture methane, and invest in wind and solar energy to offset their carbon emissions. Consumers pay to offset emissions from their travel and buy cars with environmental virtue.

The growing demand by consumers for low-carbon products may also be a function of rising energy prices, which help make emission reducing behaviors not just virtuous, but also economical. In mid-November, consumers faced a seasonal record \$3.11 per gallon for gasoline, up \$0.86 from one year ago (USDOE-EIA, 2007). Fossil fuel prices are expected to continue climbing, driven by demographic trends and

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by increasing costs of oil extraction. The world population is expected to grow by roughly half in the next 50 years and per capita income is on the rise. A growing number of people, therefore, are demanding a growing number of consumption goods, leading to greater demand for energy.

Nowhere are these trends more acute than in China, where economic development has allowed its 1.3 billion people to begin dreaming of owning cars. In China, there are presently 14 cars for every 1,000 people, whereas in the United States, there are 800 cars for every 1,000 people (OPEC, 2007; UN-ECE, 2005). If Chinese per capita energy consumption reaches that of the United States, as it seems destined to, world energy demand will more than double. China went from being a small net exporter of oil in 1993 to the world's second largest importer in 2006, behind only the United States (US-DOE-EIA, 2006). This demand-side pressure is combined with constraints on the supply-side, producing volatile and rapidly rising energy prices. The oil market is tight, with an average daily consumption of 83 million barrels, just below the world's installed productive capacity. Furthermore, oil extraction becomes more costly as firms must drill deeper and in more difficult terrain and turn to more costly and dirty extraction from oil sands.

Finally, energy security is closely linked to national security, and industrial countries, in particular, must take careful account of energy in their foreign policy. Those with high levels of import dependence often find the need for partnerships that challenge other domestic and international objectives. Oil revenues give exporting countries the liberty to adopt policies inimical to the interests of the United States and other importing countries. Importing countries may also try to secure oil supplies by adopting policies friendly to suppliers. This further reduces the ability of the United States and similarly dependent countries to affect foreign policy (Council of Foreign Relations, 2006).

These forces are changing the way the world thinks about energy and will be instrumental in forging a new energy paradigm where demand and supply of new, clean, renewable energy plays a much more prominent role. In this context, biofuel has emerged as a leading contender to replace fossil fuel, though the time until it supplants petroleum is measured in decades rather than years. Biofuel offers an important but partial solution to the pressures arising from climate change, burgeoning global energy demand, and national security. However, it is by no means the only rational response to these trends. A wide spectrum of energy conservation measures, alternative polluting technologies, and alternative clean technologies are also worthy of consideration in our energy future. For example, despite being unpalatable in some political circles, a carbon tax is recognized as the best way to address global climate change (e.g. Mankiw, 2007). This approach would internalize the cost of emissions to the polluters responsible for them. This eliminates an economic distortion derived from the fact that carbon is a non-marketed good (or bad in this case). Because non-point source pollution, such as carbon emissions, cannot be effectively observed by the regulator, taxes on inputs (such as gasoline and electricity), can be adopted instead. Internalizing the cost of carbon emissions to the polluters is unpopular, however, with 70 percent of Americans opposed to higher taxes on energy inputs (Leisurowitz, 2007).

Upward pressure on oil prices can be alleviated and demand for domestic production fulfilled (at least in part) by removal of regulatory barriers that preclude full utilization of domestic oil reserves. In the United States, it is estimated 100 billion barrels of crude oil—about 15 years of annual domestic oil consumption — lie in untapped reserves under federal land and coastal water (Ostroff, 2008). Oil supplies can also be augmented by new technologies that convert coal to liquid fuel and make use of oil sands in Canada. These technologies are costly and are much more polluting than traditional oil production.

In the race to replace fossil fuel, biofuel has received considerable attention in the popular press and among policy-makers. It is not, however, the only energy answer to climate change. The electric car, for instance, equipped with a battery and needing no liquid fuel, only requires a charge every 100 miles, is another technology alternative. Emitting only water in combustion, hydrogen is another seemingly attractive alternative fuel. The cost of engineering fuel cell vehicles powered by hydrogen is significant however. In addition, production of hydrogen can be polluting and its distribution will require new infrastructure.

Why Biofuel

Where electric and hydrogen technologies have stalled in recent years, biofuels have surged, the beneficiary of more than $6 billion in subsidies in the United States (Koplow, 2006). Not only can biofuel reduce carbon emissions, but it can be produced around the world, derived from crops like corn, soybeans, and sugar cane. It is also renewable.

Biofuel also has the advantage of requiring only minimal changes to end-use technologies (Rajagopal *et al.*, 2007). Biofuel can be distributed through existing retail gasoline networks and requires very minor adjustments to engine technology. Transportation of ethanol from the point of production in the Midwest to market is costly. It must be moved by train or truck rather than through a network of subterranean pipes that move gasoline throughout the United States. Ethanol is water soluble and would corrode existing pipes (Reynolds, 2000).

Finally, whereas carbon taxes and oil drilling are unlikely policy responses for political economy reasons, biofuel promotion has been popular among key constituencies, including environmentalists and farmers. Not only could biofuel subsidies ease tensions of the new energy paradigm, they could also boost farm income and spur rural development. A $0.51 per gallon ethanol production tax credit, and a requirement to produce 7.5 billion gallons of biofuel per year by 2012, contributed to record-high farm profits in 2007 and to reductions in traditional support payments (USDA-ERS, 2008).

The recent United States and global experience with biofuel, and the accumulated research by economists, biologists and agronomists, have called into question much of the conventional wisdom of biofuel and raised doubts about the technology's role in our energy future. A frank assessment of costs and benefits is warranted.

The Good

First, biofuel represents a partial solution to climate change, but certainly not a panacea, at least not yet. Early assessments that biofuel was carbon neutral failed to account for the considerable energy used to convert energy crops to liquid fuels, as well as the foregone carbon sequestration on lands converted from nature or food production. Life cycle analyses have attempted to determine not just the greenhouse gas savings of biofuel, but also its net energy content. Such analysis depends critically on defining system boundaries and varies by production method. Corn ethanol, the predominant biofuel produced in the United States, is considered the least efficient technology and achieves, at best, modestly positive net energy content and greenhouse gas savings. The best estimate of emission savings relative to gasoline is 13 percent, though estimates range from a 32 percent savings to a 20 percent increase (Farrell *et al*., 2006). While marginal improvements in these results can be achieved through adoption of existing technologies, significant greenhouse gas savings are not expected until the second generation of biofuel is introduced. Ethanol from sugarcane and biodiesel from soybeans and palm oil are more efficient.

Second, biofuel crops can be grown in many regions of the world and, though it is unlikely to displace any considerable share of oil in the near term, it does lessen demand for oil imports and improve energy security for oil importing countries (OECD/IEA, 2007). Figure 1 shows the capacity for different regions of the world to capitalize on renewable technologies. Importantly, developing countries have high biomass capacity, which suggests biofuel may aid rural development.

Table 1 presents estimates of potential oil displacement by biofuel production from seven principal grain and food crops. The seven crops account for 42 percent of all cropland. If the entire harvest of these seven crops were diverted to energy production, more than half of global oil demand could be met by biofuel. Dedication of such substantial land resources is unlikely. A more realistic diversion of 25 percent of these crops to energy uses would offset 14 percent of gasoline use (Rajagopal *et al*., 2007). Similar analysis suggests the United States, Canada and EU-15 can displace 10 percent of their gasoline consumption by biofuel if they recruit between 30 and 70 percent of their respective croplands. Brazil needs just three percent of its cropland to meet 10 percent of its demand with sugarcane ethanol. As energy

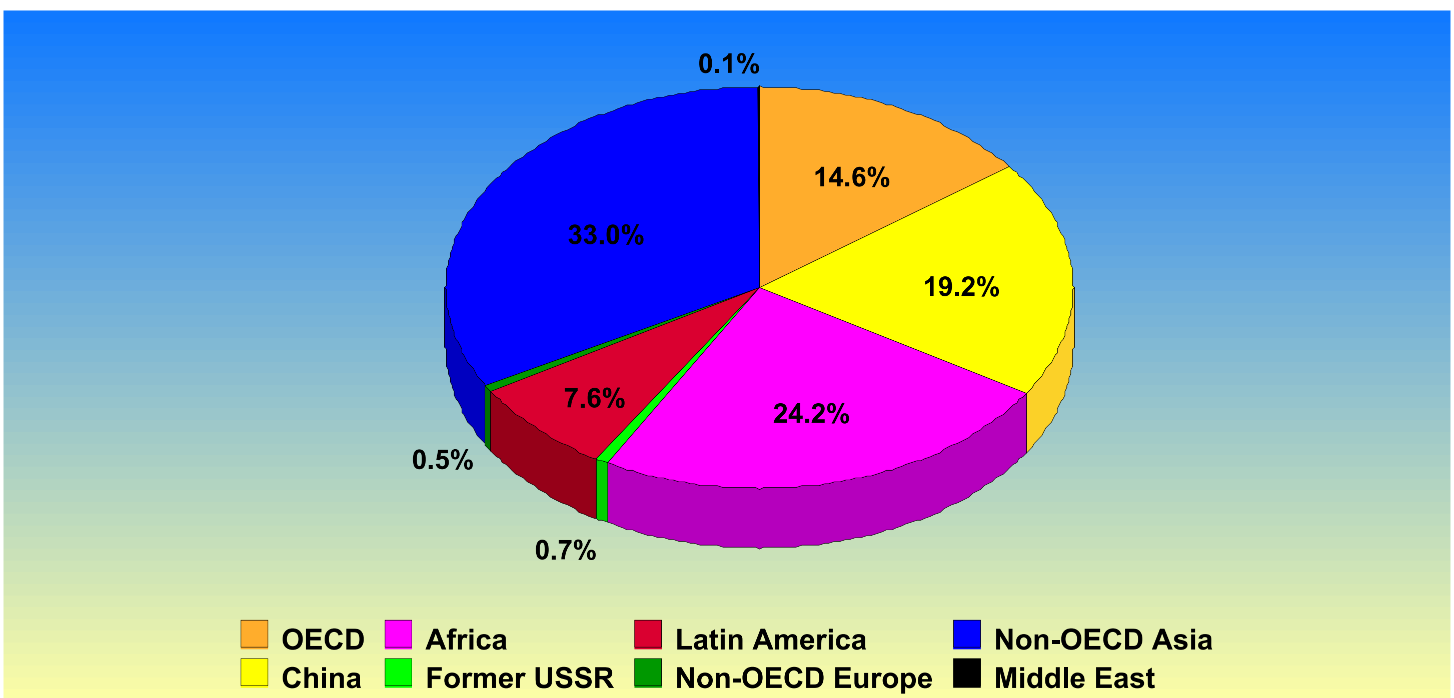

Figure 1. Distribution of Combustible Renewables and Waste (Source: IEA Energy Statistics)

Table 1. Potential Oil Displacement by Biofuel

Crop	Global Acreage	Global Average Yield	Global Production	Conversion Efficiency	Land Intensity	Maximum Ethanol	Gasoline Equivalent	Supply as % of 2003 Global Gasoline Use
	(million acres)	(tonnes/ acre)	(million tonnes)	(gal/tonne)	(gal/acre)	(billion gallons)	(billion gallons)	%
Wheat	531	1.1	602	90	41	54	36	12
Rice	371	1.7	630	114	78	72	48	16
Corn	358	2.0	711	106	85	75	50	17
Sorghum	111	0.5	59	100	21	6	4	1
Sugarcane	49	26.3	1,300	18	197	24	16	6
Cassava	47	4.7	219	48	90	10	7	2
Sugarbeet	13	18.6	248	29	219	7	5	2
Total	1,480					248	166	56

Source: Rajagopal *et al*., 2007

demand continues to grow, greater shares of cropland will be needed to displace the same shares of gasoline. These figures suggest biofuel will not soon replace gasoline as a predominant source of transportation fuel. Nevertheless, they point to the fact that biofuel can reduce oil imports.

Third, whereas the environmental and energetic contributions of current biofuel technology have been questioned (see, for instance, Searchinger *et al*., 2008 and Farrell, 2006), its role as a short-term buffer to rising gasoline prices is not in dispute, just largely ignored. The effect of biofuels on energy prices has been neglected in the literature. Following a model we developed (Rajagopal *et al*., 2007), we estimate the net welfare effect of ethanol in the short-run by comparing the current scenario to one in which there is no ethanol or biodiesel. We simulate the latter using information only on prices, quantities and elasticities of supply and demand of three major commodities that are affected by ethanol, namely, gasoline, corn, and corn's closest substitute, soybeans. This modeling approach has been used to simulate the short-run welfare effects of environmental policy (see, for instance, Lichtenberg, Parker, and Zilberman's 1988 study of pesticide regulation). We also disaggregate the effects between the United States and the rest of the world (ROW). We assume identical elasticities across the two markets, so the distribution of net benefits and costs between the two groups is directly proportional to the quantity consumed.

Absent ethanol supply, gasoline prices in 2006 would have been higher than those observed. By augmenting petroleum supply, ethanol production reduced prices for fossil fuels, benefiting its consumers. Biofuel production, however, raises the price of food commodities by reducing the supply of crops for food processing. Given elasticities of demand, we can estimate the welfare effects of ethanol production. The results are sensitive to the magnitudes of elasticities, so we simulate the distribution of benefits among consumers of gasoline, corn and soybeans under various elasticities. These simulation results are presented in Figures 2 and 3, which show the sensitivity of total net benefits to changes in elasticities of supply and demand for corn and soybeans for two sets of gasoline supply and demand elasticities, namely, (0.25, -0.25) and (0.75 and - 0.75). In Figures 4 through 7, we present results for three scenarios, which we identify as high, mid and low. The scenarios are described next.

Three Scenarios

The high scenario is an optimistic one involving high inelasticity of supply and demand for gasoline and high elasticity of supply and demand for corn and soybeans. Ethanol has the highest positive impact on gasoline prices and least negative impact on corn and soybean prices under this scenario. The low scenario is a pessimistic scenario involving low inelasticity (equivalently, high elasticity) of gasoline supply and demand and high inelasticity in food commodities. Ethanol has the least positive impact on gasoline prices and the highest negative impact on corn and soybean prices. The mid scenario assumes moderately elastic supplies and demands. The parameters of these three scenarios are summarized in Table 2 below.

In the intermediate scenario we find that gasoline consumers world-wide gained about $23.1 billion, while the total cost to consumers and to U.S. tax payers (in the form of subsidy payments) was $12.2 billion. Thus, under plausible conditions and partial equilibrium analysis, ethanol production is associated with a net benefit to consumers worldwide. Overall the ROW consumers gained $9. 5 billion, while U.S. con-

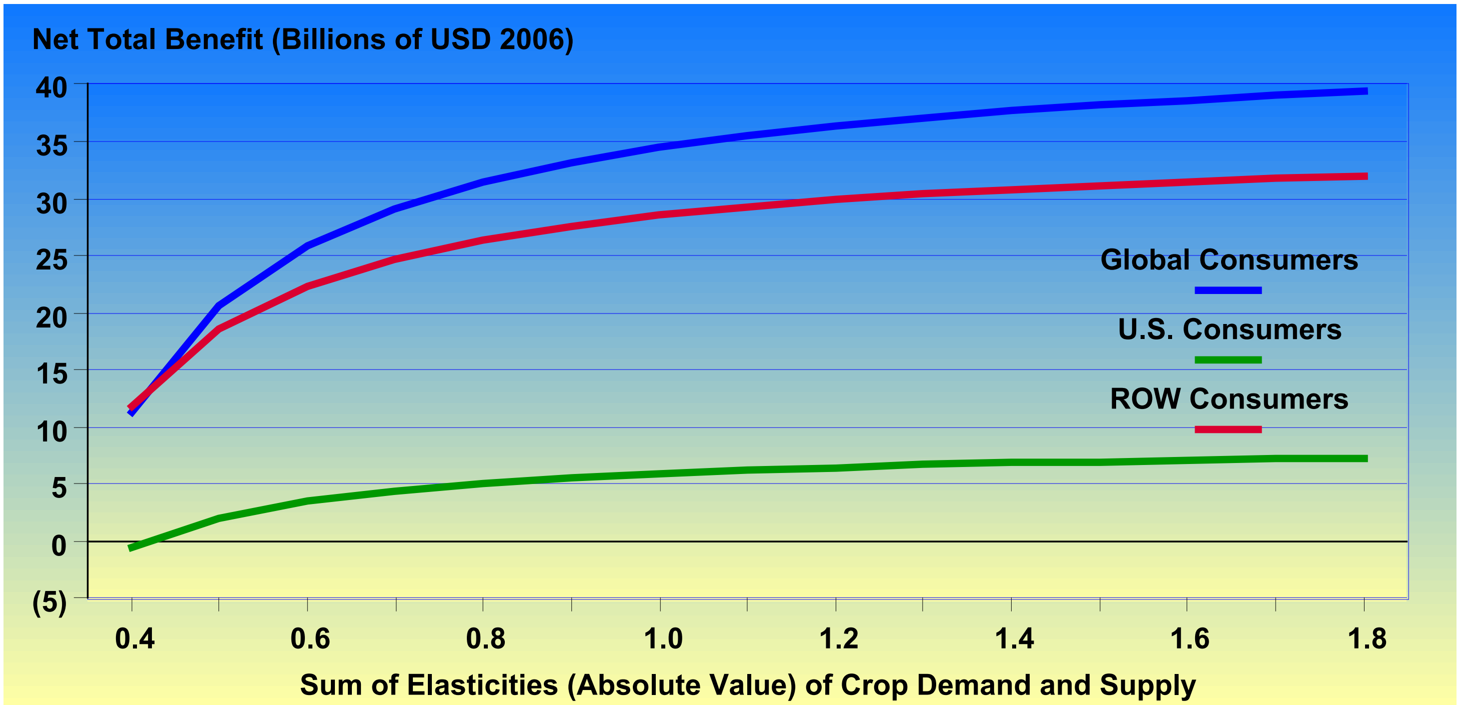

Figure 2. Total Net Benefit to Consumers (Corn, Soy and Gasoline Combined) as a Function of Sum of the Elasticities of Crop Supply and Demand for a Given Gasoline Elasticity of Supply (0.25) and Elasticity of Demand (-0.25)

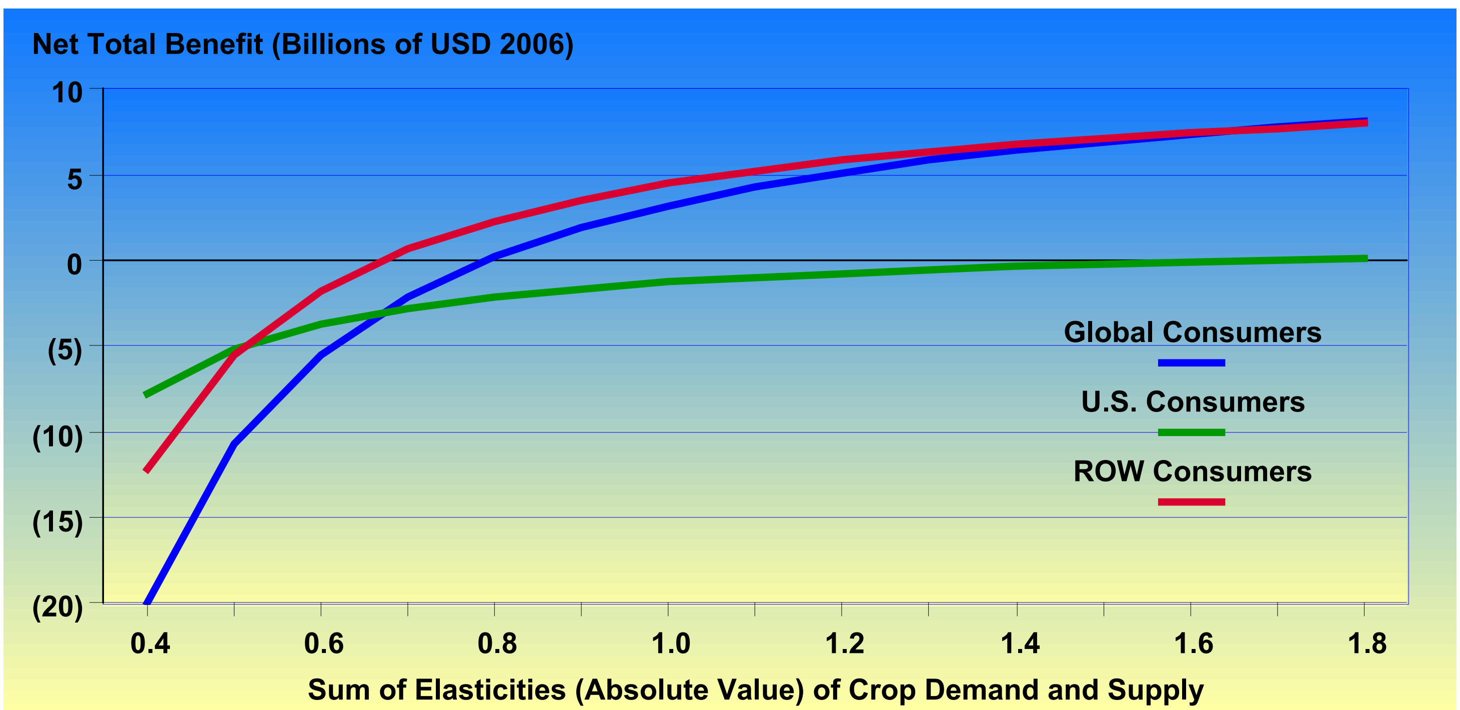

Figure 3. Total Net Benefit to Consumers (Corn, Soy and Gasoline Combined) as a Function of Sum of the Elasticities of Crop Suply and Demand for a Given Gasoline Elasticity of Supply (0.75) and Elasticity of Demand (-0.75)

Table 2. Elasticity Assumptions of Three Scenarios

	Elasticities			
Scenarios	Gasoline Demand	Gasoline Supply	Corn & Soy Demand	Corn & Soy Supply
High	-0.25	0.25	-0.75	0.75
Mid	-0.50	0.50	-0.50	0.50
Low	-0.75	0.75	-0.30	0.30

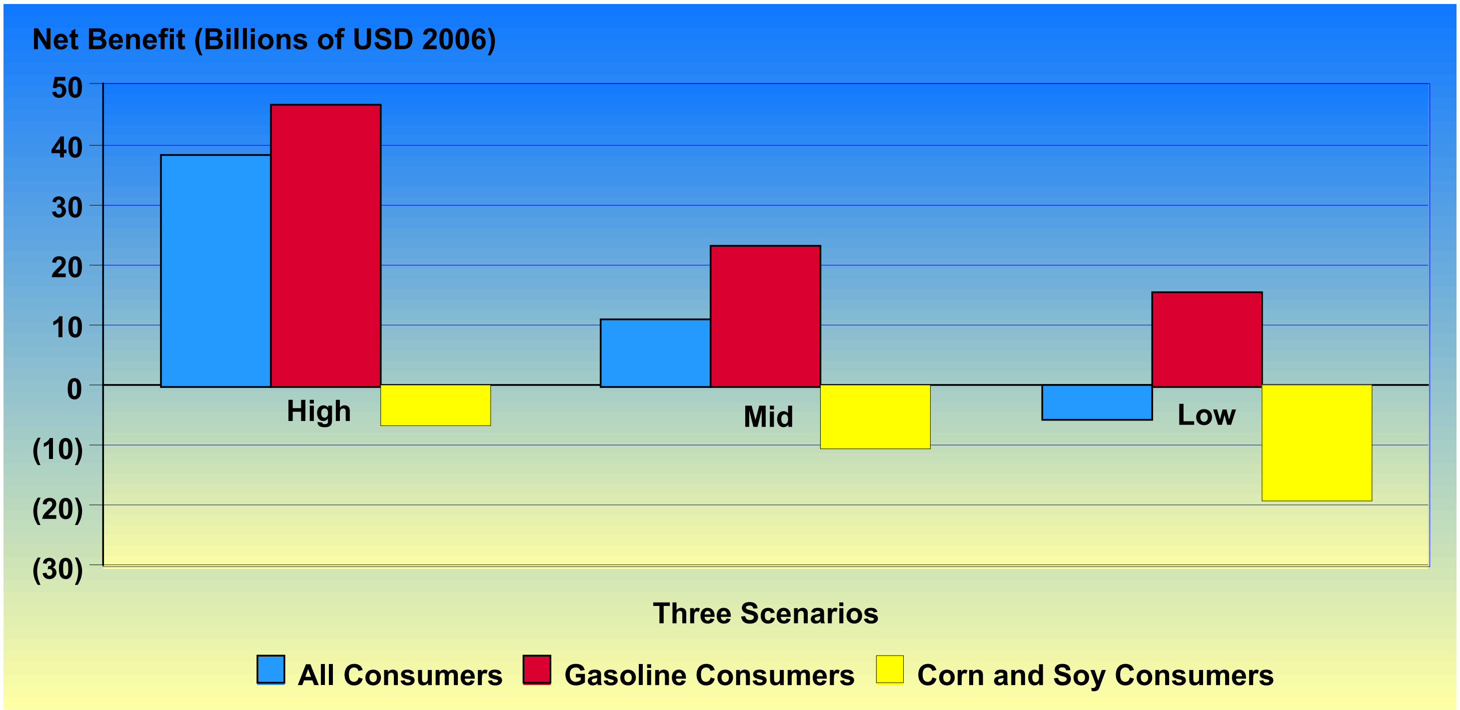

Figure 4. Net Benefits to Gasoline and Food Consumers from Ethanol Supply in 2006

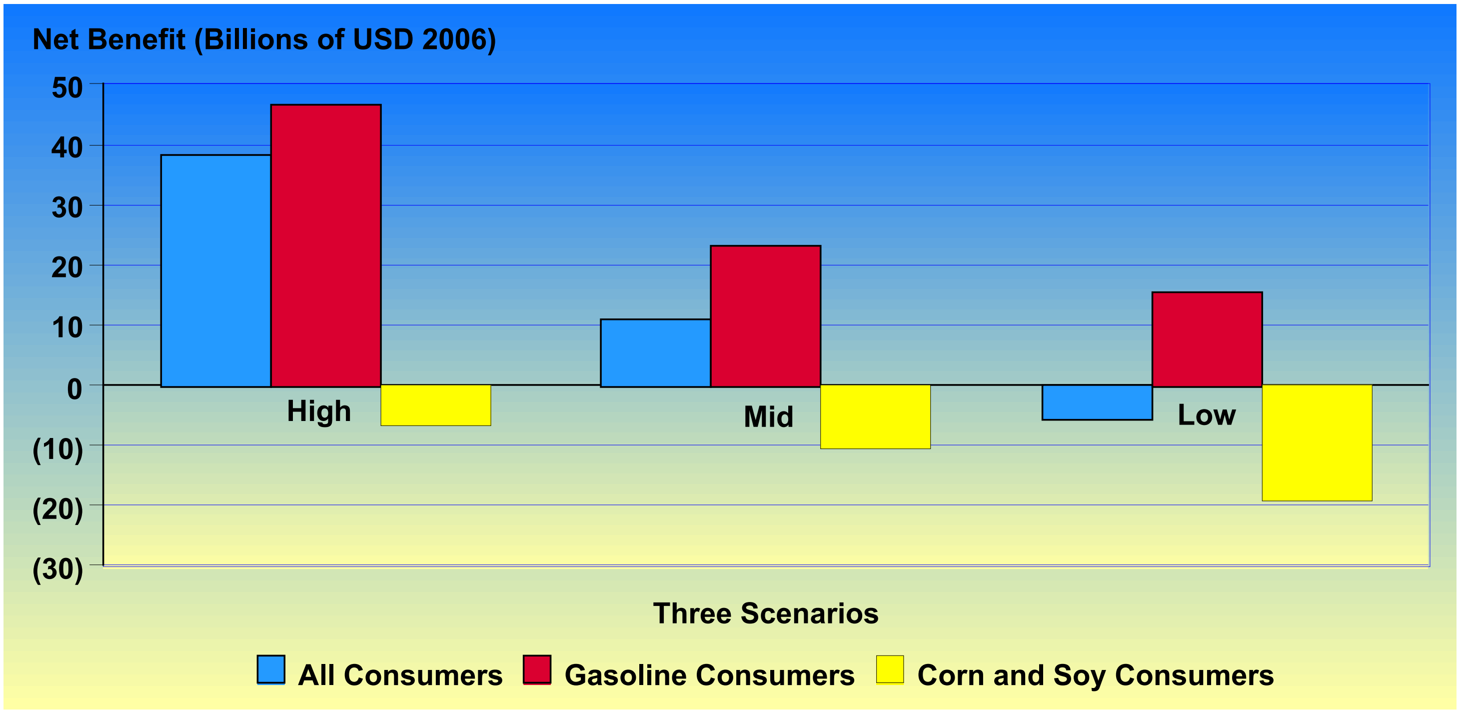

Figure 5. Net Benefits to Consumers in the United States from Ethanol Supply in 2006

sumers gained $0.5 billion (net of taxes). In the United States we find that gasoline consumers gained about $5.4 billion, while total cost to corn and soybean consumers was $2.9 billion and the cost to tax payers of the U.S. Volumetric Excise Tax Credit was $2 billion. Higher food prices also benefited U.S. producers of corn and soybeans by $3.6 billion (ROW producers gained by $9.5 billion).

While it has been claimed that ethanol reduced federal outlays for corn subsidies, our simulations reveal that corn prices would have likely remained above specified loan rates for 2006 without ethanol-induced price increases. Observed corn prices in 2006 reflect increased demand due to economic growth in large developing countries. The cost of ethanol subsidies, therefore, are not likely to have been offset by reduced subsidies to corn.

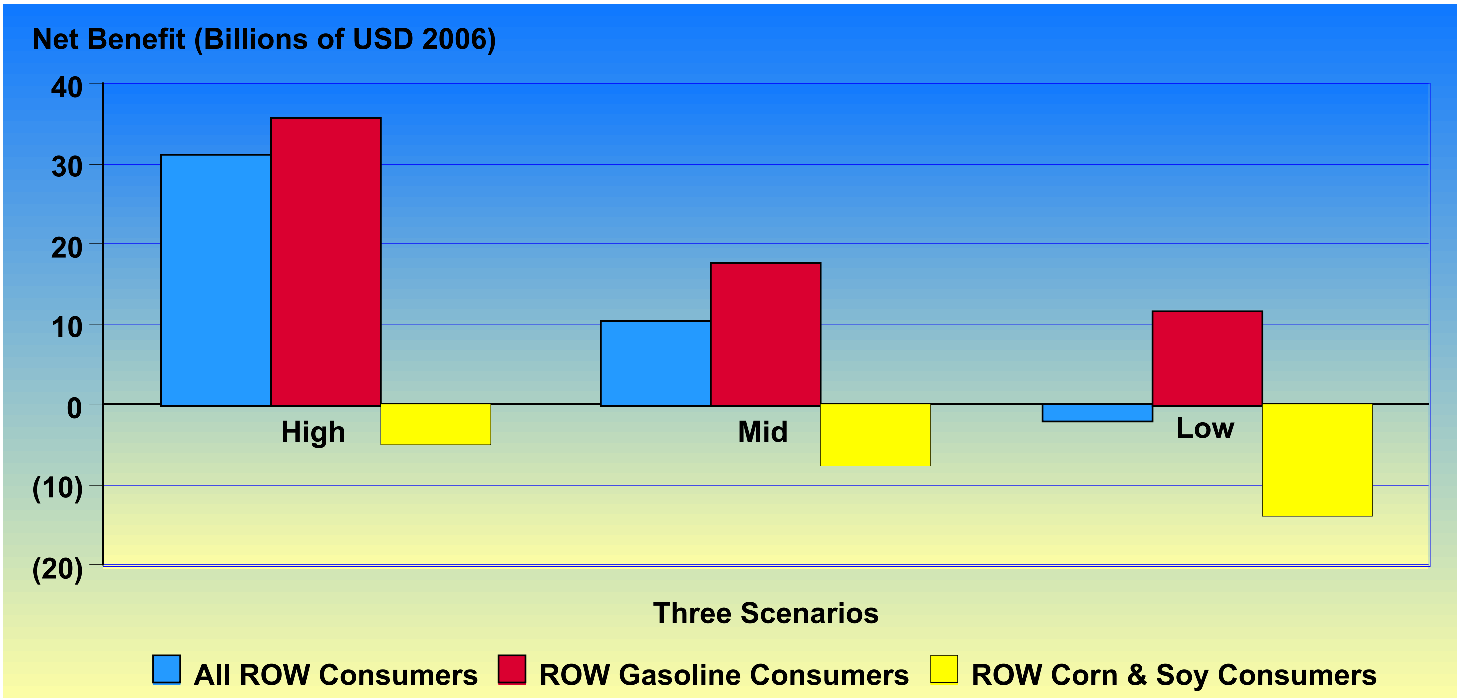

Figure 6. Net Benefits to ROW Consumers from Ethanol Supply in 2006

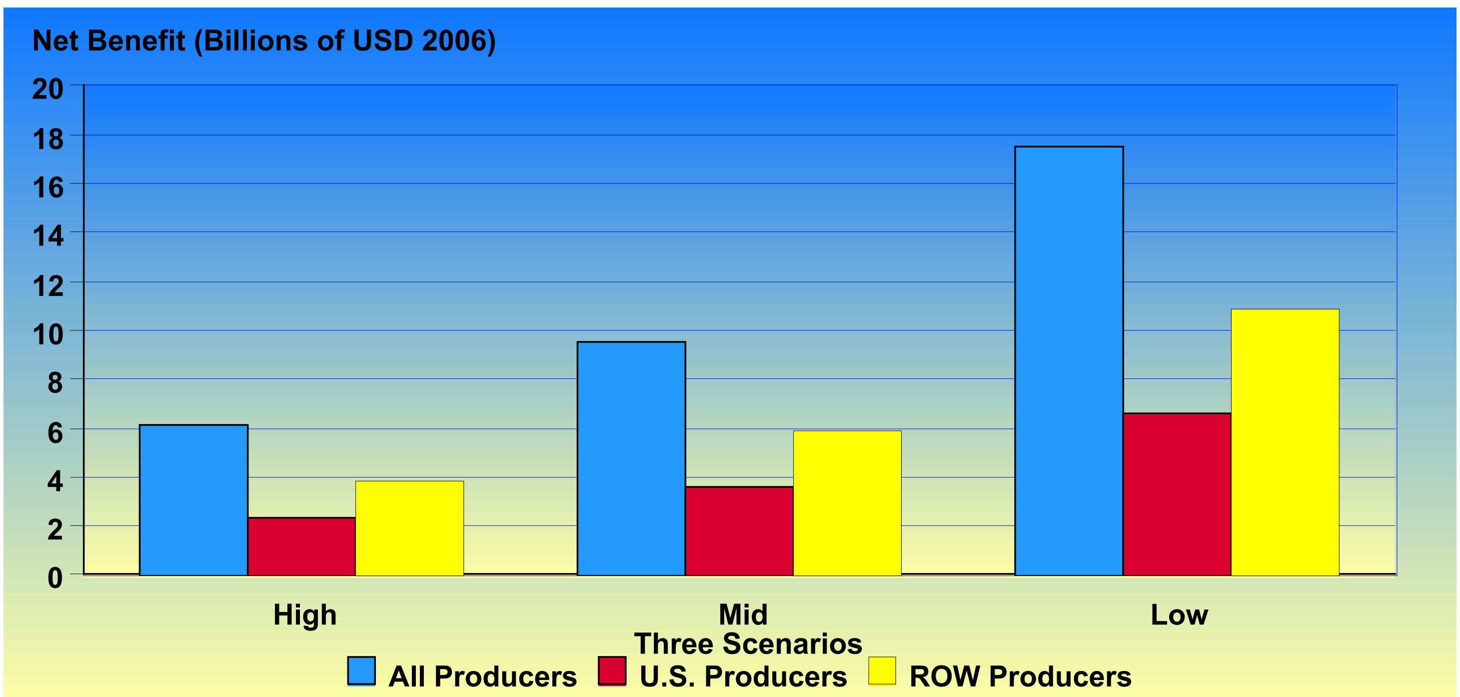

Figure 7. Net Benefits to Corn and Soy Producers from Ethanol Supply in 2006

This analysis ignores the loss to oil producers worldwide. Rhetoric among political leaders suggests these losses may not be of great concern from a policy standpoint. It should also be emphasized that this is a partial analysis. It does not consider the impact on sugar markets. It ignores market distortions, other than the production subsidy, and does not consider the effect of scarcity-induced price increases in other displaced commodities, such as wheat. We have not estimated the consumer benefit resulting from changes in emissions of carbon and other pollutants due to ethanol or the welfare effects of tariffs on ethanol imports.

The Bad

Large scale production of biofuel will impose significant stress on agriculture, which is already under pressure to reverse the trend of diminishing per capita food production even as population growth continues and productivity increases from standard inputs, like chemical pesticides, decline. The FAO reports there are 852 million undernourished people around the world and that food production per capita is decreasing (FAO, 2004). The demand for agriculture to provide an alternative source of energy adds to this pressure. Current biofuel technology is land intensive, so as production increases, land will be recruited from its two other principal uses—food production and environmental preservation. These results are already evident in the United States and around the world as food crops are replaced with sugarcane, corn, soybeans and palm (Dong, 2007; Westcott, 2007; OECD/FAO, 2007). United States farmers responded to demand for energy crops by planting the largest corn crop since 1944 (USDA, 2007). Corn prices headed close to $4, reaching $3.80 in the United States in November. Globally, corn prices have doubled since the start of 2007 and reached a 10-year high. Wheat prices reached a 10-year high and soybeans touched a two-and-a-half-year high. As a result, prices are rising for food commodities from soda and milk to beef and chicken. Livestock producers, facing high prices for corn feed, have resorted to feeding cereal scraps, trail mix, and chocolate to pigs.

In the United States, where corn is a relatively small share of the diet, the food price effect of biofuel is small. But in developing countries, in which corn is a larger part of the diet, the effect is significant. In Mexico, for instance, tortilla prices have doubled (The Economist, 2007). In China, the government has halted construction of corn-ethanol refineries in response to rising food prices (Wall Street Journal, 2007).

The demand for land imposed by biofuel production will similarly take land out of environmental preservation (Westcott, 2007; Searchinger *et al*., 2008). This will lead to deforestation and biodiversity loss. Increased biofuel production means an expanding agricultural land base, greater use of polluting inputs like pesticides and fertilizers, greater demand for water, which will mean less water for de facto in-stream uses, and greater potential for soil erosion. Economists have estimated anywhere between 1 and 16 million acres of Conservation Reserve Program land may be brought into production. Water battles are already being waged in the Mid-Western United States among different user groups along shared and depleting water resources.

Even absent biofuel, agricultural production is considered to be the biggest source of non-climatic global change (Tilman *et al*., 2001). Biodiversity loss is presently considered to be more costly than climate change (Mooney and Hobbs, 2000). Environmental services like waste assimilation, water purification, draught prevention, fire suppression, carbon sequestration, genetic diversity, and future medical breakthroughs are threatened by the loss of native lands.

Agricultural biotechnology can reduce the tension among energy, food, and the environment. We must distinguish, however, between agricultural biotechnology that improves food production and that which improves energy crop production, recognizing some technology may do both. Improvements in energy crop production may worsen the pressure biofuel exerts on food production and environmental preservation by encouraging increased bioenergy production. Improvements in food crop technology, on the other hand, are seen to unambiguously reduce the pressure on food and the environment by permitting higher yields per acre.

The Ugly

As the foregoing discussion illustrates, agriculture faces a significant challenge. Food is not in abundance today and it is expected to be even more scarce in the future as biofuel production increases. Global corn and wheat stockpiles have fallen to 25-year lows (Morrison, 2006). The stockpile system creates a stealth effect for prices, and we have yet to see the full price implications of these depletions, including increased volatility. Existing agricultural capacity can compensate for cyclical stock depletion, but rising to meet a sustained demand shift is another matter. Historically, this kind of scarcity can only be overcome by recruiting more resources to agriculture, usually in response to higher prices.

Given dramatic initial differences in per capita income, a multinational food auction would doubtless be won by higher-income bidders, with dire consequences for food security in low-income countries. History has definitive lessons for leaders whose populations enter food crises. Political consensus evaporates, leaving an ultimatum between regime change and martial law (Bradsher, 2008; Vidal, 2007; and Wong, 1982).

Low income families spend a greater share of their budgets on food relative to the rich, so higher food prices will particularly hurt the poor. Where as food is a necessity, gasoline is, in many parts of the world, a luxury consumed in greater quantities by the rich. Therefore, biofuel may pose an ugly tradeoff – the poor go hungry so the wealthy can more cheaply fuel their automobiles.

The Future

While the current generation of biofuel, made mostly from sugars and starch, may be ill-equipped to replace considerable oil consumption and make significant reductions in carbon emissions, and while it may pose an ugly tradeoff between food and fuel, the next generation of biofuels are developed and designed to do much better. The future of biofuel will convert cellulosic material to ethanol by hydrolysis and fermentation. These new conversion technologies, already at work in pilot projects, will make grasses, shrubs and trees potential biofuel feedstocks (Khanna, 2007). They will also permit the use of food crop residues, such as stalks and husks, in biofuel production. Table 3 reports potential ethanol yield from two potential cellulosic energy crops—miscanthus and switchgrass—and crop residues.

These feedstocks—and cellulosic crops generally—yield more ethanol per unit of land than ethanol from sugar or starch, and free traditional crops like corn and wheat for food uses. In addition, these crops can be grown on marginal land and are less factor-intensive than first generation feedstocks. This means the second generation of biofuel will be more environmentally friendly in terms of reducing chemical applications and erosion. However, they open up the possibility of bringing marginal land into production, which can lead to deforestation. Table 3 depicts a scenario in which 14 percent of world cropland is devoted to growing miscanthus and switchgrass to produce ethanol equal to 64 percent of world gasoline consumption. Adding crop residue to biofuel production can offset 91 percent of gasoline use (Rajagopal *et al*, 2007).

Given the constraint of land, the diversion of 200 million hectares to energy production may seem improbable and likely to hurt food production and the environment. An analysis by Waggoner (1995), however, suggests agriculture could provide a daily diet of 3,000 calories to 10 billion people using 200 million fewer hectares of cropland by 2050. But this projection requires the continuation of agricultural productivity gains observed in the past half-century, during which per capita food production increased despite a doubling of the world population. In the past, chemical pesticides and fertilizers and innovations in irrigation permitted increasing yields. Today, many pesticides suffer from resistance build-up and additional gains from mechanization and irrigation seem unlikely.

Agricultural biotechnology is demonstrated to greatly improve yield and reduce pesticide use on staple crops such as corn, soybeans, and cotton (Qaim and Zilberman, 2003; Huang *et al*., 2002; Qaim and de Janvry, 2005; Traxler *et al*., 2001; Thirtle *et al*., 2003). The current generation of agricultural biotechnology includes crops genetically modified (GM) to induce either pest resistance or herbicide resistance. The productivity gains provided by this technology lessen the impact of land lost to energy production. Regrettably, the spread of existing GM crops and the development of new transgenic traits have been hampered by regulatory barriers in Europe and elsewhere. Genetically modified crops have been banned by some countries that pursue a precautionary approach out of concern about uncertain long-term effects.

With biofuels and related technologies, the adoption process is complex and requires coordination at four different levels of the economy: farmer, processor, retailer, and consumer. Policies are needed to coordinate the adoption decisions and mitigate risk. Policy may induce demand among consumers, regulate energy companies, incent production among processors, and offer price assurances to farmers.

Adoption of biofuel will transform agriculture. The opportunities for risk-reducing and cost-saving integration can be expected to consolidate agriculture and give rise to more and bigger agribusiness. As food and energy production and environmental preservation become linked by biofuel, agricultural, energy, and environmental policy will need to be integrated. An expanded research agenda in natural resources and agriculture is needed to address the new energy challenge.

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Table 3. Oil Displacement Potential of Second Generation Biofuel

Crop	Global Acreage	Global Average Yield	Global Production	Conversion Efficiency	Land Intensity	Maximum Ethanol	Gasoline Equivalent	Supply as % of 2003 Global Gasoline Use
	(million acres)	(tonnes/ acre)	(million tonnes)	(gal/tonne)	(gal/acre)	(billion gallons)	(billion gallons)	%
Switchgrass	247	4.0	1,000	87	353	87	58	20
Miscanthus	247	8.9	2,200	87	777	192	129	44
Crop Residues			1,500	77		117	78	27
Total						396	265	91

Source: Rajagopal *et al*., 2007

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Biofuel, the Rural Economy, and Farm Structure

John Miranowski, David Swenson, Liesl Eathington, and Alicia Rosburg[1]

Introduction

Early expansion of the biofuel industry was driven by policies that provided federal and state ethanol tax credits, subsidies to reduce investment costs of smaller scale plants, EPA requirements for oxygenate additives in gasoline under the Clean Air Act Amendments and, in the case of Minnesota, that mandated a 10 percent ethanol blend initially and a 20 percent blend by 2012. Today, the ethanol industry is heavily driven by crude oil and gasoline prices, with biofuels becoming a competitive substitute for petroleum-based fuels at higher crude oil prices. In Figure 1, we can get a sense of the expansion magnitude, which went from 1.6 billion gallons in 2000 to roughly 7 billion gallons in 2007.

These plants, and particularly capacity, tend to be concentrated in the Midwestern States (Figure 2). Thus, the rural community impacts of biofuel expansion are going to be concentrated in this region. As the ethanol industry expands, a number of important changes in biofuel production have been occurring. New plants are larger scale (i.e., 50-100 million gallons per year (MGY), with some going as large as 275MGY relative to pre-2004 plants that were generally 5-40MGY), require fewer workers (i.e., 0.4 laborers/MGY as opposed 2.0/MGY in early dry mill plants), and have a norm of much higher capital costs/MGY in this era of higher crude oil prices. The structure of the industry is evolving with these changes, as well. The local ownership share is decreasing and the marginal rural economy impacts of corn ethanol production are positive but decreasing with industry expansion. These changes have important economic implications for rural communities, altering the economic impacts of further biofuels expansion.

This study examines the rural community and structural impacts of biofuel expansion, and assesses potential future impacts of further expansion of the corn ethanol industry. Ethanol industry expansion has been important to rural communities and rural America in terms of improved farm income and land rental rates, expanded job opportunities and incomes, and adding value to crops. At the same time, ethanol expansion may have impacts that raise concerns for some members of the community. Livestock producers are concerned over higher feed costs, humanitarians are concerned over potential increases in global food prices, malnutrition and starvation, and environmentalists are concerned with increased erosion and water quality problems, as well as increased greenhouse gas emissions as cropland acreage expands to meet growing demands. This analysis will focus only on economic impacts to the communities in terms of economic development, including direct and multiplier impacts on employment, value added and income in the community, and potentially offsetting economic impacts on the livestock industry.

Economic Impact of U.S. Corn Ethanol Expansion on Rural America

This assessment compares 2007 values with two future scenarios of ethanol expansion impacts. We use the IMPLAN national impact assessment model to project the economic impacts of ethanol production expansion on rural America. To assess the future economic impacts on rural communities, including the livestock industry, we use the Food and Agricultural Policy Research Initiative (FAPRI) simulations from Tokgoz *et al*., 2007. These simulations compare 2007 estimates with the 2016 baseline with \$60/bbl (billion barrels) of oil and the 2016 long run equilibrium (LRE) with \$70/bbl oil scenarios (Tokgoz *et al*., 2007). The 2016 baseline with \$60/bbl oil and 2016 LRE with \$70/bbl oil estimates are derived from current FAPRI projections for corn, ethanol and livestock production and global consumption. The simulation results also underlie the Searchinger *et al*., 2008 estimates. All of the estimates assume only corn ethanol production, using both dry-mill and wet-mill plants. Table 1 displays the primary inputs used in this exercise and the relevant technical assumptions. A survey of the current and planned ethanol firms was used to establish these industry coefficients.

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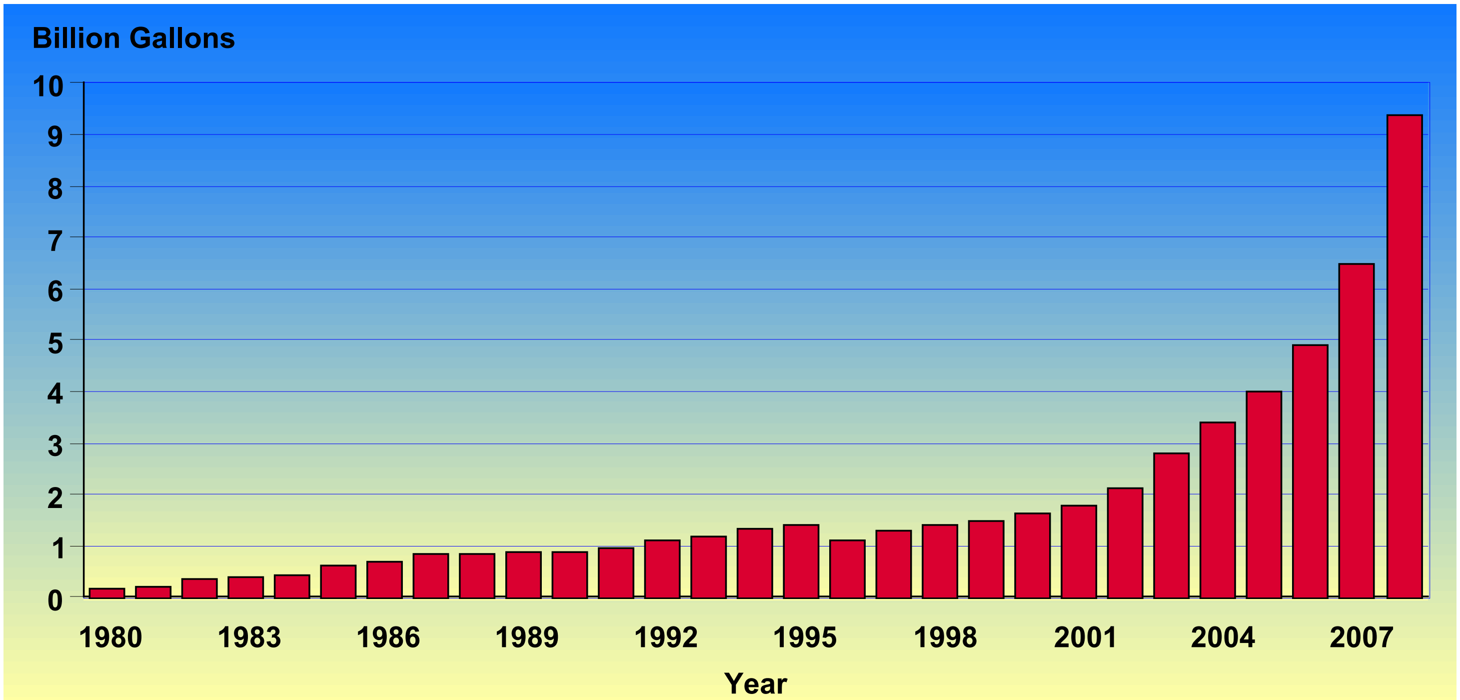

Figure 1. The Ethanol Explosion

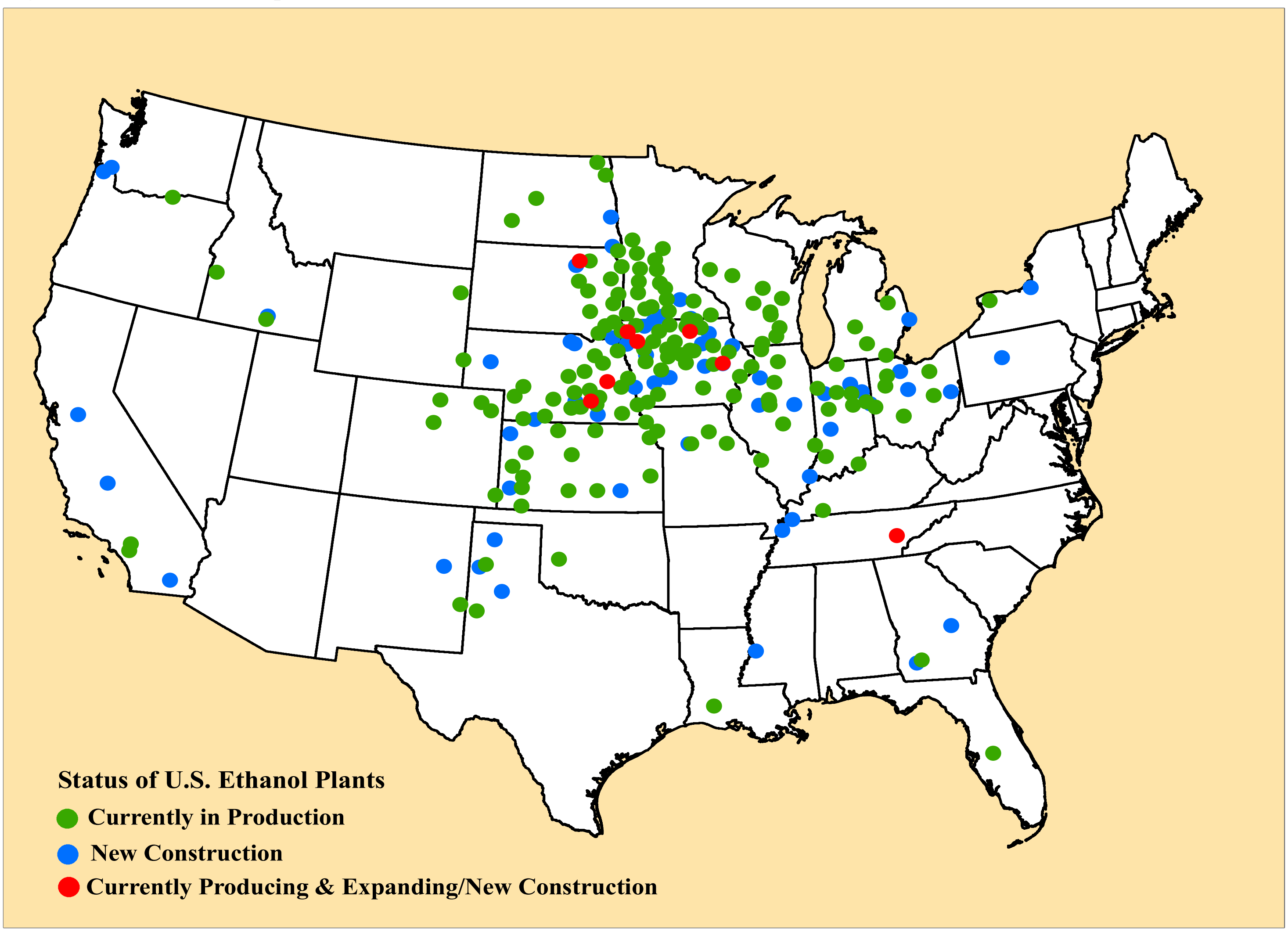

Figure 2. U.S. Ethanol Plants, 2008

Table 1. Underlying Production Characteristics and Assumptions Used in the Impact Analysis

Item	September 2007[a]	2016 Baseline with $60/bbl Oil	2016 LRE with $70/bbl Oil
Average Size (MGY)[b]	63	75	89
Corn (Mbu)	3,230	5,046	10,380
Ethanol (MGY)[c]	8,883	14,568	29,063
Plants[d]	142	194	325
Direct Jobs[e]	6,594	8,972	14,971

[a]September 2007 values were only used as a basis for building the model for projecting to future years. No impacts are reported for that period in this report.

[b]Average new plant size after 2007 is 100 MGY

[c]Plants in 2007 average 2.7 gallons per bushel and 2.8 by 2016 and thereafter

[d]Plants produce at 110 percent of nameplate capacity

eOwing to scale economies, all U.S. plants in 2005 averaged an estimated 50 jobs per plant. By 2016, the average declines to 46.4 jobs

Given the assumptions underlying Table 1, the United States needed 6,600 workers to convert 3.2 billion bushels of corn into 8.9 billion gallons of ethanol in 2007. The values for 2006 were 4,800 plant workers, 1.9 billion bushels of corn, producing 5.0 million gallons of ethanol. The 2016 baseline scenario projects a situation where the United States uses 9,000 workers to convert 5.0 billion bushels of corn into 14.5 billion gallons of ethanol. The 2016 LRE scenario would require 15,000 workers to convert 10.4 billion bushels of corn into 29.1 billion gallons of ethanol.

To derive an estimate of the national economic impact of U.S. ethanol production as projected in the FAPRI 2016 baseline and the 2016 LRE scenarios, a number of adjustments and simplifications are employed. First, two prices are used in this assessment: 1) corn value in the 2016 baseline is set at $3.16; and 2) corn value for the 2016 LRE is set at $4.43 (Tokgoz *et al*., 2007), assuming the baseline with $60/bbl oil and the LRE with $70/bbl oil price, or a $10/bbl oil price shock. It is important to note that we are estimating the national economic impacts as opposed to local economic impacts as was done by Low and Isserman (2007) and Swenson and Eathington (2006).

As the corn based biofuel industry goes through a rapid expansion phase with high ethanol and corn prices, followed by a period of lower prices, one can expect wide fluctuations in the value of output and the returns to ethanol investors. Average 2007 prices were entered into a detailed inputs and outputs direct values model. That model is sensitive to the price of all inputs, the amount of capital investment, labor requirements and costs, the overall productivity and efficiency of the operating plant, and the plant size, among other variables. That model was calibrated to average values for 2007 of 63 MGY average plant capacity. Average plant capacity for the 2016 baseline was assumed to be 75 MGY and for the 2016 LRE scenario was assumed to be 89 MGY, based on our compiled databases.

A U.S. level IMPLAN model was configured with an organic chemical sector that reflects just the ethanol industry, as opposed to the wide array of chemicals and products that the sector normally produces. Output, jobs, and value added assumptions for the baseline were inserted into the model. Next, the social accounts were modified to reflect the top 10 primary inputs into ethanol production, allowing all other standard industrial input coefficients to then rebalance the remaining costs of production. All inappropriate linkages were reduced so that the model reflected the average U.S. dry mill ethanol plant, not the average U.S. organic chemical manufacturing firm. That model was then recompiled and used to produce fixed multipliers that would be applied to the total production input estimates for the 2016 baseline and the 2016 LRE scenarios.

Model Adjustments

Jobs, labor income, and value added multipliers were adjusted downward for natural gas usage, water, electricity, and rail inputs. Only 20 percent of the predicted job and labor income increments were allowed. Expectations for value added in those sectors were also revised downward to reflect marginal, not average, gains in sales. Next, no multipliers were applied to the corn inputs as a consequence of ethanol production. While corn stocks are projected to increase in the United States due to this industry, those increases will come at the expense of other crops, and through the conversion of pasture land to row crops, the removal of land in conservation programs, and overall land quality changes. This assessment makes no attempt to estimate construction effects at the national level. The national construction industry is dependent on the overall rate of capital formation and the nature and pattern of private, public, and household investment. If we assume full employment, increases in construction activity in one subsector are typically offset by decreases elsewhere in the national construction industry.

Impact Tables

The findings of the input-output analysis are summarized in Table 2 as direct, indirect, induced, and total economic effects for each of the above categories for the 2007 crop, the 2016 baseline with $60/bbl oil, and the 2016 LRE with $70/bbl oil (i.e., the oil price shock scenario). Direct effects are attributable solely to the ethanol industry. Indirect effects reflect the value of input purchases into the direct firm, as well as the inputs their suppliers require. Induced effects, sometimes referred to as household effects, accumulate as workers in the direct and indirect industries convert their labor incomes into household purchases. The total economic effects represent the sum of the direct, indirect and induced activity.

Table 2 contains only the impacts of shocking the input-output model with the expansion of the corn ethanol industry. The impacts on the livestock industry will be considered later. The 2016 baseline with $60/bbl oil simulation indicates that in producing $27.6 billion in industrial output, almost 9,000 job holders would be paid $502 million in labor incomes. The industry would stimulate $16.9 billion in inputs production, requiring almost 11,600 jobs paying $630 million in labor incomes. When workers converted their earnings into household level purchases, they would stimulate over $3.4 billion in output and sustain nearly 26,700 jobs earning $1 billion. In the 2016 baseline, the industry links to nearly $47.9 billion in total national industrial output, almost $4 billion in value added, $2.2 billion in labor income, and 47,200 jobs. The 2016 LRE with $70/bbl oil simulation indicates that producing $69.0 billion in industrial output, almost 15,000 job holders would be paid $973 million in labor incomes. The industry would stimulate $34.6 billion in inputs production, requiring an additional 23,600 jobs paying $1.3 billion in labor incomes. When workers convert their earnings into household level purchases, they will stimulate $6.0 billion in output and sustain over 45,800 jobs earning over $3.9 billion. The total estimated impacts, including all linkages of U.S. ethanol production in the 2016 LRE scenario, would include over 84,400 jobs, $3.9 billion in labor income effects, and $6.6 billion in value added. Due to ethanol plant scale economies, labor and income needs in future plants do not grow proportionately. Above normal returns to investors are reduced to zero in the 2016 LRE model.

Impacts on the Livestock Industry of Expanded Corn Ethanol Production

The impact of expanding ethanol production on livestock production may be significant. Ethanol and livestock compete for corn as a feedstock and a feed source. Every bushel of corn used in ethanol production is two-thirds less of a bushel of corn for livestock feed (assuming that corn byproducts (dry distillers grain (DDGs)) substitute for one-third of a bushel of corn, especially in ruminant animal rations). As the demand for corn in ethanol production increases, livestock producers face higher feed costs and adjust livestock production accordingly in the long run. So we estimate the direct job change in livestock production relative to 2007, using both the 2016 baseline and 2016 LRE FAPRI projections for livestock production (Table 3). To put livestock worker displacement into a slightly different perspective, we compare the 2006 baseline livestock production with the 2016 baseline livestock

Table 2. Estimated Economic Impacts of U.S. Corn Ethanol Industry

Variables	Solutions	Direct	Indirect	Induced	Total
Output ($ billions)	2007 Crop	22.9	13.6	3.1	39.6
	2016 Baseline[a]	27.6	16.9	0.43	47.9
	2016 LRE[b]	69.0	34.5	6.0	109.5
Value Added ($ millions)	2007 Crop	669	958	1,495	3,122
	2016 Baseline[a]	970	1,185	1,800	3,955
	2016 LRE[b]	973	2,414	3,164	6,551
Labor Income ($ millions)	2007 Crop	369	503	712	1,584
	2016 Baseline[a]	502	623	1,020	2,145
	2016 LRE[b]	837	1,284	1,791	3,912
Jobs (thousands)	2007 Crop	6.6	8.5	18.6	33.7
	2016 Baseline[a]	9.0	11.6	26.7	47.3
	2016 LRE[b]	15.0	23.6	45.8	84.4

[a]with $60/bbl

[b]with $70/bbl

Source: IMPLAN 2006 Data; Iowa State University-Biofuel Impacts Study Database, 2007

Table 3. Change in Livestock Workers Required

Livestock	2007-2016	2016-LRE
	thousand	
Beef	29.7	(13.8)
Milk	34.6	(2.3)
Pork	3.4	(2.4)
Broilers	5.6	(2.2)
Turkeys	0.5	(0.2)
Eggs	2.5	(0.4)
Total Workers	76.3	(21.3)

production, and estimate the livestock worker impact in Table 3. It is important to note that the FAPRI baseline scenario reflects crop acreage reallocation in response to corn and "other crop" relative prices, trend yield growth, growing global demand for livestock and other agricultural products, and changing global production and trade flows. Thus, the 2016 baseline indicates substantial growth in U.S. livestock production and, in turn, an implied growth of 120-140 thousand in number of livestock workers required. Based on the FAPRI projections for the 2016 baseline, growing global demand for livestock products actually increases the number of livestock workers by 76 thousand. Going from the 2016 baseline to the 2016 LRE with the oil price shock does result in a livestock reduction of 21 thousand, but with over 50 thousand more livestock workers than in 2007.

Then these livestock worker changes were used to derive an estimate of the direct employment impact (assumed linear) on the livestock processing industry. These estimates of the adjustment in direct livestock employment were used to shock the IMPLAN input-output model reported in Table 4 to estimate the direct economic impacts of livestock processing changes as well as the upstream and downstream impacts associated with livestock worker adjustment associated with the expanding corn ethanol industry.

What are the livestock industry impacts of expanded corn ethanol production? Modest expansion to 15 billion gallons of corn ethanol (i.e., the level established under the Renewable Fuels Standard) should continue to have largely positive aggregate economic impacts in rural regions. Expansion beyond this level will likely have some negative economic impacts in terms of livestock industry economic impact, and partially offset the positive economic impacts of going beyond 15 billion gallons of ethanol production.

Conclusions

- Ethanol industry structure will continue to evolve, as will Midwest farm structure. Moving to biomass fuels will likely speed structural change in the future.
- Ethanol expansion is having a positive impact on the U.S. rural economy, but with decreasing marginal impacts with continued expansion.

Expansion of corn ethanol to 29 billion gallons will offset a portion of the economic gains to the rural economy created by expanding corn ethanol production to 15 billion gallons. However, expansion from a cellulosic based ethanol industry will alter these offsets.

Table 4. Estimated Economic Impact of Combined Corn Ethanol and Meat Industry Adjustments

Variables	Solution	Direct	Indirect	Induced	Total
Output ($ billions)	2007-2016	11.1	22.1	10.4	43.6
	2016-LRE	(3.1)	(6.1)	(2.9)	(12.1)
Value Added ($ millions)	2007-2016	1.6	8.0	5.6	15.2
	2016-LRE	(0.4)	(2.2)	(1.6)	(4.2)
Labor Income ($ millions)	2007-2016	1.3	4.6	3.2	9.1
	2016-LRE	(0.4)	(1.3)	(0.9)	(2.6)
Jobs	2007-2016	34.3	151.8	82.3	268.4
	2016-LRE	(9.5)	(42.2)	(22.8)	(74.5)

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Managing R&D Risk in Renewable Energy

Gordon Rausser and Maya Papineau[1]

Introduction

As crude oil prices move in the direction of $120 per barrel or higher, incentives for the U.S. economy to adjust by substituting renewable energy for fossil-based energy have intensified. In this process, governmental bodies will be pulled and pushed in the direction of subsidization support for emerging technologies. Moreover, now that corn prices have moved above $6 per bushel, another round of adjustments, substituting one source of feedstocks for another, will accelerate, including the possibility of eliminating tariffs on sugarcane-based ethanol. In the face of these dramatic market movements, public support for emerging clean energy technologies is a cornerstone of federal energy policy, whether implemented by the Department of Energy (DOE) or Department of Agriculture (USDA). Federal funds to promote clean energy are allocated on an annual basis across the spectrum of renewable energy technologies, utilizing a wide array of policy instruments, including R&D subsidization, demonstration projects, knowledge networks, education and awareness programs, tax credits, as well as direct subsidies. Moreover, given the size of market opportunities generated by the price of fossil-based energy sources, the private sector has begun to respond with material increases in renewable energy investment.

As their exposure in renewable energy technologies increases, private investors will inevitably seek public support from the government to protect the downside risk that might arise from future declines in fossil fuel prices. These technologies include, *inter alia*, cellulosic ethanol, biodiesel, sugar ethanol, corn ethanol, methanol, solar (including artificial organisms that convert sunlight into biofuel), a host of other feedstocks with genetic engineering modifications of plants, microbials, animal fats, animal waste and forest waste. State and federal governments will be drawn into support and subsidization for such potential innovations, whether the result of "learning by doing" or new discoveries. From the standpoint of societal welfare, the extent of such support is fundamentally a problem of ex-ante portfolio analysis under risk and uncertainty.

The historical experience of substitutable fossil sources of energy has revealed to all participants engaged in the development of renewable energy technologies that the prices of crude oil and natural gas will determine their economic viability. In the late 1970's the rapid expansion in the development of solar energy sources was brought to a screeching halt in the mid-1980's when crude oil prices plummeted to slightly over $10 per barrel. As a result, agents supporting each potential alternative renewable energy source will be actively engaged in lobbying to eliminate the downside risk that could well emerge (Rausser and Goodhue, 2002). For example, the coal industry has been estimated to have spent $7 million on federal lobbying in 2007 (www.politicalmoneyline.com). The framework emerging from this lobbying effort is the design of a subsidization program conditioned upon crude oil prices; if oil prices fall below $40 per barrel, the federal government would subsidize coal based liquid fuel plants, while if oil prices climbed above $80, liquefied coal companies would return to the government a surcharge. Similar structured risk swaps will be pursued by special interests investing in alternative technologies that are necessarily exposed to the risk of volatility in crude oil and natural gas prices. The implementation of such risk swaps in the commercialization of renewable energy technologies can be expected to be driven by a number of sustainable but uncertain forces, viz: global warming; geo-political risk; terrorism; the promise of genetic engineering and synthetic biology; other sources of environmental pollution; crude oil and natural gas prices; willingness of U.S. consumers to pay a premium for green energy; and U. S. rural development.

Governmental subsidization of corn and gasoline containing ethanol has been far less effective than Brazilian subsidization of sugar-based ethanol. Regardless, failure to perform an ex ante, objective analysis will likely lead state and federal governments to engage in the subsidization of selected

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technologies based on the effectiveness of lobbying efforts. Through the course of history, governments have failed badly in the design and implementation of industrialization policies. As demonstrated time and again, capital markets are far more agile than governments responding to market and commercial signals. Nevertheless, governmental support for renewable energy technologies, if properly designed, could well serve the public interest. The hope is, of course, that creating and/or supporting demand for clean energy and the cost for delivering such energy could well result in permanent and sustainable decreases in prices over the long run.

If major adjustments take place over the next decade, both public sector and private investment in renewable energy R&D will be crucial. Historically, private spending has contributed, on average, about one half of domestic R&D efforts; however, data up to 2003 suggest U.S. companies have cut their R&D spending by more than half (Kammen and Nemet, 2005). This downward trend is consistent with two well-known and related facts related to energy R&D. First, the criterion for determining the market value of R&D is the subsequent profitability of any breakthroughs, and to the extent that profitability understates the social benefits of breakthroughs, private R&D spending will tend to be underprovided by the private sector (Spence, 1984). Second, the existence of environmental externalities leads to incomplete markets and therefore under-priced or unpriced environmental goods, a second market failure that magnifies the R&D spillover effect by mitigating the profitability of new low-carbon technologies (Cropper and Oates, 1992). A combination of these factors and recent spending declines in aggregate energy R&D has led some researchers to call for increased public sector energy spending (Davis and Owens, 2003; Schock *et al.*, 1999), some at a scale equivalent to the Apollo Project of the 1960s (Nemet and Kammen, 2007).

Tempering such proposals, however, is the evidence that increased government spending "crowds out" private sector spending (Payne, 2001), and that new energy R&D crowds out other forms of R&D. This latter form of crowding out has been conjectured to affect estimates of social benefits accruing from public R&D spending (Popp, 2006). The crowding out phenomenon can also occur in the other direction, when reduced government spending is accompanied by greater levels of private spending (Heutel, 2007). This possibility is consistent with the fact that the recent downturn in company-level R&D funding has been accompanied by an almost tenfold increase in alternative energy venture capital investments between 2001 and 2007 (VentureOne, 2008). This paper presents the components of an ex-ante portfolio analysis of R&D risks in renewable energy.

Current R&D Renewable Energy Landscape

A key element in the innovation process that leads to productivity improvement is investment in building an economy's knowledge base through R&D. Both the federal government and the private sector are major players as well as stakeholders in this process, and both have an interest in successfully generating the path-breaking innovations that lead to enhanced productivity. Innovations in the renewable energy sector can create a double benefit by contributing to a nation's productivity growth while decreasing the impact of negative environmental externalities.

Public Sector

Renewable energy milestones promulgated by the Department of Energy are presented in Table 1. Ostensibly, these milestones suggest the federal government places a positive probability on path-breaking breakthroughs in cellulosic ethanol, hydrogen, solar and wind energy. Federal renewable energy R&D spending is intended, at least in part, to achieve these goals. Over the past twenty years, spending on energy R&D has remained more or less constant, whereas the share of renewable energy R&D has increased over the past ten years, as shown in Table 2.

Tables 3 and 4 present a more detailed breakdown of federal renewable energy R&D between 2001 and 2007. Both the DOE and USDA have bioenergy R&D programs. At the USDA, bioenergy R&D between 2002 and 2007 was carried out under the auspices of the Biomass Research and Development Act of 2000, which mandated that up to $14 million of Commodity Credit Corporation funds from the Farm Bill be allocated to R&D leading to the production of biobased

Table 1. DOE Renewable Energy Milestones

Cellulosic Ethanol	Cellulosic Ethanol Cost Competitive with Conventional Ethanol by 2012
	Replace 30 Percent of Today's Gasoline in 2030 with Biofuels
Hydrogen	Industry Commercialization Possible by 2012
	Fuel Cell Vehicles in the Showroom and Hydrogen at Fueling Stations by 2020
Solar	Reduce Solar Costs to Grid Parity in all U.S. Markets by 2015
Wind	Reduce Cost of Energy from Large Systems to 3 cents/kWh by 2010
	Greatly Expand Demployment of Distributed Wind Energy by 2016
	Large-Scale Offshore Wind and Hydrogen Production from Wind by 2020

Table 2. Federal Energy R&D			
Year	Total Energy	Renewable	Share of Total
	($ millions)		
1987	3,142	482	0.15
1988	3,139	416	0.13
1989	3,428	404	0.12
1990	4,047	381	0.09
1991	3,844	482	0.13
1992	3,940	558	0.14
1993	3,316	613	0.18
1994	3,475	719	0.21
1995	3,355	770	0.23
1996	2,908	644	0.22
1997	2,638	627	0.24
1998	2,810	699	0.25
1999	3,111	763	0.25
2000	3,036	746	0.25
2001	3,401	800	0.24
2002	3,580	825	0.23
2003	3,425	779	0.23
2004	3,418	712	0.21
2005	3,361	693	0.21

Source: Nemet and Kammen, 2007

industrial products. At the DOE, spending on the Biomass and Biorefinery Systems R&D program has been increasing steadily since 2004 in an attempt to reach the Program's goal of making cellulosic ethanol cost competitive by 2012. In addition, DOE's 2009 budget request proposes spending $75 million for the creation of three multidisciplinary Bioenergy Research Centers focused on generating scientific breakthroughs in cost-competitive biofuels production (USDOE, 2008b).

In contrast to recent bioenergy spending trends, Table 3 suggests federal renewable energy R&D spending in solar, wind, geothermal and energy storage technologies has declined somewhat over the past three years. DOE's 2008 budget increases funding for hydrogen technologies and biomass, but cuts wind funding by $4 million and leaves solar funding constant (USDOE, 2007a).

Federal funds also support renewable energy through channels other than R&D. The Energy Independence and Security Act, signed in December 2007, amends the Renewable Fuels Standard to require 36 billion gallons of renewable fuels production in the U.S. by 2022, up from 9 billion gallons in 2008. The Act also authorizes $500 million annually from 2008-2015 for the production of advanced biofuels that yield at least an 80 percent reduction in lifecycle green-house gas (GHG) emissions relative to current fuels (RFA, 2008a). This includes funds for small-scale 'biorefinery' demonstration projects that will produce 2.5 million gallons of cellulosic ethanol per year (USDOE, 2008a). More recently, the new Farm Bill has approved a $1.01 per gallon credit for cellulosic biofuels, whereas the $0.51 per gallon subsidy for conventional ethanol producers has been reduced somewhat to $0.45 per gallon. Facilities producing energy from wind, solar, geothermal or certain types of biomass are also eligible for a 1.5 cent per kWh tax credit for the first ten years of operation. The ethanol industry also benefits from the government's ad valorem tariff of 2.5 percent on ethanol imports, on top of a 54 cent per gallon import charge (RFA, 2008b).

Private Sector

Increasing levels of public sector spending have contributed to a favorable environment for new biofuels investments. Optimism about cellulosic biofuels has even led Vinod Khosla, head of Khosla Ventures, a prominent venture capital firm, to predict oil dropping to $35 a barrel by 2030 due to substitution of biofuels (San Francisco Chronicle, 2008). Biofuels are not the only clean energy technology to have generated increasing investor interest. Barely a week goes by without the popular media reporting on the latest company

Table 3. Federal Renewable Energy R&D, Selected Technologies						
	Hydrogen	Fuel Cells	Energy Storage	Solar	Wind	Geothermal
			($ million)			
2001	n/a	n/a	7	105	45	30
2002	n/a	n/a	78	100	43	30
2003	n/a	n/a	93	90	45	31
2004	85	73	9	86	42	26
2005	96	76	4	87	42	26
2006	80	75	3	83	39	23

n/a - not available
Source: IEA, 2007

Table 4. DOE and USDA Biomass R&D		
Year	DOE	USDA
	($ million)	
2002	92	5
2003	86	14
2004	69	14
2005	89	14
2006	90	12
2007	150	12
Source: USDOE & USDA FY Budget Summaries		

to invest in a renewable energy project, and firms are hedging their bets by pursuing a variety of options. British Petroleum (BP) and General Motors have both recently stated they foresee hydrogen as the likely 'fuel of the future' (Hargreaves, 2008), even though both are also investing significant sums in cellulosic ethanol (Baker, 2008; Sanders, 2007). Chevron has invested in multiple solar energy projects, a hybrid solar/fuel cell power plant, stationary fuel cell power plants and a biodiesel power plant (Chevron Energy Solutions, 2008). Shell's renewable energy segment is investing in a global network of hydrogen refueling stations, next-generation thin-film photovoltaic cells, and an algal biodiesel demonstration project (Shell, 2008a and b; Fortson, 2007).

Universities, the federal government, and some of the 'Big 5' fossil fuel companies have also recently come together in several high-profile public-private partnerships. BP has partnered with UC Berkeley, the University of Illinois, and Lawrence Berkeley National Laboratory, offering $500 million over ten years for research leading principally to breakthroughs in cellulosic ethanol; Chevron has offered UC Davis up to $25 million over five years for biofuels research; and Conoco-Phillips has partnered with Iowa State University and the Department of Energy in an eight-year, $22.5 million project to construct a biomass gasification system that produces synthetic diesel fuel.

Venture capital (VC) investment in biofuels, solar energy and batteries has mirrored this exuberance, as shown in Table 5 and Figure 1. Biofuels VC has witnessed a 10-fold increase between 2004 and 2007, and a 100-fold increase between 2001 and 2007; solar VC has increased from $5 million in 2001 to more than $700 million in 2007; and battery technology VC has quadrupled over the same period. To be sure, VC investments are inherently risky. The long-term value of any given renewable energy investment is dependent on both fossil-fuel prices and on the eventual technology 'winner' in the race to profitably supply a significant portion of energy services for transportation and/or electricity and heat generation. The recent Bear Stearns bailout is a reminder that in many cases, firms are rewarded with profits when they succeed, but government provides insurance against large downside risks. This 'socialized risk' structure is built into the U.S. Farm Bills, for example, and more broadly it has important implications for government energy policy. As the private sector increases its exposure in renewable energy markets, government will be increasingly be pulled in the direction of insuring against the downside risks of clean energy investments.

Technologies

In 2006, combustion technologies in the electricity and transportation sectors, respectively, generated approximately 33 percent and 28 percent of U.S. green-house gases (GHGs) (USDOE-EIA, 2007). Non-electricity uses of fossil fuels in the industrial, commercial and residential sectors generated approximately 22 percent, whereas methane and nitrous oxide from landfills and animal waste contributed another 4 percent. Altogether, these sectors are responsible for 87 percent of U.S. GHGs. Multiple renewable energy technologies have the potential to replace a significant portion of these energy services, including biofuels, hydrogen and fuel cells, electric vehicles, solar energy, wind energy, and electricity from biomass.

Table 5. U.S. Alternative Energy Venture Capital							
Year	Biofuels	Batteries	Fuel Cells	Geothermal	Hydrogen	Solar	Wind
				($ million)			
2001	2.5	4.0	7.8	7.2	9.3	4.7	0.0
2002	3.0	0.0	16.5	0.0	12.8	31.0	0.0
2003	2.5	4.8	44.8	0.0	5.0	0.7	0.0
2004	28.0	14.0	210.0	0.0	10.0	54.8	0.8
2005	56.0	7.3	91.8	0.0	8.0	107.7	0.8
2006	546.7	61.0	34.5	0.0	11.6	291.3	8.0
2007	297.7	101.7	98.5	4.0	0.0	718.7	33.8
Source: VentureOne Inc., 2008							

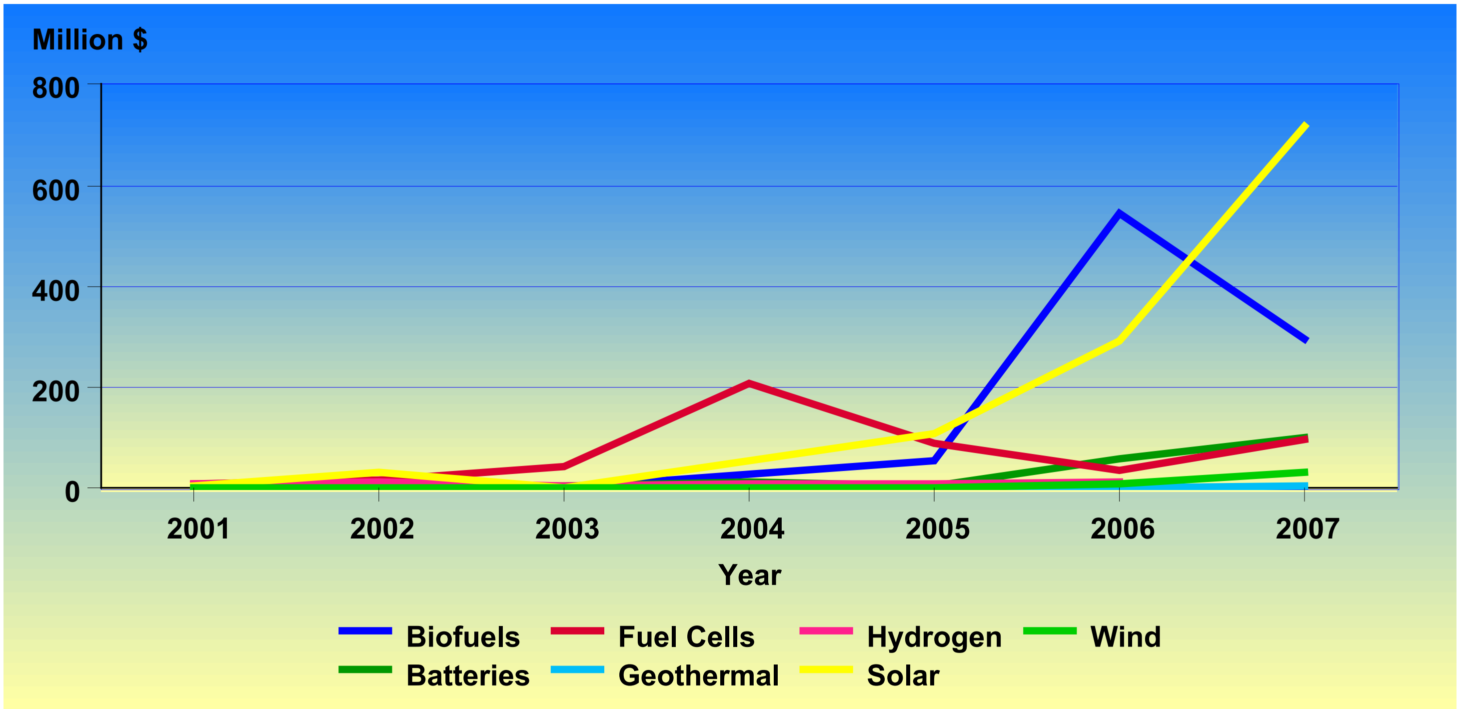

Figure 1. Clean Energy Venture Capital (US)

Ethanol and Biodiesel

Ethanol can be produced through two channels: biochemical and thermochemical conversion, as illustrated in Figure 2. In both of these processes, biomass feedstock is transformed into ethanol and other valuable coproducts. At present, ethanol is produced principally through the biochemical channel – this approach is outlined in Figure 3. Conventional ethanol production (ethanol produced from corn, sugarcane and sorghum) follows the "starch process" outlined in the top half of Figure 3. In this process, microorganisms such as yeast

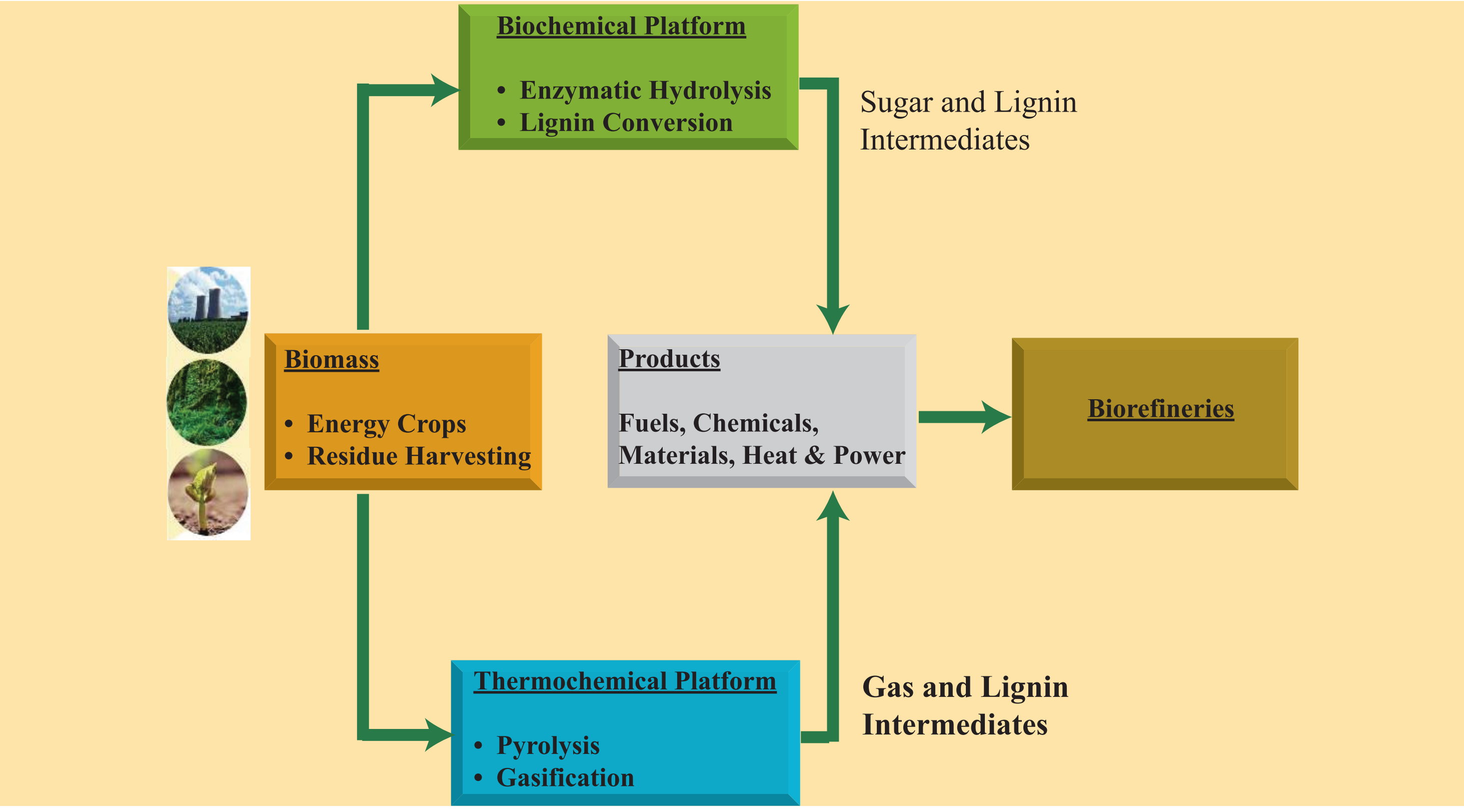

Figure 2. Alternative Paths to Ethanol Production

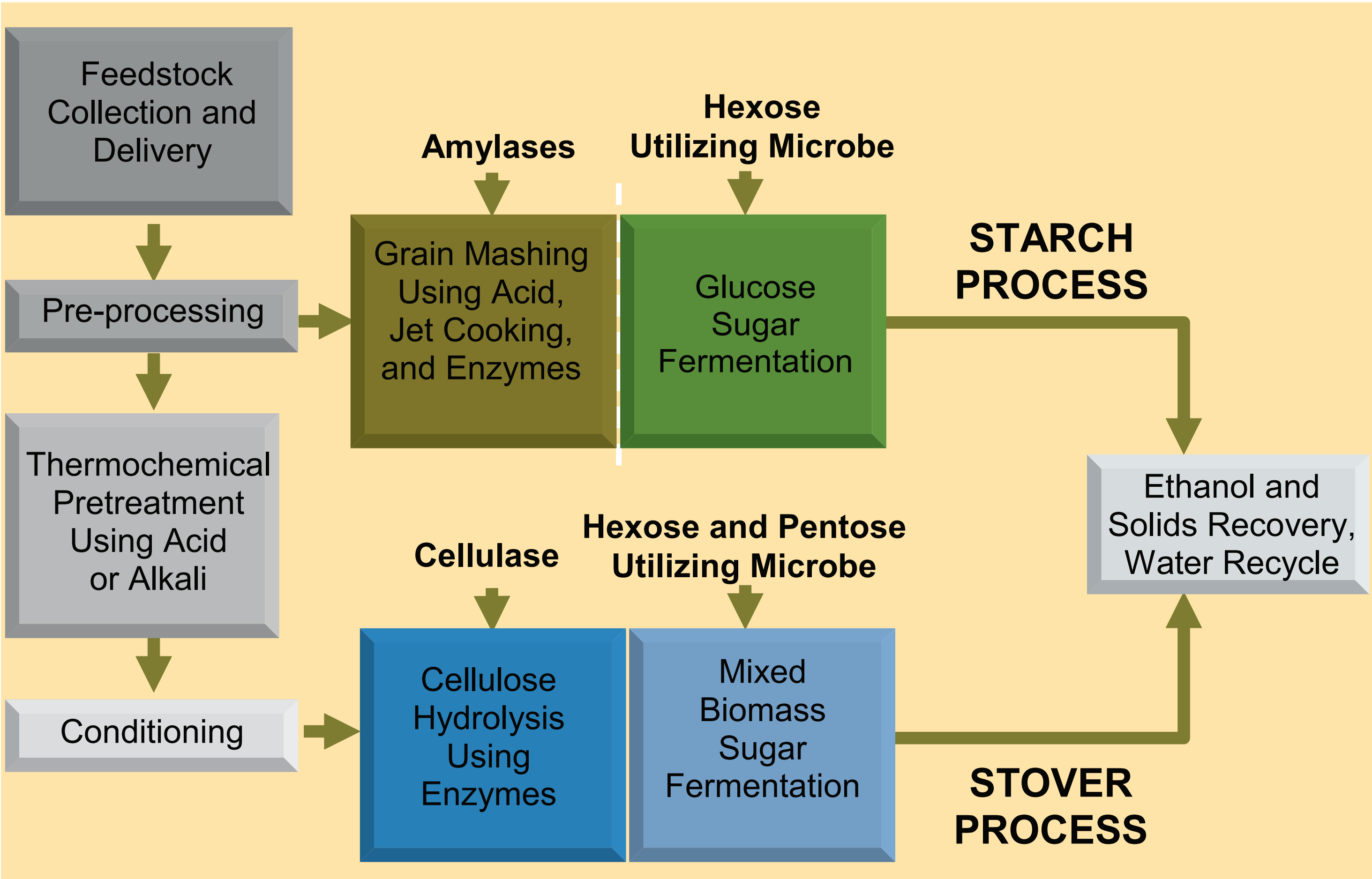

Figure 3. The Ethanol Production Process

and bacteria ferment sugar from starch and sugar crops into ethanol. Biochemical conversion can also make use of more abundant "cellulosic" biomass sources such as grasses, wood chips, and agricultural residues. Cellulosic ethanol production, as shown in the bottom half of Figure 3, involves the application of heat, pressure, chemicals, and enzymes to unlock the sugars in cellulosic biomass, followed by the application of microbes, potentially genetically engineered, to ferment the sugars into ethanol.

Biofuels can also be produced through thermochemical processes, as shown in the bottom half of Figure 2. Pyrolysis decomposes lignocellulosic biomass by heating it in the absence of air. In gasification, biomass is heated with a limited amount of oxygen to convert biomass into a hot 'syngas'. This can be combusted and used to produce electricity in a gas turbine or converted to hydrocarbons.

Conventional ethanol is currently a commercially proven fuel technology. In 2007, the industry produced a record 6.5 billion gallons, more than double that produced in 2003 (RFA, 2007). Prospects for enhanced conventional ethanol production per unit of energy input are in the area of genetic engineering. This includes the development of corn seed genetics for enhanced crop yields and the development of high-fermentable corn: corn hybrids that improve refinery yield by producing more ethanol per bushel of corn than conventional feed corn does (Rendleman and Shapouri, 2007). Potential also exists for productivity improvements through the development of thermo-tolerant yeast and new enzymes to hydrolize starch at low temperatures, and increasing the value of byproducts (NSF, 2007).

Cellulosic ethanol has not been commercially demonstrated; however, the promise of cost-competitive cellulosic ethanol has been characterized as being mostly comprised of "process improvement" (Sommerville, 2007). Potential breakthroughs in cellulosic ethanol can be separated in four broad categories. Two of these are devoted to developing low-cost hydrolysis, a key step in ethanol production whereby heat, chemicals and enzymes are applied to separate the sugars in cellulosic feedstocks. One possibility is the identification of new classes of lignin precursors that would enable production of compounds that are more easily hyrolizable. Plant products with large amounts of cellulose are held together by lignin, which current enzymes find difficult to break down, resulting in higher production costs. This leads to the second research focus: identification and large-scale replication of new catalysts that can more effectively decompose cellulose in the hydrolysis process (DellaPenna and Last, 2008; Kintisch, 2008).

Another area of focus in cellulosic ethanol is microbial genetic engineering to enhance the productivity of the fermentation process that converts plant sugars to ethanol. Current microbes used in ethanol production ferment only a subset of the available sugars, mostly glucose and xylose. Microbes that can ferment hexoses and pentoses are already known, but have not been adapted to large-scale industrial fermentation (Service, 2007). A long-term research goal rests on the possibility of developing a fermentation process for direct conversion of biomass to biofuels, rather than undergoing the intermediate hydrolysis step. This would require identification of acid-resistant thermophile organisms (Sommerville, 2007).

Researchers are also working on the potential for enhanced biodiesel production. Conventional biodiesel is a commercially proven technology, albeit at a small scale (USDOE-NREL, 2006a). These biodiesel facilities use vegetable oils, seed oils, or animal fats to react them with methanol or ethanol in the presence of a catalyst. Some researchers have stated that the potential for large scale increases in conventional biodiesel production is limited (Somerville, 2007). Nevertheless, work is ongoing to increase the value of coproducts in biodiesel production, and improve catalytic systems in biodiesel production (NSF, 2007). Genetic engineering work has also produced algae with a high lipid content that can be used as another source of biodiesel. Several projects and private start-ups in algal biodiesel production are currently underway (NSF, 2007; Fortson, 2007). Scientists have also expressed interest in algal biodiesel production for jet fuel production. Ethanol and conventional biodiesel do not have sufficient energy density to supply jet fuel, whereas 'hydroprocessing' of algal biodiesel shows promise in producing a fuel very similar to petroleum-derived commercial and military jet fuels (USDOE-NREL, 2006b).

Other Renewable Technologies

In addition to biofuels, breakthroughs in hydrogen production and fuel cell technology, electric vehicle technology, biomass, solar and wind energy may lead to one or more of these technologies supplying an increasing share of energy services in the transportation and electricity and heat generation sectors.

Hydrogen

Although the Department of Energy estimates it will take at least 30 years before mass-market use of hydrogen fuel cells produce significant carbon reductions (Plotkin, 2007), fuel cell vehicles and low-cost hydrogen production may eventually displace at least a portion of conventional gasoline vehicles. Current research in this field is focused on two hurdles to large-scale adoption of fuel cell vehicles and the required fueling infrastructure: hydrogen fueling and storage capacity enabling vehicles to travel up to 300 miles before refueling, and low-carbon, large-scale hydrogen fuel production.

In the former category, scientists are focusing on the identification of compounds that would enable hydrogen to be stored at much higher densities; condensing hydrogen gas into a usable solid fuel; compact hydrogen storage using carbon nanotubes; and reducing hydrogen vehicle weights. Low-carbon hydrogen production is being pursued through research on electrolysis; photo-electrochemical splitting; producing hydrogen from algae and bacteria that produce hydrogen naturally; and hydrogen production from biomass using anaerobic digestion or fermentative microorganisms.

In the latter category, scientists are currently investigating the fermentation of sugars and pretreated cellulosic biomass to produce hydrogen. Current work is focused on identifying microbial cultures that can directly ferment cellulosic biomass into hydrogen (NSF, 2007). Microorganisms, like green algae and cyanobacteria, can produce hydrogen by splitting water through a process called "biophotolysis" or "photobiological hydrogen production". This photosynthetic pathway produces renewable fuels without producing greenhouse gases. The scientific challenge associated with the approach is that the enzyme that actually releases the hydrogen is sensitive to oxygen. The process of photosynthesis produces oxygen and this normally stops hydrogen production very quickly in green algae. To overcome this problem, scientists are generating oxygen- and hydrogen-tolerant producing mutants from photosynthetic microorganisms by various genetic approaches (NSF, 2007).

Electric Vehicles

The Department of Energy is supporting the development of hybrid vehicles and electric propulsion technologies, and several startups are working on breakthroughs in battery technology in electric vehicle applications. The major research focus in this field is enhanced battery energy density. Current lithium-ion batteries have so far failed to compete with the energy-per-kilogram in gasoline: conventional liquid fuels hold 80 times more energy per kilogram than current electric vehicle batteries. However, several firms are working on 'next-generation' lithium-ion batteries and others are experimenting with new compounds such as barium-titanate powders that may lead to large improvements in energy density (Hamilton, 2008).

Biomass for Electricity Production

Biopower (biomass-to-electricity power generation) is a proven electricity-generating option. However, large-scale increases in biomass electricity generation may eventually compete with the biomass supply in biofuels production. With about 10 Gigawatts (GW) of installed capacity, biopower is the single largest source of non-hydro renewable electricity in the United States (USDOE, 2008c). This installed capacity consists of about 7 GW derived from forest-product-industry and agricultural-industry residues, about 2.5 GW of municipal solid waste (MSW) generating capacity, and 0.5 GW of other capacity such as landfill gas-based production. The 7 GW of traditional biomass capacity represents about 1 percent of total electricity generating capacity and about 8 percent of all non-utility generating capacity.

The majority of the capacity is produced in Combined Heat and Power (CHP) facilities in the industrial sector, primarily in pulp and paper mills and paperboard manufacturers. All of today's capacity is based on mature, direct-combustion boiler/steam turbine technology. The nearest term low-cost option for greater use of biomass in electricity production is co-firing with coal in existing boilers.

Another electricity generation option is gasification. Gasification for power production involves the devolatilization and conversion of biomass in an atmosphere of steam or air to produce a medium-or low-calorific gas. The resulting biogas is then used as fuel in a combined cycle power generation plant that includes a gas turbine topping cycle and a steam turbine bottoming cycle. Advanced biomass power systems based on gasification benefit from the substantial investments made in coal-based gasification combined cycle (GCC). The first generation of biomass GCC systems could have efficiencies nearly double that of direct-combustion systems (e.g., 37 percent versus 20 percent). In cogeneration applications, total plant efficiencies could exceed 80 percent (ODOE, 2007).

Solar Breakthroughs

Thin film photovoltaic (PV) cells and PV concentrators are likely candidates for building-integrated solar construction and utility-scale solar electricity generation, respectively, in the medium term. Recent advances in chemistry, materials science, and solid state physics can potentially lead to solar cells with nearly double the efficiency of traditional silicon-based solar cells and of plastic versions that cost just a fraction of today's photovoltaics (PVs). However, most of these novel solar cell technologies are not yet close to commercialization (Service, 2008).

Thin-Film PV

Three types of thin films have demonstrated good potential for large-scale PV: amorphous silicon, copper indium diselenide, and cadmium telluride. Others are at somewhat earlier levels of maturity (film silicon and dye-sensitized cells). Commercial interest exists in scaling-up production of thin films; as they are produced in larger quantity, and as they achieve expected performance gains, they will become more economical for large-scale commercial applications. However, to meet the economic goals needed for large-scale use, much more technical development is required. Important technology development must be carried out to (1) transfer very high thin film PV cell-level efficiencies (up to 18 percent) to larger-area modules; (2) optimize processes and manufacturing to achieve high yields and improved materials use; and (3) assure long-term outdoor reliability. Today's technology base suggests that (with adequate resources) all of these goals can be achieved, but each will be challenging (USDOE, 2008d).

PV Concentrators

Photovoltaic concentrator systems use optical concentrators to focus direct sunlight onto solar cells for conversion to electricity. The modules are mounted on a support structure and, during daylight hours, are oriented to face (or track) the sun using motors, gears, and a controller. The solar cells in today's concentrators are predominantly silicon, although solar cells utilizing materials such as gallium arsenide or cadmium telluride may be used in the future because of their high-conversion efficiencies. By using optical concentrators to focus direct sunlight onto solar cells, the cell area, and consequently cell cost, can be reduced by a factor of up to one thousand (a 1,000x concentration factor). However, large-scale utility application of PV concentrators still requires advances in higher-efficiency cells, better optics, more-robust modules, and reliable sun-tracking arrays (USDOE, 2008d).

Over the longer-term, several possible breakthroughs in solar could bring about significant productivity improvements, and therefore lower costs. These include development of inorganic semiconductor nanocrystals with the potential to improve cell efficiencies from 33.7 percent to 44.4 percent via multiple exciton generation (Service, 2008); development of materials for tandem thin film cells to push 20 percent efficiency, in which several light-absorbing materials are layered to capture different portions of the solar spectrum; high-efficiency hybrid organic-inorganic photovoltaic cells (USDOE, 2007b); and breakthroughs in the emerging field of plasmonics to increase light absorption and therefore PV cell performance (USDOE, 2007b).

Wind Energy

Electricity from wind is currently supplied on a commercial scale, and continued improvements in cost and performance of wind turbines are likely in the future. Turbine design improvements that will continue to reduce costs are projected to continue in the coming decades: lightweight, increased capacity turbines with higher turbine diameter and hub height are expected to reduce units costs up to the 2030 timeframe. Technical improvements in the form of eliminating hydraulic systems, "smart rotor" development, and flexible turbine systems driven with interactive controls are also expected (USDOE, 2007c; NSF, 2007).

Table 6. Renewable Energy Costs, Transportation Fuels

	($/MJ)
Gasoline Benchmark	0.012
Biofuels:	
Corn Ethanol	0.018
Corn Stover	0.024
Switchgrass	0.035
Miscanthus	0.024
Sugar Cane (Brazil)	0.010
Sugar Cane Bagasse	0.056
Biodiesel Algae	n/a
Biodiesel Waste	0.010-0.016
Biodiesel Vegetable Oil	0.016-0.020

Sources: Khanna, 2007; USDOE-EIA, 2007; and ODOE, 2007. Conversions to $/MJ completed by authors. One megawatt-hour contains 3600 megajoules.

Table 7. Renewable Energy Costs, Electricity

	($/MJ)
Coal Benchmark	0.011-0.014
Biomass:	
Biomass Electricity (No Cogen)	0.014-0.019
Landfill Gas Electricity	0.008-0.010
Anaerobic Digestion Electricity	0.010-0.015
Hydrogen from Wind	0.028-0.039
Solar	0.083-0.110
Wind	0.009-0.014

Sources: Khanna, 2007; USDOE-EIA, 2007; and ODOE, 2007. Conversions to $/MJ completed by authors. One megawatt-hour contains 3600 megajoules.

Current Costs

Current estimated costs of renewable energy production of potential transportation and electricity fuels are presented in Tables 6 and 7 respectively. Costs of energy from gasoline and coal are also listed as a benchmark. Estimates have been converted to dollars per megajoule (MJ) to enable a consistent comparison across technologies. Corn ethanol is currently about 30 percent more expensive than gasoline, though recent record corn prices have dramatically increased the cost of corn ethanol since the reported value is based on 2007 data.

Data presented in Table 6 indicate costs of cellulosic ethanol will have to be reduced by more than half to become competitive with gasoline. Note, however, ethanol produced from Brazilian sugar cane is already cost-competitive with gasoline – though the reported value does not include import tariffs. Electricity production from biomass is almost cost-competitive with pulverized coal, as is electricity produced from anaerobic digestion. Landfill gas electricity is already cost-competitive with pulverized coal, though this source is evidently limited in supply. Under the most favorable weather conditions, wind electricity is also cost-competitive with coal, but the variability of wind electricity costs is quite high.

Costs presented in Table 6 can be considered initial conditions in a dynamic process of productivity improvement, or equivalently, cost reduction. Production cost reductions in renewable energy technologies are expected to occur as a result of R&D investment and learning-by-doing (Papineau, 2006). Since most of the emerging renewable energy industries are still operating at a very small scale, cost reductions as a result of dynamic economies are expected to be of a much higher magnitude compared to the decline in fossil energy production costs.

Analytical Framework

The optimal allocation of R&D among the various renewable energy technologies, in both the public and private sector, is dependent upon the potential for productivity increases or cost reductions in each technology. In order to model the process of cost reduction, each technology must be represented in a common framework.

Production and Cost Representations

Each technology can be represented in a production function framework, where feedstock inputs are transformed into valuable outputs and a carbon byproduct in accordance with

$$m_{it} = r_{it} + a_i t F_{it}(L_{it}, K_{it}, m_{it}), \qquad (1)$$

where m_{it} = feedstock input for technology i at time t, $F_{it}(\bullet)$ = multi-output correspondence for technology i at time t, r_{it} = carbon byproduct, a_{it} = productive efficiency parameter for technology i at time t, and L_{it}, K_{it}, = labor and capital inputs, respectively, for technology i at time t.

This production process is consistent with the materials-balance principle, which explicitly accounts for pollution by-products as inevitable parts of the production process (Ayres and Kneese, 1969). Materials balance implies that modern production processes yield at least two outputs and require at least two inputs: the use of energy to transform matter into economically valuable outputs (e.g. ethanol and animal feed produced as coproduct) will also produce an undesirable pollution byproduct (Ethridge, 1973). Thus, every process of modern production is necessarily joint production. As explained by Pethig (2006), incorporating the materials-balance principle in theoretical analyses adds significantly more computational complexity, and environmental economists have been reluctant to explicitly incorporate it in their analyses. This means much of the production processes in present models are at variance with the law of the conservation of mass; the literature has rarely produced non-linear production models that satisfy the mass balance principle (van den Bergh, 1999).

Technical improvements can be represented as an increase in a_{it}, implying that more output can be produced from the same inputs and a constant quantity of carbon output. Given the duality between production and costs, such productivity improvements are equivalent to downward shifts in costs, or, in term of Table 6, lower costs per MJ of energy service, holding carbon output constant. In terms of initial conditions, there is a mapping between the productive efficiency of technology i at time t, or a_{it}, and the initial cost parameter b_{it}, where $b_{it}C_i$ is the unit cost of the *i*-th technology at time t.

Decision Theory

The optimal allocation of renewable energy R&D investment across the various technologies is a complex problem of decision-analytic modeling; fundamentally the problem must be structured to eliminate any of the biases often inherent in the decision-making process. Future productivity improvements among the renewable technologies, in other words increases in a_{it} or reductions in b_{it}, are an important determinant of the optimal ex-ante allocation of R&D. To estimate the growth rate of a_{it} and/or the reductions in b_{it}, expert opinion will be used to elicit the prior multivariate probability distribution around future costs or productivity measures (O'Hagan, 1998; Raiffa and Schlaifer, 1961). If $b_{it}C_i$ is the unit cost of the *i*-th technology at time t, then the quantity of principal interest is the rate of decrease of b_{it} as a function of the R&D investment in each technology. The variable C_i is an exogenously determined initial condition: in our application these are the costs per MJ from Table 6. The problem is to elicit expert opinions about the multiple b_{it}'s . Elicitation of the complete joint prior distribution is a highly complex task involving multiple parameters, however in practice it is often simplified by adopting Bayes linear methods that only require the elicitation of prior means, variances and covariances of the parameters (Goldstein, 1988).

The assessment of potential productivity and cost evolution for the various technologies must be complemented by future trajectories in the external forces mentioned in the introduction. Without determining the role of these external forces, it is not possible to evaluate the value proposition for the adoption and diffusion of any technological advancements that might take place. The market value of major discoveries and/or continued learning-by-doing (Rausser, 1999) will be determined by future political and economic conditions. The potential probability distribution trajectories for all of the external forces except for future crude oil and natural gas prices will be assessed through expert panels for a 20-year horizon. In the case of crude oil and natural gas prices, both futures markets data and available econometric models will be combined to generate composite probability distributions over the same horizon. The results of the expert panel assessments will be designed as a Bayesian structured updating process to separate those technologies that remain viable from those whose support should be terminated (Rausser and Small, 2000). The portfolio model will be constructed as a Monte Carlo simulation analysis, quantifying the updated conditional probability distribution for two categories of choice variables (i) the R&D investment in specific technologies; and (ii) policy instruments set by the government to incentivize private sector investment in renewable R&D across the various technologies.

Determination of the Optimal Portfolio

Determining the allocation of R&D investment across the technologies described in Section 2 depends on the presumed governance structure and decision-making process. In our analysis, we will draw a sharp distinction between basic and applied research and the feedback loops between each of these two categories of research (Rausser, 1999; Rausser, Simon, and Stevens, 2008). Three alternative formulations are considered, each with a different criterion function and constraint structure. In each case, the focal decision space is the allocation of R&D investment across the specified technologies, updated each period in accordance with a Bayesian learning model characterizing the underlying probability distributions on costs and/or productivity measures as well as the external forces.

Social Welfare

For this formulation, the distinction between the public sector and private sector is collapsed into a social planning framework. In this framework, a social planner is presumed to control the allocation of R&D investment based on initial conditions and ex-ante multivariate probability distributions for all renewable energy technologies and external forces. The resulting portfolio model will determine the optimal ex-ante strategy across promising technologies, isolating the scope of investment (subsidization) that services the public interest. The solution for this formulation will set the first-best outcome or benchmark for more realistic specifications.

Private Sector Conditional On Public Sector Actions

In this formulation our focus is private sector investment in renewable technologies. Initially, we shall disaggregate these investments across the venture capital community, the large oil companies, and all other sources. The behavior of private sector will be presumed to be driven by the same Bayesian learning model characterizing the underlying probability distributions on costs and/or productivity measures as well as external forces but now only with respect to applied research (Rausser, 1999). In addition, however, the private sector can be expected to take into account the R&D efforts of public sector, both basic and applied, including ongoing university and public-private research. Moreover, incentives resulting from a number of governmental policy instruments such as price subsidization, biofuels mandates, tax subsidies, credit subsidies, risk swaps, input subsidies, and trade protection will increase the amount of private sector R&D investment that would otherwise take place. The existence of such policy instruments, however, can also be expected to result in organized interest groups to be formed who will lobby the government to maintain and expand such subsidization support (Rausser and Goodhue, 2002). In other words, resources will be allocated not only to R&D investment in potential commercial technologies but also to lobbying the government to redistribute any resulting market surplus in their favor.

Public Sector Decision-Making

Due to the active intervention of the government in R&D investment and the subsidization of the private sector commercial developments, we recognize that the actual public sector decision-making will dictate a political economic analysis. A governing criterion function must be specified which incorporates both the "public interest" as well as the "specialized interest" of the private sector, or more specifically the recipients of governmental transfers (Rausser and Goodhue, 2002).

The maximization of this criterion function will be subject to the constraints represented by the private sector investment in renewable technology R&D as well as the portfolio of probabilistic assessments for potential technological advancements and the external forces. This formulation will allow an evaluation of vested-interest group formation (e.g. corn ethanol plant investors), which may emerge around the design and implementation of subsidization policy instruments. Also, in the context of this formulation, the effectiveness of the design and implementation of alternative policy instruments will be assessed in terms of incidence, i.e. who wins and who loses, along with the political economic forces. The quantification of the political economic forces will be the basis for determining which subsidization instruments will fade away versus those that will face significant exit barriers due to political power and influence.

Conclusions

A number of potential uses of our risk modeling framework can be identified. First, the public sector can determine a portfolio risk-adjusted allocation of R&D resources to renewable energy technologies. Second, with some minor modifications the private sector can do the same. Third, the framework can also be employed to evaluate grant proposals not only in terms of their potential separable impact but also their overall effect on the entire portfolio of renewable energy technology R&D efforts.

The ultimate purpose of our analysis is to explicitly recognize that the public sector will be pulled and pushed in the direction of subsidization support for emerging technologies. In essence, the government has become engaged in an industrialization policy effort that will only intensify over the next decade. We must be mindful of the fact that governments have failed badly in the design and implementation of such policies. As demonstrated time and again, capital markets are far more agile than governments at responding to market and commercial signals. Nevertheless, governmental support for renewable energy technologies, if properly designed, could well serve the public interest. The hope is, of course, that creating and/or supporting demand for clean energy and the cost for delivering such energy could well result in permanent and sustainable decreases in prices over the long run. Regardless, caution must be exercised to avoid the permanent subsidization of the private sector engaged in the commercial development of renewable energy technologies. Our proposed ex-ante portfolio analysis under risk and uncertainty is structured to temper the typical government failure that arises from "infant industry" analysis of "picking winners". The proposed analysis is the basis for generating a performance-dependent mixed strategy across alternative renewable energy technologies with exit clauses for terminating policy instruments that generate rents and subsidies to the private sector.

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Risk and Uncertainty at the Farm Level

James A. Larson[1]

Introduction

The United States has a growing focus on reducing dependence on petroleum and encouraging the production of fuels from renewable sources. The Energy Independence and Security Act of 2007 have mandated that 36 billion gallons per year of ethanol be produced in the United States by 2022, with 21 billion gallons per year from feedstocks other than corn (U.S. Congress, 2007). Perlack *et al*. (2005) and English *et al*. (2006) estimate that more than a billion tons of lignocellulosic feedstock could be produced annually for ethanol production in the United States. With the more aggressive goal, lignocellulosic materials such as switchgrass, corn stover, wheat straw, and wood waste products would be needed to fill the gap (De La Torre Ugarte, English, and Jensen, 2007).

While the lignocellulosic biomass-to-ethanol industry is not yet commercially viable, the U.S. Department of Energy has set a goal for its research and development efforts to make lignocellulosic ethanol cost competitive with petroleum by 2012 (U.S. Department of Energy, Office of the Biomass Program, 2008). Substantial research dollars have been allocated by federal, state, and private entities towards making lignocellulosic conversion technologies commercially viable. Currently, several projects are being planned to demonstrate the feasibility of biomass-to-ethanol technologies. For example, Dupont Danisco and The University of Tennessee using private, as well as State and Federal funding, are jointly planning to operate a pilot lignocellulosic biorefinery using corn stover and switchgrass as feedstocks (The University of Tennessee, 2008a, 2008b). The University of Tennessee Biofuels Initiative contracted with 16 farmers in spring 2008 to plant 723 acres of switchgrass to provide feedstock to the plant. The biorefinery is scheduled to be operational in December 2009.

Switchgrass may have certain advantages as a dedicated perennial energy crop because of its wide adaptation and ecological diversity in the United States (McLaughlin *et al*., 1998). In addition, switchgrass may be a more efficient way to produce renewable energy than with corn production. Schmer *et al*. (2008) in a study of production on 10 switchgrass fields on marginal cropland in three Midwest Sates found that switchgrass produced 540 percent more renewable than nonrenewable energy used in the production of the feedstock. However, compared to other agricultural commodities, transportation costs from the grower to a biorefinery for biomass crops such as switchgrass may be relatively high due to its bulkiness and low energy densities. Thus, the relatively high transportation costs for biomass feedstocks may result in a more locally-grown market situation for biomass feedstock. Epplin *et al*. (2007) has suggested that the development of a biomass-to-ethanol industry using dedicated energy crops may follow one of two paths. One possible direction is a vertically integrated system where the biorefinery leases (or purchases) lands and directly manages the production, harvest, storage, and transportation of feedstocks. Another alternative for the processing plant is to enter into long-term production and harvest contracts with individual local farmers. Under this market scenario, the processor likely will have an interest in providing production contracts or other incentives to induce farmers to supply sufficient feedstocks to keep the plant operating at capacity.

A number of researchers have evaluated the economic feasibility of using lignocellulosic feedstocks for bioenergy and bioproduct production including McCarl, Adams, and Alig (2000); Dipardo (2001); Haq (2001); Bernow, Dougherty, and Dunbar (2000); and English, Menard, and De La Torre Ugarte (2004). In addition, numerous studies have estimated the cost of producing energy crops in the United States, including Downing *et al*. (1996); Duffy and Nanhou (2001); Graham *et al*. (1995); Johnson and Baugsund (1990); Mooney *et al*. (2008); Perrin *et al*. (2008); Vadas, Barnett, and Undersander (2008); Vaughan, Cundiff, and Parrish (1989); and Walsh *et al*. (1998).

Not understood as well is how the emerging industry of interrelated feedstock producers, biorefineries, and auxiliary service providers, such as transportation and storage, will be

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structured and how each will bear and/or share business and financial risks. Analyses by Bhat, English, and Ojo (1992); Cundiff (1996); Cundiff and Marsh (1996); Cundiff, Dias, and Sherali (1997); Epplin (1996); Thorsell *et al*. (2004); Bransby *et al*. (2005); Sokhansanj, Kumar, and Turhollow (2006); Mapemba *et al*. (2007); Kumar and Sokhansanj (2007); and Popp and Hogan (2007) have evaluated some of the aspects of the costs and risks of harvest, storage, and transportation of biomass feedstocks. A biomass-based energy industry may have a very different set of business and financial risks than for coal and oil industries. For example, severe drought and flood events are not uncommon in the United States, can cover large geographic areas, and may have substantial negative impacts on production. Thus, as with other agricultural commodities, weather and the growth and development characteristics of biomass crops may have very large impacts on the quantity and quality of biomass produced for energy production in any one year, and on the storage, transportation, production decisions for the biorefinery. Thus, an important aspect of risk for the industry will be with on-farm production of bioenergy crops.

If perennial switchgrass is to be used as a feedstock for ethanol production, it will need to compete with other crop and livestock activities in terms of expected profit and the variability of profit (risk). Thus, the unique growth and development characteristics of a perennial biomass feedstock such as switchgrass may influence its risk and return tradeoffs with other farming activities. In addition, the logistics of harvest, storage, and transport of switchgrass may affect risk and return for a producer. The objective of this paper is to explore some of the potential on-farm business and financial risks that may be associated with producing a dedicated bioenergy crop such as perennial switchgrass.

Potential Sources of Risk

As defined by Robison and Berry (1987), risk happens when the uncertain outcome of a choice made by a decision maker alters the well-being of that decision maker. Risk is usually thought of in terms of variation around the expected outcome or in terms of deviations below the expected outcome. From a risk standpoint, farmers are most often concerned about the probability of incurring low net revenues, in addition to the expected net revenue, when considering the adoption of a new agricultural technology or enterprise. Farmers typically face both business and financial risks when making production, marketing, and financial decisions. The five major sources of business risk in agriculture are: 1) production or technical risk, 2) market or price risk, 3) technological risk, 4) legal and social risk, and 5) human sources of risk (Sonka and Patrick, 1984). Production risks include precipitation, temperature, wind, pest, fire, and theft events that can negatively impact yields, production, and income. Price risk can occur for both crop inputs purchased and crop outputs sold. Technological risk arises from the potential of a current investment to be diminished by technological improvements that may occur in the future. Legal and social risk can arise from several sources. These include changing government policies and risks associated with legal contracts for debt and for the purchase of inputs and the marketing of outputs. Human sources of risk are often related to the labor and management functions of the firm. By contrast, financial risk relates to the farmers' ability to bear risks using liquidity (e.g., cash reserves), leverage (i.e., the proportion of the firm's assets financed with owner equity and debt obligations), leasing, and insurance as risk management tools (Barry and Baker, 1984).

Because switchgrass is a perennial crop, it only needs to be planted once in a lifespan of ten years or more. The potential factors that may influence the on-farm business and financial risks associated with perennial switchgrass production are outlined based on two key points in the lifecycle of the stand: 1) establishment (years 1-3) and 2) the annual harvest and storage of the crop.

Establishment (Years 1-3)

The first key stages of switchgrass establishment are seed germination, emergence, and development of the root system (Smart and Moser, 1999). Switchgrass can be difficult to establish because of seed dormancy, soil moisture and temperature conditions with spring planting, and weed competition (Rinehart, 2006). Particularly in upland varieties, freshly harvested seed have a high percentage of dormant seeds that can be reduced by properly aging the seeds for up to one year (Guretzky, 2007). Seedling growth is best at temperatures between 75°F and 85°F and thus is best established when soil conditions are warm and moist in the spring (Guretzky, 2007). Weeds such as crabgrass germinate more readily in cooler soils than can switchgrass and can provide serious competition during establishment (Rinehart, 2006). Thus, weed control during the establishment phase is critical. Effective herbicides to control weeds (particularly other grasses) in switchgrass have not yet been labeled for switchgrass. However, weeds may also be controlled in the establishment year by clipping them above the growing switchgrass to prevent seed production (Rinehart, 2006). Research has shown that expected switchgrass yields are similar across seeding rates but that low seeding rates may increase variability of yields during the establishment phase (Mooney *et al*., 2008). Weed control may be a more critical factor during establishment especially with lower seeding rates.

The University of Tennessee Biofuels Initiative contracted with 16 farmers to plant 723 acres of switchgrass in spring 2008 to supply feedstock to a pilot biorefinery scheduled to operational in 2009 (The University of Tennessee, 2008a). Of the total switchgrass area planted spring 2008, 164 acres (23 percent) were replanted in 2008 because of a lack of soil moisture for germination and emergence due to drought conditions (Garland, 2008). Soil moisture problems may have been particularly acute on soils where switchgrass was planted after winter wheat. University of Tennessee Extension personnel managing the project believe there is a possibility of replanting another 144 acres (20 percent) in 2009 because of establishment problems.

Typically, it takes three years for switchgrass to reach its full yield potential after establishment (Walsh, 2007). Mooney *et al*. (2008) reported that first- and second-year switchgrass yields across several landscapes and soil types in an experiment at Milan, TN, averaged 14- and 60-percent of third-year yields. Harvest can still be conducted in the first two years after establishment, though some experts recommend not harvesting the crop in the first year to allow more root establishment to take place (Walsh, 2007).

Farmers may be reluctant to grow switchgrass as a dedicated energy crop because of the upfront costs to establish the stand and the delay in the uncertain revenue stream from selling biomass to a biorefinery. As the planting of switchgrass is ramped up to meet the potential demand from biorefineries, seed prices may jump because of the time needed to expand seed stocks, further exacerbating establishment costs. Producers who have production contracts shorter than the lifespan of the stand may find themselves holding an asset that does not have value if the contract is not renewed. The market for switchgrass may be limited to bioenergy production though there may be limited uses of the crop as hay and pasture. Because the perennial switchgrass stand is a durable asset that lasts more than one year, it may be subject to technological risk in that newer, higher yielding varieties may be developed before the end of the useful life of the stand. The traditional uses of switchgrass have been for feeding cattle, anchoring soil, restoring grasslands, and providing wildlife habitat. Other more limited potential uses include a material for low quality fiber board, paper, and as a base for growing mushrooms. There is likely to be tremendous potential for variety improvement of switchgrass with traits geared toward producing ethanol (i.e., maximizing dry matter production and enhancing conversion-to-ethanol properties) rather than traditional uses.

Another potential source of risk is for farmers primarily dependent on leased land. Because switchgrass is a perennial that may be under contract for a number of years, and requires fewer inputs after establishment than many annual crops, landowners may opt to manage the switchgrass themselves using custom input application and harvest services. Thus, a potential reduction in land area that can be leased for other crop production may increase rents in a given area. Rising rents may potentially increase production costs for farmers not growing switchgrass. In addition, producers unable to rent as much land as they are accustomed to may not be able to spread their fixed costs over as large a crop area and thus may increase financial risks.

Harvest and Storage

For bioenergy production, the projected harvesting time for switchgrass is once in the fall after a killing freeze (Rinehart, 2006). After a freeze, nutrients move into the root system, minimizing the harvest of nutrients and their replacement, and maximizing the lignocellulosic material for conversion to ethanol. The coarse and fibrous switchgrass harvested after a killing freeze may increase repair and maintenance costs of equipment and reduce the lifespan of equipment compared with other forage-type materials. Reported yields of switchgrass vary between 1 and 16 tons per acre (Rinehart, 2006). With the large amount of biomass to be harvested, machine and labor time per unit of crop area will likely increase at an increasing rate for each additional ton harvested, thus machinery and labor costs will likely be higher for switchgrass (Cundiff, 1996). In addition, higher precipitation in the fall and winter months may limit field days and increase harvest times and biomass losses relative to other potential harvest periods (Hwang and Epplin, 2007).

The projected ethanol production capacity of a commercial sized biorefinery using lignocellulosic feedstocks is about 50 million gallons per year—half the size of a typical biorefinery that used corn grain as its feedstock (Port, 2005). A biorefinery of this size using switchgrass as a feedstock would require between 1,520 (90 gallon of ethanol per ton conversion rate) and 1,950 (70 gallons per ton conversion rate) tons per day of material to supply the plant. This translates into 554,800 to 711,750 tons of biomass to be processed per year. Assuming large rectangular bales placed in 32 foot high stacks, a storage yard of over 100 acres would be needed to store the annual production needs of a 50 million gallon per year plant (Womac and Hart, 2008). Given that switchgrass will likely be harvested only once-a-year and yields will vary from year-to-year because of weather, the logistics of storage and transportation of the feedstock will be critical.

The once-a-year harvest, coupled with the large area required to store switchgrass, will likely require storage of a substantial amount of biomass away from the plant on the farm. Precipitation and weathering may affect the quality and dry matter losses of bales delivered to the plant and thus the yield of ethanol from a ton of switchgrass (Wiselogel *et al*., 1996; Sanderson, Egg, and Wiselogel, 1997). In addition, the weight of bales transported to the biorefinery may be influenced by the level of exposure to precipitation while being stored on the farm. In a study by English, Larson, and Mooney (2008), uncovered round bales of switchgrass after 100 days of outside storage showed a 5 to 10 inch area of weathering along the bale's outer edge, and bale weights increased an average of 117 lbs/bale. Uncovered on-farm storage may increase transportation costs to the biorefinery as well, especially in areas that have high precipitation such as the southeastern and midsouth areas of the United States. Thus, a processor may require that stored bales be protected from precipitation and weathering. In addition, large numbers of switchgrass bales under storage may be a fire hazard and present liability issues for the farmer. Who pays for the on-farm protection and storage of the crop—the farmer or the biorefinery? All of the aforementioned issues affect risk and return, and thus the potential willingness and ability of farmers to produce switchgrass for bioenergy production.

Risk Management and Switchgrass Production

Potential Risk Management Benefits

Notwithstanding the potential risks of producing switchgrass, it may also provide some potential risk management and risk diversification benefits after the establishment phase. Switchgrass requires less water than most crops currently cultivated because of a deep and extensive root system (Bransby *et al*., 1989). Switchgrass requires about 25 inches or less of water per season, compared to 26 inches for corn and 39 inches for cotton (Brouwer and Heibloem, 1986; Stroup *et al*., 2003; Smith, 2007). Thus, switchgrass is more drought resistant than other crops (Bransby *et al*., 1989) and may provide higher yields than many annual crops in drought years. In wet springs when planting of annual crops may be difficult or impossible, switchgrass may reduce the probability of a crop failure due to weather because it is planted only once every 10 or more years. Switchgrass may tolerate very wet conditions during the growing season better than many annual crops and thus may provide higher yields. In addition, switchgrass requires less pesticides and fertilizers than most crops currently grown in the United States (Bransby *et al*., 1989; Rinehart, 2006). Nitrogen fertilizer requirements are generally less than for corn averaging 40 to 80 pounds of nitrogen to produce one acre of switchgrass compared with 100 to 200 pounds of nitrogen to produce an acre of corn grain.

Prior Risk Management Research

Several studies have evaluated the potential risk and returns to biomass crop production. Lowenberg-DeBoer and Cherney (1989) simulated yields, costs, and net revenues of switchgrass in Indiana based on weather, fertilizer, time of harvest, and a constant output price. They found that applying little or no nitrogen and harvesting the grass after maturity was the risk efficient management for switchgrass production.

Larson *et al*. (2005) developed a farm-level risk programming model based on yield and price variability to evaluate the ability and willingness of farmers to provide biomass feedstocks for a northwest Tennessee 2,400 acre grain farm. They found that the opportunity to diversify the farm crop enterprise mix through biomass production using a marketing contract by a processor may improve mean net revenues and reduce the variability of net revenues. The production of switchgrass provided positive risk management benefits to the farm while the production of wheat straw and corn stover did not. However, at the higher contract prices, additional labor resources would be needed by the representative farm to allow more production of biomass. Thus, a contract design might need to include provisions for harvesting and hauling services to be provided by the processor in addition to a guaranteed price.

Larson, English, and He (2008) and He, Larson, and English (2008) evaluated the risk management benefits of several potential contract types that could be used reduce the risk of switchgrass production. The four potential types of contracts analyzed in this study offer different levels of biomass price, yield, and production cost risk sharing between the representative farm and the processor. Results indicate that a contract price above the energy equivalent price in a spot market type contract would be needed to induce biomass production on the representative farm. A contract that makes annual payments based on the expected biomass yield over the life of the contract rather than on annual yield induced the largest amount of production (primarily switchgrass) under risk aversion. Because of the price and yield protection offered with this type of contract, biomass production was generally induced at lower contract prices.

United States Government Biomass Risk Management Programs

The recently-passed Food, Conservation and Energy Act of 2008 (U.S. Congress, House of Representatives, 2008) establishes a Biomass Crop Assistance Program (BCAP) to encourage farmers to produce annual or perennial biomass crops in areas around biomass processing plants. Producers can contract with the USDA to receive biomass crop payments of up to 75 percent of establishment costs during the first year. Subsequent annual payments then offset the so-called "lost opportunity costs" until the dedicated energy crops are fully established and begin to provide farmers with revenue. In addition, the BCAP program provides for cost-share payments up to $45 per dry ton for the harvest, storage, and transport of biomass crops to a processing plant. Eligible participants for the BCAP program include producers located within a "project area" defined as an economically viable distance from a biomass processing plant. Contracts with the BCAP program will run for five to ten years depending on the type of biomass crop grown. Producers will also be required to contract with a biomass-to-energy conversion facility to receive payments.

University of Tennessee Biofuels Initiative Risk Management Programs

The Governor of Tennessee signed legislation in 2007, establishing the Tennessee Biofuels Initiative (University of Tennessee, 2008a, 2008b). This initiative teams the University of Tennessee with an industrial partner to construct a lignocellulosic ethanol conversion research and commercial facility. The University of Tennessee partnered with Dupont Danisco to select a site near Vonore in East Tennessee south of Knoxville (The University of Tennessee, 2008b). The biorefinery will utilize corn stover and switchgrass as a feedstock. As part of the initiative, three-year contracts to grow switchgrass for the plant were offered to 16 farmers on 723 acres with a set payment of $450 per acre per year. To receive the full annual payments after harvest, farmers are required to follow and document a set of prescribed production practices. Farmers were given seed to partially offset the costs of establishing the switchgrass stand. In addition, to help farmers manage input price risk, budgeted energy costs were converted to diesel fuel equivalents and contract payments for switchgrass production were tied to the change in the diesel fuel price based on the last week of October 2007 U.S. Energy Information Agency published price levels. Farmers are responsible for harvest and on-farm bale handling and storage. The contract has the biorefinery being responsible for loading and hauling the switchgrass from the contractor's property to the biorefinery.

Case Study

The potential impacts of weather and input prices on the distribution of yields and production costs for switchgrass grown as a feedstock for energy production are explored in this section. In addition, the potential impacts that the 2008 Food, Conservation and Energy Act BCAP planting and harvest payments described previously may have on the distribution of production costs were evaluated.

Yields and production costs for two contrasting agricultural soils in Tennessee were used for the evaluation (USDA-NRCS, 2005). Loring soils are commonly found in West Tennessee and are moderately well drained with slopes ranging from 0 to 20 percent. Crops typically grown on Loring soils include corn, cotton, soybeans, and wheat. Dandridge soils are found in East Tennessee and are shallow, excessively drained, and have slopes ranging from 2 to 70 percent. Agricultural uses include pasture and hay for beef cow-calf production.

Methods and Data

Switchgrass production costs (SGC) include establishment expenses incurred in the first year of production and recurring annual costs for nutrients, pest control, and harvest and storage and can be modeled using:

(1) $$SGC_{i,j,t} = EST(DFP)_j + NIT(DFP_t,NFP_t) + HERB(NFP_t) + MOW(DFP_t)_j + RAKE(DFP_t)_j + BALE(DFP_t,SGY_{i,t})_j + STAGE(DFP_t,SGY_{i,t})_j + STORE(SGY_{i,t})_j + OTHER + RRL_i,$$

where i is soil type, j is switchgrass production incentive offered by the biomass processor, and t is production year; EST is switchgrass establishment expenses amortized either over the life of a contract to produce switchgrass or over the expected life of the stand ($/acre); NIT is nitrogen fertilization costs; MOW, RAKE, BALE, STAGE, and STORE are the labor, operating, and ownership costs of mowing, raking, baling, handling, and storing switchgrass ($/acre); OTHER are the other costs of production that do not vary with i, j, or t ($/acre); and RRL is the rental rate (opportunity cost) on land ($/acre). The variables assumed to be random in equation **(1)** were diesel fuel price (DFP, $/gal), nitrogen fertilizer price (NFP, $/lb), and switchgrass yields (ton/acre). After establishment, diesel fuel and nitrogen fertilizer are the two most costly inputs that would be purchased in each year of production. Higher yields increase field time per acre to harvest and handle switchgrass, thus increasing fuel, labor, and ownership costs.

A 100 year distribution of switchgrass production costs was simulated for each soil type using equation **(1)**. The variables treated as random in the simulation were switchgrass yield, nitrogen fertilizer price, diesel fuel price, and machine time for harvesting and handling switchgrass as a function of yield. The ALMANAC crop model (Kiniry *et al*., 1992) was used to generate random switchgrass yields for the Loring and Dandridge soils. A 100 year set of prices for nitrogen fertilizer and diesel fuel were simulated using the @Risk simulation model in Decision Tools (Palisade Corporation, 2007). Price data for estimating the nitrogen fertilizer and diesel fuel distribution parameters for @Risk were obtained using 1977 through 2005 prices reported in Agricultural Statistics (USDA-NASS, 1977 through 2007 Annual Issues). Prices were inflated to 2007 dollars by the Implicit Gross Domestic Product Price Deflator (Council of Economic Advisors, 2008) before estimating probability density function parameters using the Best Fit model in Decision Tools (Palisade Corporation, 2007).

Switchgrass production costs were estimated using budget parameters produced by The University of Tennessee Department of Agricultural Economics (Gerloff, 2008; Mooney *et al*., 2008; English, Larson, and Mooney, 2008). Establishment costs were amortized over an assumed contract period of five years and treated as an annualized cost in the simulation. Nitrogen fertilization was assumed constant at the Extension recommended level of 60 lb nitrogen/acre. The Extension budget only recommends that phosphorous and potassium be applied on deficient soils and thus it was assumed that none was applied in the simulation. Farmers were assumed to be responsible for harvest, which included all machinery, labor, and materials expenses for mowing, raking, baling, bale handling, and on-farm storage. The contract assumes the biorefinery was responsible for loading and hauling the switchgrass from the contractor's property to the biorefinery.

Mowing and raking costs remained constant on a per-acre basis for all yield levels in the simulation. Machine and labor time and twine for the baling and handling operations were assumed to be a function of yield. To accomplish this, the capacity of the large round baler was assumed to be 5.5 tons per hour (i.e., one hour of machine time with a 5.5 ton yield). Bale handling also was assumed to operate at a rate of 6 tons per hour (Mooney *et al*. 2008). Bales were assumed to be stored under a tarp on a gravel pad. Materials and labor costs to construct the pad and annual labor and other costs to affix the tarp to the bales annually were from English, Larson, and Mooney (2008). Gravel pad and tarp costs were based on the largest expected yield over the simulation for each soil type. The useful lives of the tarp and pad with no salvage value were assumed to be five years, the same length as the contract for switchgrass. Land rental (opportunity) costs assumed were $68/acre for crop land (Loring soil) and $20/acre for pasture land (Dandridge soil) (Tennessee Department of Agriculture, 2008).

The effects of University of Tennessee Biofuels Initiative and BCAP type planting and harvest incentives on switchgrass production costs were evaluated for each soil type. The three incentive scenarios evaluated were: 1) no incentives, 2) an establishment incentive to reduce planting costs, 3) a harvest incentive to reduce harvest, handling, and storage costs, and 4) a combination of the establishment and harvest incentive. For the planting incentive, total budgeted machinery, materials, and labor costs for planting were reduced by up to 75 percent and amortized over the assumed contract period of five years. For the harvest incentive, the estimated on-farm harvest, handling, and storage costs were reduced by up to a maximum of $30/ton in the simulation. If harvest and handling costs were less than $30/ton, the lower cost was used to calculate the amount of cost reduction with the incentive. The harvest incentive scenario assumes that $15/ton of the subsidy would be allocated to the transport of bales from the farm to the biorefinery.

Results and Discussion

On the East Tennessee Dandridge soil, switchgrass yields averaged 5.7 tons/acre and varied between 2 and 11.2 tons (Table 1). By comparison, yields averaged 9.1 tons/acre and varied between 1.7 and 15.6 tons on the more productive West Tennessee Loring soil (Table 1). There was a 39 percent chance that yields on the Dandridge soil would be 5 tons/acre or less compared with a 25 percent probability on the Loring soils (Figure 1). Results indicated that switchgrass production was more risky because of a higher frequency of low yields on the Dandridge soil when compared with the Loring soil.

Assuming no production incentives, total switchgrass production costs per acre were lower on the East Tennessee Dandridge soil than on the West Tennessee Loring soil. On the Dandridge soil, total production costs averaged $389/acre and ranged from $288/acre to $562/acre (Table 1). By comparison, the average cost of producing switchgrass on the Loring soil was 26 percent more at $523/acre. About two-thirds of total costs for each soil type came from harvest, handling, and storage activities (Table 1). Larger harvest costs because of higher yields coupled with a higher opportunity cost on land contributed to higher production costs on a land-area basis for the Loring soil. Notwithstanding the lower total costs on a land-area basis, the average cost per ton was higher on the Dandridge soil than on the Loring soil. Dandridge soil production costs averaged $75/ton and varied between $45/ton and $150/ton (Table 1). By contrast, Loring soil production costs averaged $71/ton and

Table 1. Simulated Switchgrass Yields and Production Costs for Two Contrasting Tennessee Soils Assuming No Production Incentives

Soil Type	Unit	Mean	Standard Deviation	Minimum	Maximum
Loring:					
Yield	tons/acre	9.1	3.9	1.7	15.6
Harvest Cost[a]	$/acre	345	103	159	527
Total Cost	$/acre	523	104	338	711
	$/ton	71	34	43	203
Dandridge:					
Yield	tons/acre	5.7	2.1	2.0	11.2
Harvest Cost[a]	$/acre	260	57	161	424
Total Cost	$/acre	389	58	288	562
	$/ton	75	23	45	150

[a]Mowing, raking, baling, handling, and storage machinery, materials, and labor costs

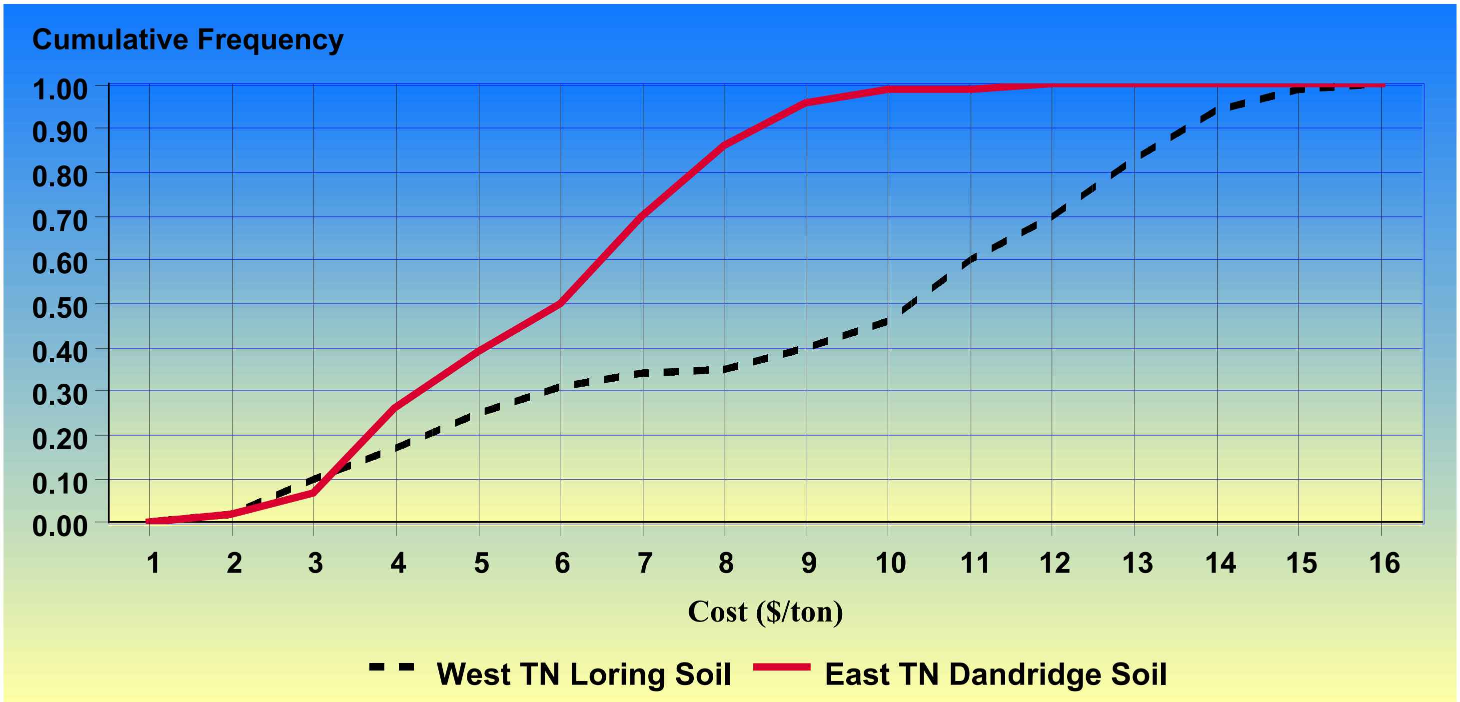

Figure 1. Probability Distribution of Yields for Switchgrass Grown as a Dedicated Energy Crop for Two Contrasting Tennessee Soils

fluctuated between $43/ton and $203/ton (Table 1). For production costs less than $100/ton, the Loring soil had a higher probability of producing a lower per ton cost than the Dandridge soil (Figure 2). For example, the frequency of total production costs being $60/ton or less was 64 percent for the Loring soil compared with only 32 percent for the Dandridge soil (Figure 2).

The distribution of production costs for each soil type also can be used to evaluate the frequency of positive net revenues for a given switchgrass price that might be paid by

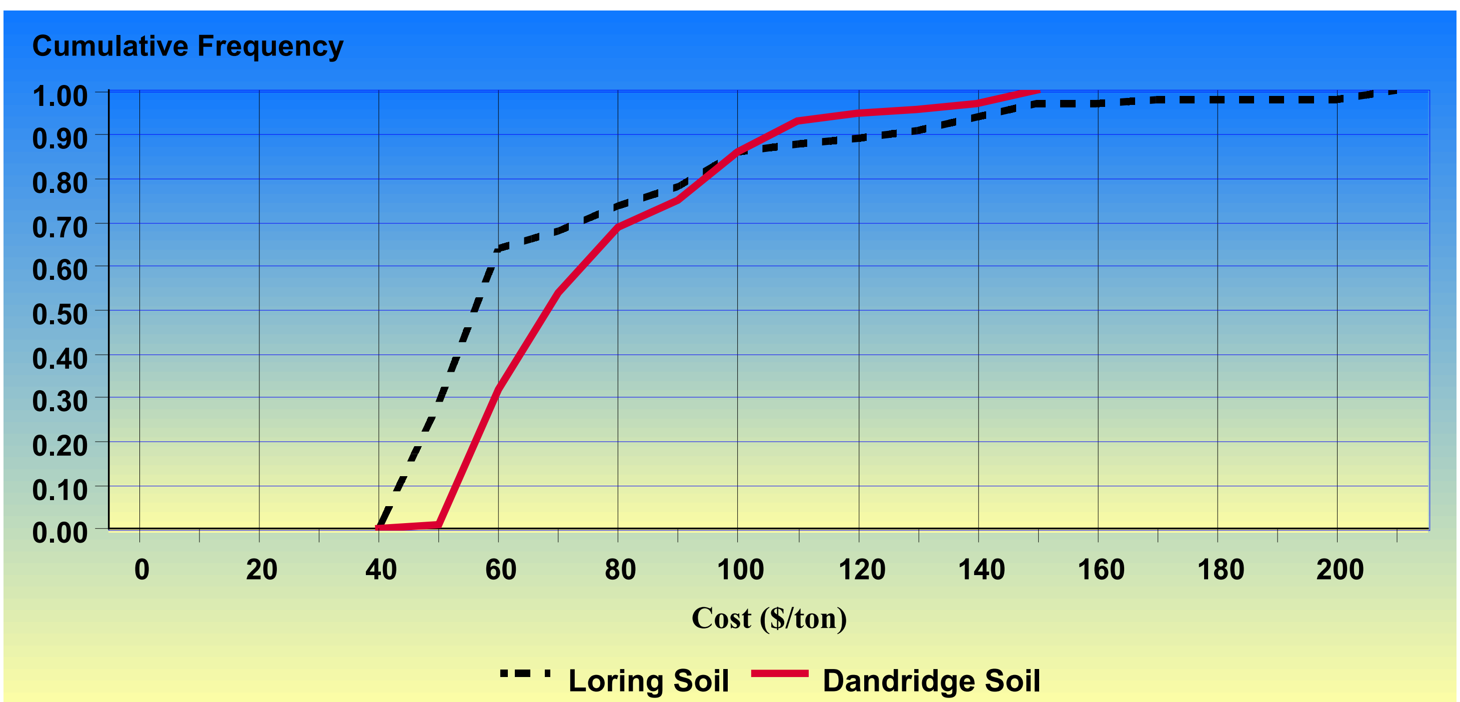

Figure 2. Probability Distribution of Total Production Costs ($/ton) for Switchgrass Grown on Two Contrasting Tennessee Soils Assuming No Production Incentives

the biorefinery to a farmer. For example, the frequency of net revenues greater than zero is 64 percent for the Loring soil but only 32 percent for the Dandridge Soil at a $60/ton biomass price. Generally larger yields over which to spread production costs contributed to the higher frequency of a lower cost per ton of producing switchgrass on the more productive Loring soil. The results suggest that production costs per ton are lower and the frequency of a positive net revenue for a given switchgrass price might be higher in West Tennessee than in East Tennessee.

The 75 percent cost share for establishing switchgrass reduced mean production costs by 12 percent to $62/ton on the Loring soil and 14 percent to $64/ton on the Dandridge soil (not shown). The $30/ton harvest payment had a larger impact on production costs than the planting establishment payment. The $30/ton harvest cost share reduced mean production costs by 43 percent to $41/ton on the Loring soil and 40 percent to $45/ton on the Dandridge soil (not shown). With both payments, the chance of achieving a production cost of $60/ton or less increased from 64 percent to 87 percent on the Loring soil (Figure 3). The impact of the establishment and harvest payments on the frequency of obtaining production costs of $60/ton or less was greater on the Dandridge soil, jumping from 32 percent to 91 percent (Figure 4). Results indicate that the planting establishment and harvest cost share payments had a larger impact on the frequency of attaining lower production costs on the more marginal East Tennessee Dandridge soil than on the more productive West Tennessee Loring soil.

Summary and Conclusions

This paper evaluated some of the potential on-farm business and financial risks that may be associated with producing switchgrass as a dedicated bioenergy crop. The potential sources of risk based on the growth and development characteristics of perennial switchgrass and weather were identified. Difficulties in establishing the switchgrass stand and low yields the first three years after establishment and the harvest, storage, and transportation of feedstocks as affected by weather presents significant risk management challenges for both farmers and processors.

A simulation case study evaluated the potential impact that weather and input-price risk might have on the distributions of production costs for switchgrass on two contrasting Tennessee soil types. The Loring soil is located in West Tennessee and is more productive than the Dandridge soil in East Tennessee. In addition, the impacts of the Biomass Crop Assistance Program (BCAP) risk management tools specified in the Food, Conservation, and Energy Act of 2008 on the distribution of switchgrass net revenues for the two soil types were evaluated.

Results indicated that switchgrass production was more risky on the Dandridge soil because of a higher frequency of low yields. Generally smaller yields over which to spread production costs contributed to the lower probability of

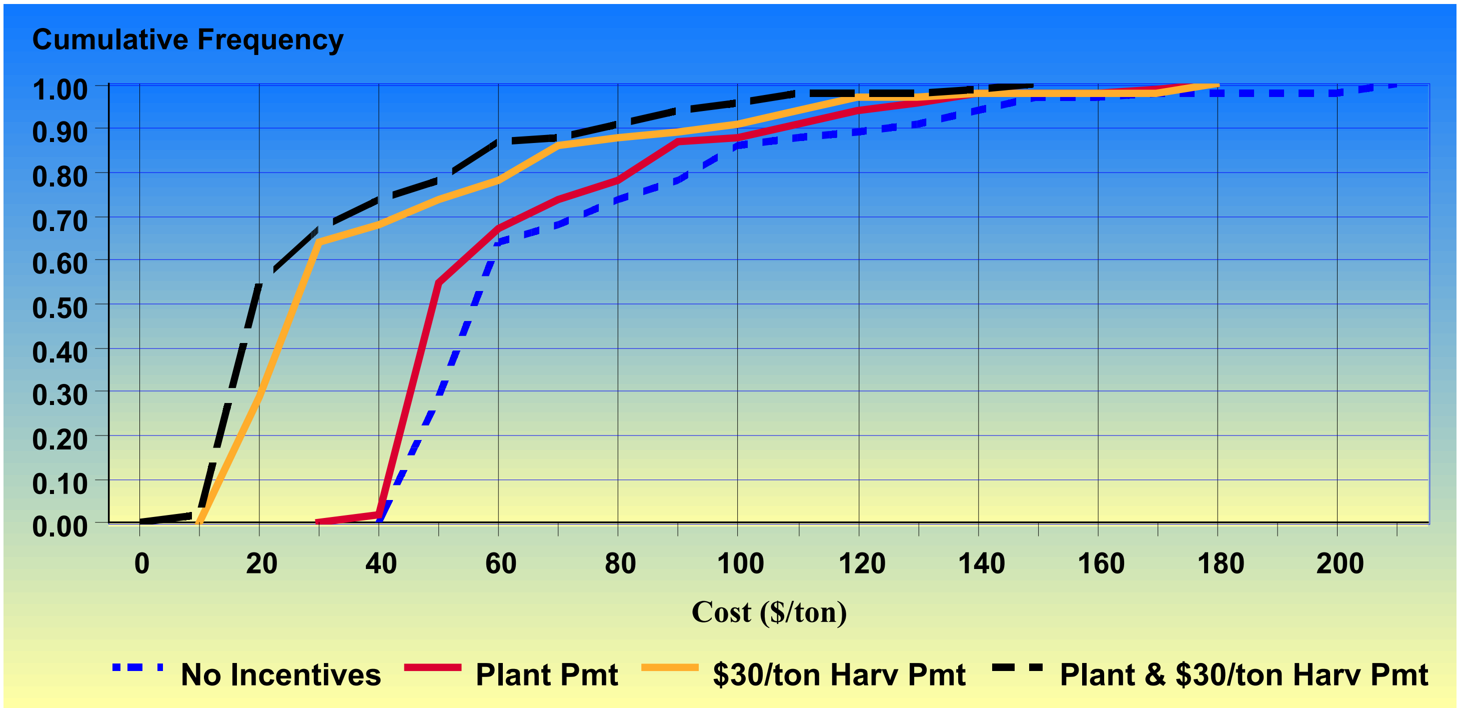

Figure 3. Probability Distributions of Production Costs for Switchgrass Grown on a West Tennessing Loring Soil Assuming No Cost Incentives (No Incentive), a Switchgrass Establishment Cost Incentive (Plant Pmt), a Switchgrass Harvest Cost Incentive ($30/ton Harv Pmt), and an Establishment and Harvest Cost Incentive ($30/ton Plant & Harvest Pmt)

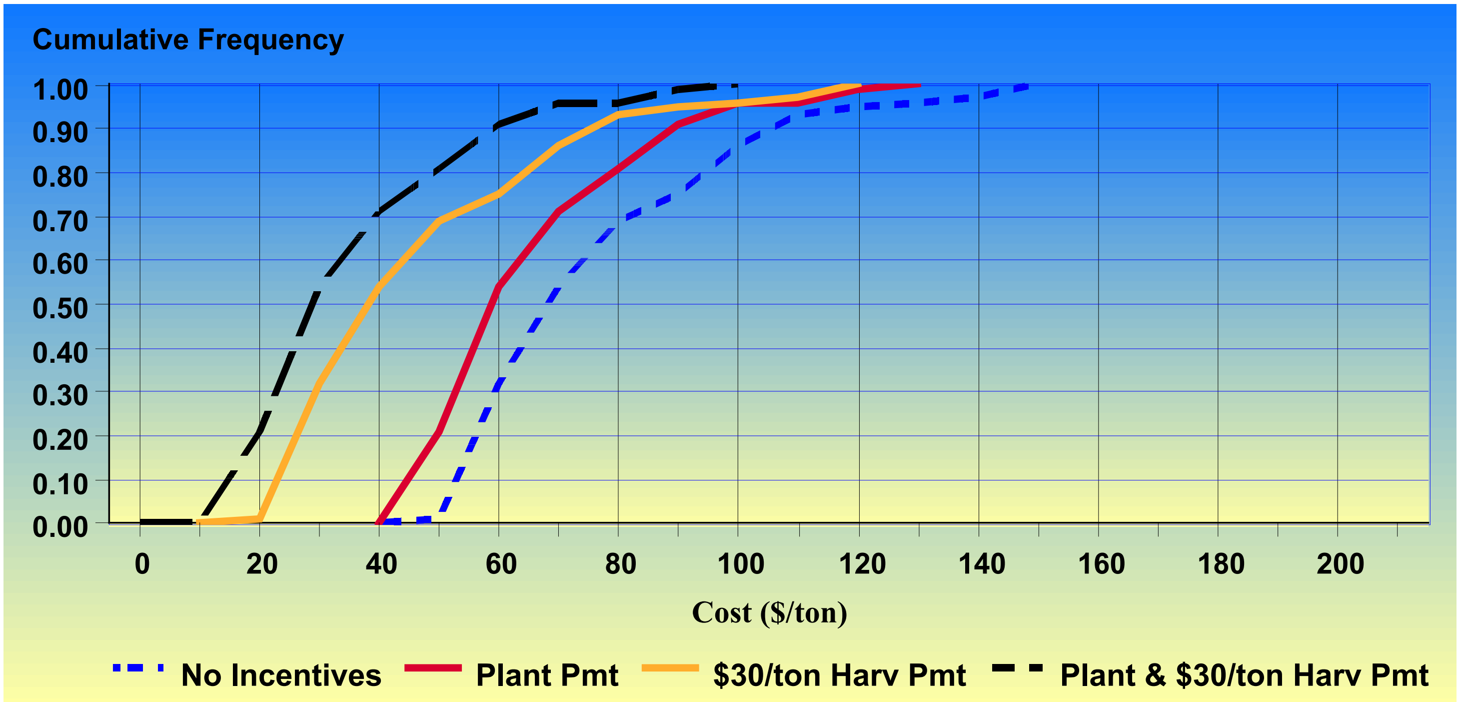

Figure 4. Probability Distributions of Production Costs for Switchgrass Grown on an East Tennessing Dandridge Soil Assuming No Cost Incentives (No Incentive), a Switchgrass Establishment Cost Incentive (Plant Pmt), a Switchgrass Harvest Cost Incentive ($30/ton Harv Pmt), and an Establishment and Harvest Cost Incentive ($30/ton Plant & Harvest Pmt)

having a lower cost per ton on the more marginal Dandridge soil relative to the Loring soil. Thus, for a given switchgrass price, the probability of a positive net revenue might be higher for the Loring Soil because of lower production costs per ton than for the Dandridge soil. In addition, the BCAP planting establishment and harvest cost share payments had a larger impact on frequency of attaining lower production costs on the more marginal Dandridge soil than on the more productive Loring soil. Thus, policymakers and other decision makers may want to target BCAP payments to more marginal lands to maximize the potential soil erosion, water quality, and other benefits of growing switchgrass.

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Policy Risk for the Biofuels Industry

Wyatt Thompson, Seth Meyer, and Pat Westhoff[1]

Policy Risk for the Biofuels Industry

Risk is by no means new to participants in agricultural markets. Commodity producers have long recognized the importance of output and input price variability, and many exploit futures markets to reduce risk – a tool available to agricultural commodity buyers, as well. Price risks are also addressed by agricultural programs that are designed to pay more as prices fall relative to some benchmark level, such as the marketing loan program, counter-cyclical payments, and insurance programs tied to revenue or price.

Booming biofuel use of selected agricultural commodities as feedstocks has introduced a new element of risk. While many observers debate the contribution of biofuels to rising price levels, the potential that biofuel demand for agricultural commodities introduces a new source of price variability should not be lost. Nor should these risks be viewed too narrowly. Biofuel policy represents a critical source of risk. The new links between motor fuel and agricultural commodity markets must be seen through the prism of subsidies to biofuels, policies that mandate minimum levels of use, and tariffs that reduce imports. New and rapidly evolving energy policy defies easy understanding. Policy changes outpace implementing rules, leaving market participants uncertain about the exact form these policy mechanisms will take. Thus, critical uncertainties about even the current marketing year are not yet resolved.

In this paper, we delineate some of the key policy risks for the biofuel industry. Our objective is to demonstrate how biofuel policies can affect markets in the near- and medium-term future. The assessment is informed by discussions with administration officials in the Environmental Protection Agency, the Departments of Energy and Agriculture, and elsewhere, but is fundamentally our own and follows closely the text of the law and the rules of implementation set out for an earlier version of biofuel policies. Finally, we represent biofuel policies in a large-scale structural model of agricultural commodity and biofuel markets to test how these policies affect markets.

New Links

The petroleum price is a key source of uncertainty for the biofuel sector. This price has long been a source of uncertainty, but recent price increases have occurred at such a pace that projections of the petroleum price have been outpaced time and time again.

The motor fuel market represents a link between petroleum and agricultural markets that was not pronounced in the past. But growing ethanol use led to a new and possibly much more elastic demand for corn in the United States (Tyner, 2007). Focusing on ethanol, the relationship between gasoline and ethanol prices has not been historically stable (Figure 1). The 2006 spurt in ethanol demand led to a high ethanol price relative to the gasoline price (Westhoff *et al*., 2007). But the potential for the price premium seems to be exhausted (De Gorter and Just, 2007, p.15). Recent events reflect expectations that the marginal consumers will opt to buy based on energy content. If judged based on current futures of wholesale prices (namely the refiner's price of the gasoline input to retail fuels and the Omaha rack price of ethanol), the ratio of ethanol-to-gasoline price ranges from 70 to 80 percent. To consider the consumer's perspective, however, requires adjustments for margins, taxes, and tax credits. Assuming the margins are the same and using a simple average of state taxes for different fuels, the implied ratio of ethanol retail price to gasoline retail price in current futures markets ranges from 65-72 percent. This ratio is quite close to the energy content of ethanol relative to an equal volume of gasoline.

There are two lessons relevant here. First, the pricing of ethanol and gasoline must reflect their new relationship as

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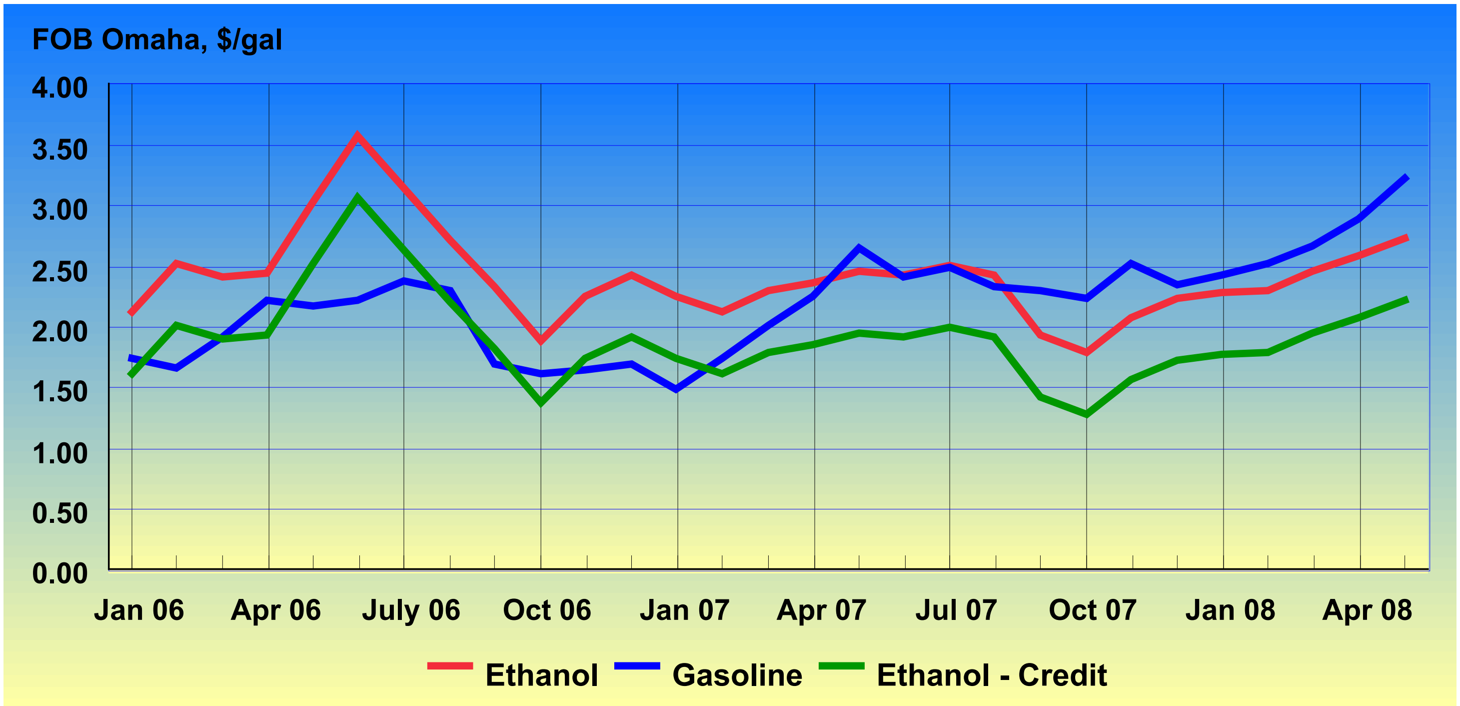

Figure 1. Gasoline and Ethanol Prices

Sources: Nebraska Ethanol Board; Nebraska Energy Office (prices)

substitutes, leading to certain expectations about how demand evolves. Current events suggest that the additive use market is saturated and further expansion in ethanol use will be as a substitute to gasoline. Sharply higher petroleum prices are expected to lead to higher ethanol prices through biofuel demand and, consequently, to more purchases of biofuel feedstocks. Second, assessment of risks based on past relationships alone may be betrayed by changing circumstances. For example, forward-looking analysis that perpetuated the price premium allotted ethanol historically for its role as an additive might mislead. Rapidly expanding biofuel markets have generated new patterns of interaction.

New and changing U.S. biofuel policies may similarly lead to new patterns of interaction. Next, federal biofuel policies are defined to set the stage for assessing how these policies affect markets.

Tax Credits and Tariffs

Federal biofuel policies include tax credits for biofuel use and a tariff on ethanol imports. The ethanol tax credit is $0.51 per gallon of ethanol. For biodiesel, the tax credit amounts to $1.00 per gallon of biodiesel made of virgin oil and half that or $0.50 for biodiesel made of recycled oil. The tax credit is provided to fuel blenders, agents who buy processed fuel inputs and mix them into retail fuels to sell to retailers, based on the amount of biofuels they use. Traders must pay a tariff on ethanol imports that are not within the scope of any preferential arrangement. Set to expire in 2008, The Food, Conservation, and Energy Act of 2008 (U.S. Congress, 2008), enacted in June 2008, extended the tariff through 2010. The tax credit currently set to $0.51 per gallon will likely decrease to $0.45 per gallon for 2009 and 2010, and then it is scheduled to expire (The Food, Conservation, and Energy Act of 2008).

These policies are fairly straightforward and have been in operation for some time. As such, the remaining discussion of federal policies focuses on the mandates, including some speculation about how they will operate. This background sets the stage for analyzing the market price effects of these policies.

Mandates Defined

The Energy Independence and Security Act (EISA) of 2007 (U.S. Congress, 2007) amended the Renewable Fuel Standard (RFS) mandating biofuel use that was first introduced in the Energy Policy Act of 2005. The new RFS is a hierarchy of mandates (Figure 2). The potential market effects of these mandates are sensitive to context, as discussed later, but also on how they are implemented. In this paper, some care is taken to explain one set of expectations regarding how these mandates will operate.

These mandates are not so readily disaggregated as Figure 2 might lead one to believe. The overall RFS can be met by any biofuel that meets any of the categories, plus other biofuels that meet a lower threshold. Likewise, the sub-mandate for advanced biofuel has two sub-mandates of its own, namely for biodiesel and for biofuels based on cellulosic or agricultural waste feedstocks. The overlap means that the "other advanced" is the amount by which the advanced biofuel man-

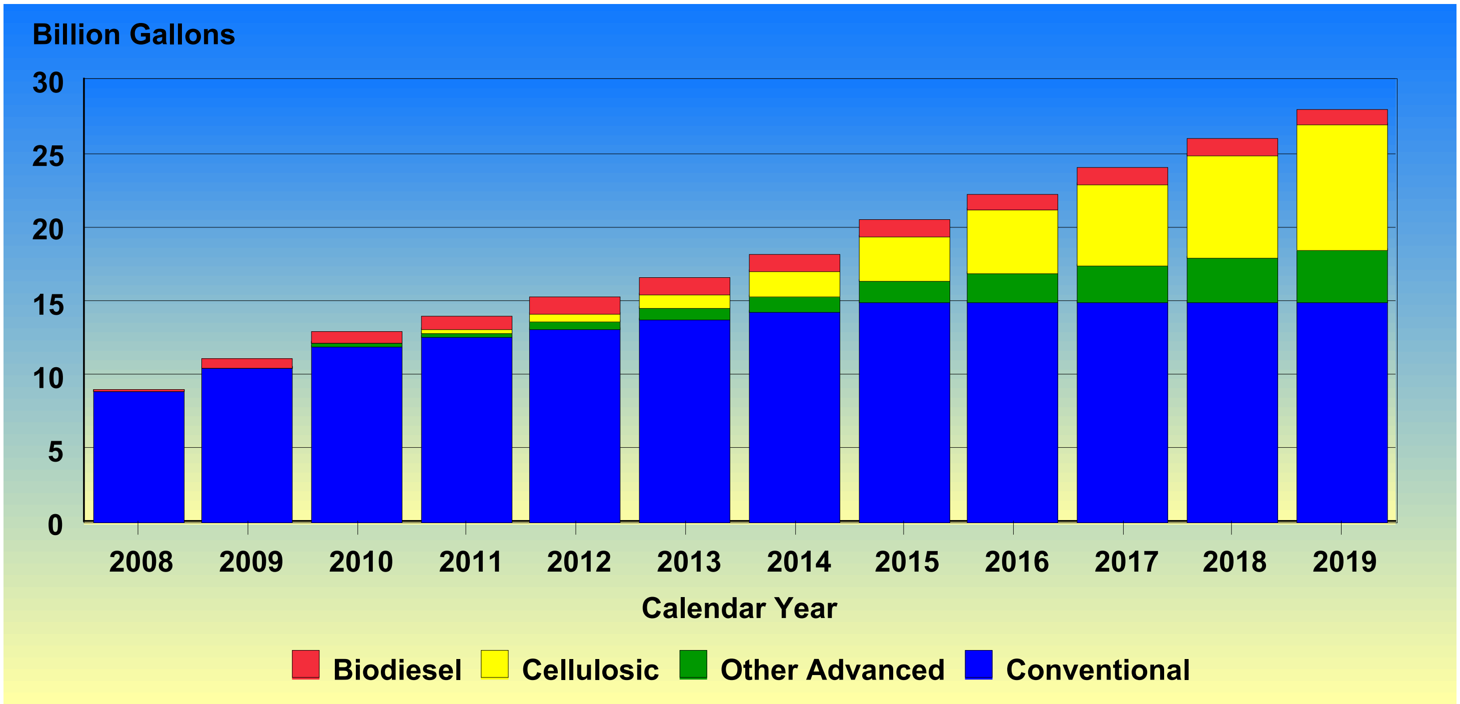

Figure 2. Renewable Fuel Standards of the Energy Independence and Security Act
Source: Energy Independence Security Act of 2007. Note that this graph implies that there are explicit mandates for "conventional" and "other advanced" biofuels, but there are not. These two categories are the remainders of the total and advanced mandates after taking sub-mandates into account, as described in the text.

date that exceeds these two sub-mandates. But if either one of the sub-mandates is surpassed, then there need be less other advanced biofuel. Likewise, the part of the RFS that is not advanced, often called "non-advanced" or "conventional", could be met entirely by advanced biofuels, at least theoretically. The reverse is not true. No conventional biofuel, no matter how abundant, can count against the advanced biofuel mandate, let alone the cellulosic biofuel mandate.

The numbers of the RFS are unlikely to map to exact requirements in any particular year. First, not all fuels are equal, and a gallon of certain biofuels is likely to count as more than one gallon towards the mandate based on the "equivalence value". The EISA introduces a separate mandates for different biofuels differentiated by feedstock. (A biofuel must also meet certain lifecycle greenhouse gas emission reduction targets, with the least stringent requirements for the overall RFS and, hence, for conventional fuels.) These sub-mandates presumably replace the equivalence value system that was used under previous law to add up units of fuel based on differing feedstocks. But that does not remove the problem of comparing units of fuel themselves. The rules to implement the law are expected to continue to use equivalence values so that each unit of biofuel is put on an ethanol basis based on its energy content relative to ethanol. If a biofuel has more energy as compared to ethanol, then it will count more towards the RFS. Biodiesel is likely to have an equivalence value of 1.5 or perhaps more.

There are automatic and discretionary mechanisms for mandate flexibility. The EISA makes room for waivers under conditions that outline in very broad terms what criteria to use. In the event that a sub-mandate is waived, then the broader mandate may also be decreased. For example, a waiver of cellulosic biofuel need not require an offsetting increase in other advanced biofuels. The consequences of a waiver vary by mandate, but may include setting a new and lower mandate or, in the case of cellulosic biofuel, paying a subsidy per unit. (In the analysis below, the cellulosic biofuel mandate is assumed to be waived. As required in the EISA, the waiver leads to a subsidy per gallon of cellulosic biofuel used.) Even without an official waiver, the part of the burden that applies in a particular year may be shifted somewhat forward and backward. Deficits in meeting the mandate on an individual basis are likely to be permitted, but with the provision that the agent makes good on the deficit plus full mandate in the next period. Rollover provisions will likely permit up to 20 percent of one year's mandate to be met by biofuels used in the previous year, provided they were not already counted against the earlier year's mandate.

Mandate Operation

The first incidence of the RFS is on fuel blenders. These agents buy input base fuels, including gasoline that is refined but not yet ready for retail and ethanol, and then sell the mixed fuels to retailers. If judged based on the implementing rules written for its predecessor, then each blender will be responsible to meet the share of the EISA mandates that is determined based on that blender's share of total motor fuel, with certain exceptions. In general, each blender will have to show that its share of the national RFS for each biofuel type has been met.

The mechanism for proving biofuel use will be the Renewable Identification Number (RIN). Each RIN corresponds to a gallon of biofuel[2]. Biofuel makers generate a RIN for each gallon they produce that qualifies to count towards a mandate. In proving that the biofuel qualifies, the determination will also be made as to what level of RFS could be met with the RIN based on the feedstock and the greenhouse gas emission threshold. RINs can be traded independently of the biofuel, and already are. Thus, a blender who does not use any biofuels at all can meet its share of mandates through purchased RINs. Conversely, a blender who uses much more than its share of mandates may find that its profitability is increased by selling extra RINs to competing blenders who chase RINs in order to meet their own share of the mandates. Because blenders can trade RINs, the mandates will be binding or not binding nationally. Local conditions may only determine if the area is a net buyer or seller of RINs.

The hierarchical nature of the mandates necessarily generates a hierarchy in the values of RINs. A sub-mandate can be binding even when a broader mandate is not. For example, the biodiesel mandate may be binding even though the advanced biofuel mandate is met at market prices through some combination of qualified biofuels. In this case, RINs that meet the biodiesel mandate will take on a value that exceeds the value of RINs that meet the advanced biofuel mandate. Similarly, even should the advanced biofuel mandate become binding, the overall mandate may not be binding, in which case the price of RINs that meet the advanced biofuel mandate are bid higher, whereas the price of RINs that meet the overall mandate would not. The converse is not true. A RIN that counts towards a broad mandate but fails to meet the criteria of a sub-mandate only counts towards the broader mandate, so its value may be lower than RINs that can be used for sub-mandates. Thus, the price of RINs that can count towards a sub-mandate necessarily also count towards the broader mandate, so its value will never be less than the price of RINs that meet a lower threshold and count only towards a broader standard, but the price of sub-mandate RINs could be higher.

Policy Risks

Policies change. The new Farm Bill lowers the tax credit that blenders receive per unit of biofuel throughput and extends the tariff on ethanol imports to 2010. Only shortly after the rules to implement the first RFS were disseminated and before the initial levels of the RFS rose very much at all, Congress passed a law to change those minimum targets and the President signed this law. Here, the consequences of the mandates, tax credit, and tariff are explored to highlight how policy changes could influence market outcomes.

The basis of the analysis is a large-scale structural model of agricultural and biofuel markets. Biofuel policies are represented based on how they affect the incentives of market participants, as described elsewhere (FAPRI-MU, 2008b). The context matters, as different conditioning factors may increase the likelihood that the mandates are binding. This assessment benefits from being (1) forward looking and (2) partially stochastic. Both characteristics differentiate this analysis from, for example, Tyner and Taheripour (2008) who consider variations in the exogenous petroleum price over fixed intervals for 2006 base data and De Gorter and Just (2007) who consider the cases of 2006 and 2015 with less formal investigation into changing context. In contrast, this analysis projects market indicators on an annual basis for the next ten years, taking into account short-term fixed factors and adjustment processes, and key exogenous data are varied over ranges determined based on historical variations. This latter element, the partial stochastic simulation process, allows for variations in yields, both trend and year-to-year shocks, key demands, and other variables, including the petroleum price. As a consequence of 10-years of annual data and 500 simulations for varying conditioning factors, the simulation process generates 5,000 observations for each price and quantity, as well as other output such as consumer and government costs.

The elimination of each policy and all policies relative to the baseline that assumes they are continued for the next 10 years can result in large decreases in the ethanol price (Figure 3). Relative to the FAPRI-MU baseline created in early 2008, and based on a much lower petroleum price than recent events warrant, the elimination of the EISA mandates would cause the ethanol price to be 10-15 percent lower, eliminating the tax credit would lead to a reduction of less than 5 percent in the ethanol price, and the tariff elimination would result in a 5 percent lower ethanol price. Removing all three would lead to a 30 percent decline in ethanol prices. A key lesson from these results is that the policy effects may overlap. In the case that the EISA mandates are broadly binding, then eliminating the tax credit, a policy change that would normally decrease the willingness of blenders to push through more biofuels, shifts the burden of costs from taxpayers to consumers with little or no effect on quantities.

The degree to which the mandate is binding is highly situation-specific. The higher petroleum price, observed since the beginning of 2008, has caused increased gasoline prices and, consequently, an increase in consumer willingness to buy substitute biofuels. This event decreases the likelihood

[2]Technically, RINs are issued per batch of production or imports. The digits of the RIN are coded to specify the volume, as well as other characteristics, of the batch of biofuel with which they are associated.

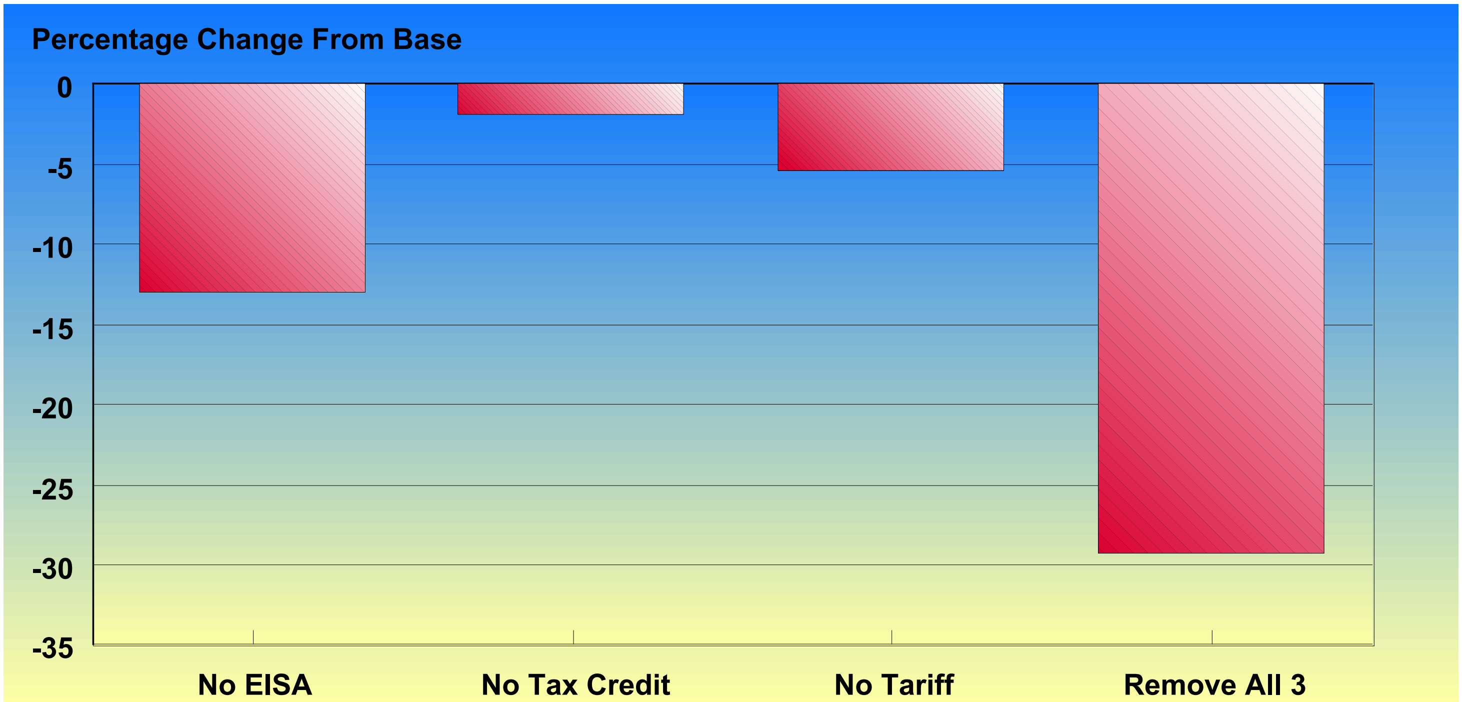

Figure 3. Effect of Removing Biofuel Policies on the Ethanol Price, 2011-2017 Average
Source: FAPRI-MU, 2008a.

that the mandates will be binding. Even more recently, Midwest flooding that may jeopardize the corn crop in some areas caused sharp increases in corn and other agricultural commodity prices. Higher corn prices that decrease the supply of ethanol increase the likelihood that the overall mandate will be binding. The stochastic output can be disaggregated based on the petroleum price to consider the first of these two changes in context. Whereas the overall average 2008-2017 petroleum price in the baseline assumptions is $67 per barrel, the average of the 10 percent highest price series is $107. While well short of current futures prices, which average $130-140 at the time of writing, the $40 difference suffices to highlight the how critical the surrounding conditions are when assessing the effects of the mandates (FAPRI-MU, 2008a).

The risks of policy changes for the biofuel sector vary substantially depending on whether or not mandates are binding (Figure 4). If all policies were removed and the oil price was $67 per barrel, then ethanol production would average 8.9 billion gallons from 2011 to 2017, as opposed to almost 15.6 billion gallons with policies in place. Under the conditions with the higher petroleum price of $107 per barrel, ethanol production would be 17.6 billion gallons with the support and would decrease to 13.1 billion gallons without support. The difference is largely explained by the EISA mandates. The elimination of EISA mandates hardly matters if the petroleum price is high because the mandates are rarely binding, whereas the elimination of EISA mandates explains most of the change if petroleum prices are low because the mandates would likely be binding.

The RIN value is a key indicator of the degree to which a mandate is binding, if at all. As biofuel market participants consider risks from policy changes or from different external conditions, the RIN value must be a key consideration. Even if a mandate is binding and quantities do not change, the RIN value will change first and most for a change in policy or setting. If positive and large, then RIN value would be a key element of profit or cost for blenders, depending if they buy or sell RINs, and would play a critical part in determining the price that blenders are willing to pay for biofuels.

The RIN values will vary inversely with petroleum prices if they are positive and are more likely to be positive as petroleum prices fall (Figure 5). The “core RIN value” is defined as the price gap between the wholesale price at which blenders buy biofuels that meet the corresponding mandate and the wholesale-equivalent of the retail price at which they sell that biofuel on to retailers. That is to say, the core RIN value is the degree to which the mandate is binding and excludes speculative value about the potential to rollover the RIN into the subsequent year and all transaction costs.

Stochastic analysis generates a range of possible RIN values. As EISA mandates grow over time (Figure 2), the degree to which a mandate may be binding is likely to increase over time (Figure 6). The price of the RIN per gallon of biodiesel was expected to be the highest of the three estimated here based on FAPRI baseline assumptions as to ranges of petroleum prices, corn yields, and other variables. The advanced RIN value must necessarily be lower than the biodiesel RIN

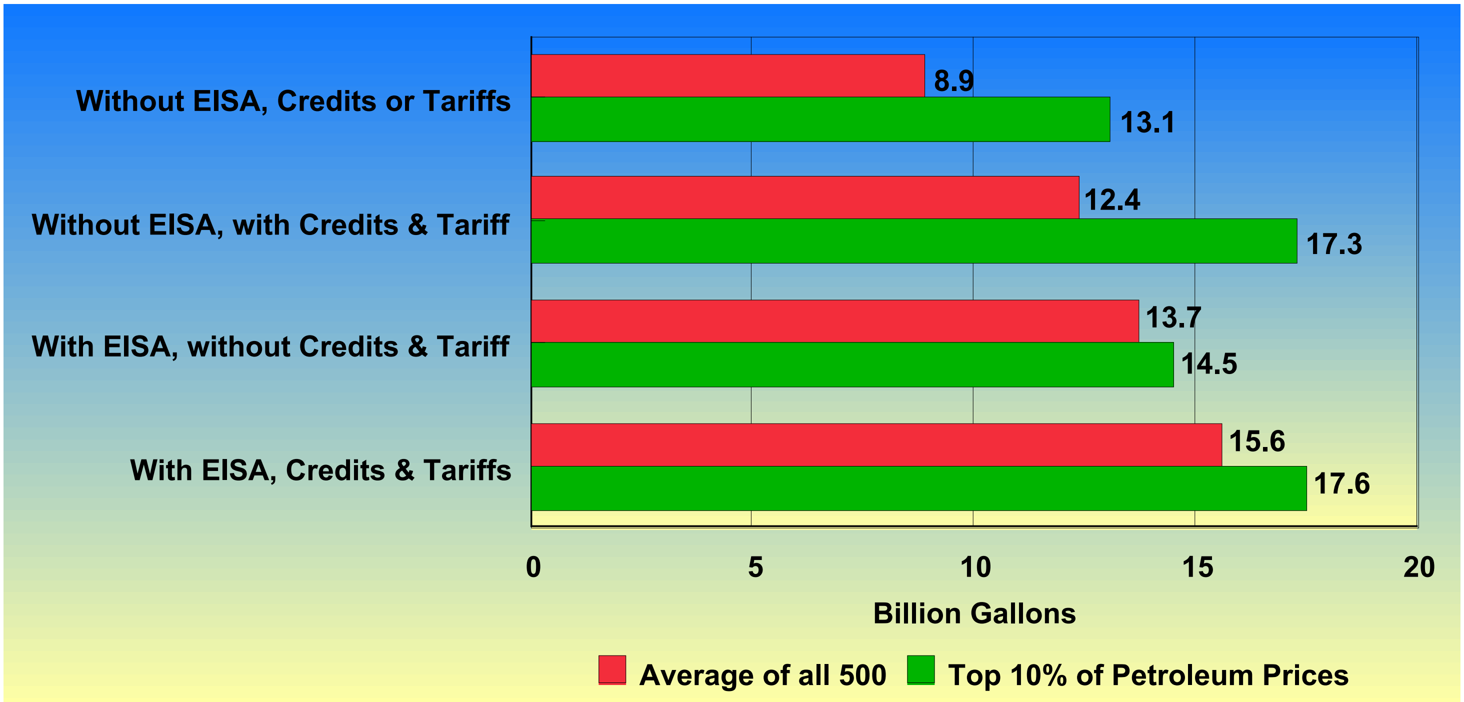

Figure 4. Effect of Removing Biofuel Policies on the Ethanol Production, 2011-2017 Average
Source: FAPRI-MU, 2008a.

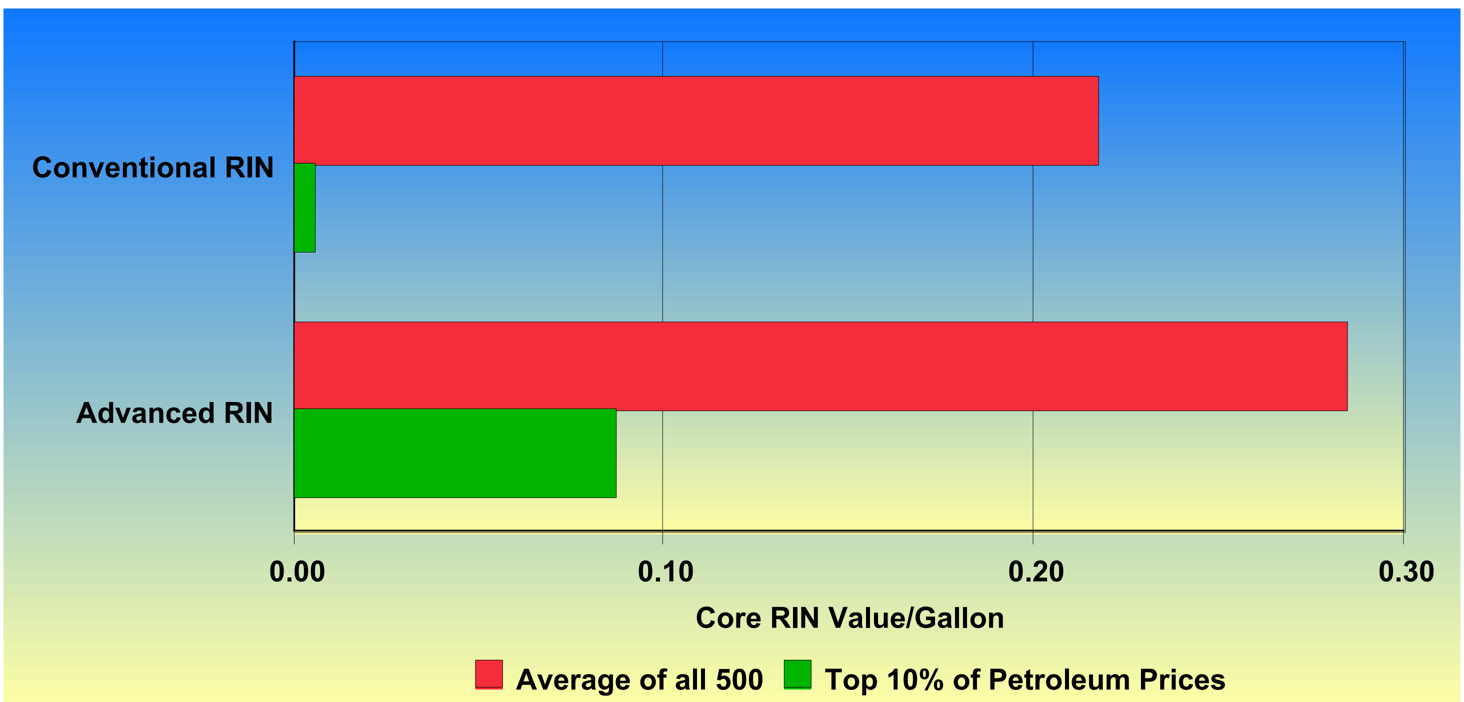

Figure 5. Core RIN Values, 2011-2017 Average.

value because of its position in the mandate hierarchy (and towards which biodiesel counts extra according to its equivalence value). This RIN value is also estimated to tend to be positive after 10-years based on these assumptions. Under the baseline assumptions about petroleum prices and corn yields, RINs that count towards the overall mandate are likely to take only a smaller value per gallon. If the petroleum price were higher, then the RIN values would be lower. In this case, the greater consumer willingness to buy biofuels implies that the mandates tend to be less binding.

Summary

The short-run limits to supply and demand responses to changing biofuel market conditions in the form of large in-

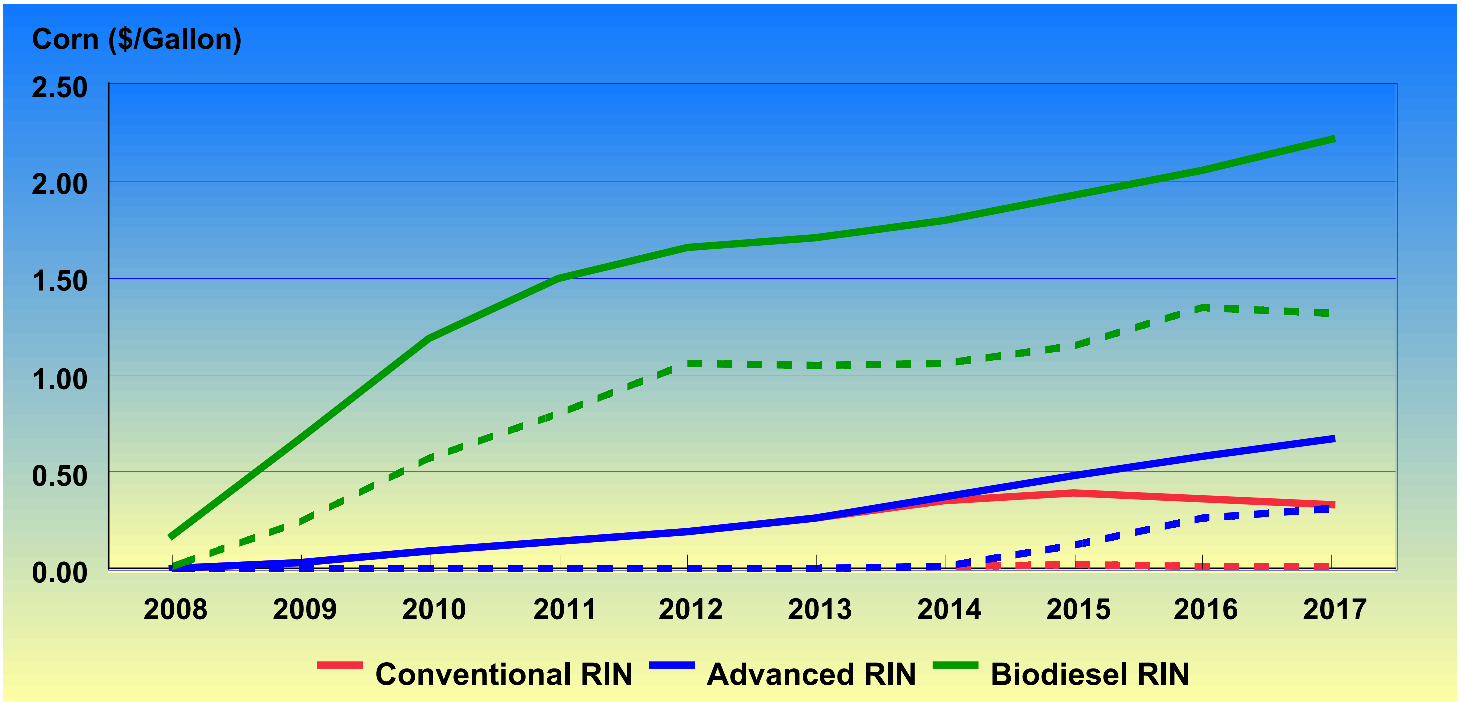

Figure 6. Core RIN Values by Year, for Average and High Petroleum Prices

Note: Solid lines represent annual average RIN core values from 500 stochastic simulations; dashed lines represent RIN core values for the 50 stochastic simulation results associated with the highest petroleum prices.

vestments in biofuel production capital and consumer adoption costs lead to a greater role for expectations. But the links between motor fuel markets and agricultural commodity markets have been recognized. The potential for policies to influence, or even sever, these links is perhaps less well recognized, however, and the potential that biofuel policies represent a new source of risk may not be so well known.

Policies do and have changed. With the ethanol tariff set to expire at end of 2008, the Farm Bill of 2008 extended it to 2010, and also reduced the tax credit. Whereas the mandate requiring minimum levels of biofuel use were introduced in the 2005 Energy Policy Act, the Energy Independence and Security Act of 2007 revised the mandate system only shortly after rules were written to implement the previous ones. Given such a rapidly evolving policy framework, market participants must be aware how policy changes can affect markets.

Mandates can have a defining role on market quantities if binding, but have almost no effect on quantities if they are not binding. Thus, the context is critical to assessing how mandates will affect markets as they grow over time or if they are revised further through new legislative action. Key determining factors, such as the petroleum price and weather-induced supply shocks, must be taken into account to assess whether or not the mandates are binding. More subtly, the effects of other biofuel policies, such as the tax credit, depend on whether or not the mandate is binding.

The Renewable Identification Numbers (RINs) will be a useful measure of the degree to which a mandate is binding and a key element of profitability and costs for market participants if a mandate is binding. As such, they may represent a new potential focus of policy intervention. For example, policy makers may use the RIN value as a measure of the degree to which the mandate affects markets and may introduce some mechanism to address the case of very high RINs. Such a policy might reflect concerns about agricultural commodity market events as much as biofuel markets, although the indirect links between RIN value and crop prices may be judged too imprecise. Such speculation about possible future policy initiatives invites further research.

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Bioenergy Ownership and Investment Models for Rural America

Anthony Crooks, James Baarda, and David Chesnick[1]

Background

In 2006, the U.S. Department of Agriculture commissioned Informa Economics Inc., a consulting firm headquartered in Memphis, Tennessee, to study business models in use in the renewable transportation fuels industry. In addition to providing a full description of the basic business models used in biofuels production, the objectives of the study were to:

- Articulate the advantages and disadvantages of each model and the conditions of the marketplace products and raw materials, sources of capital and regulatory and tax environment that most favor use of each particular model; and

- Assess public policy and USDA Rural Development programs to align particular models to conditions best suited to promote renewable energy development.

In this paper the Informa Economics findings are summarized and business organization and investment systems from the perspective of farmers and rural community development are discussed (Informa Economics, Inc., 2007a and 2007b). The enormous variety and flexibility of business firms as found in specific circumstances lets us only summarize general models. Important characteristics of each type can be significantly modified and adapted to individual circumstances.

Business Firms

Business firms are organized to address several processes inherent in any business (Hansmann, 1996; Klein and Coffee, 1990). Businesses in the bioenergy industry are no exception. Some business characteristics take on added importance when the focus of the inquiry is on the position of the farmer and the role of rural communities. The processes of most interest for our purposes include:

- Investment for capital acquisition;
- Obtaining adequate financial resources;
- Expertise in:
  - Operations and management;
  - Technical design and operation;
  - Purchase of commodity;
  - Marketing of product and byproducts;
- Obtaining sources of supply;
- Identifying and developing markets;
- Risk management;
- Distributing profits, benefits, or losses;
- Satisfying legal requirements, establishing appropriate rights and obligations; and
- Implementing entry and exit strategies.

Each business type will tend to have advantages and disadvantages in each of the identified areas.

During the current decade, ethanol industry growth accelerated as petroleum prices increased and oxygenate methyl tertiary butyl ether (MTBE) was banned. Farmer-owned facilities participated in this growth to an even greater extent than in the previous decade. In November 2006, farmers and other rural investors owned 50 out of the 107 operating ethanol facilities, or 37 percent of production capacity, and they participated significantly in industry's high profit margins. At that time half of industry capacity was in the hands of firms structured as either limited liability companies or partnerships (LLC and LLP), or as cooperatives. The other half of the industry was controlled by investor-owned corporations such as Archer Daniels Midland, which owns 20 percent of the industry's production capacity, and by privately held corporations such as Cargill and Abengoa Bioenergy that owned the remaining 30 percent.

A number of diverse business structures developed in the ethanol industry in the past 15 years. A cross-section of the industry, with respect to producer and capacity, reveals four main business model types:

Corporate Model

An ethanol producer may be a corporation (typically a C corporation) or a subsidiary of a corporation. Internal staff

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manages the plant(s) and the functions of grain procurement, biofuels marketing and coproduct marketing. The corporation does not own or manage farmland but purchases grain from others. If the corporation produces biodiesel, it is very likely to own integrated oilseed-crushing operations. Some corporations also provide third-party grain supply and biofuel and coproduct marketing services to other producers. Profits, losses, and risks are shared by the corporation's investor-owners. Farmers supplying the commodity to be processed only receive payment for the commodity delivered to the corporation. Rural communities benefit from employment opportunities and share the burden of infrastructure use if the facility is located in a rural area but do not necessarily share in returns to investment.

Archer Daniels Midland (ADM) is a prime example of this model of ownership. It is a vertically integrated agribusiness conglomerate and is also the largest biofuel producer in both the United States and the world, with more than 1 billion gallons of annual production capacity. The corporation owns an extensive network of grain elevators and is one of the world's largest agricultural processors of soybeans, corn, wheat and cocoa.

ADM is a Delaware corporation and its stock is listed on the New York Stock Exchange. With net sales and other operating income of $36.6 billion in fiscal 2006, ADM is the largest example of the corporate business model for biofuels. It operates seven ethanol production facilities: Decatur and Peoria, Ill.; Cedar Rapids and Clinton, Iowa; Columbus, Nebraska; Marshall, Minnesota; and Wallhalla, North Dakota. It is building two new 275-million-gallon plants at its Cedar Rapids and Columbus sites.

ADM has an experienced internal sales force to market its ethanol. It began offering ethanol-marketing services to independent ethanol producers last year. The corporation controls substantial transportation assets, including 20,000 railcars, 2,000 barges and 1,500 tractor trailers. It has coproduct merchandising capability through its ADM Alliance Nutrition subsidiary.

"ADM is uniquely positioned at the intersection of the world's increasing demands for both food and fuel," says ADM Chief Executive Officer Patricia Woertz.

The Farmer-Owned Model

The farmer owned businesses are generally structured legally as either cooperatives or LLCs or similar organizations. Farmers have a majority ownership in the facility. In a coop, or a coop within an LLC or which owns an LLC, members have contractual delivery obligations (grain and/or oilseeds) to the facility under terms established for efficient plant operation. They have access to storage, including on-farm bins and limited storage at the facility. In the case of cooperative ownership, the business may also have separate grain-elevator operations.

The Chippewa Valley Agrafuels Cooperative (CVAC) is an example of the farmer-owned business model. It was formed in the early 1990s with the intent of establishing an ethanol facility in Benson, Minnesota. CVAC was formed with more than 650 shareholders, which included producers, elevators and local investors. Planning for the ethanol plant began in 1993. CVAC teamed up with the designer/builder Delta-T Corporation to form Chippewa Valley Ethanol Co. LLC (CVEC). Delta-T chose to become an equity investor when local producers faced a significant shortfall in their original equity drive.

CVEC's original capacity was 15 million gallons, later expanded to 20 million gallons. As the size of new ethanol plants increased, to stay competitive CVEC expanded, to 45 million gallons in 2003. In late 2006, CVEC signed a letter of intent with Fagen Inc. to build a new 40-million gallon facility next to the existing facility.

To improve its market position and diversify its revenue stream, CVEC and a group of other ethanol producers founded Renewable Products Marketing Group. RPMG was established to collectively and cost-effectively market ethanol by aggregating sales in volumes demanded by buyers. RPMG members also used their combined buying power to reduce costs on enzymes and other raw materials.

CVEC teamed up with Pete's Wicked Ale in 2003 to produce Shakers Original American Vodka, a premium brand. CVEC has proven that the farmer-owned business model can be adaptive, progressive and offer business strengths that go well beyond an assured grain supply.

Farmers participate in farmer-owned organizations both through their supply of commodity and by sharing in the benefits of any profits generated by the producer, either as direct distribution of profit or enhancement of the value of their investment. In a cooperative, margins are distributed in proportion to the amount of commodity delivered rather than on the basis of investment only. Investment coming from rural communities also means that ownership benefits are returned to the community in some fashion. The unique roles of cooperatives as business forms amenable to rural development have been noted in numerous studies focusing on general development issues (Coon and Leistritz, 2005; Martin, 2006; Merret and Walzer, 2001; Holmes, Walzer, and Merrett, 2001; Zeuli and Deller, 2007; and Zeuli et al., 2003). Examples of studies of cooperatives' specific contributions to communities as unique business types include Bhuyan and Leistritz, 1996; Folsom, 2003; Zeuli and Deller, 2007; and Zeuli et al., 2003.

The "Engineer/Builder-Owned" Model

The Engineer Model or Builder-Owned model separates out and remixes several functions of a business type. These firms either own facilities outright or maintain a significant ownership interest, along other investors, in individual plants. In either case, the design/build firms maintain a controlling interest in management. Because of their ownership in multiple facilities, these firms have the scale to support an internal staff that conducts grain procurement and biofuels/coproduct product marketing. They may also provide these services to unaffiliated plants.

From the Broin family's small-scale entry into the ethanol industry in the 1980s, it would have been difficult to predict the extensive role that the Broin Companies now plays across the ethanol-supply chain today. The family built a small plant on its farm in Kenyon, Minnesota, in 1983. The Broins then purchased and refurbished a foreclosed ethanol plant in Scotland, South Dakota in 1987.

From such small beginnings, Broin & Associates began providing ethanol facility engineering and construction services for other organizations. By the end of the 1990s, Broin Companies provided a range of services to ethanol producers and became the prototype engineer-owned business model.

Renamed POET in May 2007, this group of companies provides a comprehensive array of services for ethanol producers. In 1991, it began operating a center for plant design, engineering, construction and research. A management company was formed in 1994 to provide management services for Broin-designed plants. Dakota Gold Marketing was established in 1995 to market Dakota Gold Enhanced Nutrition Distillers Products. In 1999, Ethanol Products was formed to market ethanol and carbon dioxide.

Twenty-three operating ethanol plants with a combined production capacity of over 1.1 billion gallons have been designed and built by POET. An additional five plants totaling 375 million gallons were under construction or development in December 2007.

POET retains an equity interest of 20-25 percent in its partners' plants. With its engineering and construction capabilities, ownership and management of partner plants, as well as its ethanol and distillers grains marketing services, POET has pioneered the "engineer/builder-owned" business model.

The "Franchise" Model

The Franchis Model also separates out and remixes several functions of a business type. This is not a vertically integrated model, but rather is characterized by a dependence on third-party service providers to link the firm to its supply chain. The plant is a "cookie-cutter" facility designed and built by one of the major engineering firms (consortiums), and its production process is monitored remotely by the builder.

Third-party service providers are depended upon to procure feedstock (grain or oil) and to market biofuels and coproducts. New operations under this model are generally required by their financial institution(s) to enter into long-term agreements with these service providers. In turn, the service providers might invest a modest amount of capital in the facility.

ASAlliances Biofuels LLC (ASA) was formed in 2004 by Americas Strategic Alliances LLC, a firm specializing in merchant banking and investments. ASA's business plan combines top-tier service providers with sophisticated financial partners. Each facility is to be built by Fagen Inc. and located adjacent to an existing Cargill Inc. grain elevator.

In 2006, ASA began construction on two planned ethanol facilities located in Albion, Nebraska, and Bloomingburg, Ohio. Each of these plants have an annual capacity of 110 million gallons. Construction began on a third facility in Linden, Indiana in 2007.

Cargill Inc. is contracted to provide corn and natural gas procurement services and ethanol and distillers grains marketing and transportation services. United Bio Energy Management LLC will provide operational and maintenance support.

In addition to negotiating contracts with the construction, grain supply, product off-take and facilities management firms, ASA put together the group of equity backers for the three facilities and obtained the required debt financing. A group of private equity firms comprised of American Capital Strategies Ltd., Laminar Direct Capital, L.P. (a member of the D.E. Shaw group), U.S. Renewables Group LLC and Midwest First Financial Inc., provided a significant portion of the equity and all of the subordinated debt to ASAlliances Biofuels. Challenger Capital Group Ltd., a Dallas-based, full-service investment bank, secured $148 million in equity and subordinate debt.

In September 2007, VeraSun Energy Corp. announced plans to acquire the three ethanol plants from ASAlliances Biofuels LLC for $725 million. The acquisition is expected to increase VeraSun's total production capacity to approximately 1 billion gallons by the end of 2008.

In a sense, the "farmer-owned" and "engineer/builder-owned" business models can be viewed as variations of the "franchise" model. However, they also have elements of vertical integration that differentiate them from the pure "franchise" model. Farmer-owned operations are linked to the farmer segment of the supply chain, and in some cases there is integration with a grain elevator. This arrangement can reduce, but not eliminate, the need for a feedstock supply agreement for ethanol operations.

Third-Party Marketing Organizations

The advent of third-party marketing organizations is an important development in the industry and has become a key component of certain business models, especially the "franchise" model. As of December 2007, 120 companies owned 134 ethanol facilities in operation with 66 facilities under construction.

Third-party marketing organizations alleviate a particularly inefficient system where fuel blenders to have to purchase ethanol from 100 or so different firms. It is costly for each of these facilities to have internal sales staff for ethanol and distillers grains (the main coproduct product of dry-mill ethanol production). Moreover, rail carriers favor unit train shipments of about 100 cars and a limited number of origin and destination points (preferably one of each). These preferences are reflected in their rate structures.

Until recently, it was necessary for a company to have a minimum of 100 million gallons of annual production to justify having an internal sales staff. However, given the proliferation of individual plants of that size, the minimum size has increased. Although there is no set rule, operations producing an aggregated 300 million gallons annually are more likely to use an internal sales staff. However, virtually all new entrants into the industry are encouraged by their lenders and debt holders to use a third-party marketing company, at least until they've gained sufficient industry experience.

Energy Corp. owns eight plants with 560 million gallons of annual production, and has an additional 330 million gallons of capacity under construction.

On March 31st, VeraSun announced its merger with US BioEnergy Corp. of Inver Heights, Minnesota, after the transaction was approved by a majority vote of shareholders of both companies. The merger combined the nation's No. 3 and No. 4 ethanol producers into one company. VeraSun owns and operates 10 ethanol production facilities with an annual capacity of 980 million gallons per year (MMGY). With its seven other facilities currently under construction or development the company expects to have a capacity of approximately 1.64 billion gallons, making VeraSun the largest ethanol producer in the United States.

CHS Inc., the nation's leading farmer-owned energy and grain-based foods company, which owned about 20 percent of U.S. BioEnergy, and voted in favor of the VeraSun merger, now owns about 8 percent of VeraSun. CHS has marketed ethanol-blended fuels for more than 25 years and currently is one of the nation's largest suppliers of blended fuel products, which it distributes through 64 terminals.

Cellulosic Ethanol Applications

In the future, as the cellulosic ethanol industry matures, the issues of cost, legal structures and management are expected to become even more acute. Capital expenditures per gallon of capacity for cellulosic plants are estimated to be at least three times those for a corn-based plant of equivalent capacity. Between the total cost of a facility and obtaining the rights to use cellulosic ethanol technology, it is possible that only large corporations and private equity funds have the financial resources to provide the equity for such ventures, especially given the associated risk.

Given the importance of intellectual property in cellulosic ethanol and the fact that some of the main engineering companies serving the corn-based ethanol industry are also devoting resources to cellulosic ethanol, the engineer/builder-owned business model are likely to rise in prominence.

Collection and storage systems have yet to be established for crop-based feedstocks, although central milling locations exist for some forest and paper products. Given the scale of the investments and the role of intellectual property in cellulosic ethanol, it is possible that the farmer-owned business model will struggle to be relevant in the new industry, at least under circumstances where complete farmer ownership is required. However, farmers will still be the main source of cellulosic feedstock. It is possible that farmers will be able to participate beyond mere supply where hybrid business models are developed to bring feedstock producers into the ownership structure. Examples of such arrangements may include:

- Direct outside ownership interests in a cooperative such as with preferred stock, ownership using new LLC cooperative statutes, direct LLC formation with farmer control, or the use of corporate statutes with desirable structuring, financing, and operating provisions;
- Co-ownership between farmer-owned organizations and others in which each entity contributes an efficient element of the overall business process as noted at the beginning of this paper. Jointly-owned subsidiaries would be such examples, and
- Farmers' contributions could be recognized absent full ownership through contractual arrangements. This method may require less investment but compensate farmers for their unique role in the enterprise through production of a product with limited alternative use.

The Broin/POET system of partnering with farmers and other rural investors seems to be adaptable for this purpose of tying together capital, intellectual property and feedstock. But the feedstock supply linkage will need to be enhanced. Given the legal and management issues discussed above, it seems imperative to ensure that any necessary adaptations to more "traditional" legal structures and management systems be put in place during the next few years if farmers and other rural investors are to participate fully in the cellulosic ethanol industry of the future.

Business models are likely to become even more complex with the advent of cellulosic ethanol. While corn is the predominant feedstock for today's ethanol industry, a variety of feedstocks – corn, agricultural wastes, dedicated energy crops such as switchgrass and miscanthus, forestry products and others – are expected to be used by the cellulosic ethanol industry of tomorrow. The feedstock producers of tomorrow are therefore likely to be much more than row crop farmers. The "farmer-owned" business model will have to expand to embrace these new commodities to the extent such farmers wish to participate more fully in the emerging industry. The touchstone of success for new developments will depend on how well new or traditional business structures address the eight characteristics of business outlined previously, in particular what position farmers have in the system and the economic and social impacts on rural communities.

With the advent of new biorefineries and new technologies, the number and specialization of coproducts should multiply and require a more diverse and complicated mix of third party marketing firms. In the case of some products with highly technical applications, the use of specialized marketing firms or long-term off-take agreements will be necessary because of the extraordinary expense of a facility having internal staff to perform such a highly specialized and technical sales function.

It is quite likely that more business models will be created by the advent of cellulosic ethanol. And we can expect them to be even more complex than today's business models. From farmers' and rural communities' perspective, business models effectively meeting their needs may require imagination and creativity that challenges current capabilities and capacities. However, experience has shown throughout the country's history that such challenges are precisely what fuel innovation upon which growth and development depend.

New Investment Models to Reverse Decline of Local Ownership

A little more than one-third of ethanol-industry capacity is owned by farmers and other local investors, according to the Renewable Fuels Association. However, only 15 percent of new or expanding biofuel plant construction is owned by such investors. A key reason for this shift is that the larger plants being built today require larger amounts of equity.

Equity investment at this scale can be difficult to obtain from farmers and other rural investors living in close proximity to a proposed facility. But if local investment wanes, so does the flow of returns from biofuel to the communities were it is produced.

Based on the analysis conducted by Informa and interviews carried out during the course of this project, Informa formulated several investment models that may be used to facilitate investment by farmers and other rural residents in the renewable energy sector. This article briefly describes each of these models.

In a "closed-ended renewable energy fund" investment would be limited to farmers and other rural residents seeking to invest in energy projects. The funds would be managed by a professional or an institution. These funds would need to be large enough to invest across multiple facilities. For example, a $300-million-capitalization fund could own almost all the equity in three 100-million-gallon-per-year ethanol facilities. While it is uncertain how much money farmers and other rural investors would be willing to invest in such a fund, some parameters can be placed around potential contributions. Per-person investments by farmers and other rural investors tend to be small, in relative terms, generally around $10,000 to $50,000. Farmers with gross sales of more than $100,000, a mean net worth of at least $1 million and a debt-coverage of at least $50,000 are seen as the most likely candidates for participations in a renewable energy fund. Nearly 300,000 farms would be embraced by these characteristics. A $10,000 investment from each could attract $3 billion into the fund; sufficient to provide equity for more than 625 million gallons of cellulosic-ethanol at $8 per gallon of capacity using 60 percent equity and 40 percent debt financing, or 3.5 billion gallons of corn-ethanol, at $2.00 per gallon using 40 percent equity and 60 percent debt.

Under a program similar to Rural Business Investment Program (RBIP) administered by the Small Business Administration, Rural Business Investment Companies (RBICs) could be established and allowed to issue "debenture guarantees." Debentures issued by an RBIC could be pooled with other issues and sold to outside investors. Backed by the federal government, the debentures would carry lower premiums. The modifications of the RBIP program for an RBIC biofuel investment projects program would be straightforward:

- Relax the maximum, $6 million-net-worth restrictions of the existing program, to avail the fund to biorefinery financing;
- Relax dividend pre-payment requirements, to generate more cash flow to equity holders; and
- Lower leverage fees for debentures would have to be significantly to be competitive against market interest rates.

In recent years, ethanol producers enjoyed relatively high margins and short debt-payback periods. Thus the debt market does not demand a high-risk premium from ethanol producers. Furthermore, ethanol plants with a high probability of financial success are able to secure adequate debt financing in the market.

The “new markets tax credit” (NMTC) program is funded and managed by the U.S. Treasury Department’s Community Development Financial Institutions (CDFI). The Models for Funneling Local Investment Capital into Biofuel Production program permits taxpayers to receive a credit against federal income taxes for making qualified equity investments in designated Community Development Entities (CDEs). These CDEs could invest in biofuel facilities to supplement farmers’ equity, thereby leveraging the initial investment. Some modifications would be needed for the biofuel sector:

- The CDE would pledge to invest in a portfolio of qualified biofuel projects.
- Create a new tax credit model to mirror the investment mechanism of the NMTC, but targeted specifically for biofuels and renewable industry investment.

Farmer groups and rural residents have demonstrated an ability to raise $5 million to $20 million from a limited number of investors in a short period of time. However, moving beyond the $20 million level has proven difficult. A way to expand the size of this group would be to offer a “production tax credit” for projects with minimal rural involvement to outside investors to help farmers finance biofuel facilities. The program would requite an outside investor to match the farmers’ investment in exchange for the project’s tax credit. This is similar to the program for wind generated electricity.

Substantial amounts of equity are already flowing into (and out of) renewable fuel projects. And farmer-investors can easily become shareholders in a number of publicly traded ethanol companies. But a farmer’s investment into the biofuel-corporation goes outside the community. There is no rural ownership of that investment. Nor is there any rural area multiplier effect from those corporate returns. The returns from a locally owned biofuels facility recirculate within the rural community and stimulate additional economic growth. Studies cited previously on cooperatives’ impacts on rural economic development as well as others explore this characteristic in varying detail.

Tapping Farm Equity Key to Greater Local Ownership

For local investment in rural opportunities such as renewable energy to succeed, enough equity must be available to pursue these investment opportunities. One part of the investment-model study included an examination of the amount of equity available in the rural communities that could be available for rural investment. This section reviews basic findings.

U.S. farm business assets in 2006 were $1.98 trillion and are forecast to increase 27 percent to $2.51 trillion in 2008. Farmland value in the United States generally follows farm income and return to assets. However, since 2004, net farm income declined while rural real estate increased substantially. This pattern followed the same pattern of real estate values throughout the rest of the country. Farm real estate which accounted for 85 percent of farm sector assets in 2006 is projected to increased 30 percent to $2.2 trillion in 2008 and represents 87 percent of total farm sector assets.

Clearly there is significant value in land held by farmers. But what portion of these assets is already leveraged? Total farm business debt is projected to climbed 10 percent in 2008, to $228 billion. Real estate debt for farm businesses accounts for more than half of total farm debt outstanding and has increased steadily from $67.6 billion in 1990 to an estimated $121 billion in 2007. Farm business equity is expected to continue rising in 2008 as the increase in farm asset values exceeds the rise in farm debt. Farm sector equity should be about $2.29 trillion in 2008, up from $2.00 trillion in 2007. The increase in assets relative to debt lifted farmers’ net wealth; debt-to-equity fell from 17.4 percent in 2002 to an estimated 10.0 percent in 2008.

This growing stock of equity capital can be used to finance investments in rural communities. But while U.S. farmers hold a significant amount of assets and equity relative to debt, the ability to take on more debt is largely dependent on the ability to generate enough income to service their debt obligations. One way to measure the amount of additional mortgage available is to look at the unused debt repayment capacity. The debt-repayment capacity is based on the maximum debt service that operators would be able to pay given total income and farm and non-farm expenses. Figure 1 illustrates these two values from 1970 to 2006. During this time period, there was only one year when the debt level was more than the repayment capacity. In 1981, the aggregate debt payments exceeded the ability to repay these loans, which resulted in many farm foreclosures. Farmers could boost their debt load by nearly $1 trillion.

Changing circumstances could affect the income available for debt coverage -- falling commodity prices, input price increases, or crop failure. However, the risk associated with commodity price fluctuations for the farm operator may also be partially offset by their investment in a biofuel facility.

If it is true that more than one out of every four farmers, and about half of agricultural landlords, are 65 or older and this group controls more than one-third of all farm assets,

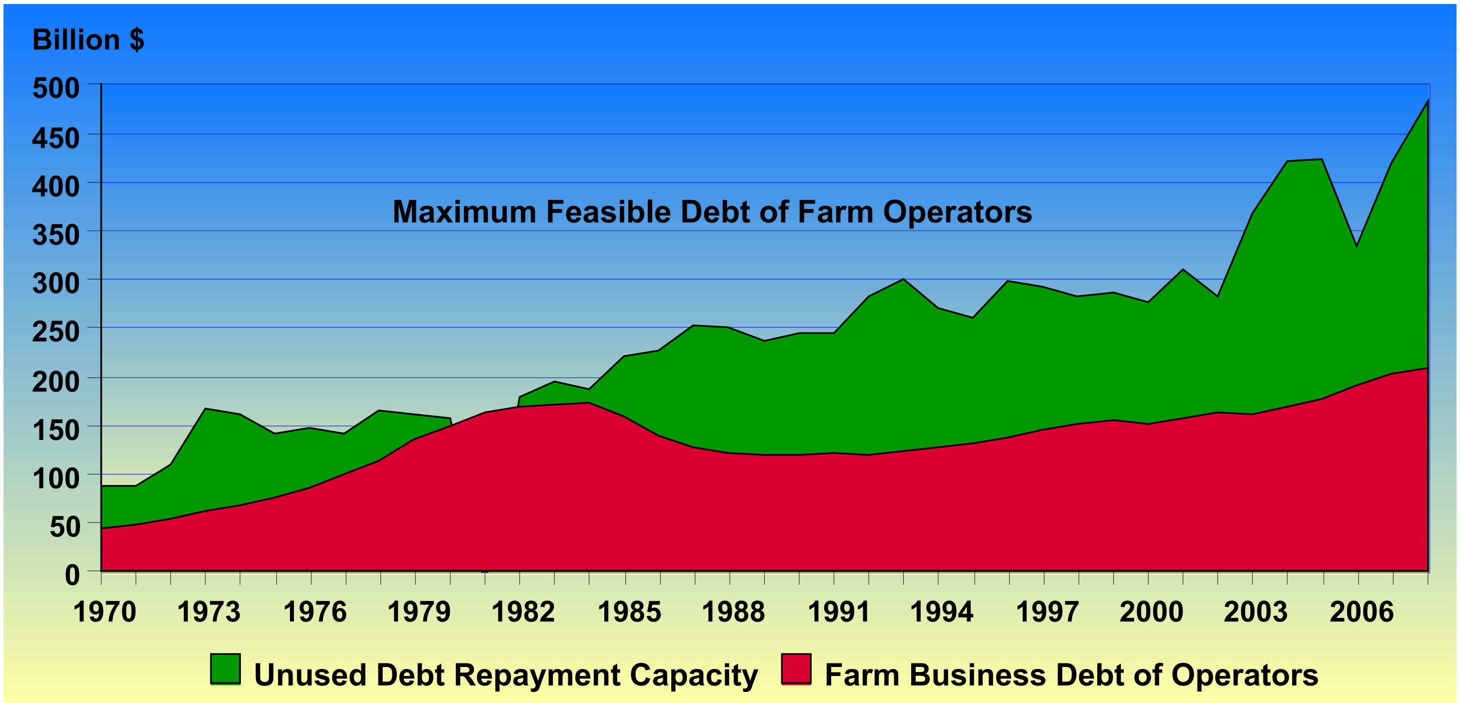

Figure 1. Debt Repayment Capacity

how might this affect the attitude of farmers with respect to mortgaging the farm for investment purposes? In addition to working longer past traditional retirement age, farm-operator households tend to have several income sources and different forms of wealth, compared with the general population. Moreover, fewer farm operators are covered by employer-sponsored pensions than are non-farmers. But, a majority of farm operators save from current income on a regular basis and have accumulated diversified financial portfolios, including individual retirement savings.

Theoretical availability of funds for investment in biofuel businesses does not indicate that increasing farm-level debt to make off-farm investments in biofuels is an appropriate financial strategy. An analysis of such investment would include:

- Risks of loss inherent in a new and volatile industry, especially where the firm is new and of relatively small size in the industry;
- Risks that markets and technologies will change significantly rendering the business and its technology obsolete;
- A balance of the cost of debt with its established repayment and servicing obligations again unknown and non-guaranteed return on funds invested in biofuels firms;
- Portfolio investment issues where investment is being made in associated but non-countercyclical equity; and
- The free rider problem in which the increase in price received for grain delivered may not be appropriately attributable to investment because the increase in price inures to all producers, not just the investing producer.

Numerous other factors may determine the desirability of direct farmer investment in biofuels businesses generally (Serra, Goodwin, and Featherstone, 2004) and specifically related to a biofuels firm (Jensen, English, Menard, and Zhang, 2004).

Conclusions

The substantial changes to farming and rural communities brought about by the growth of the biofuels industry continue to have an enormous impact on farming and rural communities. How the benefits of such events are distributed will depend largely on the structure of business organizations that participate in the industry. For those focusing on the welfare of farmers and rural communities, current issues of industry structure are critical. Such issues are in a state of change. Flexibility of response to the evolving industry, including creative designs for business arrangements, may be the greatest challenge to farmers and rural communities that may benefit from the phenomenal growth of the biofuels industry.

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Factors Determining Corn-Based Ethanol Plant Site Selection, 2000-2007

Lance A. Stewart and Dayton M. Lambert[1]

Introduction

As investors continue to look for optimal sites for ethanol plants, investigating the factors determining community comparative advantage with respect to attracting outside investment has flourished. A new ethanol plant may create local jobs, and increase the tax base and income through the backward and forward linkages agriculture has with the economy (Novack and Henderson, 2007). Existing ethanol plants are usually located near ample feedstock supply, reliable transportation systems, and close to adequate water and energy sources (Rose, Detch, and Morgan, 2005). But no matter the geographic location, the long-run profitability of an ethanol plant depends on minimizing production costs (Dhuyvetter, Kastens, and Boland, 2005). Low-cost production is achieved by minimizing feedstock procurement, natural gas, and labor costs. Feedstock procurement costs decrease when feedstock supply is abundant and transportation infrastructure is reliable. Ethanol producers depend on efficient transportation and coproducts handling, as well as availability of other resources required to produce biofuels (Baker and Zahniser, 2006). The natural gas used in the fermentation process is another important cost. On average, grain-based ethanol plants use 34,800 Btu of thermal energy per gallon of ethanol (Shapouri and Gallagher, 2005). Thus, proximity to natural gas pipelines and distribution centers may be an important location determinant (Shapouri and Gallagher, 2005). Additionally, to increase profitability, ethanol producers can market coproducts such as Distillers' Dried Grains with Solubles (DDGS), a relatively high protein livestock feed supplement. Therefore, locating near livestock operations may also reduce DDGS transport costs (Baker and Zahniser, 2006). Statewide and federal policies influence site selection. Most states with significant ethanol production typically have some form of ethanol subsidy, incentive, or initiative (Parcell and Westhoff, 2006). Several studies identify the geographic attributes attractive to ethanol producers with respect to siting plants (e.g. Baker and Zahniser, 2006; Dhuyvetter, Kastens, and Boland, 2005). However, research identifying the location determinants at the national level remains limited.

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This study examines the influence local market factors, transport and utility infrastructure, labor, state policy and demographic characteristics have on ethanol plant location decisions in the contiguous forty-eight United States for the years 2000 through 2007. Regression analysis and clustering methods measure the factors influencing the likelihood an ethanol plant locates in a given county. The procedure isolates clusters of counties more likely to attract investment. It is hypothesized that location determinant effects vary spatially; suggesting that comparative advantage with respect to attracting ethanol plant investment will vary across the urban – rural geography. Appreciating the geographic diversity of location determinants and their relationship with site selection decisions provides a model for ranking communities competing for ethanol plant investment.

Conceptual Framework, Empirical Model, and Estimation Procedures

The same factors influencing food manufacturing plant location determine ethanol plant location choices; namely market access, agglomeration economies, and infrastructure (Henderson and McNamara, 2000). Supply-oriented food processors locate near agricultural inputs to minimize procurement costs. The ethanol industry falls into the supply-oriented firm type because feedstock costs dominate ethanol production costs. Conceptually, the location decision is represented as $Z_i = g(\mathbf{M}_i, \mathbf{L}_i, \mathbf{I}_i, \mathbf{P}_i, \mathbf{F}_i)$, where Z_i is the site choice in location *i*, g(•) is a cost minimizing site-selection function, and **M**, **L**, **I**, **P**, and **F** are vectors of community attributes including input and product markets (**M**), labor attributes (**L**), infrastructure (**I**), state incentives (**P**), and local fiscal characteristics (**F**) influencing production costs respectively. Details of the variables making up the location determinants in M, L, I, P, and F are discussed below. Also, descriptive statistics of variable are included in Table 1.

Table 1. Descriptive Statistics of Location Determinants

Variable	Description	Location Determinants	Mean	Standard Deviation
ANN	Location Announcements (2000-2007)		0.020	0.140
ACTIVE	Active Ethanol Plants (2000-2007)		0.035	0.183
FARMPROP	Farm proprietor income/nonfarm proprietor income (2000)	M	0.190	0.557
CATTLE	Cattle, plus surrounding counties (1000,000s head)	M	2.007	2.045
CORN	Average total corn production plus surrounding counties (1990-2000) (100,000s bushels)	M	171.266	217.756
STORE	Farm product warehousing operations (Location Quotient) (2000)	M	2.117	13.963
NATGAS	Natural gas distribution centers (Location Quotient) (2000)	M	3.308	8.114
GAS	Gas stations, plus surrounding counties (2000)	M	6.894	3.429
ESTAB	Existing ethanol plant before 2000 (1 = yes)	M	0.010	0.106
HERFEMP	Employment concentration index, 2000 (between [0,1])	L	0.121	0.052
WAGE	Average wage per worker ($), 2000	L	12.307	2.761
HS00	% with high school diploma, 2000	L	77.321	8.732
TRUCKLQ	Trucking companies (Location Quotient), 2000	I	2.076	1.897
ROAD	Road density (road miles/county area)	I	0.457	0.272
RAIL	Rail density (rail road miles/county area)	I	0.307	0.402
RIVER	River adjacency	I	0.326	0.469
FISC	Per capita income taxes/county expenditures, 2000	F	0.337	0.229
TAX	State excise tax incentive (2001) (1 = yes)	S	0.133	0.339
PRODCR	Ethanol producer credit program (2001) (1 = yes)	S	0.233	0.423
MTBE	Methyl tertiary-butyl ether ban, 2000 (1 = yes)	S	0.185	0.388
IRR2000	Waldorf's (2006) 2000 rurality index (between [0,1])		0.501	0.177
HLAND	Heartland (1 = yes)		0.178	0.382
NOCRES	Northern Crescent (1 = yes)		0.138	0.345
FRUIT	Fruitful Rim (1 = yes)		0.091	0.288
NOGRTPL	Northern Great Plains (1 = yes)		0.058	0.235
PRGATE	Prairie Gateway (1 = yes)		0.128	0.334
BRANGE	Basin and Range (1 = yes)		0.064	0.245
MISSPORT	Mississippi Portal (1 = yes)		0.054	0.226
SOSEA	Southern Seaboard (1 = yes)		0.155	0.362

This closely follows the methodology used by Lambert *et al*. (2008) in their analysis of ethanol plant location decisions in metropolitan and nonmetropolitan counties. This research differs in that a bivariate probit regression jointly models ethanol plant location announcements and plants operating from 2000 to 2007. It is hypothesized that the location decisions of established plants influence the site selection decisions of new plants. Negative correlation between the location decisions of established and new plants may suggest competition for limited feedstock resources. That is, given an established ethanol facility, a newly proposed facility will tend to locate farther away from the established plant to access feedstock sources not consumed by the active operation.

County-level factors are regressed against variables indicating where ethanol plants became operational from 2000 to 2007 and ethanol plant location announcements between the same period (equation 1):

$$\Pr[Z_i^t = 1] = \Phi_{BVN}(RI_i, RI_i{*}\mathbf{M}_i, RI_i{*}\mathbf{L}_i, RI_i{*}\mathbf{I}_i, RI_i{*}\mathbf{F}_i, RI_i{*}\mathbf{P}_i, \mathbf{M}_i, \mathbf{L}_i, \mathbf{I}_i, \mathbf{F}_i, \mathbf{P}_i, \beta^k, \rho),$$

where Pr = probability; $t \in [ANN, EST]$; Z_i is a binary variable indicating if there was at least one active ethanol plant or ethanol plant announcement in a county between 2000 and 2007; Φ_{BVN} is the standard bivariate normal cumulative density function; $\mathbf{M}_i$, $\mathbf{L}_i$, $\mathbf{I}_i$, $\mathbf{F}_i$, and $\mathbf{P}_i$ are the location determinants in county i; and RI is a rurality index (Waldorf, 2006). When the location unobserved factors associated with decisions are not correlated, $\rho = 0$, and plant announcement and active plant location equations are estimated separately.

The RI is a function of population, population density, the percent of the population designated as rural or urban according to the U.S. Census (2000), and the distance between a county and a metropolitan statistical area (OMB, 2007). The RI is a continuous variable, bounded between [0, 1]. Counties with an RI score of 1 are remote, low population density counties (e.g., "rural"). The converse is true for counties with a RI score of 0 (e.g., "urban"). Location determinants were interacted with RI to test the hypothesis that the geographical effects of location determinants vary with respect to plant site selection, given the location of a county in the rural – urban continuum. The marginal effects of a location determinant are therefore a continuous function of the rurality index. The marginal effects of the location determinants are discussed looking at their effects in groups of counties falling into the RI categories of 0 – 0.2, 0.4 – 0.6, 0.6 – 0.8, and 0.8 – 1.0. Thus, discussion focuses on the spatial variability of the marginal costs of the location determinants in the context of this rural – urban continuum.

Data Sources

Plant location and announcement information was collected from the Renewable Fuels Association (RFA) (2008). The total number of active ethanol plants as of January 3, 2008 was 141, with 70 ethanol plant location announcements. The 2000 cutoff point was chosen for two reasons. First, all plant location announcements documented by RFA occurred during or after 2000. "Announcements" are defined as plants reporting zero production because plants were not yet constructed. Whether these plants actually begin production is not important because it is the location determinants associated with a county which initially elicited interest. Second, 78 percent (110) of the active ethanol plants began production in or after 2000, following the recent interest on expanding renewable fuel supplies in the United States.

Location determinants measured in 2000 (or prior to 2000) were used in the regression analysis to avoid potential simultaneity problems. To assess the feedstock input and coproduct output determinants on the site selection decision, crop and livestock production data for the year 2000 were collected from the National Agricultural Statistics Service (NASS) (2000) to assess the feedstock input and coproduct output determinants on the site selection decision. Demographic variables were extracted from the 2000 Census files, and information about state policy incentives was obtained from the U.S. Department of Energy (USDOE-EIA, 2001). Interstate and state highway miles, county physical attributes, navigable rivers, and per county miles of class I and II rail lines were from the GIS and mapping software ESRI (2006). Information on trucking and natural gas distribution establishments was extracted from the U.S. Census County Business Pattern files (2000). Waldorf's (2006) RI was constructed using 2000 census data and the Office of Management and Budget (OMB) urban core/non-core county classification system (OMB, 2007). There were 3,064 usable observations in the final data set after eliminating counties with incomplete information.

The goal of this study is to provide not only an economic analysis of agriculture's ability to contribute to the Congressional goal of supplying 18 billion gallons by 2016, but to also evaluate the impact the pursuit of this goal could have on this nation's environment if cellulosic ethanol is not feasible by 2016. The first objective of the study is to evaluate the ability of production agriculture to contribute 18 million gallons of corn-ethanol. The second objective is to estimate the potential environmental impacts on the nation's resources as a result of this emerging industry.

Location Determinants

Market potential of an area depends on the ability to meet demand conditional upon the supply of competing goods. Larger product markets are penetrated by exploiting lower transportation costs, which increases the competitiveness of a site. Ethanol plants locate where primary input transportation and coproduct distribution costs are minimized (Dhuvyetter, Kastens, and Boland, 2005). Net feedstock costs account for the largest share of ethanol production costs (about 55 percent of the per-unit costs) (Shapouri and Gallagher, 2005). Profit margins will decrease and coproducts marketing will become more important as the ethanol industry grows and becomes more competitive (Dhuvyetter, Kastens, and Boland, 2005). Distiller's grains (DG) may supplement livestock diets and locating near livestock operations and selling DG to livestock feed producers can potentially offset feedstock procurement costs.

Three variables measure the effects of product markets on the location decision of grain-based ethanol plants. Assuming that ethanol is primarily used as a fuel additive, the per-county number of retail gasoline businesses, and the sum of the retail gas stations in surrounding counties may account for market potential (GAS). We use retail gas businesses as a demand proxy only, based on the assumption that areas with higher concentrations of gas stations typically have higher concentrations of fuel consumers. The number of blending facilities in a county would be the ideal measure. Admittedly, the retail gas businesses only roughly approximate demand potential. The total head of cattle per county plus cattle in surrounding counties (CATTLE) measures potential access to DG markets (NASS, 2000). DG is marketed in wet and dry forms, and may need to be stored or dried before it is shipped to demand centers. Therefore, a location quotient (LQ) of farm product warehousing operations

(STORE) measures the influence storage facilities have on ethanol plant location decisions.[2]

Three variables measured the impact of access to input markets on ethanol plant site selection. Ethanol production relies heavily on the agricultural sector given feedstock demand as well as DG markets. Farm proprietor income divided by nonfarm proprietor income in a county measures the relative importance of farming on the location decision, based on the assumption that counties with relatively more income generated from farming proxy areas with a comparative advantage with respect to feedstock production (FARMPROP). It is expected that ethanol producers are more interested in the total quantity of feedstock available rather than feedstock yield. Due to the limited ability of a single county to supply all of a large ethanol producer's feedstock demand, larger operations will likely import corn from surrounding counties. The average total bushels of corn produced from years 1990-2000 in a county was added to the sum of the average total bushels of corn produced in surrounding counties to gauge access potential to corn feedstock (CORN). Strategic barriers to entry into product markets due to the presence of preexisting plants may be a factor in the location decisions (Fee, Milon, and Williams, 2004). As more ethanol plants locate in a given county, competition for that area's resources increase. We include the number of active ethanol plants located in a county prior to 2000 as a measure of barriers to entry (ESTAB). There were at least 31 active plants producing ethanol prior to the year 2000. It is hypothesized that counties with existing active ethanol plants are less attractive to new plant investment.

Manufacturing productivity is influenced by labor quality (McNamara, Kriesel, and Deaton, 1988). Higher quality workers are typically more productive, which leads to increased productivity at a higher level of output at the same or lower costs, thereby increasing profits. It is hypothesized that a high-quality labor force will attract potential ethanol plant investment. The percent of persons over twenty-five with a high school diploma in each county (in 2000) measures labor quality effects on plant site selection (HS00).

Locations with lower labor costs have lower operating costs, increasing the attractiveness of the area (Schmenner, Huber, and Cook, 1987; Smith, Deaton, and Kelch, 1978; and McNamara, Kriesel, and Deaton, 1988). It is hypothesized that higher labor costs will be negatively correlated with ethanol plant site selection. The 2000 annual manufacturing wage per worker in each county measured labor cost effects on the location decision (WAGE).

Manufacturing productivity depends on available labor. A deep labor pool requires less recruiting and would meet the needs for a larger number of diverse firms. A diversified work force also increases the likelihood of acquiring workers with the necessary skills to fill positions at different levels of production. A Herfindahl index was used to measure the effects of a diversified workforce on the location decision of potential ethanol plant locations (Davis and Schluter, 2005). More individuals are employed by a single sector as the index approaches one.

Infrastructure consists of the physical and natural features supporting community and commercial needs by creating access to regional, national, and international markets. Ethanol production requires transportation systems to acquire inputs and to distribute ethanol and allied coproducts. Transportation networks include federal and state roads, railroads, and navigable waterways. The total county road network miles, including state highways and the federal interstate system, was divided by the county area to measure road network potential (ROAD). A similar measure was constructed for county railroad networks (RAIL). It is expected that these transportation measures will be positively correlated with ethanol plant sites. County adjacency to a river (RIVER) was used to measure the influence of river transportation opportunities on plant location decisions. Location quotients measured the influence of truck transport establishments (TRLQ). Ethanol plants use natural gas in the distillation process, which accounts for the second highest variable operating expense (Shapouri and Gallagher, 2005). Choosing sites with historically low natural gas and sufficient supplies allow ethanol firms to hedge against unavoidable fluctuations in fuel prices by keeping procurement and usage costs low. Adequate access to natural gas is also an important determinant for plant location. Location quotients were constructed to measure the influence of natural gas distribution centers (NATGAS) on site selection.

Nine states (California, Colorado, Connecticut, Iowa, Maine, Michigan, Minnesota, Nebraska, and New York) had completely banned methyl tertiary-butyl ether (MTBE) by 2001 (USDOE-EIA, 2001). MTBE was no longer used as a fuel additive in these states and ethanol became a likely substitute. The adverse environmental effects associated with MTBE induced the demand for a replacement in which the eco-friendly status of ethanol made it a prime candidate as a comparable gas-additive. By July 2001, eight states had passed an excise tax supporting ethanol producers (Alaska, Connecticut, Hawaii, Idaho, Illinois, Iowa, Minnesota, and South Dakota) (USDOE-EIA, 2001). The federal excise tax for ethanol producers was designed to make ethanol more competitive as a gasoline additive. It is hypothesized that counties in states with this policy will be more competitive (TAX). Also, by July, 2001 ten states (Kansas, Minnesota,

[2] Location quotients are a measure of specialization in a given sector. Communities highly specialized in a given sector are more likely to export that particular service or good (Shaffer, Deller, and Marcouiller, 2004).

Michigan, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, Wisconsin, and Wyoming) authorized ethanol producer incentives crediting corn sold for ethanol production (PRODCR) (USDOE-EIA, 2001). This is a supply-side policy, and should have a greater effect in relatively rural, grain producing areas.

Fiscal policy includes the government expenditure patterns and tax policies of counties and states. Higher state spending can be a benefit in some instances, but states with high corporate taxes are less attractive with respect to attracting plant investment (Goetz, 1997). County-level per capita property taxes were normalized by total county expenditures per capita (in 2000) to measure fiscal policy effects on the location decision (FISC).

Regions exhibiting greater likelihood of attracting ethanol plant investment relative to other areas are identified using the selection probabilities estimated with the regressions. Spatial clustering techniques are applied using a Local Indicator of Spatial Association (LISA) to identify groups of counties forming high-probability location clusters (Anselin, 1995). A 5 percent level of significance discriminates areas that are more likely to attract ethanol plant investors.

Results and Discussion

Product markets had varying effects on an active plant siting, depending on the rurality of the county (Table 2). The relative importance of farming in a county (FARMPROP) was positively associated with active and announced plant locations. However, the effect is increasingly negative moving away from metropolitan areas. The marginal effects in Table 3 indicate that farming areas just beyond urban centers are more attractive to ethanol producers than farming areas located in the most remote counties, suggesting that farming practices in extremely rural areas may be less likely to have access to infrastructure needed for ethanol production. Likewise, the total average corn production in a county is a positive determinant for attracting both announced and active ethanol plants. But remote areas appear to have a negative association with announced and established ethanol plants location, again suggesting the importance of infrastructure that may be scarce in more remote locations. Farm storage operations are an important location determinant for established ethanol plants in rural areas, perhaps because many urban areas do not typically specialize in warehousing agricultural products. It could be argued that established ethanol plants already command available storage facilities, limiting supply for new plants. The number of cattle in more rural areas is a significant determinant for attracting ethanol plants. Due to the increasingly competitive nature of the ethanol industry, plants entering the industry may have strong incentives to locate near DG markets to lower input procurement costs. Plant announcements from 2000-2007 were negatively associated with plants active prior to 2000, suggesting that entering firms avoid locations with established ethanol plants already competing for feedstock resources. The number of retail gasoline stations outside of urban areas was positively related with ethanol plants. Conversely, announced facilities were positively correlated with retail gas stations in urban areas. Given that the number of retail gasoline stations in a given area proxies demand potential, it appears that established ethanol plants from 2000-2007 may have saturated locations near urban markets.

Wages had a negative effect on plant location announcements in urban areas. Labor quality appears to be an important consideration for plant location. Rural areas become more attractive to potential ethanol plant investors as the number of individuals with high school diplomas increases. Labor pool diversity in rural areas appears to be an important factor in plant location. The probability of a plant locating in a county decreases the less diverse the workforce is, which may correspond with a more homogenous economy.

Road density in rural areas is an important location determinant for active ethanol plants. However, road density was not correlated with proposed plant sites. New plants flooding the ethanol market at the turn of the century probably occupied prime locations first, including well developed primary and secondary road networks, which in turn may have sent new ethanol plants in search of sites with access to secondary transportation sources, such as rail lines or river access. Counties with well developed rail systems may have a comparative advantage over other counties with respect to attracting potential ethanol plant investment. Urbanized counties with access to river transportation services were positively correlated with plant location announcements, but more remote rural areas may not have the infrastructure to support such activities. The number of trucking establishments in more urban areas appears to be an important determinant. Counties with relatively more trucking facilities may be able to support the transportation demand of ethanol plants. Access to natural gas distribution centers did not appear to be a factor with respect to plant location announcements in either urban or rural counties.

State excise taxes were positively correlated with ethanol plant announcements. In addition, producer credit incentives were a positive location determinant for established ethanol plants in rural areas. The ban on MTBE was not a significant factor with respect to plant location announcements but it was positively correlated with active ethanol plant sites in more urban areas. Per-capita property taxes became an increasingly negative factor in rural areas with respect to attracting ethanol plants.

The spatial distribution of the estimated site selection probabilities for grain ethanol plant announcements and ac-

Table 2. Bivariate Probit Estimates, 2000-2007

	Announced		Active	
Variable	Estimate	T test[a]	Estimate	T test
CONSTANT	1.379	0.776	1.499	0.929
FARMPROP	2.408	3.459	2.472	3.875
CATTLE	-0.045	-0.729	0.151	2.647
CORN	0.002	3.056	0.002	4.412
STORE	-0.009	-0.977	-0.044	-1.960
NATGAS	0.036	1.901	0.003	0.114
GAS	-0.104	-2.233	0.120	2.810
ESTAB	-7.376	-3.604	0.492	0.666
HERFEMP	8.078	2.975	-0.287	-0.097
WAGE	-0.163	-3.133	0.022	0.648
HS00	-0.021	-1.083	-0.056	-3.010
TRUCKLQ	0.424	3.101	0.303	2.452
ROAD	-0.675	-1.158	-0.766	-1.531
RAIL	-0.870	-2.015	-0.471	-1.307
RIVER	0.831	3.770	-0.155	-0.741
FISC	-1.442	-2.166	0.991	1.705
TAX	-0.282	-0.811	0.122	0.432
PRODCR	-0.049	-0.154	-0.342	-1.229
MTBE	-0.007	-0.024	1.110	4.623
RI2000	-13.457	-3.991	-12.254	-4.020
RI FARMPROP	-3.091	-3.301	-3.044	-3.546
RI CATTLE	0.218	1.976	-0.135	-1.324
RI CORN	-0.004	-3.649	-0.003	-3.261
RI STORE	0.021	1.148	0.070	1.952
RI NATGAS	-0.036	-1.329	-0.028	-0.672
RI GAS	0.132	2.079	-0.118	-2.025
RI ESTAB	1.220	0.312	-1.709	-1.096
RI HERFEMP	-11.452	-2.451	-10.589	-1.927
RI WAGE	0.251	2.550	-0.093	-1.224
RI HS00	0.118	3.088	0.165	4.587
RI TRUCKLQ	-0.534	-2.489	-0.363	-1.961
RI ROAD	0.284	0.206	2.332	1.987
RI RAIL	4.988	4.456	2.221	2.284
RI RIVER	-1.781	-3.771	-0.088	-0.211
RI FISC	1.317	1.087	-2.810	-2.516
RI TAX	1.375	2.202	0.514	1.025
RI PRODCR	0.065	0.110	1.549	2.955
RI MTBE	0.737	1.446	-1.113	-2.480
N	3064			
Log likelihood	-584.152			
ρ	-0.988			
Psuedo R^2	0.229			

[a] T tests of 1.645, 1.961, and 2.577 are significant at the 10%, 5%, and 1% levels respectively.

Table 3. Marginal Effects[a]

Plant Announcements	Rurality Index				
Variable	0.0 - 0.2	0.2 - 0.4	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0
GAS	-0.000291	-0.001872	-0.000680	-0.000044	0.000044
FARMPROP	0.006735	0.043122	0.015460	0.000924	-0.001105
HS00	-0.000030	0.000412	0.000675	0.000232	0.000250
HERF00	0.022244	0.135197	0.042161	0.000233	-0.006582
RAIL	-0.001190	0.018250	0.029116	0.009924	0.010690
TRUCK	0.001188	0.007676	0.002811	0.000189	-0.000168
RIVER	0.006130	0.012140	-0.000995	-0.000874	-0.000820
CATTLE	-0.000075	0.000589	0.001143	0.000406	0.000446
CORN	0.000004	0.000011	-0.000007	-0.000005	-0.000006
TAX	-0.000373	0.004407	0.012129	0.007710	0.013862
Active Plants	Rurality Index				
Variable	0.0 - 0.2	0.2 - 0.4	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0
GAS	0.001027	0.001994	0.001082	0.000195	0.000443
FARMPROP	0.020623	0.036848	0.016915	0.001786	-0.008689
HS00	-0.000377	-0.000154	0.000473	0.000312	0.003017
HERF00	-0.012808	-0.081871	-0.099345	-0.040246	-0.319396
STORE	-0.000353	-0.000547	-0.000164	0.000025	0.000608
ROAD	-0.005071	-0.001575	0.007114	0.004527	0.043349
RAIL	-0.002365	0.004622	0.011387	0.005666	0.049718
TRUCK	0.002537	0.004587	0.002162	0.000255	-0.000774
TXEXC	0.006752	0.003491	-0.007374	-0.005103	-0.050047
CORN	0.000016	0.000025	0.000008	-0.000001	-0.000022
PRODCR	-0.001388	0.003350	0.013306	0.012205	0.012079
MTBE	0.038224	0.045907	0.019838	0.002861	0.003977

[a]The marginal effects of a location determinant are a continuous function of the rurality index. For the unconditional marginal effects of a continuous factor, see Greene, 1993

tive plants are presented in Figures 1 and 2. The differences between the two spatial distributions are worth noting. The estimated site selection probability clusters (in black) for active ethanol plants are fairly concentrated in the Corn Belt. The spatial distribution of the estimated site selection probability clusters suggests that some counties in Iowa, Southern Minnesota, Eastern and Western Nebraska, Southwestern and Southeastern South Dakota, the Northern half of Illinois, a small region of California, the Texas panhandle region, Northern Oklahoma, and the mid-region of Kansas exhibit qualities attractive for established ethanol plants. On the other hand, the spatial distribution of the estimated location probability clusters of ethanol plant announcements (also in black) appears to be more dispersed. Areas in Idaho, Southern Texas, Southern California, Arizona, Wyoming, Ohio, and Pennsylvania appear to be attracting new ethanol plant investment. Also, areas with low probabilities of attracting ethanol plants are less common in the plant announcement location probability clusters, suggesting that as profits continue to become realized and the ethanol industry becomes progressively saturated, prime locations will be occupied leaving plants entering the industry searching for second-best location alternatives.

Conclusions

This analysis used regression and spatial clustering techniques to isolate which location determinants were important with respect to attracting ethanol plant investment from the years 2000 to 2007. Many of the factors hypothesized to be important were statistically significant. The relevance of location determinants varied depending on the rurality of a county, and whether the plant was active or just entering the industry. Some rural areas exhibited comparative advantage with respect to attracting ethanol investment but it appears that the most rural communities may deter potential investment. The main drivers behind the decision to locate an ethanol plant are access to feedstock and the absence of previously established ethanol plants. In addition, access to coproduct markets and transport infrastructure is also important. Some

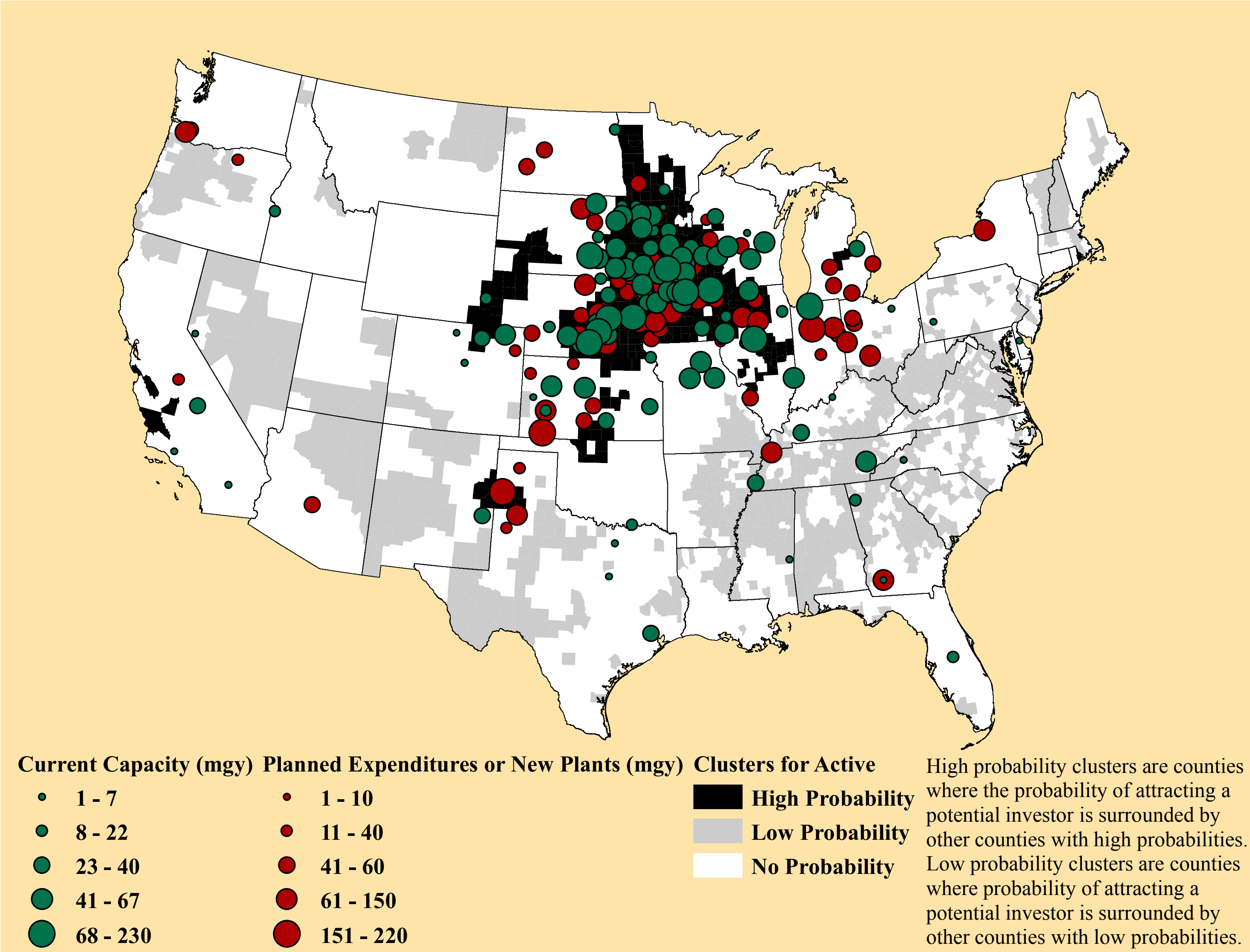

Figure 1. Established Plant Location Probability Clusters

infrastructure variables in rural areas, such as farm product storage operations and road density, were important determinants for established plants, but were not important for new plant announcements. This may be due to established ethanol plants occupying prime locations first, thereby leaving new plants to select more marginal sites. Local fiscal policy and state incentives influenced the location decisions of potential ethanol investors. There appears to be potential with respect to recruiting ethanol plant investment in some rural areas, but extremely remote areas may lack comparative advantage with respect to physical infrastructure and transportation capability.

These findings are a first-step towards understanding the interaction between ethanol plant location and local factors that provide comparative advantage to counties considering ethanol plant recruitment as a development strategy. The results are encouraging for some rural areas, but access to and the ability to provide desirable location determinants should be kept in perspective. Ethanol production is not a new technology, but the recent flurry of activity in the ethanol market indicates the industry is still in its infancy. As profit margins and access to prime locations wane, fewer firms will enter the market. As the controversy over rising fuel costs continues and demand for food and fuel from corn is pushed to the limit, the role of cellulosic feedstock will become increasingly important. Future studies analyzing location determinants will prove interesting as alternative feedstocks emerge in the ethanol industry.

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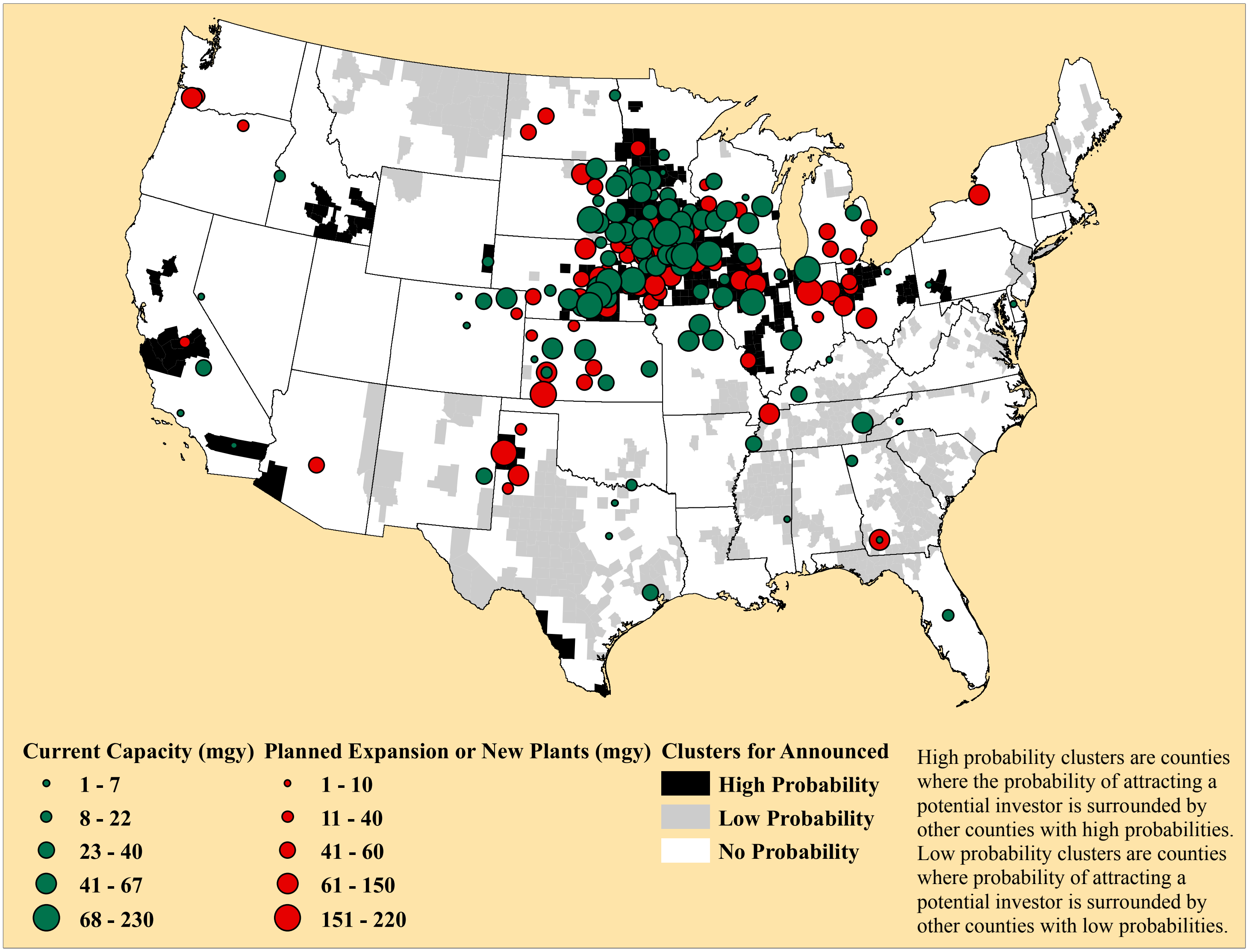

Figure 2. Announced Plant Location Probability Clusters

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Spatial Optimization and Economies of Scale for Cellulose to Ethanol Facilities in Indiana

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Introduction

Ethanol output has grown significantly in recent years, both in Indiana and across the United States. With the desire to promote cleaner, renewable fuels, both the federal and state governments have instituted subsidies intended to increase output. In December 2007, Congress passed and the President signed the "Energy Independence and Security Act of 2007", which contains a renewable fuel standard (RFS) requiring 35 billion gallons of ethanol by 2022, of which at least 16 billion must come from cellulosic sources (U.S. Congress, 2007). Additionally, recent increases in gasoline prices compared to the historically low prices experienced in the United States likely will continue to put upward pressure on the demand for substitutes. As less expensive production technologies in ethanol manufacturing come online, ethanol substitution levels in fuel mixtures may continue to increase.

While there is much excitement about this ethanol boom and the potential for profit, there are also undesirable outcomes for participants in closely related markets. Specifically, with corn being the primary input for the ethanol production process, livestock producers dependent on corn as a feed ingredient have been negatively impacted by rising corn prices. Such factors also impact food markets as higher costs for feed are passed on to consumers of chicken, eggs, dairy, beef, and pork through higher prices. Thus, while ethanol shows great potential as a cleaner fuel that could decrease U.S. dependence on foreign oil, there are concerns about how increased ethanol output levels and the induced demand for corn will impact the affordability of certain dietary staples.

Given the potential for adverse price effects in food markets, there is a desire to develop alternative sources of the raw materials needed for ethanol production. Materials rich in cellulose show great potential as ethanol feedstocks. Not only can they be converted to the necessary precursors for ethanol production, but many cellulose sources are natural byproducts of other farming and manufacturing processes. Corn stover and wood trimmings are two common examples of byproducts of corn farming and logging respectively (Perlack *et al*., 2005). Furthermore, some high energy sources of cellulose that would be grown as primary crops can be grown on terrains hostile to corn and other crops, thus in some cases being produced on currently uncultivated lands without having to displace food production.

Recently, the "Billion-Ton" study investigated the potential for U.S. grown biomass sources to provide enough ethanol to replace 30 percent of domestic fuel consumption (Perlack *et al*., 2005). In short, the authors conclude this would be feasible, with cellulose based sources making up a substantial portion of the over 1.3 billion dry tons of biomass resources projected to be available for conversion to fuels.

The state of Indiana has benefited from the push for ethanol and other biomass based fuels. The large quantity of farmland dedicated to growing corn has made Indiana an attractive site for the construction of conventional corn to ethanol dry grind manufacturing facilities. With the push for alternative biomass to produce ethanol, it is useful to begin assessing how Indiana can position itself to take advantage of cellulosic materials if the Billion-Ton study projections are correct. The Billion-Ton study anticipates that 18.3 million dry tons of cellulose feedstocks would be available in Indiana given proper land utilization. As these sources are developed, and firms begin to construct facilities for conversion to ethanol, there will be many questions affecting the welfare of firms and citizens alike. For instance, where should manufacturing facilities be located and how large should they be? Which locations will best take advantage of the cellulose source materials with respect to minimizing costs? What impact will a potentially large network of facilities have on our roads and highways? What will be the impact of new manufacturing facilities and some newly cultivated land on the Indiana job market and the environment?

The intent of this paper is to begin to answer some of these questions and to provide a framework for follow-up studies.

[1] Perkis is a Ph.D. candidate; Tyner is a Professor; Preckel is a Professor; and Brechbill is a Graduate Student, all respectively, in the Department of Agricultural Economics at Purdue University, West Lafayette, Indiana.

Specifically, it seeks to determine an optimal spatial distribution of ethanol plants within the state of Indiana given the projections of biomass availability projected by the Billion-Ton study and detailed cost information for harvesting, storing, and shipping biomass products (Brechbill and Tyner, 2008). Additionally, this paper provides guidance regarding the optimal size of ethanol facilities based on economies of scale. One of the key assumptions is that conversion facilities will use all of the cellulose materials grown within Indiana, and only these materials, in the production of ethanol. This is acknowledged to be a strong assumption, but one which should not dramatically alter the findings of the study. Since crop costs grow with increased shipping distances one would expect that only crops near the borders would be shipped across state lines, and there is no reason to believe that more crops would be shipped in one direction or the other. It is therefore believed that the impact of this assumption on the conclusions should be small.

Projections of optimal plant locations have been made in the past. Notably, Nelson projected plant locations across Indiana for 40 equal output sites (Nelson, 1981). However, Nelson focused on agricultural residues without taking into account cellulose source crops which are specifically grown for conversion to ethanol. Additionally, Nelson made regional assumptions of harvest rates not required here due to the detailed county level data provided by the Billion-Ton study. Given expected residue and crop outputs in this data, a specific county level analysis can be performed by combining the yield data with inter-county distances and transportation costs. Additionally, this paper considers some of the larger throughput rates anticipated to benefit from economies of scale based on historical experience from fermentation of corn-based sugars (Dale and Tyner, 2006).

Another series of papers exemplified by English, Menard, and De La Torre Ugarte (2000) has a broader scope by investigating the impact of corn stover and other biomass output expectations on the economies of several corn-growing states including Indiana, even including output prices and other factors for sensitivity analyses. However, the authors focus on economy wide results at the state level as opposed to county level output decisions, the main focus of this paper's spatial distribution plan. Additionally, this paper utilizes the most recent county yield estimates (Billion-Ton study) and biomass cost information (Brechbill and Tyner, 2008) for Indiana.

This paper will focus on the anticipated 14.6 million dry tons per year of corn stover and switchgrass available to be processed by biochemical conversion (Perlack *et al*., 2005). This process breaks the cellulose down to simple sugars using enzyme hydrolysis, and then ferments the sugars to produce ethanol. Enzymatic hydrolysis and fermentation are currently used to convert corn to ethanol and would be conducive to the cellulose sources considered in this study. These sources are corn stover, an agricultural residue from corn production, and switchgrass, a high energy primary crop (USDOE, 2006). In addition to considering the optimal spatial distribution and size of plants given the projections of the Billion-Ton study, an additional scenario will be tested making more conservative assumptions with respect to collection rates of corn stover, as well as land utilization and biomass conversion rates for both corn stover and switchgrass.

Methodology

Focusing on biochemical conversion facilities, it is assumed producers can utilize one of two plant sizes, a large plant (100 million gallons/year) or a small plant (50 million gallons/year), in order to convert Indiana's projected corn stover and switchgrass into ethanol. It is also assumed that this conversion process will be robust enough to handle either of the two feedstocks in varying proportions within one plant. While this might assume an optimistic level of manufacturing robustness, the key components of each material which are hydrolyzed are similar. It seems feasible that enzyme mixtures, as well as technological modifications of the crops themselves, could be developed to provide such robustness. Finally, the following simplifying assumptions are made: (1) each county will have at most one manufacturing facility, (2) the construction and operating costs are identical for each plant except for the biomass raw material costs and an economy of scale factor which will be represented by an added per gallon cost for the smaller plant, and (3) cost differences exist only in the growing (switchgrass), harvesting, and transportation costs of the biomass raw material mixture which is input into the process.

The objective for firms is to maximize their profit, which is revenue less costs. Since plants of modest size are assumed, individual plants should not have an impact on the price of ethanol and unit revenues are thus assumed to be identical for each site regardless of its location. Thus, to maximize profits, firms must focus on minimizing their costs. Since construction and operating costs are assumed to be identical for each site, optimization focuses on the production, harvesting and transportation costs of biomass. Specifically, how do the relative costs for each crop impact the choice of the input mix in order to minimize costs.

This model will assume that costs are minimized over all sites, even though each site may be owned by a different enterprise. While this appears to be more of a central planning solution than one of competitive firms maximizing profits, the general results should be similar, with plants locating based on the comparative advantages relative to surrounding counties (Nelson, 1981). In reality plants will likely contract for cellulose raw materials before the plant is even constructed. The early plants will locate in least cost areas and will contract for available raw material in those areas. Since the purpose of this exercise is to determine the use of all biochemically converted cellulose sources, it is assumed that the price of ethanol is sufficiently high that all plant sites are constructed and able to make a positive profit. Otherwise, not all sites would be constructed and continue operating. As sites are constructed to convert the total supply of materials, firms acting competitively will locate in order to minimize total costs.

The amount of dry biomass shipped between counties is designated X_{ijk}, where i is the set of counties where biomass is produced, j is the set of counties where ethanol is potentially produced, and k is the set of biomass feedstocks (corn stover and switchgrass). The relevant parameters for the cost minimization model are as follows:

p_k – production cost for biomass feedstock k ($/dry ton shipped with profit)

s_k – fixed shipping cost for biomass feedstock k ($/dry ton shipped)

f – freight rate for shipping biomass ($/dry ton shipped/mile)

d_{ij} – distance from county i to county j (miles)

C^p – added plant cost for a 50 Mgal facility (reflecting diseconomies of scale)

N – total plant capacity needed (100 Mgal/year)

l – fractional storage loss of biomass feedstock

b_{ik} – amount of biomass k produced in county i (dry tons/yr)

c_k – million gallons of ethanol per dry ton of biomass

The binary (0-1) variables I_j^{50} and I_j^{100} represent the number of 50 million and 100 million gallon ethanol plants respectively in county j, and the model is optimized by minimizing the total cost C as follows:

$$\min_{x_{ijk},I_j^{50},I_j^{100}} C = \sum_i \sum_j \sum_k \left(p_k + s_k + fd_{ij}\right) x_{ijk} + \sum_j I_j^{50} C^p$$

$$\frac{1}{2}\sum_j I_j^{50} + \sum_j I_j^{100} = N \quad \text{subject to:} \quad (1)$$

$$I_j^{50} + I_j^{100} \leq 1 \text{ for each j} \quad (2)$$

$$\sum_j x_{ijk} \leq (1-l) b_{ik} \text{ for each k and i} \quad (3)$$

$$\sum_i \sum_k c_k x_{ijk} \geq 50 I_j^{50} + 100 I_j^{100} \text{ for each j} \quad (4)$$

$$x_{ijk} \geq 0 \text{ for each i, j, and k} \quad (5)$$

$$I_j^{50} = 0,1 \text{ for each j} \quad (6)$$

$$I_j^{100} = 0,1 \text{ for each j} \quad (7)$$

The optimization problem has several constraints. Constraints 2, 6, and 7 imply that any county can have at most one plant of either size, 100 Mgal or 50 Mgal, and that fractional plants are not permitted. Constraint 1 requires that the total amount of ethanol produced will exactly exhaust the feedstock resource base. Finally, constraints 3, 4, and 5 require that the amount of biomass supplied by a county cannot exceed the amount available from the farms in that county after taking collection/storage losses into account, and the amount of biomass supplied to each manufacturing site must be sufficient to cover the production level. The problem is implemented using GAMS version 22.5 (Brooke *et al*, 2005).

To determine the sensitivity of the model to biomass availability and total statewide ethanol output levels, several of the strong assumptions of the Billion-Ton study are relaxed in a second application of the model, with each adjustment of assumptions resulting in lower ethanol yields for Indiana in what is considered a more conservative scenario. For instance, our base case assumes that all cropland is managed with no-till methods. When this assumption is relaxed, corn stover recovery rates drop from 70 percent to 52.5 percent (Table 1). Additionally, land utilization rates for the base case are assumed to be 100 percent whereas a rate of 75 percent in the second application recognizes that land owners may choose not to participate. Finally, conversion rates are decreased in the second application to reflect technical inefficiencies which are likely as manufacturing facilities begin to convert cellulosic biomass to ethanol for the first time (Tiffany, 2007).

Experience has shown that corn dry grind facilities are typically sized between 20 and 100 million gallons, with plants producing at or over 80 million gallons reaping most of the economies of scale associated with capital expenditures (Dale and Tyner, 2006). On a dry cellulosic biomass input basis, there is some evidence suggesting that economies of scale might be optimized when crossing over 2,000 metric tons per day, roughly equating to 65 million gallons per year (Huang *et al*., 2006). The plant sizes of 50 and 100 million gallons are chosen for simplicity. Aside from the belief that these will aptly represent the low and high economy of scale regimes, the fact that 100 is divisible by 50 provides some interpretive benefits to the model. Namely, investors deciding upon a single 100 Mgal plant or two 50 Mgal plants will have to weigh the tradeoffs between the economy of scale benefits of a larger plant and the reduced transportation costs associated with distributing production sites more broadly.

Given these plant sizes, assumed conversion rates, and the resource constraints, the maximum amount of ethanol expected to be produced in the base case is 1,050,000,000 gallons per year (Table 1). This number is very high compared to estimates developed in other papers which apply further constraints beyond the Billion-Ton study based on several present day realities. The recent work of Brechbill and Tyner (2008) is one example. Using the assumptions of the second application will allow for the effects of biomass density to be

Table 1. Indiana Ethanol Supply Capabilities from Major Cellulosic Sources				
	Billion-Ton Projection		Conservative Estimate	
	Corn Stover	Switchgrass	Corn Stover	Switchgrass
Projected Yearly Dry Tons of Biomass	9,887,958	5,348,497	6,206,723	5,348,497
Corn Stover Clearance (%)	70%	N/A	52.5%	N/A
Land-Use Rate	100%	100%	75%	75%
Adjusted Yearly Dry Tons of Biomass	9,228,761	5,348,497	3,258,530	4,011,373
Storage Losses	8.4%	8.4%	8.4%	8.4%
Ethanol Conversion (gal/dry lb biomass)	81.4	79.0	69.7	67.6
Volume Ethanol (mil gal/year)	688	387	208	248
Total Volume Ethanol (mil gal/year)	1,075		456	
Total Ethanol Assumed (mil gal/year)	1,050		450	

Sources: Projections are taken from the Billion-Ton study with no-till methods, adjusting for 70 percent corn stover harvest rate as opposed to 75 percent. Conservative estimates are taken from Billion-Ton study with current tillage methods, adjusting for 52.5 percent corn stover harvest rate as opposed to 75 percent. Ethanol conversion figures are taken from McLaughlin *et al*., 1999 and Spatari, Zhang, and Maclean, 2005 for the projects and from Tiffany, 2007 for the conservative estimate. Storage losses are calculated (see notes for Table 2).

tested, as 450,000,000 gallons are expected to be produced annually given the more conservative estimates of this scenario.

The costs being minimized are a combination of raw material costs, transportation costs, and economy of scale costs (the added cost of operating a small plant). Because corn stover is a residue, the cost of growing corn stover is only the marginal cost of additional fertilizer applied because of nutrients lost when the stover is removed. For the base case, harvesting, handling and storage costs are added, taking storage losses and a 15 percent profit premium into account, to provide a product cost of \$33.68 per dry ton of shipped material (Table 2). Harvesting costs assume a corn stover clearance level of 70 percent, with 30 percent remaining on top of the soil past the harvest. Bales are net wrapped to minimize costs during handling. Fixed and variable transportation charges are applied at a rate of \$2.20 per dry ton and \$0.15 per dry ton-mile respectively. Miles are measured as the distance between the county of the farm and the county of the

Table 2. Raw Material and Transportation Costs for Harvested Crops and Shipped Product				
	Billion-Ton Projection		Conservative Estimate	
	Corn Stover	Switchgrass	Corn Stover	Switchgrass
Seeding & Establishment Costs (\$/harvested dry ton)	0	4.51	0	4.51
Equipment Cost (\$/harvested dry ton)	1.86	1.31	1.86	1.31
Fertilizer/Herbicide Costs (\$/harvested dry ton)	15.63	15.41	15.63	15.41
Harvest Costs (\$/harvested dry ton)	5.25	2.88	4.85	2.88
Handling Costs (net wrap) (\$/harvested dry ton)	3.97	3.97	3.97	3.97
Storage (\$/harvested dry ton)	0.11	0.09	0.11	0.09
Land Rent (\$/harvested dry ton)	0	14.00	0	14.00
Total Raw Material Cost (\$/harvested dry ton)	26.83	42.17	26.43	42.17
Storage Losses (loss %)	8.4%	8.4%	8.4%	8.4%
Profit (% of raw material cost)	15%	15%	15%	15%
p_k: Total Raw Material Cost (\$/shipped dry ton w/profit)	33.68	52.95	33.18	52.95
s_k: Shipping Costs, Fixed (\$/shipped dry ton)	2.1962	1.8919	2.4466	1.8919
f: Freight Costs, Variable (\$/shipped dry ton-mile)	0.1498	0.1498	0.1498	0.1498

Sources: Raw material costs for corn stover and switchgrass, as well as shipping charges and storage/transportation losses, are taken from a concurrent Purdue University working paper (Brechbill and Tyner, 2008). All costs account for residence times of harvesting, storage, and transportation.

plant. This cost takes into account the round trip between the farm and the manufacturing facility. Similar estimates using the conservative assumptions of the second case can also be found in Table 2.

Switchgrass is grown as a primary crop, and therefore requires seeding and establishment costs not present for corn stover. Additionally, a land rental fee is assumed to represent the value of the land's next best alternative use. Adding these costs together with the harvest and storage costs, and assuming a 15 percent profit premium, results in a raw material cost of $52.95 per shipped ton. Shipping costs are then added in an identical manner to that of corn stover (Table 2).

Because transportation costs are based on the mileage between a farm in one county and a potential manufacturing site in another county, the distances between counties are required as part of the optimization problem. In this analysis, the distances between county seats are utilized as a proxy for transportation distances. Latitude and longitude coordinates were obtained for each county seat using arcGIS. Using these measures, the Haversine formula was implemented to determine the distance between county seats on the globe (Sinnott, 1984). Given that this method would produce no shipping charges for transit within a county, a distance of 10 miles is assumed for intra-county transportation.

As previously mentioned, a cost factor C^p is added for each facility, with the value equaling zero for a 100 Mgal plant and positive for a 50 Mgal plant. This factor represents the added cost of producing at a low output level and not taking advantage of the economies of scale. For instance, when producing ethanol from corn, the savings in capital expenditure is calculated to be on the order of $0.23 or greater when doubling the plant size from 50 to 100 million gallons (Dale and Tyner, 2006). Since C^p is included as an annual operating cost, it will have to be converted to a capital cost by implementing a financial analysis similar to those performed on corn ethanol plants. Specifically, what level of capital savings provides the same net present value (NPV) benefit as saving the added cost of C^p by operating at a larger level? Assumptions for the financial analysis are listed in Table 3.

It is expected that if C^p is set to zero for a 50 million gallon facility (i.e., no economies of scale), that only small facilities will be used in an attempt to spread production more broadly over the state and minimize shipping distances. As C^p increases, the ideal spatial distribution of facilities should include some larger plants as the benefits of running a large scale operation would outweigh the costs of longer shipping routes. Thus, the model will be optimized over various levels of C^p to determine at what level of diseconomy of size makes it preferable to utilize larger plants, either occasionally or throughout the state.

Results

The increase in capital expenditure needed to make large plant sizes economical is modest (Table 4). At a total capital investment (TCI) level just under $0.07 per gallon, at least three large plants are needed to minimize costs. Increasing TCI in very small increments results in optimized scenarios with more and more large plants until costs are minimized by operating as many large plants as possible (ten to be exact) at TCI levels of almost $0.17/gallon and higher.

Based on this cost minimization approach, a large number of counties chosen for the biochemical production of ethanol from cellulose sources (corn stover and switchgrass) are located in the top half of the state independent of the economies of scale. As Figure 1 demonstrates, when no economies of scale are assumed, all ethanol is produced using 50 million gallon plants, a majority of which are located in the northern half of Indiana, with roughly one third being located in the southern half (using Indianapolis in Marion County as an unofficial dividing line between the two halves). While the counties are spread out within regions, there are still several instances of neighboring counties having facilities, especially in the northwest region of the state. Several plant locations in the northwest tend to be the lowest cost operations in the state (Figure 1).

With respect to crop usage, there is a strong correlation between corn stover use and cost. As demonstrated by Table 5, which ranks the counties by corn stover use, the top five plants with respect to reducing costs all utilize the highest levels of corn stover. In fact, the ranking of cost reduction is almost identical to the ranking of corn stover usage, with plants incurring greater costs as they switch from corn stover to switchgrass. In fact, the highest cost plants are the three plants located in the southwest portion of the state (Figure 1)

Table 3. Assumptions for Financial Analysis to Annualize Economies of Scale[a]

Assumption	Value
Project Years	25
Start-Up Years/Operating Years	2/23
1st/2nd Year Capital Investment Split	40% / 60%
Investment Hurdle Rate (Real)	8.7%

[a]Would cover increased shipping distances associated with larger plant sizes.
Source: Assumptions taken from dry mill model (Dale and Tyner, 2006)

Table 4. Operating Cost Savings and Their Economy of Scale Equivalents[a]

Operating Costs, c_j^p ($/gal ethanol)	Economy of Scale[b] in capital Investment $/gal ethanol	Target Number of 100 Mgal Plants, High IN Output	Target Number of 100 Mgal Plants, Moderate IN Output
$0.000	$0.000	0	0
$0.003	$0.034	0	0
$0.006	$0.067	3	0
$0.009	$0.101	5	0
$0.012	$0.134	8	0
$0.015	$0.168	10	1
$0.018	$0.201	10	2
$0.021	$0.235	10	2
$0.024	$0.268	10	3
$0.027	$0.302	10	3
$0.030	$0.335	10	4
$0.033	$0.369	10	4
$0.036	$0.402	10	4

[a]Lead to the transition from 50 million gallon facilities to 100 million gallon facilities for the production of cellulose source ethanol.

[b]Economies of scale for ethanol from corn are over $0.23/gallon based on scaling up from a 50 Mgal facility to a 100 Mgal facility (Dale and Tyner, 2006).

and are the only three plants to use over 60 percent switchgrass.

This trend carries over into the larger economies of scale scenario in which as many plants as possible are of the large variety (Figure 2). In this scenario, the top four plants in corn stover use are in northwest portion of the state. The two highest cost plants are located in the southwest and utilize significant levels of switchgrass.

By relaxing some of the assumptions from the Billion-Ton study, less cellulosic biomass is produced and collected in each county, resulting in a drop of total ethanol produced in Indiana. In this case, the highest cost and lowest cost plants are located in the same regions as the base case with the low cost plants still using mostly corn stover and the high cost plants using the most switchgrass (Figures 3 and 4). However, with the lower density of cellulosic biomass materials, greater economies of scale are required to allow for large plant sizes to be produced. While economies of scale of $0.17/gallon ethanol allow for most plants to be converted to 100 Mgal facilities in the base case, this value only allows firms operating under conservative assumptions to consider such facilities in the low cost regions, with the full conversion to 100 Mgal facilities occurring at $0.33 / gallon ethanol (Table 4).

Discussion

The state of Indiana has a large potential for producing biomass sources containing cellulose, which can be biochemically converted to ethanol. This analysis optimizes the overall utilization costs of these biomass resources through the selection of optimal plant locations and sizes. However, this analysis is really a two-step optimization problem. The first step is performed by the Billion-Ton study, in which land utilization is optimized based on crop potentials and current land use. For instance, since switchgrass is not a residue but a primary crop, its production requires ground preparation, seeding, and land rental fees making it more costly to grow than corn stover which is a residue of corn. Currently it would be foolish to grow switchgrass on land capable of producing corn, as both corn and corn stover can be used to produce ethanol. Therefore, switchgrass would be chosen for lands less economically suited for producing corn. These factors are taken into account in the land utilization choices of the Billion-Ton study, which are therefore taken as a given, having already balanced the trade-offs between costs and benefits. While there are likely still arguments to be made for alternate land utilization strategies, they should not affect the general conclusions of this analysis.

From the analysis presented here, it is clear that current costs would dictate a high concentration of facilities within corn stover producing areas. There is ample corn stover in the

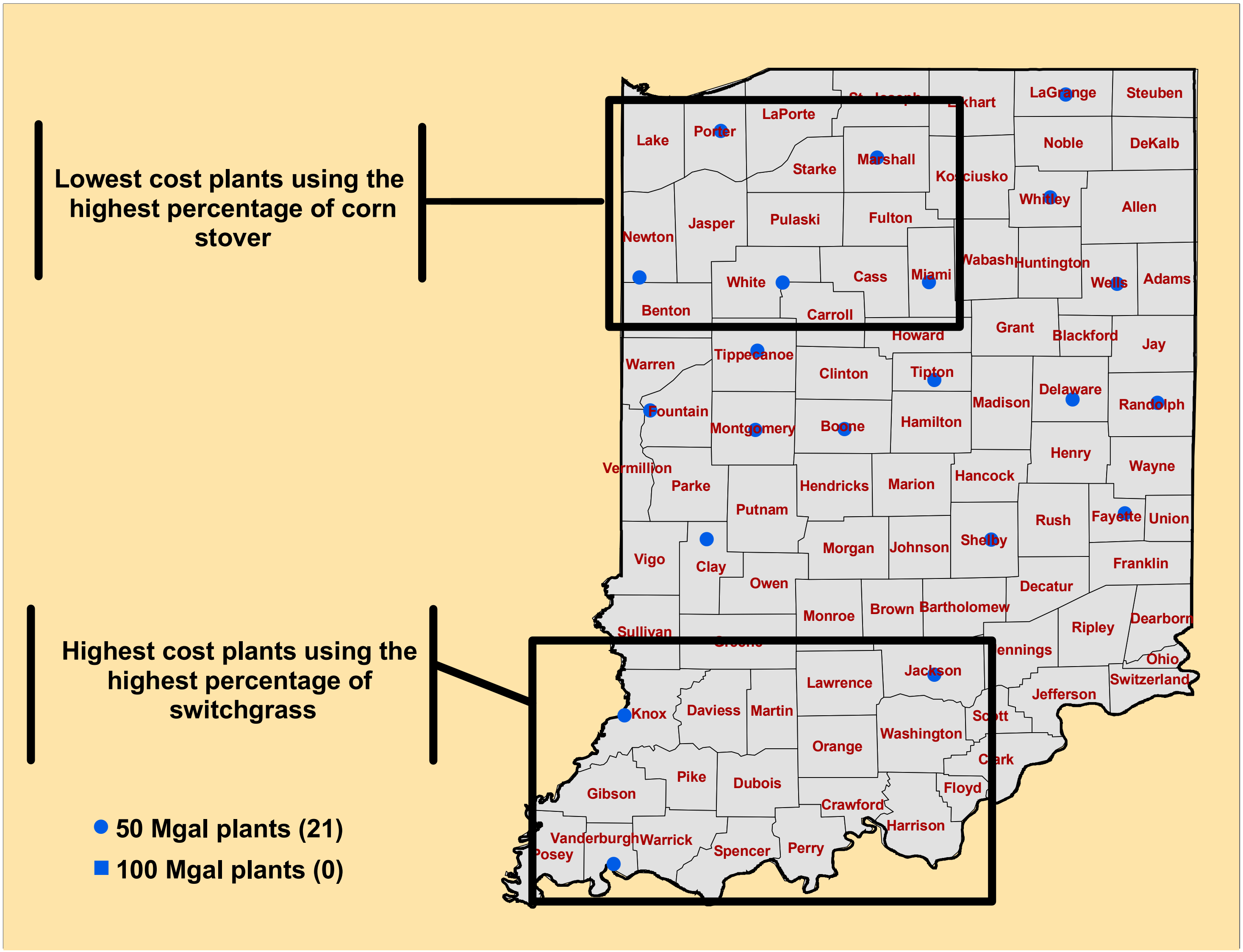

Figure 1. Optimal Counties of Manufacturing Sites for the Biochemical Conversion of Corn Stover and Switchgrass to Ethanol Based on Billion-Ton Study Projections and No Economies of Scale

northwest to support a proportionally large number of facilities, regardless of the assumptions. In areas where the land is better suited to growing switchgrass and corn stover is in short supply, raw material costs are higher due to the added costs of establishing, seeding, and renting the land. The facilities projected for two counties in the highlighted region of the southwest are prime examples, with the highest switchgrass level usage, very low corn stover farm yields, and the highest cost facilities.

If the assumed cellulosic source yields from the Billion-Ton study hold true, it is likely large plant sizes of 100 million gallons or more will minimize costs. The model predicts that economies of scale for TCI above $0.17/gallon ethanol would provide a sufficient incentive to outweigh increased shipping costs, and economies of scale for corn are at least $0.23 / gallon ethanol. Assuming that technological developments lead researchers to enzymes which can chemically break down cellulosic materials into fermentable sugars, the actual process differences between corn and cellulose conversion are (1) preparation of the material for the enzymatic conversion and (2) processing and use of the byproducts. If neither of these cause large differences in the cost structures for corn and cellulosic conversion, and assuming that yields are high enough to match the Billion-Ton study projections, then there likely would be more larger plants as suggested in Figure 2. However, another unknown is whether or not there will be diseconomies of scale due to the requirement for handling very large amounts of cellulosic materials. For example, a 100 million gallon plant with a yield of 70 gallons per ton operating 360 days per year 24 hours per day would need 3968 tons of raw material per day. Using 13 ton trucks, that amounts to over 300 trucks per day or 12 per hour (Popp and Hogan, 2007).

To the degree that the assumptions of the Billion-Ton study do not hold true, the results of the conservative scenario may be more applicable for predicting the spatial distribution

Table 5. Cost Ranking and Biomass Percentages for Each Plant Site Based on Cost Minimization Procedure[a]

Plant Location	Low Cost Ranking[b]	% Ethanol from Corn Stover[c]	% Ethanol from Switchgrass
Marshall	2	99%	1%
Porter	4	97%	3%
White	3	97%	3%
Newton	1	95%	5%
Miami	5	94%	6%
Shelby	6	85%	15%
Tipton	7	83%	17%
Tippecanoe	8	76%	24%
Boone	9	76%	24%
Randolph	10	64%	36%
Lagrange	11	63%	37%
Montgomery	13	61%	39%
Wells	12	59%	41%
Whitley	16	51%	49%
Delaware	15	51%	49%
Fountain	14	49%	51%
Fayette	17	48%	52%
Clay	18	41%	59%
Knox	19	38%	62%
Vanderburgh	20	24%	76%
Jackson	21	24%	76%

[a]Billion-Ton assumptions without economies of scale.
[b]1 is the lowest cost plant and 21 is the highest cost plant.
[c]While plants using close to 90 percent or higher of corn stover are likely to operate with this single input, no such restriction was placed on the model.

and size of plants. For instance, if no-till methods are not implemented or a significant proportion of land owners do not employ their land in the production and harvesting of cellulosic biomass, then economies of scale of a 100 Mgal facility may not be sufficient to cover the costs associated with the larger shipping distances which would be required to collect material. In this scenario, if economies of scale were similar to corn, it is likely that one or two large plants could be supported in the corn stover rich part of Indiana, with smaller plants filling out the rest of the state (Table 4).

An assumption was made pertaining to the robustness of manufacturing facilities and their ability to handle various proportions of the two major biomass sources. It may turn out that facilities are constructed to handle only a single biomass feedstock. However, this should not alter the main conclusions presented here. A firm wanting to convert only corn stover would most likely locate in the northwestern part of the state where corn stover supplies are ample, while a firm focusing on switchgrass conversion would likely locate in the south. All the crops should still be utilized based on the assumption that ethanol prices are high enough to yield any facility operator a positive profit, regardless of the crop type used. Producers utilizing higher cost crops would simply have lower profits.

Finally, the issue of naming specific counties as being "ideal" for ethanol production facilities could be misleading. Other than anticipated crop yields and distances between counties, no data was collected on any distinguishing characteristics of the counties such as infrastructure, local government incentives, or industrial zoning. A small change in raw material production costs or shipping charges could easily shift the ideal location for a facility into a neighboring county. The important conclusions here pertain to the quantity and spatial distribution of plants within certain regions of the state and the costs of operating in those regions more than the exact counties where sites might be located in the future. Additionally, as switchgrass and other primary cellulosic sources continue to be developed and optimized for the specific purpose of ethanol production, further shifts in ideal plant locations are likely to occur.

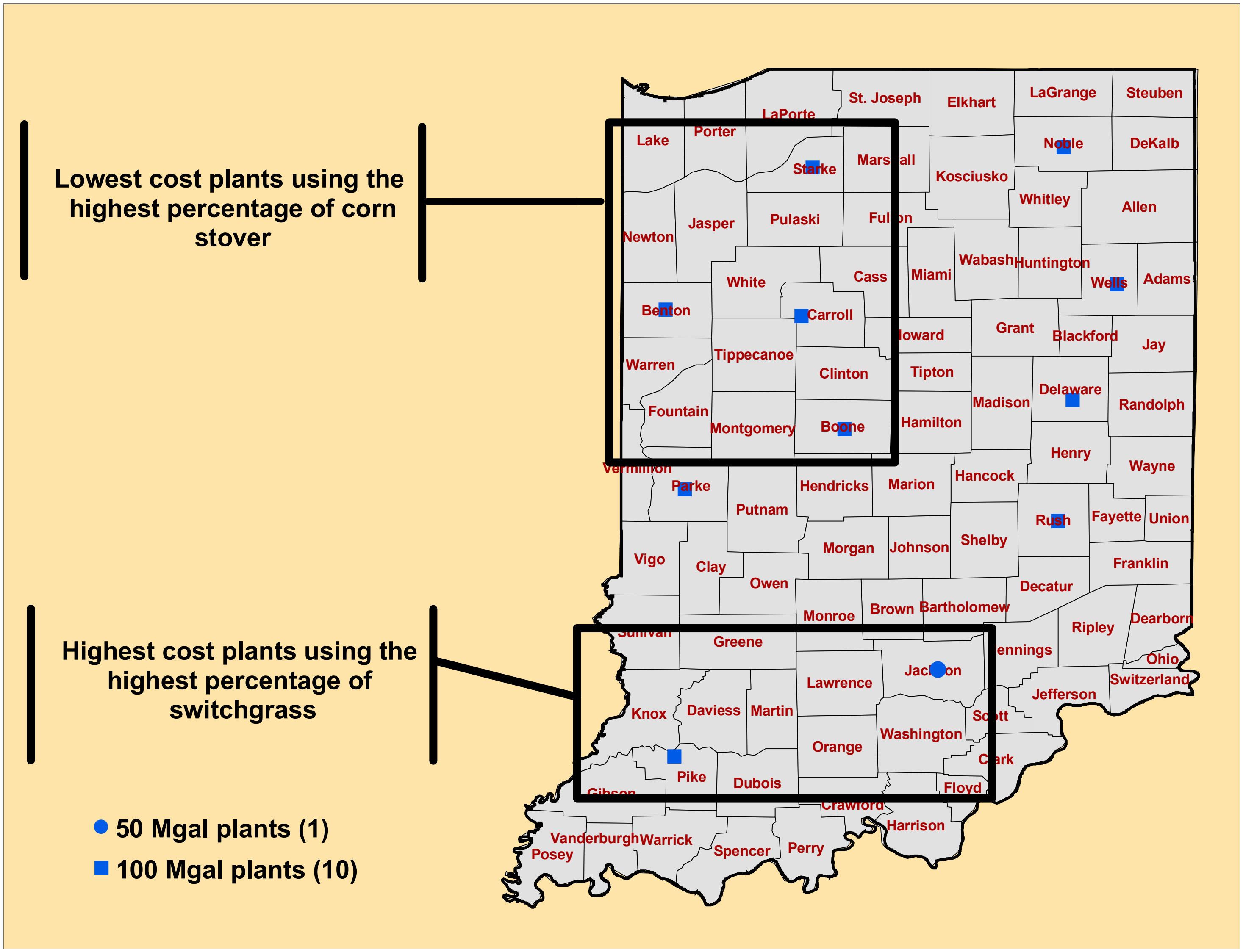

Figure 2. Optimal Counties of Manufacturing Sites for the Biochemical Conversion of Corn Stover and Switchgrass to Ethanol Based on Billion-Ton Study Projections and Economies of Scale

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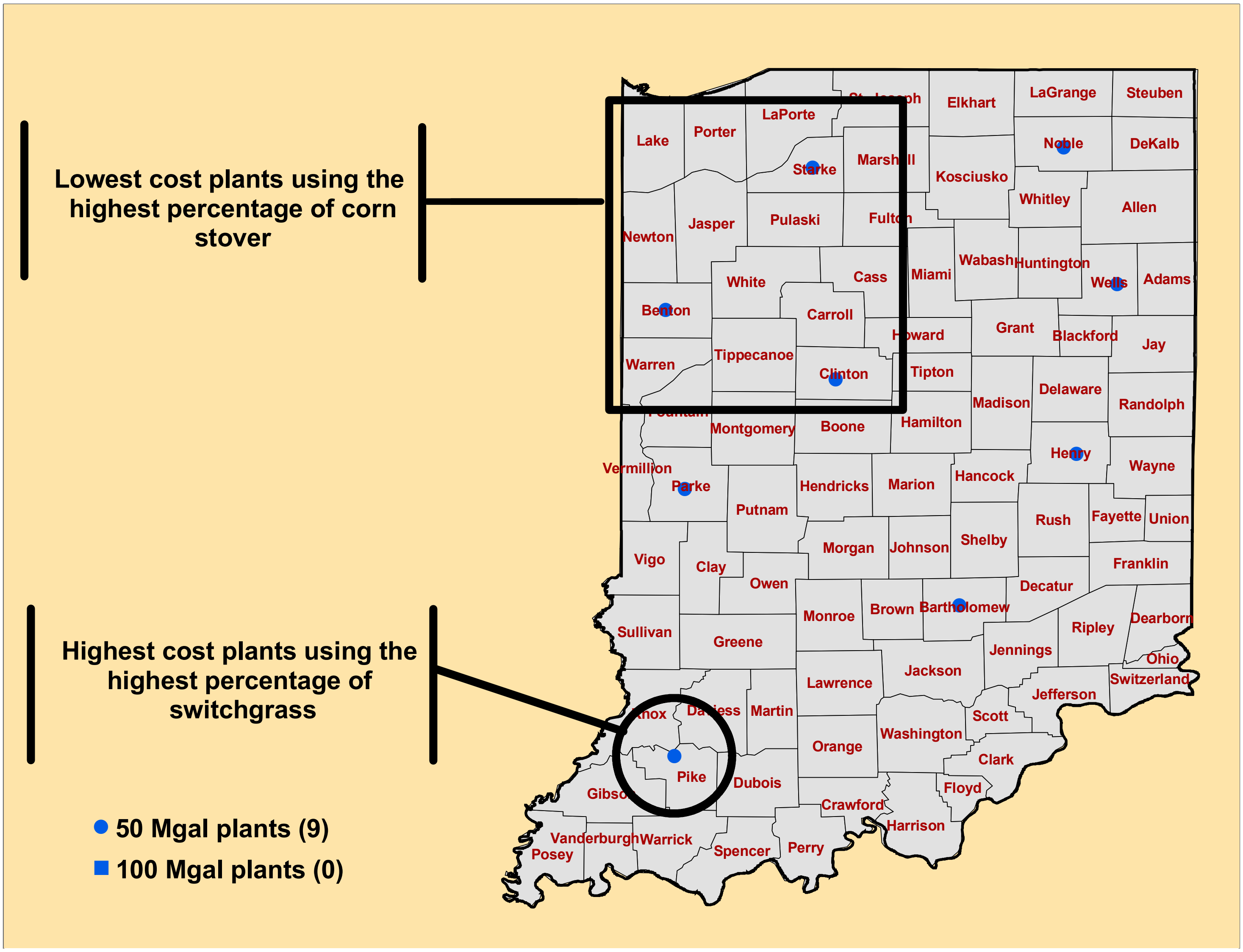

Figure 3. Optimal Counties of Manufacturing Sites for the Biochemical Conversion of Corn Stover and Switchgrass to Ethanol Based on Conservative Total Yield Estimates and No Economies of Scale

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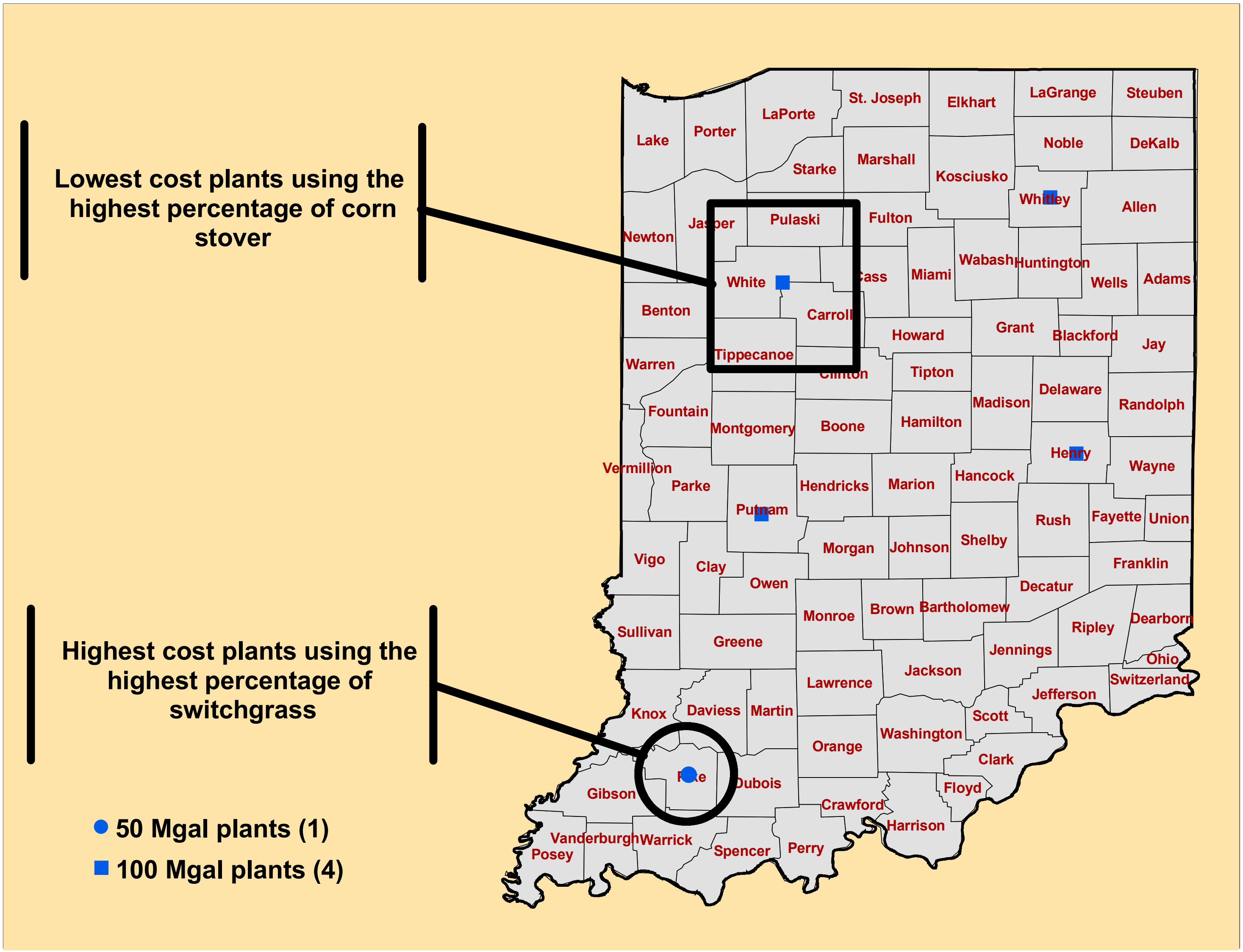

Figure 4. Optimal Counties of Manufacturing Sites for the Biochemical Conversion of Corn Stover and Switchgrass to Ethanol Based on Conservative Total Yield Estimates and Economies of Scale

Economic Feasibility Of Supplementing Corn Ethanol Feedstock With Fractionated Dry Peas: A Risk Perspective

Cole R. Gustafson, Scott Pryor, Dennis Wiesenborn, Abhisek Goel, Ron Haugen, and Andrew Wilhelmi[1]

Introduction

North Dakota ranks 12th in national production of ethanol with four operational plants and three additional plants under construction (Renewable Fuels Association (RFA), 2007). Growth of the corn-based ethanol production has contributed to increased corn demand and prices. In North Dakota, ethanol plants face great feedstock supply risk as corn production in the region is highly variable due to the state's arid and northern climate.

Fractionated dry pea, or field pea (*Pissum sativum* L.), are a potential ethanol feedstock replacement alternative for corn. This interdisciplinary study develops an engineering process model of pea fractionation, quantifies fractionation process costs, and determines if pea fractions enhance corn ethanol fermentation. Results are used to form a stochastic simulation model of a typical 100 million gallon per year (mgy) ethanol plant that evaluates the profitability and risk of using fractionated peas as a partial feedstock replacement for corn in the proportion of 10 percent in an effort to mitigate rising corn prices and supply risk.

Background

An extensive body of research has been reported on the fractionation of peas for human consumption (Fedec, 2003; Owusu-Ansah and McCurdy, 1991). Dry peas can be fractionated by either wet milling or dry milling with air classification. Wet processing is used to produce more highly purified protein and starch, but this process is more difficult and requires higher amounts of energy for drying and refining of effluent streams. Dry milling is less expensive to build and operate, and is effluent free (Emami and Tabil, 2002; Nichols *et al*, 2005).

Nichols *et al*., (2005) investigated the actual ethanol yield of starch-enriched field peas in a laboratory setting and found the yield to be 0.48 g ethanol/g pea starch, which is 85 percent of the theoretical yield. Therefore, if the whole pea were used, and assuming 46 percent starch on a dry basis, and allowing for the typical efficiencies of conversion, production of 3.4 gallons of ethanol from 100 pounds of field peas could be expected. Although, the general ability of the pea starch to be fermented has been shown, no controls using ground corn were used for rate and yield comparisons. Further, cost estimates of the fractionation process were not provided.

Similarly, few economic models have embodied corn ethanol supply risk. Tiffany and Eidman (2003) developed a deterministic model to assess ethanol plant profitability and scale economies. Larson, English, and He (2008) examined the effect of alternative contracting mechanisms on ethanol plant feedstock supply risk. However, the focus was on a cellulosic ethanol plant and did not address increasing supply risk facing traditional corn ethanol plants.

The objective of this study is to test the hypotheses that pea fractions compete economically with corn, reduce corn ethanol plant supply risk, and lead to increased corn ethanol plant efficiency.

Economic Corn Ethanol Plant Simulation Model

The economic corn ethanol plant simulation model is structured assuming the operation of the plant will be to maximize expected profit. Profit is set equal to gross revenue minus variable cost minus fixed costs. Gross revenue (GR) of an ethanol plant is modeled by summing the revenue from selling three outputs: ethanol, dry distillers grains with solubles (DDGS), and protein from the pea fractionation as follows:

$$\hat{G}\hat{R} = \hat{P}_1 Q_1 + \hat{P}_2 Q_2 + \hat{P}_3 Q_3$$

where Q_1 is the number of gallons of ethanol produced, P_1 is price of a gallon of ethanol, Q_2 is the quantity of DDGS produced, P_2 is the price of DDGS, Q_3 is the quantity of pea protein produced, and P_3 is the price of pea protein sold. Ethanol,

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DDGS, and pea protein prices are all stochastic. Variable costs (VC) of producing ethanol include:

$$\hat{VC} = \hat{W}_1 + \hat{W}_2 + E_1 + E_2 + L_1 + Y_1 + C_1 + H_1 + M_1 + M_2 + F_1$$

where W_1 is cost of dry peas, W_2 is the cost of corn, E_1 cost of energy (both natural gas and electricity), E_2 cost of enzyme, L_1 cost of labor, Y_1 cost of yeast, C_1 cost of other chemicals, H_1 cost of water, M_1 miscellaneous expenses, M_2 plant maintenance and repair expenses, F_1 expenses related to licenses and fees. Fixed cost can be calculated as follows:

$$FC = D_1 + I_1$$

where, D_1 is depreciation expense and I_1 is interest expense on debt finance.

Distributions of net returns over variable costs were obtained from the iterations of the model for each pea supplementation strategy[2]. The variability of each random variable was simulated using Monte Carlo procedures in @Risk (Palisade Corporation, 2007). Five thousand iterations were conducted, at which the stopping criteria were satisfied. BestFit, a distribution estimation procedure contained in @Risk, (Palisade Corporation, 2007) was used to estimate the statistical distributions of these variables.

Empirical estimation of the model required specification of an engineering process model for the pea fractionation, determination of pea fractionation operating and investment costs, impacts of pea fractions on the efficiency of corn fermentation, and calibration of the pea/corn ethanol simulation model with local empirical data. Each of these is discussed in the following subsections.

[2]A detailed mathematical model, list of data sources, and summary statistics regarding distributions of stochastic variables is available from the senior author.

Engineering Process Model

An engineering process model was developed to determine economic investment and operation costs of fractionating dry peas (Figure 1). The model consisted of 6 distinct steps resulting in 16 different product streams.

Detailed methods regarding construction of the engineering process model for fractionating field peas, equipment specifications, and model results are reported by Wilhelmi *et al*. (2007). The model indicates that 35,000 lb/h (dry basis) of peas are needed in this plant to replace 10 percent of the corn feedstock on a starch basis. A single-stage fractionation process produces 26,000 lb/h starch-rich fraction for blending with corn, and 11,000 lb/h protein-rich fraction.

Process Cost Analysis

Two leading manufacturers of milling and air classification equipment provided detailed operating and investment cost information for the fractionating process. However, these companies provide equipment that is typically scaled for the food processing industry (13,000 lb/hr) which would not be of sufficient scale for a large ethanol plant. In order to process sufficient quantity of peas for a 100 mgy ethanol plant operating with a 10 percent pea starch feedstock, the use of three parallel sets of pin mills and air classifiers were modeled. Operating and investment costs for a single unit were tripled to determine final pea fractionation costs for a plant that was capable of processing 35,000 lb dehulled peas/hr.

The cost of equipment for unloading, cleaning (including magnetic separator), destoning, and dehulling was estimated at $1.6 million (Weber, 1987, with equipment cost indexing to 2006). Thus, total direct handling and fractionation equipment costs ranged from $6.1 to $7.0 million. A cost factor

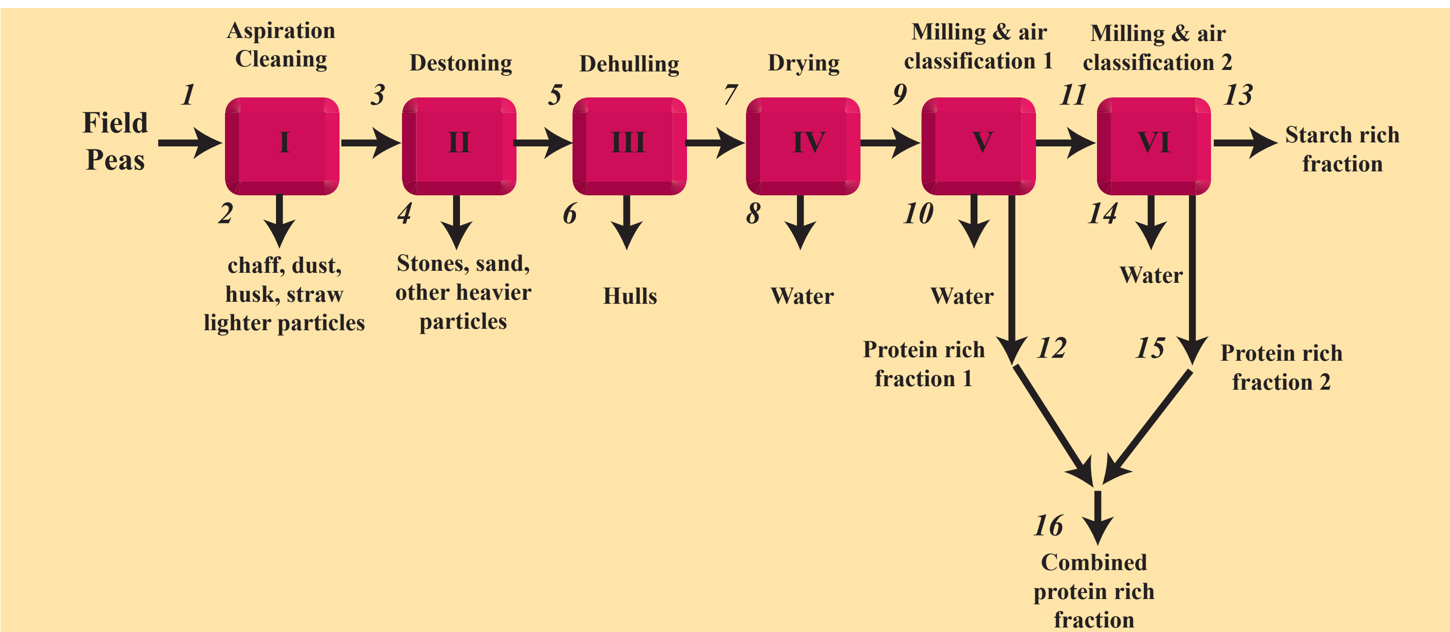

Figure 1. Process Diagram for Dry Fractionation of Field Peas

of 4.55 was used to extrapolate direct equipment cost to total plant costs (Peters, Timmerhaus, and West, 2003), which includes equipment installation, instrumentation, piping and electrical, buildings, yard improvements, service facilities, land, engineering and supervision, construction, contractor's fee, contingency and working capital. Thus, total fixed-capital investment for the pea-fractionation plant was estimated to be $28 to $32 million.

Enhanced Fermentation Productivity With Pea Starch

Several fermentation trials were conducted to evaluate fermentation kinetics, rate, and final yields of supplementing corn feed stock with varying proportions of pea starch (Pryor, Lenling, and Wiesenborn, 2008). The laboratory-scale dry mill fermentation protocol used was a scaled-down process based on that reported by Singh *et al*. (2005). Figure 2 shows the estimated ethanol yields using a carbon dioxide evolution method from initial fermentation experiments with pea starch replacing a portion of corn feedstock. This simple evaluation method estimates ethanol production based on weight loss during fermentation. The weight loss is assumed to be carbon dioxide evolution which can then be related to ethanol production. The method tends to slightly overestimate actual ethanol production because of loss of other volatiles such as ethanol and water vapor; these losses are erroneously quantified as carbon dioxide evolution and contribute to higher ethanol production estimates. Several follow-up experiments were completed using analysis with High Performance Liquid Chromatography (HPLC) to confirm the trends found using this method (Pryor, Lenling, and Wiesenborn, 2008).

As seen in Figure 2, fermentation rates appear to be more rapid with increasing proportions of pea starch. Yields follow a similar trend although the mean yield for the 10 percent pea starch fermentations was slightly higher than that for a 30 percent supplementation. Although final yields between control and experimental treatments were not statistically different at the 95 percent confidence level (p=0.098), fermentation rates are higher for pea-starch treatments and there is potential for reducing total fermentation times without negatively effecting yields. Reduced fermentation times could lead to increased ethanol plant capacity because more batches could be completed annually with a fixed sized plant.

The economics of a large-scale ethanol plant depends heavily on both rates and yields of ethanol from incoming feedstocks. Based on a 13 percent final ethanol concentration, a 0.5 percent difference in ethanol concentration would lead to a 4 percent change in annual capacity. Similarly, a difference of one or two hours in a 50-hour fermentation can have measurable consequences over the course of a year. Therefore, ethanol plant efficiency was assumed to increase 10 percent in this study when pea starch was substituted for 10 percent corn feedstock. This assumption of increased efficiency lowered per gallon cost of ethanol as investment costs were spread over greater production.

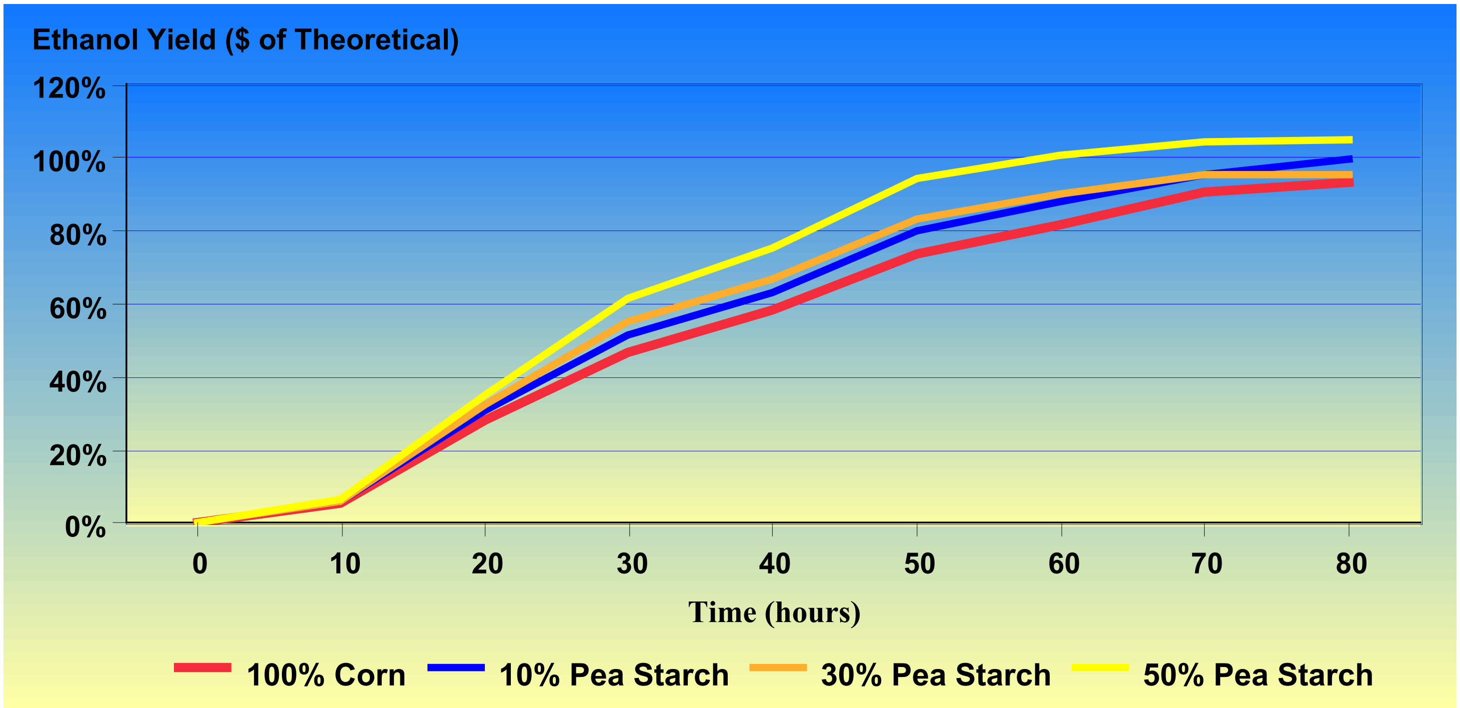

Figure 2. Estimated Ethanol Yields of Corn/Pea Starch Co-fermentation Based on Weight Loss Throughout Fermentation. Note: Ethanol yeilds are expressed as a percentage of yields expected if all starch present was fermented to ethanol.

Calibration Of The Empirical Model With Local Data

A stochastic profitability model of a 100 mgy ethanol plant was constructed to simulate net profit of three alternative options of supplementing corn feedstock with fractionated dry peas in proportions of 0 percent, and 10 percent. Risks included in the model were variability in both output and raw material prices as well as feedstock supply uncertainty. In particular, prices of ethanol, DDGS, corn, and dry peas were stochastic as were production yields for corn and peas. The model is calibrated with local yield distributions, prices, and production cost information from central irrigated (corn) and western dryland (pea) regions of North Dakota.

Data used to calibrate the stochastic model were obtained from various sources. Monthly average inflation adjusted ethanol rack prices for the period 1982 to 2006 as reported by the Nebraska State Government Energy Office (2007) because North Dakota does not have an active market for ethanol. Ethanol produced in the plant is sold locally at this price as basis is negligible. Monthly average inflation adjusted wholesale cash prices of DDGS from 1981 to 2006 at Lawrenceburg, Indiana provided data to estimate the DDGS price distribution. Again, DDGS are sold locally so transportation costs and basis are assumed to be negligible. Monthly North Dakota corn prices were collected from historical National Agricultural Statistics Service (USDA-NASS, 2007) data from 1985-2007 to estimate the price distribution. However, given recently strong corn prices, the mean corn price was increased to $3.50 in the base model. Moreover, a $0.10/bu price increase reflecting basis change was added to incorporate the impact a new ethanol plant has on local corn prices (McNew and Griffith, 2005). Likewise, the pea price distribution was estimated in a similar manner with 2000-06 NASS data (earlier data were not collected), and the mean pea price increased to $7.50/cwt, reflecting current market prices and parity with a corn price of $3.50. The value of the enriched fraction of pea protein is assumed to equal soybean meal (Lardy, 2007). The prices of enzyme, yeast, chemicals, water, labor, management and quality control, maintenance, miscellaneous expenses, licenses, fees and insurance for a gallon production of ethanol were obtained from Tiffany and Eidman (2003).

Corn yield distribution was based on annual county-level production data for the period 1964- 2006 (USDA-NASS, 2007) from counties within 60 miles of the plants location (Jamestown, North Dakota). A plant located in this region of irrigated and dryland corn production could expect to source 77 percent of needed corn from the area (Johnson, 2007). The remainder is transported from eastern North Dakota at an additional cost of $0.20/bu. In years when production surrounding the plant is below the historic average, additional corn is imported posing a supply risk to the ethanol plant. The value of corn supply risk is assumed to be the quantity of additional corn needed to be imported multiplied by the additional transportation cost and prevailing price. The distribution of pea yields was also estimated with 1964-2006 NASS data from producing counties in North Dakota.

Technology, investment and financial assumptions regarding the ethanol plant were: 1) the cost of building a plant is assumed to be $1.02 per gallon capacity for a 100 million gallon per year plant (Eidman, 2008), 2) the plant is capitalized with both equity (40 percent) and debt (60 percent), 3) the plant is expected to produce 2.75 gallons of ethanol and 18 pounds of DDGS per bushel of corn (Eidman, 2008), 4) the plant is expected to produce 5.30 gallons of ethanol per 100 pounds of dry peas (Nichols *et al*., 2005), and 5) the plant life is expected to be 15 years (Tiffany and Eidman, 2003).

The substitution of dry peas for corn in the ethanol production process increases the rate of fermentation decreasing the time taken to produce ethanol. Therefore, the 100 mgy ethanol plant was assumed to have higher efficiency with production capability increasing to 110 mgy. The plant processing dry peas will have a higher output while additional capital cost is expected for the cost of pea fractionation equipment. In addition, the value of DDGS also changes with pea supplementation. The plant scenario producing ethanol with 10 percent of its corn being replaced with dry peas is expected to produce 2.03 per gallon of ethanol per bushel of dry peas, 2.59 gallons of ethanol per bushel of corn, and 17.37 pounds of DDGS per bushel of corn (Wihelmi *et al*., (2007). Finally, estimated correlations between yields and prices of corn and dry peas were not included due to lack of significance. They were not expected to be significant given the local nature of this study.

Economic Results

Economic results for the base 100 mgy ethanol plant located in central North Dakota that uses 100 percent corn for its feedstock is marginally unprofitable at a local net price ratio of corn ($3.50/bu) and ethanol ($1.38/gal).[3] When the plant is simulated stochastically, results show it is losing $0.15/gal of ethanol produced after all variable and fixed costs of production are deducted. The net profit distribution in Figure 3 shows that the plant profit is expected to be from -$0.61/gallon to $0.52/gallon at a 90 percent of probability as depicted in the distribution of net income (Figure 3).

Inclusion of supply risk raises costs as the firm faces an expected corn supply risk of $0.009/gal of ethanol produced on an on-going basis because local corn production in the surrounding region periodically falls below historical average as displayed (Figure 4).

[3]An enterprise budget detailing revenue, costs, and profit for both the 100 percent corn and 90 percent corn-10 percent pea scenarios that are input into the simulation models are available from senior author upon request.

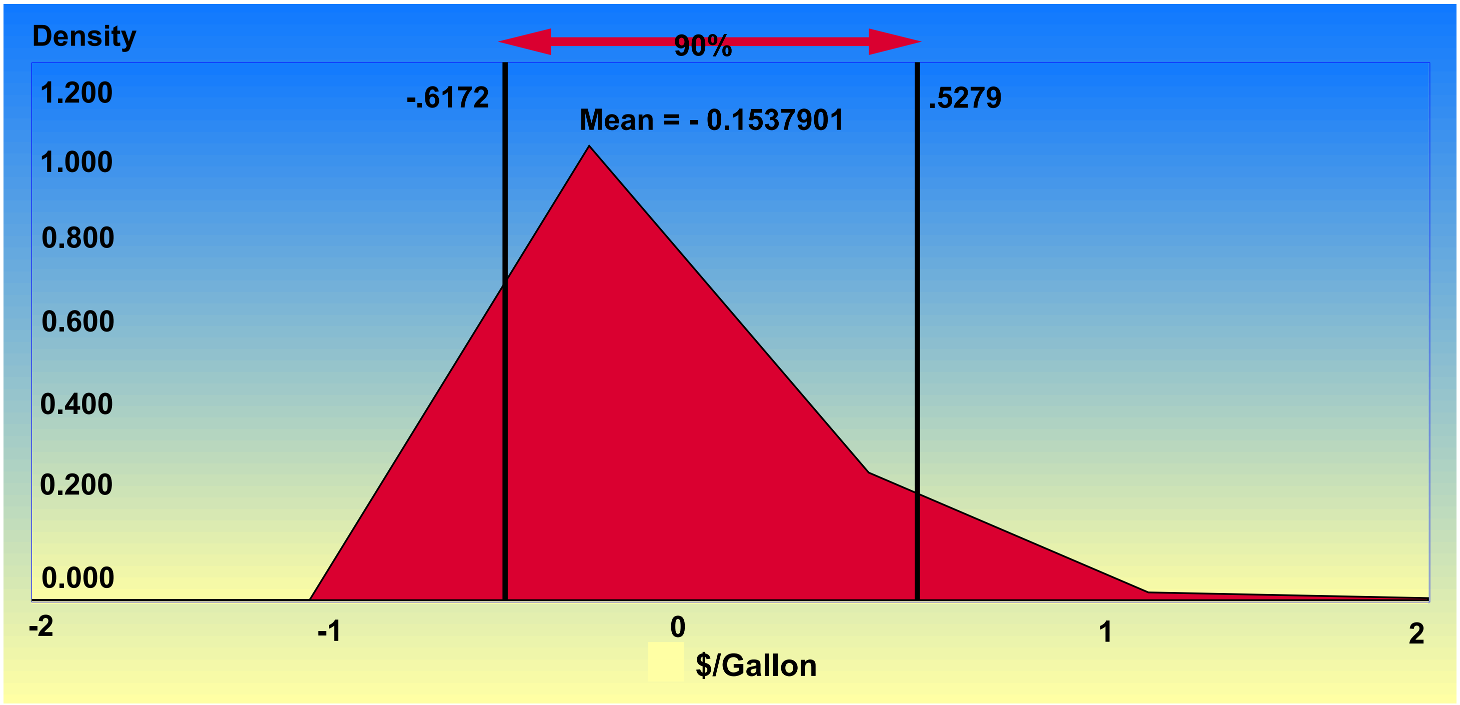

Figure 3. Distribution of Ethanol Plant Net Income/Gallon, 100 Percent Corn Feedstock

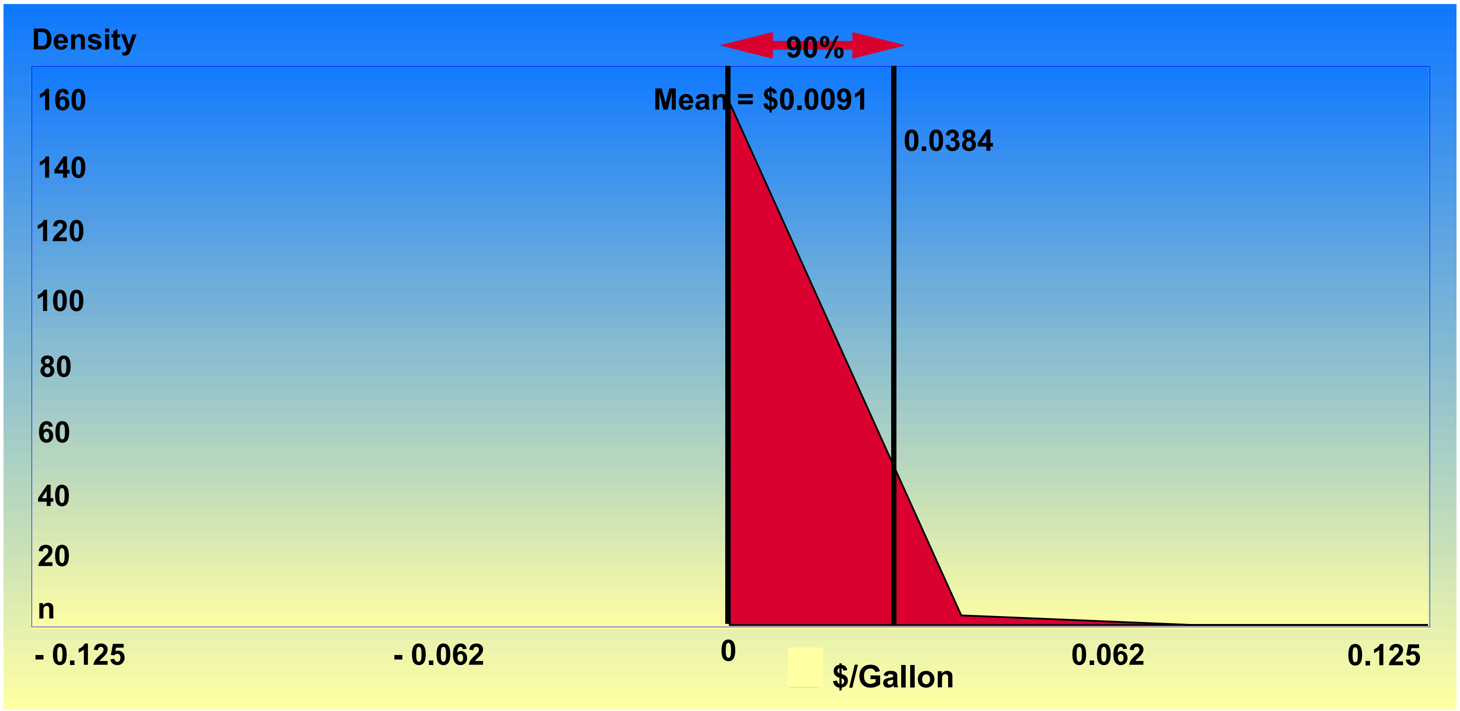

Figure 4. Ethanol Plant Corn Supply Risk, 100 Percent Corn Feedstock

The distribution of the supply risk (Figure 4) showed the processor incurred additional hauling costs of $0.009 gal/ethanol produced, on average, because corn production in the region periodically falls below historical average production. While corn is the largest cost item for an ethanol plant, this level of supply risk is negligible due to the plant's location in a region of irrigated corn production. The sensitivity of corn supply risk was tested by constraining local supply even further with the assumption that only 50,000 bu. of corn was available locally instead of 70,000 bu. This raised corn supply risk an additional $0.01/gal and reduced ethanol plant profitability from $-0.14 to $-0.15.

Profitability of the ethanol plant is highly sensitive to corn prices. When corn prices drop 40 percent to $2.16/bu., ethanol plant profitability improves to $0.412 per gallon. However, as corn prices increase 40 percent to $5.04/bu., plant profitability quickly erodes to $-0.70 per gallon. Breakeven corn price is just under $3.24/bu. after all variable and fixed costs of production are deducted.

Substitution Of Ten Percent Peas For Corn

Despite the assumption of increased plant efficiency, the replacement of 10 percent of the corn feedstock with pea starch leads to lower plant profitability. The investment cost of fractionation equipment to process the quantity of peas needed to replace 10 percent of the corn utilized in a 100 mgy ethanol plant totals $28 million. At present corn, pea, and investment prices, expected ethanol net income averages $-0.43 per gallon of ethanol produced when 10 percent of the corn feedstock is replaced with peas. The large investment cost required due to use of three smaller processing mills are not offset by lower pea prices. The distribution of 10 percent pea net income is shown in Figure 5. The net profit distribution shows that expected profitability of the plant ranges from - $0.91/gallon to $0.27/gallon with 90 percent of probability.

Not only are expected profits lower, but the variability of profits increase due to more variable pea production and prices. The replacement of corn with 10 percent peas does partially mitigate firm supply risk as shown in Figure 6. Overall corn supply risk decreases by $0.001 as dry peas are substituted for 10 percent of corn.

However, the displaced corn has a negligible impact on profits due to the higher total cost of using peas. Net income per gallon of ethanol produced with 10 percent peas is still highly sensitive to corn prices. At present corn and pea prices, corn prices would have to rise to $4.34 for peas to become breakeven with corn (e.g. point at which net income with 100 percent corn falls to $-0.431).

Investment cost of fractionation equipment could be an important determinant of profitability. As noted earlier, commercial scale equipment to support a 100 mgy ethanol plant is presently not available. Thus, a smaller pea fractionation system was replicated 3x to meet plant needs. As industry demand for larger fractionation equipment evolves, investment cost per dry weight of peas processed will likely fall, which in turn would increase plant profitability. To gauge the sensitivity of peas to fractionation equipment investment costs, additional model runs were performed assuming investment costs dropped 10-90 percent from the base cost of $28 million. Results show that a 10 percent discount in pea fractionation investment cost has only a marginal impact on ethanol plant net income as profits only increase $0.003/gal. Even a 90 percent drop in pea equipment investment raises net income only $0.40/gal to $-0.031/gal.

The viability of pea supplementation likely depends on potential changes in the feed value of the DDGS. Peas may have a positive benefit, because of enhanced lysine, which is the limiting amino acid for at least some feeds. It is unknown however whether lysine is influenced by fermentation.

Conclusions and Recommendations

Fermentation analyses in this study show that supplementing corn in a conventional dry-grind ethanol plant with a starch-enriched product from fractionated field peas should have neutral or slightly positive impact on ethanol production

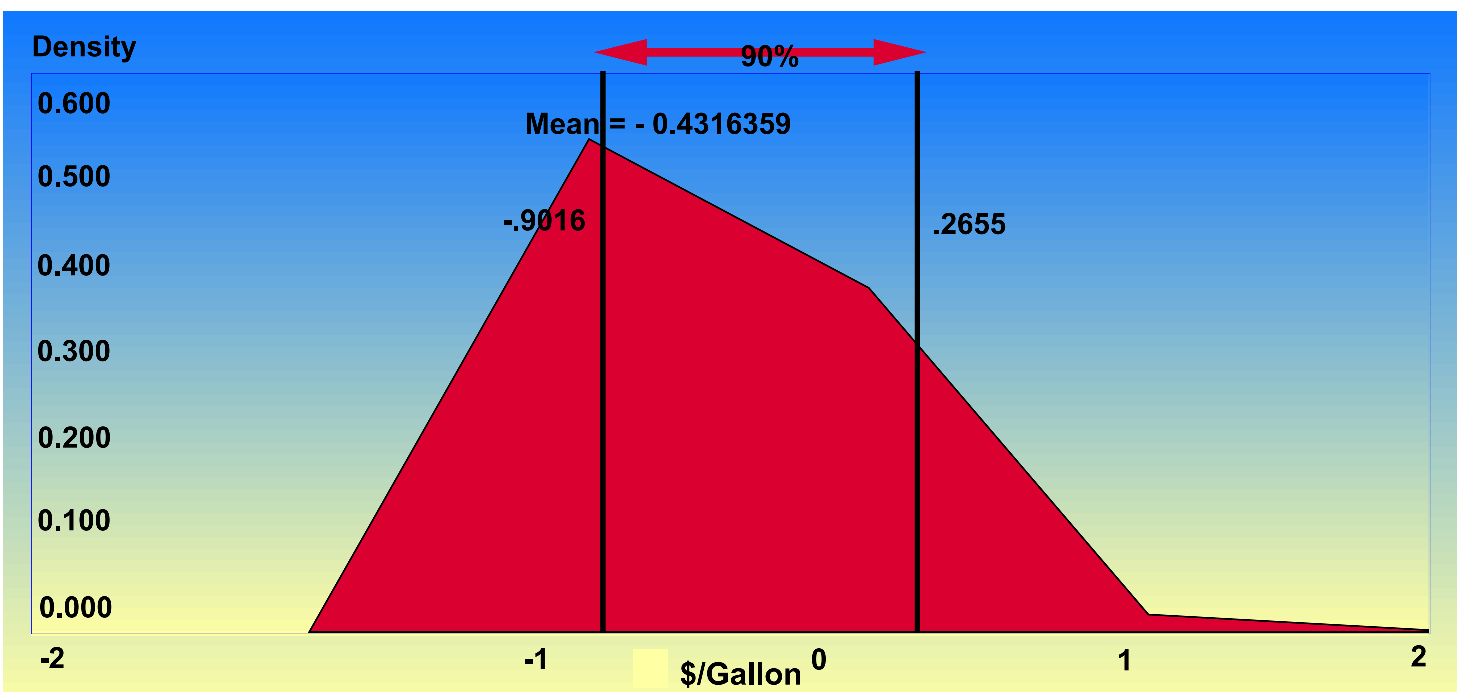

Figure 5. Distribution of Ethanol Plant Net Income/Gallon, 100 Percent Corn Feedstock

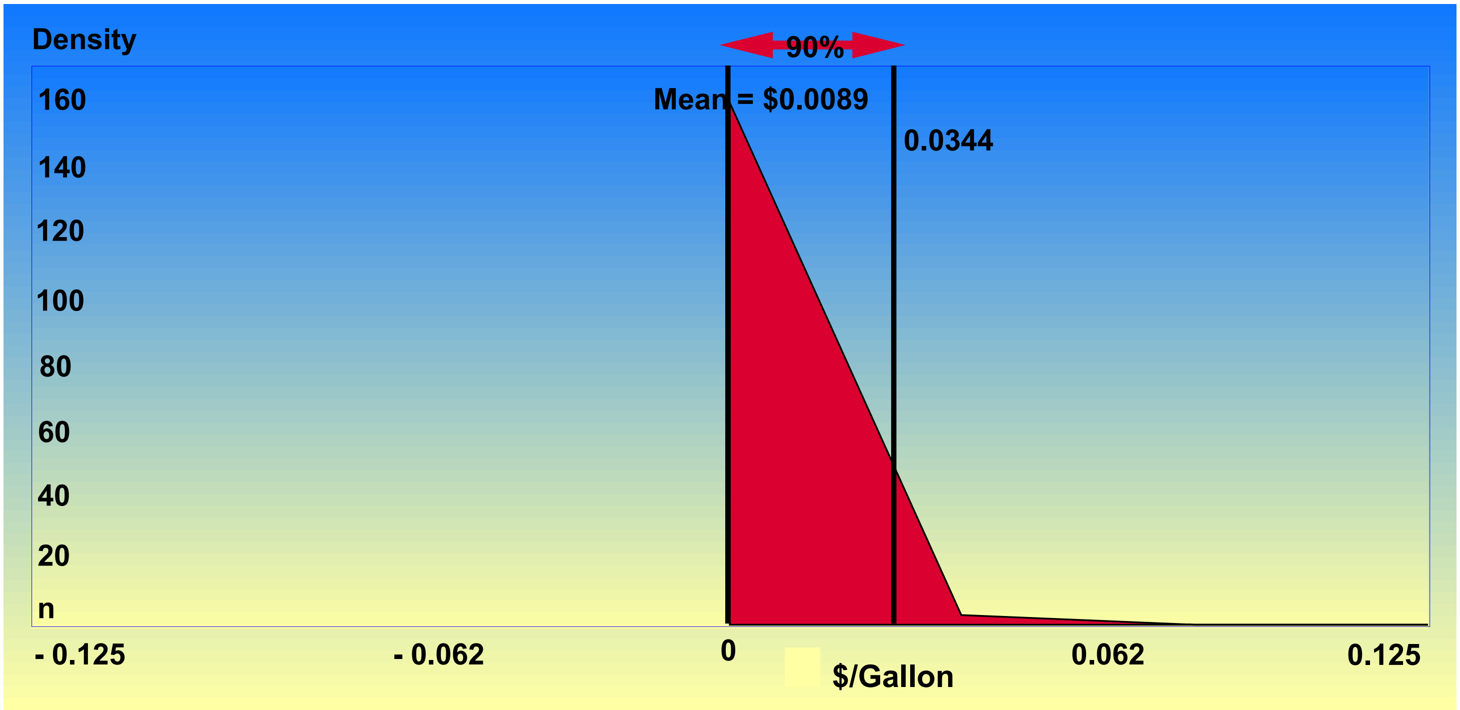

Figure 6. Ethanol Plant Corn Supply Risk, 90 Percent Corn/10 Percent Peas

rates given similar initial starch loadings. The engineering and economic analyses show that the investment and power costs for dry milling and air classifying that is presently available is prohibitively expensive to be commercial. However, an even more significant factor is high pea feedstock prices, relative to corn. Corn prices would have to rise more than 20 percent before peas breakeven. An alternative approach not investigated is to mix whole or dehulled peas with corn without fractionation. One disadvantage of use of whole or dehulled peas is an increase in inert solids (protein and fiber) in the saccharification and fermentation steps. This feedstock dilution would likely reduce overall ethanol capacity instead of increase it as assumed in this study. The corn ethanol industry moved away from wet milling in recent years; however, the rapid growth in that industry has spurred the development of new wet-fractionation processes for all feedstocks, including corn.

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The Cellulosic Biorefinery: Coproduct Extraction from Biomass

Danielle Julie Carrier and Edgar Clausen[1]

Current Biofuel Industry

This nation is experiencing an unprecedented effort aimed at increasing its energy independence for a number of worthy reasons: replacing fossil fuels with biofuels dampens the need to import oil from politically unstable oil-producing countries; in certain situations, biofuels recycle carbon; and, U.S. rural areas, where biorefineries operate, benefit from economic revitalization. Grave consequences, in terms of rural exodus and political unrest, may affect this nation if total or at least partial energy sustainability is not attained within a short time-frame.

Currently the United States uses 140 billion gallons of gasoline and diesel annually. Approximately 7 billion gallons of ethanol and 450 million gallons of biodiesel were produced in 2007. This already met the federal mandate for 2012 specified in the Energy Policy Act of 2005. This phenomenal growth of the corn to ethanol industry has been coupled with the generation of copious quantities of byproducts. More than one third of the corn that is processed to ethanol ends up as a byproduct, either dried distillers grains with solubles (DDGS) or dried distillers grains (DDG). The sale of DDGS or DDG is an important component of the corn to ethanol process, as up to $0.10 per liter of ethanol produced, depending on sale price, is garnered by the biorefinery. Currently, corn to ethanol byproducts are used as animal feeds to the beef, dairy, swine and poultry industries and also are being investigated as aquaculture feed (Rosentrater, 2007). Because corn to ethanol byproducts are high in fiber and low in starch, they are also being investigated for their potential use in human foods (Rosentrater, 2007). This work is indicative of the complex nature of the corn to ethanol processing industry, illustrating that to be profitable (as in the petroleum industry) many products must stem from the processing plant.

There are currently 146 corn to ethanol plants in operation and another 61 under construction. In 18 months, the estimated production capacity of these 207 corn to ethanol plants will be 13.7 billion gallons. The corn to ethanol industry is undergoing phenomenal growth, owing to a demand for liquid fuels, known processing technology, and the benefits from existing infrastructure with respect to corn cultivation, postharvest technology, and manutention. Although the growth of the corn to ethanol industry is unprecedented, if all the corn produced in the United States were converted to ethanol, about 40 billion gallons of ethanol could be produced, which is far less than the 140 billion gallons or so required yearly by the U.S population.

Upcoming Biofuel Industry

To substantially increase the quantity of biofuels, cellulosic materials will need to be harnessed as a feedstock for liquid fuel conversion. Conversion technologies for cellulosic biomass are centered around either the hydrolysis of cellulose and hemicellulose in biomass, followed by fermentation of the resulting sugars to ethanol (Lynd *et al*., 2002); the gasification of cellulose, hemicellulose and lignin to produce synthesis gas (syngas), followed by the conversion of CO, CO_2 and H_2 to ethanol or other alcohols by fermentation or by catalyst-based processes (Brown, 2003); or the conversion of organic compounds in biomass through fast-pyrolysis to a dark-brown liquid, which can then be combusted for energy (Brown, 2003).

Depending on the conversion technology, 10-25 million tons of dry biomass feedstock are required to produce 1 billion gallons of liquid fuel. Recently, it was reported that cellulosics, such as switchgrass, can produce as much as six times more renewable energy than non-renewable energy consumed to produce the biomass (Schmer *et al*., 2008). Such promising numbers show that renewable fuel production from cellulosic crops is feasible, especially as oil prices are drastically on the rise.

Approximately one billion dry tons of biomass feedstock will be required annually to ensure that the United States can produce up to 30 percent of its liquid fuel demand from renewable resources (Perlack *et al*., 2005). On average, forest

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resources will generate 368 million dry tons per year, while agricultural resources, including energy crops, will contribute 998 million dry tons per year (Perlack *et al*., 2005). Current mandates require 21 billion gallons of cellulosic ethanol be produced by 2022. This will require more than 250 million dry tons of biomass. Nonetheless, back of the envelope calculations indicate that a 50 million gallon liquid fuel production facility, capable of producing 80 gallons of ethanol per ton of biomass, will require 1,838 tons of dry biomass per day. Assuming a biomass yield of 8 tons per acre, approximately one 50 million gallon liquid fuel production facility will draw biomass from an area of 122 square miles (67 miles x 67 miles at a 3 percent density). It is important to note that these numbers are only speculations and no 50 million gallon or more commercial plant has been constructed. However, with DOE funding, six production scale refineries will become reality in the near future (USDOE, 2007). Soperton, Georgia will soon be home to the first commercial cellulosic ethanol plant, setting the stage for the essential infrastructure needed in handling the 2,000 ton per day or so of required feedstock.

Importance of Coproducts in Biofuel Industry

As mentioned earlier, coproducts, in the form of DDG or DDGS, are important to the vitality of the corn to ethanol conversion process. Although not usually extracted in the current dry-mill based ethanol industry, corn germ oil and corn fiber oil can also be extracted in the wet-mill process, adding value to the overall corn processing operation (Singh *et al*., 2001). Coproducts are also an important component of the cellulosic conversion process. As shown in Figure 1, McAloon *et al*. (2000) outlined the unit operations for coproduct production in the biorefinery in terms of energy. Beer column bottoms, consisting largely of lignin, will be obtained from the processing of the fermentation solids and will be processed in a triple-effect evaporator before being recovered and combusted in a fluidized bed combustor. Lynd *et al*. (2008) showed through calculations that the thermochemical conversion of fermentation waste products to heat or electricity enhances the economics of the cellulosic biorefinery. Aside from energy production, McAloon *et al*. (2000) reported that the transformation of lignin into

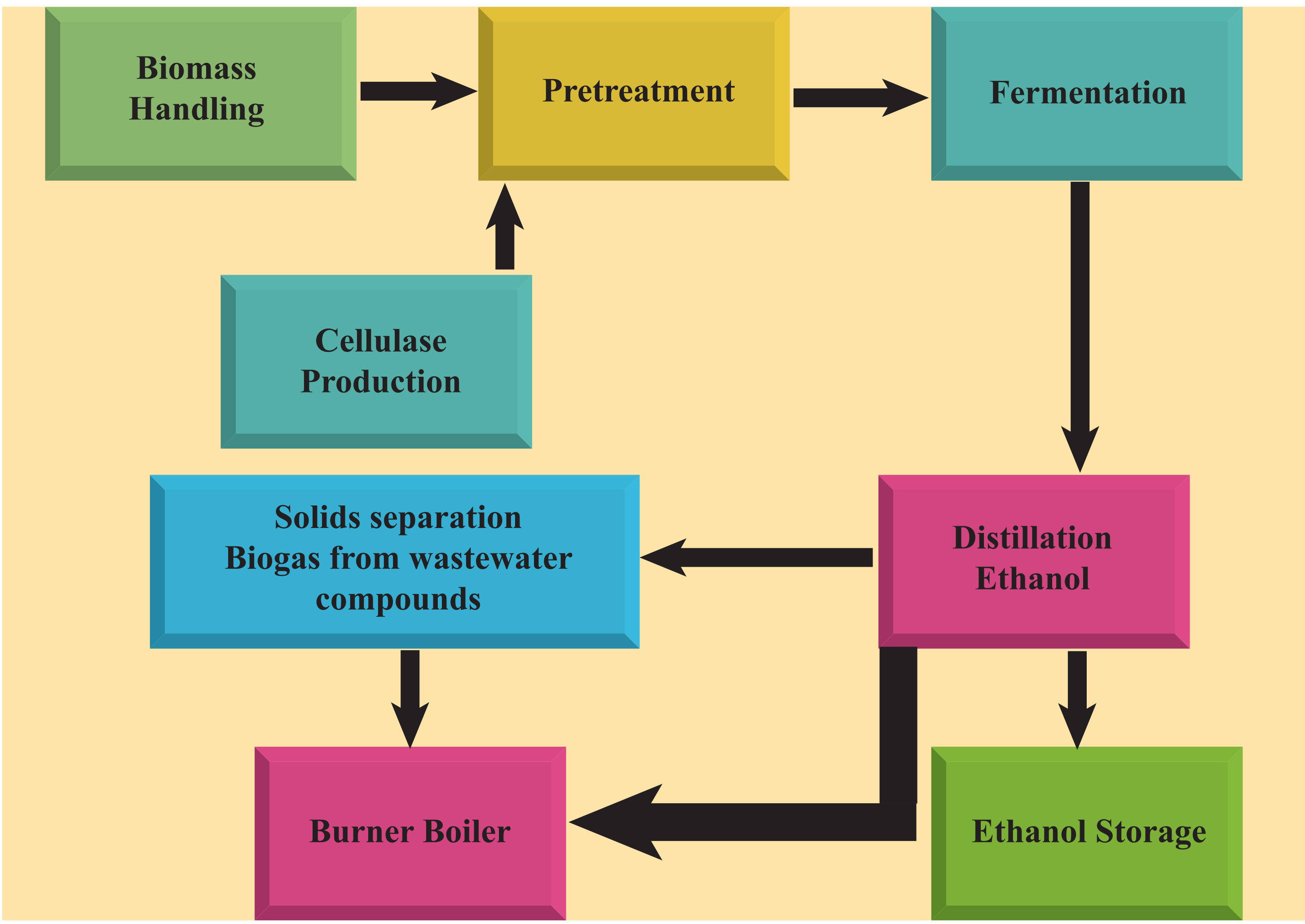

Figure 1. Schematic of Biorefinery

higher-value coproducts is important to the long-term commercial viability of the biorefinery, and that the recovery of interstitial cell matter could also be valuable, but would require significant purification.

Extraction of Coproducts in the Lignocellulosic Biorefinery

As stated by Hess, Wright, and Kenney (2007), the economic competitiveness of cellulosic ethanol production is highly dependent on feedstock cost, which contributes 35-50 percent of total ethanol production costs. In addition to a $30 to $36 per dry ton payment to the producer, Kumar and Sokhansanj (2007) estimate a harvesting, storage, and transportation cost between $40 and $48 per dry ton of biomass, depending if the feedstock is harvested as a bale, a loaf, or ensiled.

In an effort to increase revenues from a given feedstock, valuable phytochemicals could be extracted prior to the biochemical or thermochemical conversion at the site of the biorefinery or a site of close proximity. This extraction step could occur especially if a biochemical process is used because the dry biomass needs to be in contact with water during the dilute acid pretreatment step. Figure 2 shows how a slip stream for phytochemical extraction could be integrated in the biochemical biorefinery scheme. This phytochemical extraction scheme could be nestled within the biorefinery or could be part of a different operation located in proximity to the biorefinery. Phytochemical extraction could also be practiced in a thermoconversion biorefinery on the condition that the revenue obtained from the extraction of the phytochemicals warrants an extraction and an additional feedstock drying step. Either from a biochemical or a thermochemical biorefinery, these phytochemicals could find use in human and animal health care products, cosmetic applications, and as essential ingredients in green cleaning products. According to market research surveys, there is a growing preference among consumers for phytochemicals in the foods they consume, as well as other personal care and household products they utilize. Growth in the use of phytochemicals is predicted in the flavor industry, which includes beverages, confectionery, savory, dairy, and pharmaceuticals (Market Research.com, 2008). It is important to note that for the extraction of coproducts from lignocellulosic biomass to be workable, the

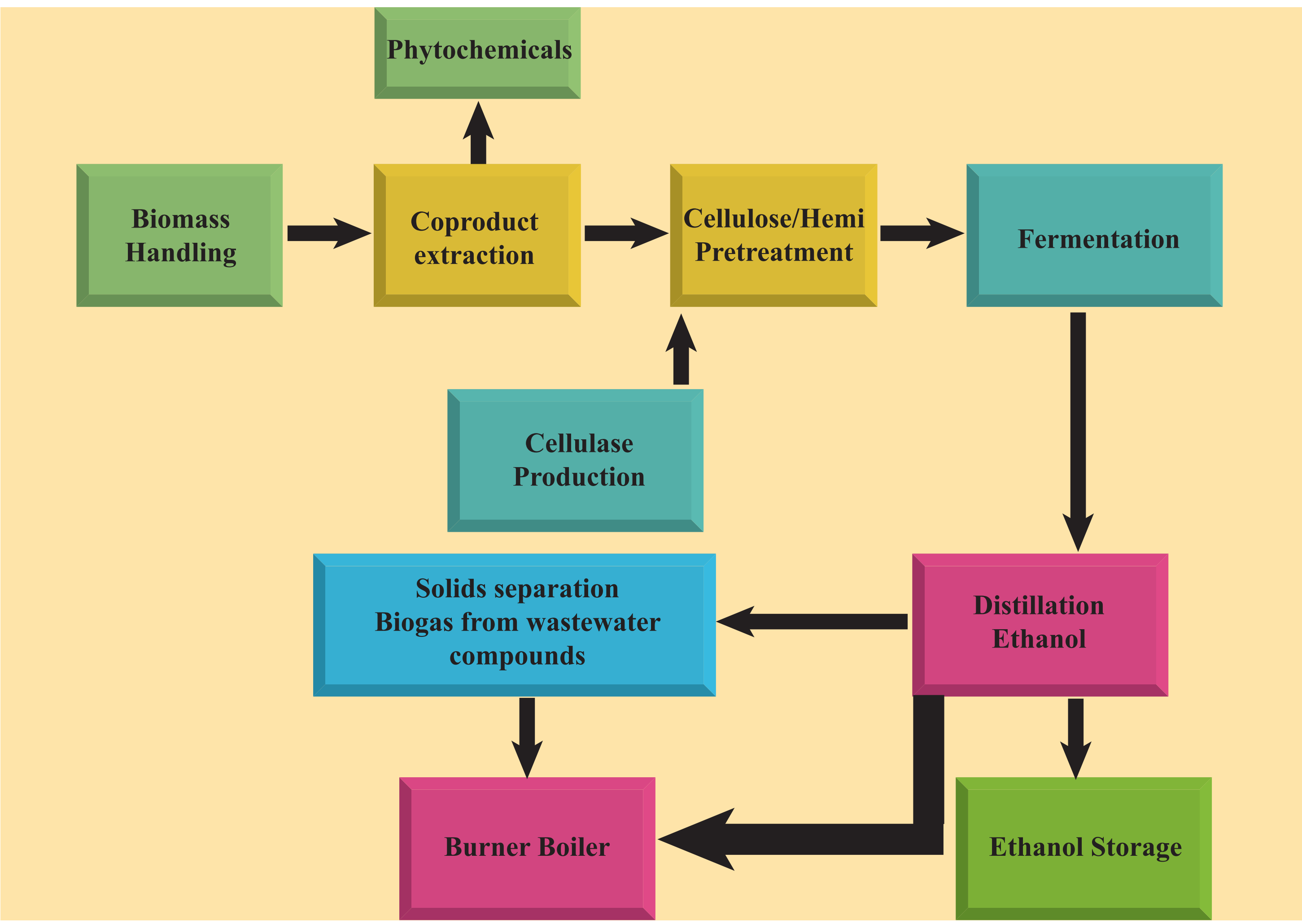

Figure 2. Biorefinery with Coproducts Extraction

extraction step must not hinder the conversion to energy by decreasing yields or adding processing steps.

There is a rich tradition in the phytochemical literature that presents organic solvent extraction schemes for all classes of plant-derived compounds. Scientific journals, such as *Phytochemistry*, *Phytochemical Analysis*, *Journal of Chromatography B*, or *Planta Medica* contain a multitude of articles detailing the required methodology for phytochemical extraction with solvents such as acetone, benzene, or hexane. Although the use of organic solvents is common in the pharmaceutical industry, organic solvent use for the extraction of phytochemicals is costly because of purchase price and inherent handling protocols. Additionally, the use of organic solvents is not deemed 'green' technology because of disposal and other environmental problems. Several alternatives techniques to organic solvent extraction are available for phytochemical extraction, namely supercritical fluids, pressurized liquids, and subcritical water extraction.

The application of subcritical water extraction to phytochemicals is novel as an environmentally compatible "green" technology, and is based on the exposure of the biomass to hot liquid water under pressure. The temperature of the water for extraction typically ranges from 100-180ºC in a pressurized system, well below the critical temperature of water (King, 2006). The use of subcritical water to extract high value phytochemicals permits extraction without concerns about solvent recovery or disposal. Additionally, the extraction of phytochemicals with subcritical water could serve as a biomass pretreatment step in the saccharification/fermentation process, and thus serve an important dual purpose. Thus, the extraction of valuable phytochemicals from biorefinery-destined biomass with subcritical water could harmonize well with the existing biochemical biorefinery.

The USDA and DOE (Perlack *et al.*, 2005) Biomass as Feedstock for a Bioenergy and Bioproducts Industry study estimates that approximately one billion dry tons of biomass feedstock will be required annually to ensure that the United States can produce up to 30 percent of its liquid fuel demand from renewable resources. Thought was given as to the distribution of the one billion dry tons of biomass feedstock that will be required annually. The U.S. DOE (2006) presented a list of the most plausible energy crops that will be grown in the various regions throughout the United States (Figure 3). Successful bridging of the extraction of phytochemicals to the biorefinery can only occur when valuable phytochemicals are present in targeted energy crops. Not all energy crops fulfill this criterion.

Energy Crops with Potential Coproducts

It is most likely that cellulosic plants in the near future will be using a feedstock supply system that relies on current infrastructure and technologies (Hess, Wright, and Kenney, 2007). The thermoconversion-based cellulosic plant in Soperton, Georgia will be drawing on existing forestry supply logistics. Other cellulosic plants that are being planned will be based on the supply of agricultural residues, like wheat straw and corn stover, which is somewhat supported by existing crop harvesting infrastructure. However, the mid-term 50 million gallon facility will consume 2,000 dry tons of agricultural residues per day and will rapidly exhaust regional residue and waste capacities. To address this supply issue in cellulosic feedstock, energy crops will need to augment the feedstock portfolio. Energy crops will be developed regionally as outlined in Figure 3. Collection, storage, preprocessing, transportation and handling practices, logistics, and infrastructure will need to be developed for specific energy crops (Hess, Wright, and Kenney, 2007). While developing energy crop-specific logistics and infrastructure, particular energy crops can warrant value-added processing for the extraction of useful phytochemicals. A few of these energy crops are discussed below.

Black locust (*Robinia pseudoacacia* L) is a multipurpose tree species that can be used for livestock browse and as an energy crop in the eastern United States. The flavonoid acacetin, present in a whole tree extract of black locust is significantly cytotoxic against a human tumor cell line (Tian and McLaughlin, 2000). A water-soluble lectin, robin, initially discovered in black locust inner bark, is most likely the toxic principle for humans which consume the plant (Hui, Marraffa, and Stork, 2004). Toxalbumins are composed of an alpha chain and a beta chain that is linked by a disulfide bond. The beta chain binds to cell surface glycoproteins where it is transported to the endoplasmic reticulum of the cell. The alpha chain inhibits the 60s ribosomal subunit and prevents protein synthesis. Although currently viewed as toxic, it is possible that an extremely biologically active molecule like robin may prove to have uses in advanced therapies.

Eucalyptus is a native from Australia and its genus comprises more than 700 different species. Interestingly, there are currently more than 45 million acres of this tree planted in 90 countries, making this one the most widely planted 'working' tree in the world. As shown in Figure 3, Eucalyptus is grown in California and Florida; however, there are agronomic trials currently underway to examine its hardiness in the Southeastern United States. Eucalyptus is desirable and widely planted because it is a fast growing and high yielding hardwood. Currently, the genome of Eucalyptus is being sequenced through the Eucalyptus Genome Network project, through U.S. DOE support. From the phytochemical perspective, Eucalyptus contains phytochemicals such as flavonoids (Abd-Alla *et al.*, 1980) and monoterpenes (Dayal, 1988). The most famous Eucalyptus-derived phytochemical is the monoterpene 1,8-cinenol, which is an active ingredient in Listerine® mouthwash. Eucalyptus preparations were

Figure 3. Herbaceous and Wood Crop Possibilities as Suggested by the Department of Energy
Source: USDOE, 2006

shown to be active against methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococcus (Sherry, Boeck, and Warnke, 2001). Thus, Eucalyptus would be an excellent candidate to demonstrate the feasibility of subcritical extraction of useful phytochemicals and conversion of the biomass to liquid fuels, indicating that the concept of bridging two unrelated research areas is possible.

Annual production of grain sorghum in the United States is 10-20 million metric tons. About 12 percent of the grain sorghum produced in the United States is used for ethanol production (Hwang *et al*., 2004). Recently, there has been interest in sorghum as a cellulosic crop that could be used in the lignocellulosic biorefinery. As shown in Figure 3, sorghum grows throughout the Midwest. In addition to being a source of starch and of cellulose, a wax-like material can be extracted from whole kernels and from stalks of sorghum. This wax-like material contains policosanols, which are a mixture of long-chained primary alcohols, comprised mainly of docosanol (C_{22}), tetracosanol (C_{24}), hexacosanol (C_{26}), octacosanol (C_{28}), triacontanol (C_{30}) and dotricontanol (C_{32}) (Irmak, Dunford, and Milligan, 2005; Hwang *et al*., 2004). The policosanol concentration of sorghum can be up to 1,200 mg per kg of sorghum grains (Hwang *et al*., 2004). Policosanols have been reported to improve blood lipid levels, reduce platelet aggregation, ameliorate exercise performance in coronary heart disease patients, and increase muscle endurance (Taylor, Rapport, and Lockwood, 2003). Currently, policosanols are being consumed to reduce low density lipoprotein (LDL) levels, while increasing high density lipoprotein (HDL) levels (Taylor, Rapport, and Lockwood, 2003). Policosanols are currently available as a dietary supplement. Reports suggest that 5–20 mg per day of mixed C_{24}– C_{34} alcohols, specifically C_{28} and C_{30}, lower low-density lipoprotein (LDL) cholesterol by 21–29 percent and raise high-density lipoprotein (HDL) cholesterol by 8–15 percent (Hargrove, Greenspan, and Hartle, 2004). As the clinical significance of policosanols becomes established and the development of organic solvent-free extraction methodology is developed, the extraction of these phytochemicals could be added to the lignocellulosic biorefinery.

Sweetgum (*Liquidambar styraciflua* L.) is a deciduous tree that grows in the southeast United States. The trunk of these trees produces a fragrant resin called styrax, which is used in incense, perfumes, soaps, cosmetics, and medicine. Styrax was reported to contain styrene, vanillin, cinnamic acid, borneol, and bornyl acetate (Willie and Brophy, 1989). Essential oils can be extracted from sweetgum leaves and were reported to contain 30.1 percent of terpinen-4-ol, 18 percent alpha-pinene and 12.8 percent sabinene. *L. styraciflua* essential oil composition is similar to that of Australian tea tree oil, which is used in the herbal industry. It is worth noting that tea tree oil is a player in the $1.9 billion plant-derived chemical industry (Fredonia Group, 2008). With expanding aroma therapies and interest in green cleaning products, an increase in essential oils could be foreseen. Sweetgum biomass could be extracted by subcritical water prior to energy conversion.

Switchgrass, *Panicum virgatum* L., is a warm-season perennial grass that grows throughout the Midwest and the Southeast. Schmer *et al*. (2008) demonstrated that switchgrass can produce 540 percent more output energy than the input energy supplied to grow and harvest the biomass, giving credence to the concept of cellulosic ethanol. Switchgrass is rapidly being developed as an energy crop. During the spring of 2008, the Oklahoma Bioenergy Center sponsored the planting of 1,000 acres of switchgrass near Guymon, Oklahoma that will be used as feedstock by a cellulosic biorefinery in Hugoton, Kansas. In addition, Tennessee through the Tennessee Biofuels Initiative sponsored in the initial year the planting of 720 acres with plans to plant 6,000 acres of switchgrass over a three year period.

Like sorghum, switchgrass contains policosanols. Oklahoma-grown switchgrass has total policosanol contents ranging from 105 - 182 mg/kg (Vandhana Ravindranath *et al*., 2008), which is less than what is contained in sorghum. However, the composition of individual policosanol alcohols of switchgrass and sorghum differ. Oklahoma-grown switchgrass was shown to contain of 0.4-1 percent of C_{26} alcohols, 10-16 percent of C_{28} alcohols, 35-40 percent of C_{30} alcohols, and 46-50 percent of C_{32} alcohols, while the alcohol distribution in sorghum was 0–1 percent C_{22}, 0–3 percent C_{24}, 6–8 percent C_{26}, 43–47 percent C_{28}, 40–43 percent C_{30}, and 1–4 percent $C_3$2, indicating a lower C_{32} content than that of switchgrass (Hwang *et al*., 2004). It may be possible that future bioactivity-based research shows that the individual alcohol composition of the policosanol dietary supplement plays a role in conferring LDL lowering activity. If such were the case and high proportions of C_{32} are desired, then switchgrass policosanols could be used. In addition to policosanols, switchgrass contains 320 - 400 mg/kg of α – tocopherol if harvested prior to frost (Vandhana Ravindranath *et al*., 2008). It is important to note that the results reported by Vandhana Ravindranath *et al*. (2008) were based on hexane extraction, and this would not be feasible in a cellulosic biorefinery scenario. However, as subcritical water or supercritical extraction methods are developed, policosanol extraction from switchgrass coupled to the cellulosic biorefinery could be possible.

In addition to policosanols, switchgrass contains the flavonoids quercitrin and rutin. By extracting switchgrass biomass with 90ºC water, yields of 184 and of 193 mg per kg of switchgrass were obtained for rutin and quercitrin, respectively (Uppugundla *et al*., 2008). Moreover, 18 μM preparations of both rutin and quercitrin were shown to inhibit the oxidization of LDL by 70 and 80 percent, respectively, as determined the thiobarbituric reactive substance (TBARS) assay (Uppugundla *et al*., 2008). The extraction of switchgrass flavonoids was performed at 90ºC, which is well below the recommended water pretreatment temperatures of 140 and 240ºC, indicating that the extraction of phytochemicals could be harmonized with cellulosic biorefinery operations.

Infrastructure Needs of the Cellulosic Biorefinery

With the implementation of the cellulosic biorefinery comes the movement of large masses of feedstock, where 2,000 to 5,000 dry tons per day will need to be delivered at the doorstep of the biorefiney on a daily basis. Various scenarios for bringing the feedstock from the field to the door of the plant have been explored. Kumar and Sokhansanj (2007) modeled the transportation costs of chopped or ensiled biomass, of round or square bales, or of 2.4 x 3.6 x 6 meter loafs from the field to the cellulosic biorefinery. Of these possibilities, the loafing procedure, at $37 per dry ton, was the least costly. To harvest, transport, grind, and store forage type feedstock, existing machinery could be used and modified. Gathering and postharvest processing of woody feedstocks will most likely draw on technology from the current logging industry. Storage stations will have to be put in place, as the feedstock will be harvested once or twice per season, yet will be converted throughout the year. In regions where feedstocks containing useful phytochemicals are converted to biofuels, subcritical water based extraction facilities could be on-site or off-site from the biochemical cellulosic biorefinery. The phytochemical-exhausted biomass will be wet and could immediately be pretreated, as needed, using a dilute acid protocol.

Conclusion

The economic competitiveness of cellulosic ethanol production is highly dependent on feedstock cost, which constitutes 35-50 percent of the total ethanol production costs. In addition to a $30 to $36 per dry ton payment to the producer, a harvesting, storage and transportation cost between $40 and $48 per dry ton of biomass will also be required, depending if the feedstock is harvested as a bale, a loaf, or ensiled. In an effort to increase the revenues from a given feedstock, coproducts can also be obtained from feedstock during conversion. Thermochemical conversion coproducts are currently incorporated in the biorefinery layout that is proposed by Lynd *et al*. (2008). In addition to thermochemical conversions, valuable phytochemicals could also be extracted with subcritical water prior to the biochemical or thermochemical conversion at the site of the biorefinery or a site of close proximity, thereby adding value to the feedstock. It is important to note that the concept of extracting coproducts from biomass prior to conversion is still in its infancy. Rightfully so, all efforts are currently directed at cellulosic ethanol production. However, as the cellulosic ethanol biorefineries become a reality, it will then become interesting to investigate the production of secondary stream processes, such as coproduct extraction. At that point it will be become critical to generate positive as well as negative information on potential coproduct extraction, so that comprehensive economic evaluation of this process can be prepared.

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The Economics of Biomass Collection and Transportation and Its Supply to Indiana Cellulosic and Electric Utility Facilities

Sarah C. Brechbill, Wallace E. Tyner, and Klein E. Ileleji[1]

Introduction

Biomass is poised to become an important energy source in the United States due to concerns regarding oil imports and the environment. Federal and state policies are beginning to mandate the use of renewable energy, some of which must come from cellulosic sources. This likely will result in more research and development being devoted to cellulosic energy production, and it will be important to know how much these feedstocks will cost to obtain. The development of cellulosic bioenergy will require finding an economically and environmentally sustainable method for obtaining large quantities of biomass feedstock (Hettenhaus, 2006).

The primary objective of this analysis is to determine up-to-date cost estimates for the production, collection, and transportation of corn stover and switchgrass from Indiana farms of different sizes that are located at various distances from an electric utility plant or biofuels plant looking to purchase biomass. Results from this analysis only consider costs from the field to the plant door and do not consider costs associated with adapting boilers to be able to burn biomass or capital expenditures on future cellulose conversion facilities. This analysis also creates information on biomass feedstock supplies for three specific Indiana electric utility plants and estimates CO_2 breakeven prices that equate the cost of using biomass for 10 percent of heat production to the cost when using 100 percent coal.

Parameters and Assumptions

With a number of studies arriving at similar aggregate conclusions for the cost of biomass collection, it is important to understand the parameters and assumptions behind these total cost figures and what might make one result different from another. Table 1 outlines the parameters used in this analysis and their sources. Table 2 outlines the input cost assumptions.

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Biomass Harvest, Collections, and Transportation Cost Analysis

Corn Stover

Collection scenarios include baling only from a windrow, raking and baling, and shredding, raking and baling. Each scenario removes 38, 52.5, or 70 percent of available stover on the ground respectively. With each increase in the amount of stover that is removed, the field is subject to more soil compaction, soil erosion, and water erosion. Agronomic effects from stover removal must be balanced with the economic question of how much stover is too little when it comes to ensuring that revenue from stover exceeds the additional costs of collection. Overall, different soils and locations will need to be treated differently with respect to how much stover can be safely collected and removed.

For each ton of stover removed, additional nutrients are applied during the annual fertilizer application. Table 3 outlines the per ton cost of additional nitrogen, phosphorus, and potassium.

Switchgrass

Establishment costs incurred during one year are amortized at an interest rate of 8 percent over the 10 year life of the stand. Field preparation includes mowing the field and spraying glyphosate to kill existing grasses. Production year costs include those incurred during the maintenance and harvest of switchgrass. Specific parameters of interest are in Table 1.

Collection and Harvest

Harvest with traditional hay equipment is either custom hired or done with owned equipment. While new harvesting technologies that collect both corn grain and corn stover in one pass are being used on a trial basis, these technologies are not widespread and considering the use of hay equipment (after corn grain harvest is complete) seems more appropriate for producers deciding to collect corn stover in the short run. Per ton custom rates for each activity are calculated by dividing the average custom rate by the amount of biomass removed

Table 1. Parameter Assumptions

Parameter			Sources
Corn Stover			
Corn Stover Yield	4.25 tons/acre		Atchison and Hettenhaus, (2003); Glassner, Hettenhaus, and Schechinger, (1998); Lang, (2002); Quick, (2003); Sokhansanj and Turhollow, (2002)
Removal Rates	Scenario 1	38%	Glassner, Hettenhaus, and Schechinger, (1998) ; Lang, (2002); Montross et al., (2003); Perlack and Turhollow, (2002); Petrolia, (2006); Richey, Lechtenberg, and Liljedahl, (1982); Schechinger and Hettenhaus, (2004); Sheehan et al., (2003); Shinners, Binversie, and Savoie, (2003)
	Scenario 2	52.5%	
	Scenario 3	70%	
Nutrient Replacement	Nitrogen	15.9 lbs/ton of stover removed	Fixen, (2007); Lang, (2002); Nielsen, (1995); Petrolia, (2006); Schechinger and Hettenhaus, (2004)
	Phosphorous	5.9 lbs/ton of stover removed	
	Potassium	30 lbs/ton of stover removed	
Switchgrass			
Switchgrass Yield	5 tons/acre		Brummer et al., (2002); Duffy and Nanhou, (2001); Kszoz, McLaughlin, and Walsh, (2002); Perrin et al., (2003); Popp and Hogan, (2007); Tiffany et al., (2006); Walsh, Becker, and Graham, (1996)
Land Rent	$70 per acre		Dobbins and Cook, (2007); Duffy and Nanhou, (2001); Popp and Hogan, (2007)
Seeding	7 lbs of pure live seed/acre		Duffy and Nanhou, (2001); Lawrence et al., (2006); USDA-NRCS, (1986); Rinehart, (2006); Teel, Barnhart, and Miller, (2003); Tiffany et al., (2006); Walsh, (2007)
Establishment Year	Phosphorous	30 lbs/acre	Duffy and Nanhou, (2001); Popp and Hogan, (2007); Tiffany et al., (2006)
	Potassium	37 lbs/acre	
	Lime	2 tons/acre	
	Glycophosate	2 qts/acre	
	Atrazine	1.25 qts/acre	
	2,4-D	1.25 pts/acre	
Production Year	Nitrogen	80 lbs/acre	Duffy and Nanhou, (2001); Gibson and Barnhart, (2007); Kszos, McLaughlin, and Walsh, (2002); Lawrence et al., (2006); Popp and Hogan, (2007); Rinehart, (2006); Teel, Barnhart, and Miller, (2003); Tiffany et al., (2006); Walsh, (2007)
	Phosphorous	3.15 lbs/ton of switchgrass removed	
	Potassium	13.25 lbs/ton of switchgrass removed	
	Atrazine	1.25 qts/acre	
	2,4-D	1.25 pts/acre	
Baling and Transportation			
Dry Matter Loss (in 6 months)	Twine	18.80%	Collins et al., (1997); I-FARM, (2007); Shinners, Binversie, and Savoie, (2003)
	Net Wrap	8.40%	
	Plastic Wrap	6.15%	

Table 1. Parameter Assumptions (Continued)

Parameter			Assumptions
Baling and Transportation			
Bale Dimensions	Weight	1000 lbs	Popp and Hogan (2007)
	Diameter	5 feet	
	Width	5.5 feet	
Transportation	Load Capacity	26 bales or 13 tons	Popp and Hogan (2007)
	Gas Mileage	6.73 miles/gallon	Berwick and Farooq (2003)
	Average Speed	50 miles/hour	Tiffany et al., (2006)

per acre. These decrease as the corn stover removal rate increases and are lower for switchgrass due to higher yields.

Under the owned equipment condition, an annual per ton payment is calculated for farm sizes including 500 acres, 1000 acres, 1500 acres, and 2000 acres. Total owned equipment costs are based on amortized equipment cost at 8 percent interest, fuel requirements, and labor requirements. These decrease as the corn stover removal rate increases and are even lower for switchgrass. Per ton owned equipment costs also decrease as the farm size increases.

Baling Options, Handling, and Storage

Baling options included in this analysis are twine, net wrap, and plastic wrap. Dry matter loss is highly dependent on the length of time in storage and the baling option chosen. An associated dry matter loss as a percentage of the total per ton product cost is added to account for an assumed six months of on the ground storage at the edge of the field. An extended storage premium is used to offset lost crop production. The extended storage premium is equal to half of the net revenue lost due to land being used as storage. This accounts for half of producers not losing the production area while the other half suffer a loss. Each producer is paid a per ton profit of 15 percent of the product cost to offer an incentive to producers beyond covered costs to participate in biomass production. For corn stover and switchgrass, this net profit averages $4.55 and $7.22 per dry ton respectively. For an acre under the assumptions of this analysis, net profit from corn stover averages $10.25 per acre and net profit from switchgrass averages $36.11 per acre. Exact decisions on profit payments will vary from plant to plant.

Transportation

The one way distance from the field to the plant ranges between 5 and 50 miles at intervals of 5 miles. As with harvest, transportation can be either custom hired or owned, and the associated costs are calculated in the same manner.

Results Analysis

A set of cost averages for corn stover and switchgrass served as a preliminary benchmark for comparison and serves to highlight the differences in cost for various farm sizes and management decisions (Tables 4 and 5). These cost averages include all removal rates and bale packaging options considered in this analysis for each farm size and equipment decision.

Bale Packaging

For both corn stover and switchgrass, baling with net wrap is always the cheapest option for a given farm size, distance to the plant, equipment choice, and removal scenario. The slightly higher cost of net wrap is offset by a lower dry matter loss. Plastic wrap, however, involves an added cost that is nearly twice as much as net wrap, but the additional dry matter loss savings is only about 2 percent.

For corn stover, plastic wrap is always the most expensive option, followed by twine and net wrap. However, for switchgrass, twine is always the most expensive option, followed by plastic wrap and net wrap. This is because the higher value per ton of switchgrass results in dry matter loss playing a relatively more important role in determining the total per ton product cost.

Equipment Choice Results

Removing stover increases the fuel, labor, and equipment costs, but it increases the collected stover yield per acre. Larger farms are able to remove any amount of stover at a less expensive per ton cost than smaller farms. Thus incurring a higher cost due to more passes through the field can be paid off by being able to spread the extra cost incurred for each acre over more collected tons of stover.

Small farm sizes likely will have higher costs by using owned equipment and will be forced to use custom hired equipment should they choose to harvest stover. Larger farm sizes will likely find owned equipment to be the lower cost option due to the large amount of acres over which to spread their costs. Limitations posed by weather on the window of time available for harvest have not been considered. Depending on the schedules and workloads of either producers or custom operators, adverse weather conditions could serve to shorten the harvest window.

Table 2. Input Cost Assumptions

Input	Price	Units	Sources
Fertilizer:			
Anhydrous Ammonia	$536.00	Cost per ton	NASS, Agricultural Prices, 2007
Liquid Nitrogen	$270.00		
Urea	$450.00		
MAP	$421.00		
Potash	$277.00		
Lime (and application)	$13.76		Halich, 2007
Seed:			
Cave-In-Rock-Switchgrass	$9.50	Cost per lb	Sharp Brothers Seed Company
Herbicides:			
Glyphosate	$28.90	Cost per gallon	NASS, Agricultural Prices, 2007
Atrazine	$12.20		
2,4-D	$15.90		
Custom:			
Stalk Shredder	$8.56	Cost per acre	Halich, 2007
Rake	$5.40		
Bale	$8.52		
Mower	$10.03		
Fertilizer/Seed Application	$5.13		
Herbicide Application	$5.41		
Owned:			
Stalk Shredder (14' wide, 10 year lifespan)	$10,277	Cost per unit	Laughlin and Spurlock, 2007
Rake (8.5' wide, 8 year lifespan)	$4,105		
Baler (large round, 8 year lifespan)	$24,579		
Rotary Mower (15' wide, 10 year lifespan)	$12,547		
Packaging:			
Twine	$20.75	Cost per roll	Montana Custom Hay
Net Wrap	$200.00		
Plastic Wrap	$80.00		Tudor Ag
Labor:			
Field Worker Wage	$9.46	Cost per hour	NASS, Indiana Agriculture Report, 2006
Ag. Truck Driver Wage	$14.37		Bureau of Labor Statistics, 2006
Fuel:			
Highway Diesel	$3.93	Cost per gallon	Energy Information Administration, 2008
On-Farm Diesel	$3.53		

The switchgrass analysis does not have the same numerous combinations of management decisions as corn stover, because there is not a variable removal rate. However, the resulting equipment choices for farms of various sizes are similar to those for corn stover.

Transportation Results

The transportation results in Table 6 are averaged over custom and owned equipment. The difference between transportation costs for corn stover and switchgrass is be-

Table 3. Corn Stover Nutrient Replacement

	Fertilizer Used	Fertilizer Composition	Price Per Ton of Fertilizer	Price Per Pound of Nutrient	Pounds to Replace Per Ton of Stover Removed	Nutrient Replacement Cost Per Ton of Stover Removed
N	Anhydrous Ammonia	82-0-0	$536.00	$0.327	15.9	$5.20
N	Liquid Nitrogen	28-0-0	$270.00	$0.482	15.9	$7.67
N	Average					$6.44
P2O5	MAP	11-52-0	$421.00	$0.404	5.9	$2.39
K2O	Potash	0-0-61	$277.00	$0.227	30	$6.81
Total						$15.64

Table 4. Average Product Only Per Ton Costs by Farm Size/Equipment Decision

Farm Size	Corn Stover Cost	Switchgrass Cost
	Dollars per ton	
Custom	$33.95	$55.92
500 acres	$38.10	$57.26
1000 acres	$35.03	$55.11
1500 acres	$34.01	$54.40
2000 acres	$33.50	$54.04

cause capital transportation costs are spread over more tons in the case of switchgrass due to its higher yield. The average marginal transportation cost per mile is $0.20.

Biomass Supply

To apply these costs to the situation of a particular coal power plant, supply curves are generated based on the location of the plant and the available supply of biomass in the area. Data for biomass supply is available from a recent study by Oak Ridge National Laboratory sponsored by the Department of Energy and the Department of Agriculture that determines the total biomass availability for the United States (Perlack *et al*., 2005). Supply for both corn stover and switchgrass are given separately, and it is assumed that supply from both sources can be produced and used at the same time. Since data are available for Indiana only, supply that might potentially come from neighboring states is assumed to be similar to the supply from Indiana. It is assumed that 53.5 percent (or an average of the removal rates used in this analysis) of corn stover is feasibly and sustainably collected. Land participation rates of 50 and 75 percent are assumed for both corn stover and switchgrass to account for the expected percentage of potential land that will actually have biomass collected or harvested from it.

Using Figure 1 shows each plants location and their concentric supply circles (Figure 1), and assuming that the biomass in each county is evenly distributed, the fraction of county area within each circle is used to determine the fraction of available biomass from each county that is located within a given circle. The total amount from all counties within a given circle corresponds to the x-axis of the supply curve, which therefore is measured in both miles and tons. The Knox county plant in southern Indiana has a smaller available amount of corn stover at all distances relative to the other two plants. The Marion county plant is located in a metropolitan area, which makes its overall supplies of either biomass source less abundant until the rural surrounding counties are reached. The Tippecanoe county plant is located in a highly agricultural area and has large potential supplies of both corn stover and switchgrass.

Supply Costs

A set of average costs that are a function of one-way distance to the plant serve as the costs associated with the available supply. Table 7 indicates these costs in both dry ton units and MMBTU units. These biomass costs per MMBTU can be compared to a coal cost per MMBTU of $1.56. These biomass costs per MMBTU can be compared to a coal cost per MMBTU of $1.44 for Illinois Basin coal with heat content of 11,800 BTU per pound or a coal cost per MMBTU of $1.56 if the heat contents of the three plants considered in this analysis are averaged (10,994 BTU per pound). Either way the coal price is calculated, the biomass cost per MMBTU is always lower. This coal cost is calculated from the assumed price of coal per ton of $34.31 based on EIA market prices as of January 2008 and an average of the high heat values for the plants included in this analysis.

Table 5. Average Product and Transportation Cost Per Ton by Farm Size/Equipment Decision

Biomass Type and Distance from Plant	Custom	500 acres	1000 acres	1500 acres	2000 acres
			Dollars per ton		
Corn Stover:					
5 miles	$36.49	$42.80	$38.48	$37.04	$36.32
10 miles	$37.87	$43.47	$39.15	$37.71	$36.99
15 miles	$39.26	$44.14	$39.82	$38.38	$37.66
20 miles	$40.64	$44.81	$40.49	$39.05	$38.33
25 miles	$42.03	$45.48	$41.16	$39.72	$39.00
30 miles	$43.41	$46.15	$41.83	$40.39	$39.67
35 miles	$44.80	$46.82	$42.50	$41.06	$40.34
40 miles	$46.18	$47.49	$43.17	$41.73	$41.01
45 miles	$47.57	$48.16	$43.84	$42.40	$41.68
50 miles	$48.95	$48.83	$44.51	$43.07	$42.35
Switchgrass:					
5 miles	$58.45	$60.52	$57.84	$56.94	$56.50
10 miles	$59.84	$61.19	$58.51	$57.61	$57.17
15 miles	$61.22	$61.86	$59.18	$58.28	$57.84
20 miles	$62.61	$62.53	$59.85	$58.95	$58.51
25 miles	$63.99	$63.20	$60.52	$59.62	$59.18
30 miles	$65.38	$63.87	$61.19	$60.29	$59.85
35 miles	$66.76	$64.54	$61.86	$60.96	$60.52
40 miles	$68.15	$65.21	$62.53	$61.63	$61.19
45 miles	$69.53	$65.88	$63.20	$62.31	$61.86
50 miles	$70.92	$66.55	$63.87	$62.98	$62.53

Biomass Demanded

The amount of biomass demanded depends upon the size of each plant and the amount of heat production that is to come from biomass. For this analysis, biomass makes up from 1 to 10 percent of total heat production. Information regarding the demand for fuel inputs from the coal plants comes from the 2005 Coal Power Plant Database by National Energy Technology Laboratory and the Environmental Protection Agency Clean Air Markets Data.

Table 6. Average Per Ton Transportation Costs for Corn Stover and Switchgrass

Distance	Transportation Costs for: Corn Stover	Switchgrass
	Dollars per ton	
5 miles	$3.30	$2.70
10 miles	$4.12	$3.52
15 miles	$4.93	$4.33
20 miles	$5.74	$5.14
25 miles	$6.56	$5.96
30 miles	$7.37	$6.77
35 miles	$8.18	$7.58
40 miles	$9.00	$8.40
45 miles	$9.81	$9.21
50 miles	$10.62	$10.02

The tons of biomass required per year to produce a given percentage of heat production can be calculated with the following equation:

total Btu/hour × fraction of heat from biomass × (Btu/lb of biomass / 2000) × operating hours/day × operating days/year = ***tons of biomass/year***

Supply Curves

Supply curves for each biomass source are created for each plant at each land participation rate by plotting the amount of biomass available at each distance against the cost of collection and transport of the given distance. The vertical lines on these graphs represent the possible fractions of total heat production from biomass. Increases in the land participation

Figure 1. Plant Locations and their Concentric Supply Circles

rate simply make more biomass available at a lower cost and shift the vertical lines to the left. Where these vertical lines hit the x-axis, the amount of biomass required and the one-way distance from the plant to the furthest ton are indicated. At the point where the vertical line and the supply curve intersect, the associated value on the y-axis indicates the per ton delivered cost for the furthest ton required. The area below the supply curve up to each vertical line indicates the total cost associated with acquiring the amount of biomass needed to generate a particular percentage of heat assuming that the biomass and transportation costs are treated separately. Figure 2 is an example from the Knox county plant that shows the general structure of the supply curves. In this case, the plant uses corn stover up to 105 miles from the plant and then begins using switchgrass located near the plant. In other words, corn stover located 105 miles from the plant costs the same as switchgrass located next to the plant. Ten percent of heat production, however, can be produced from corn stover that is approximately 80 miles from the plant.

The Marion county plant is a larger plant and requires more biomass to meet requirements. For enough biomass to produce 10 percent of heat, the plant must go out between 35 and 45 miles. This increase in distance is accounted for by the proximity to a large metropolitan city and by the large size of the plant.

The Tippecanoe county plant is a small plant located in an area that is abundant in both corn stover and switchgrass. Regardless of the type of biomass or the land participation rate, 10 percent of heat production could be obtained by going less than 10 miles from the plant.

CO_2 Emissions Reductions

This use of biomass in place of coal will serve to reduce the greenhouse gas emissions. This analysis will consider the value of reductions of CO_2 emissions from using biomass in place of coal. While there are also reduction for other emissions such as SO_2, due to limited data regarding emissions

Table 7. Supply Analysis Costs by One-Way Distance				
Distance	Corn Stover Cost		Switchgrass Cost	
	Dollars per ton	Dollars per MMBtu	Dollars per ton	Dollars per MMBtu
5 miles	$38.22	$2.52	$58.05	$3.99
10 miles	$39.04	$2.57	$58.86	$4.05
15 miles	$39.85	$2.62	$59.68	$4.11
20 miles	$40.66	$2.68	$60.49	$4.16
25 miles	$41.47	$2.73	$61.30	$4.22
30 miles	$42.29	$2.78	$62.12	$4.27
35 miles	$43.10	$2.84	$62.93	$4.33
40 miles	$43.91	$2.89	$63.74	$4.39
45 miles	$44.73	$2.95	$64.55	$4.44
50 miles	$45.54	$3.00	$65.37	$4.50

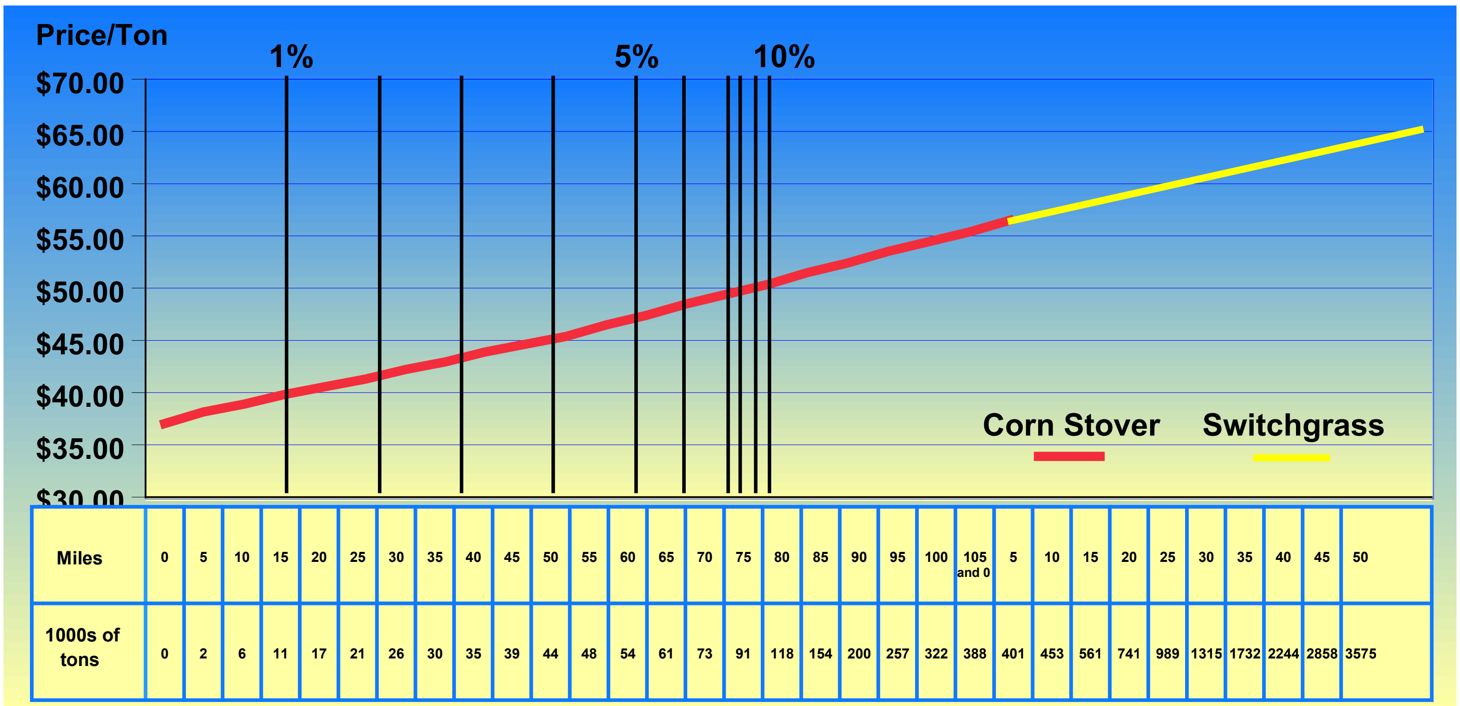

Figure 2. Knox County Biomass Supply Curve

and biomass combustion, only the value of reduction of CO_2 emissions is calculated. From Ney and Schnoor (2002) and Spatari, Zhang, and Maclean (2005), the net emission reductions in tons of CO_2 equivalent from using one ton of biomass instead of coal are 2.88 and 2.60 for corn stover and switchgrass respectively. In the case of switchgrass (but not for corn stover), an indirect leakage effect occurs when land is shifted into biomass production. This serves to negate a portion of the CO_2 sequestration from switchgrass. This analysis did not take that effect into account, but the net CO_2 reduction for switchgrass may be lower as a result. Total CO_2 emissions for each plant are calculated by assuming that a ton of coal generates 2.86 tons of CO_2 when completely combusted (Hong and Slatick, 1994).

Assuming a CO_2 per metric ton price of $5.75, the reduced costs from less coal and less CO_2 emissions can be calculated. The carbon credit price is from the market rate for Carbon Financial Instruments (CFIs) on the Chicago Climate Exchange. One CFI contract consists of 100 metric tons of CO_2 equivalent, and the market price as of March 2008 was $5.75 per metric ton of CO_2 (or $5.22 per short ton).

Table 8 estimates the percent difference in total input costs relative to the coal only case. In all cases, the use of biomass as it offsets some coal costs and CO_2 emissions is not enough to offset the costs incurred from purchasing the biomass. Total input costs when biomass is used are calculated by adding together the savings from less coal, the savings from reduced emissions, and the total amount spent on biomass. The sav-

Table 8. Percent Change in Total Feedstock Costs[a] to the Plant When Using Biomass, by Location and Proportion of Co-fire

Fraction of Heat from Biomass	Knox County, IN		Marion County, IN		Tippecanoe County, IN	
	Corn Stover	Switchgrass	Corn Stover	Switchgrass	Corn Stover	Switchgrass
0.05	1.67%	5.30%	0.32%	4.83%	0.41%	5.46%
0.10	5.98%	10.97%	1.26%	10.47%	0.81%	11.31%

[a]Total feedstock costs for 2006 is estimated at $25,938,360 for Knox County; $477,915,080 for Marion County; and $5,350,405 for Tippecanoe County

ings from sequestered carbon occurring from root establishment by switchgrass was not included in this analysis. Further information is needed to develop a firm estimate on the amount of carbon that would be sequestered during a 10-year perennial crop such as switchgrass.

This is information for plants to determine how much additional cost they are willing to incur in order to incorporate biomass or "go green." Table 9 provides breakeven per ton CO_2 prices for the case of producing 10 percent of total heat production from biomass. These can be compared to the current price from the Chicago Climate Exchange of $5.22 per ton of CO_2. Breakeven prices for the use of corn stover are much lower than those for switchgrass due to the extra feedstock costs that must be covered in the case of switchgrass. These breakeven prices also signal the level of carbon tax that would be necessary to induce firms to use biomass as a substitute for coal under a carbon tax system. Carbon (instead of CO_2) breakeven prices are 3.67 times the values in Table 9.

Conclusions

Corn Stover

Other than nutrient replacement and harvesting activities, there are no additional costs for collecting corn stover. This makes corn stover the less costly option compared to switchgrass without any consideration of transport distance. Management decisions such as removal rate and equipment decisions can also change corn stover per ton costs. Total costs per dry ton for transporting corn stover 25 miles range between $39 and $45.

Switchgrass

The decision to plant switchgrass is accompanied by the input and activity costs that relate to its establishment, production, and harvest. These additional costs make switchgrass the more expensive option compared to corn stover.

Table 9. CO2 Breakeven Per Ton Prices

	Corn Stover	Switchgrass
Knox County, IN	$10.03	$14.57
Marion County, IN	$6.35	$15.24
Tippecanoe County, IN	$5.79	$14.46

Total costs per dry ton for transporting switchgrass 25 miles range between $59 and $64. A recent study by Perrin *et al.* (2008) determined switchgrass production costs on a commercial scale. The results were very similar to this analysis; however, yields and fertilizer rates varied among cooperating producers.

Supply Situations

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

The current resources of the individual producer are likely to dictate whether one decides to pursue biomass production or not. Therefore, from the perspective of the plant, there may be much uncertainty as to how much of the area supply might actually be brought in. This uncertainty may lead plants to contract their supply of raw material before making any plant investment.

Future Work

Future work on this topic would be to find ways to reduce the cost of producing and transporting biomass. Since both corn stover and switchgrass involve many inputs and activities for their production and transportation, large reductions in cost could be achieved by reducing the costs of numerous steps and components. Examples of ways to reduce costs might include further development of efficient commercial corn stover harvesters or research to increase switchgrass yields.

These results might also be used in exploring the potential for a cellulosic ethanol plant in Indiana and where the optimal plant location might be. Based on the results of this analysis and assuming 70 gallons of ethanol can be produced from one ton of biomass, Indiana corn stover could produce between 115 to 185 million gallons of ethanol annually, and Indiana switchgrass could produce between 175 to 280 million gallons of ethanol annually, depending upon the land participation rate. These projections are based on current conditions in the state and could be larger should land use and tillage changes be adopted.

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Rural Policy for the 21st Century

Thomas C. Dorr[1]

Remarks

Good morning. Thank you for that very generous introduction. And thanks to the Farm Foundation for convening this very timely discussion of biofuels and the bioeconomy. It is a distinct pleasure to be with you again today.

From a public policy standpoint, what is both fascinating and challenging about the current situation is that we are at a point of transition. There is a world of difference between dealing from strength versus dealing from weakness. This is true in any field … and it is certainly true as one thinks about rural policy, the rural economy, and the emerging bioeconomy. We are now dealing from strength.

For many years, all of us here have recognized the exciting potential of the carbohydrate economy. But now it's getting real.

The bioeconomy is moving from concept and aspiration to reality … from the labs to the marketplace. This is being led by the rapid buildout of biofuels. But it also extends to an ever-broader range of non-fuel biobased products as well.

This process is still in its early stages. But it is not too early to recognize that this evolution builds the case for important changes in government priorities and policy … changes that are indeed already underway.

This isn't always easy. Old perceptions, old attitudes, and old policies often die hard. As we saw in the debate on the 2008 Farm Bill, the old dependency-oriented, program-oriented model is still entrenched. At the federal level, in fact, it has been a long battle simply to gain recognition of the fact that rural policy is bigger and broader than farm policy.

It has been an even harder battle … one that is still underway … to persuade policymakers that markets and entrepreneurial activity, not government programs, should be the primary economic drivers in rural America.

[1]Dorr is the Under Secretary for USDA's Rural Development Agency in Washington, D.C.

Change in this area is slow, but gradually we have begun to challenge old assumptions. Many of you are familiar with the American Farm Bureau Federation's MAPP report, which was published in 2005.

That was a landmark piece of work … not least for the observation that farmers are now more dependent on rural communities than rural communities are dependent on farmers. The Farm Bureau is right about that, and policy needs to catch up with that insight.

Sixty million people live in rural America, and 58 million of them don't farm. More than 95 percent of the total rural income is earned off the farm. Even farm families, as a group, earn most of their incomes from non-farm employment. Virtually all the new jobs and most of the prospects for economic growth occur off the farm.

Clearly distributed computing, broadband, and modern transportation have rewritten the rules of the game. They have made rural communities probably more competitive today than at any prior point in our lifetimes. The growth of the bioeconomy is an important dimension of this new rural economy … but it is just one dimension. We are now dealing from multiple strengths.

At USDA Rural Development, we recognized five or six years ago that we were in a fundamentally new ballgame.

Not too many years ago, we were viewed … and we viewed ourselves … as a lender of last resort. But today we are essentially an investment bank for rural America with a combined portfolio of more than $100 billion in business, infrastructure, housing, and community facilities.

Not so long ago, we were oriented primarily to conventional government loan and grant financing. But today … while loans and grants remain part of the tool kit … we have shifted our emphasis to technical support and loan guarantees in order to maximize leverage and engage private capital.

The old assumption, from the 1930's forward, was that rural America was starved for credit and capital … and that government programs were therefore the engine of growth. But the new reality is that rural America is awash in latent investment capital in amounts that frankly dwarf the resources government is likely to bring to the table.

Net farm equity alone has more than doubled in this decade to nearly $2.3 trillion … and that of course is just one portion of the rural economy. To put that in perspective, USDA Rural Development has a total Budget Authority this year of $2.3 billion. Net farm equity alone is 1,000 times larger. Anyone who expects government programs to pull the train is expecting the tail to wag the dog.

Much of that growth in farm equity, by the way, is a product of the growth of biofuels. Agriculture is shifting to a food, feed, fiber, and fuel economy. That is reflected in commodities prices, farm incomes, and land prices. There are multiple impacts.

As a result the old policy model needs to change. And it is clear that the bioeconomy, especially biofuels, creates incentives, opportunities, and a policy environment that empowers and facilitates that change. Renewable energy in fact is probably the greatest new opportunity for wealth creation in rural America in our lifetimes, America last year sent $330 billion abroad to pay for imported oil. It will be higher this year.

If we can displace a billion barrels of imported oil with biofuels, that alone is a potential market larger than today's net farm income. That's clearly a goal worth pursuing … and it's an incentive that is now drawing record amounts of private capital into the arena.

So what are the policy implications?

First, as I suggested earlier, I take as a starting point the observation that government is no longer driving the train. This is a fundamental change. It doesn't mean that government can or should simply walk away. Not at all …

- The President, for example, proposed and the new Farm Bill contains several initiatives to accelerate the commercialization of cellulosic ethanol and dedicated energy crops. This is appropriate and important.
- Government has a critical role to play in sponsoring basic research, and we will continue to do that. Many of the new technologies are not mature.
- Government also has a strategic role to play in helping new and emerging technologies cross the "Valley of Death." We will continue to do this as well.

But as the buildout continues, our sights need to shift. Markets will drive private investment. Government's role as a direct financing agency will become very secondary, and eventually incidental.

As just one example, a couple of years ago I was still giving speeches patting USDA on the back for having been involved in a majority of the biodiesel plants in operation at that time. I can't do that any more. I don't know what the percentages are today, but most of the financing is private. This is a sign of success. We have reached liftoff.

That changes the mission and we are still feeling our way. But over the last four or five years we have commissioned a series of studies that have begun to outline new policy priorities.

We began with a study by *Informa Economics*, which examined the connections between broadband and the growth of the ethanol industry.

Ethanol is the first major new industry to arise in rural America since the advent of broadband. We suspected that wasn't a coincidence … and we were right. The *Informa* study very persuasively demonstrated that broadband and distributed computing were essential factors in enabling a highly dispersed industry to achieve economies of scale.

A second study examined investment models with an eye toward reducing transaction costs and facilitating the aggregation of local capital. I mentioned earlier that net farm equity now approaches $2.3 trillion. That's doubly relevant when it comes to biofuels because farmers already own the underlying resource. We grow the feedstocks. With regard to biofuels, we hold our future in our own hands.

But raising $40 million for a small ethanol plant, or $100 million, or $500 million in $10,000 increments is a challenge. The alternative is to raise it in two or three transactions with money center banks or venture capital firms. This is an economy of scale issue, and if we want to encourage local equity participation, it is a problem we need to solve.

A third study analyzed business structures to identify strategies for encouraging entrepreneurial initiative and local ownership.

The traditional coop model is appropriate for some purposes, but it also has familiar limitations. In the more dynamic and innovative business environment that exists today, there is an investor premium on transparency, transferability, liquidity, and equity appreciation.

In this environment, business forms such as new generation coops, LLC's, and a variety of partnership arrangements clearly hold great promise. Our role in this area is simply to inform, explain, and expand the toolkit available to rural investors. When farmers are sitting on $2.3 trillion in equity, what they need is probably not a government check … what they need is a roadmap and technical support.

Finally, we have begun an open-ended discussion of regulatory and logistical issues related to the development of distributed energy resources. A substantial new infrastructure needs to be built. This will involve roads, rail, barges, and pipelines. It will involve transmission corridors for distributed, rural wind and solar power. It will involve environmental and land use permitting, rights of way, and utility pricing structures. The technical potential of biofuels and biobased products is just the beginning of the story. Government has to get the industrial policy questions right as well.

So in the final analysis, we won't walk away from our traditional programs. We'll still provide loans, grants, and loan guarantees. But I am convinced that our success will ultimately rest not on the federal dollars we bring to the table nearly as much as it will rest on the entrepreneurial spirit and private investment we can catalyze.

This is the critical need today. We are realigning ourselves as an agency to focus greater resources on outreach, education, and technical support.

<u>And we could use your help</u>. May I suggest in closing … especially for those of you associated with the land grant colleges … that this is an area that richly deserves more research, more outreach, and more education.

The potential is there, in rural America. We hold our future in our own hands. With your help, we can and we will develop the entrepreneurial orientation and technical business skills to capitalize. Thank you.

Infrastructure for the Bioeconomy

Frank Dooley[1]

Background

Well before the recent rapid expansion in U.S. ethanol production, the voice of agricultural had expressed concerns about the state of infrastructure necessary to support grain transportation (Frittelli, 2005). Different modes (truck, rail, or barge) have advantages in export or domestic movements of grain. Policy debates about transportation tend to focus on a particular mode, while the grain supply chain is multi-modal and extremely competitive by nature. Investment in rail infrastructure is typically market driven because Class I railroads[2] own their right-of-way. In contrast, trucking and barge firms operate over publicly supported infrastructure and thus, policy concerns drive questions for highway investment or refurbished locks and dams. The policy debate is further complicated because most grain first moves over local roads and bridges. Other governmental transportation policies influencing the movement of grain include programs to maintain short line railroads and to improve access to intermodal ports, thereby facilitating the growth of export grain shipment via containers.

History has taught us that changes in federal transportation policy have important ramifications upon the grain marketing system. Grain moves from the field to end users seeking a minimum cost solution over a complex network of highways, railways, or waterways. The flow of grain is dependent upon the location and size of grain elevators, the receiving capability of grain buyers, the availability of trucks, rail or barges and power units, and rate structures, as well as the transportation infrastructure.

For example, grain flows shifted following truck and rail deregulation in 1980. Over the next decade, the U.S. rail system was reshaped through mergers, rail line abandonments, the creation of short line railroads, and changes in rail rate structures favoring multiple-car train movements of commodities like grain. In response, the grain marketing system adjusted by constructing new elevators designed to load multicar shipments. With reductions in shipping rates of 30 percent or more for volume shipments, more grain moved through these elevators.

The extensive public debate preceding passage of the deregulation legislation led to careful planning for changes in the grain and transportation systems. The academic community was an important part of this discussion with studies like Fedeler and Heady (1976) and many others outlining potential outcomes. This is not to say that the resulting change was not disruptive, but rather that it was anticipated.

The growth of the ethanol industry has been closely tied to agricultural and energy policies since 1978. Policies supporting ethanol have served various legislative purposes over time, including rural economic development, energy independence, clean air as a substitute for methyl tertiary-butyl ether (MTBE), and national security. The oil price increases since 2004 have once again led to legislation supporting ethanol as a gasoline alternative, most recently underscored by the expansion of the Renewable Fuels Standards in the Energy Independence and Security Act of 2007.

In short order, the proportion of the U.S. corn crop used for ethanol went from 11 percent in 2004 to 33 percent in 2008. Thus, once again the grain and transportation systems are in a process of readjustment as the location of markets for corn has suddenly shifted and new markets arose for ethanol and dried distillers grains with solubles (DDGS). Unlike prior shifts in grain utilization or transportation policy, there is scant evidence of careful consideration of this change upon the grain transportation system or infrastructure. For example, a recent report by the Congressional Budget Office (2006) on long term issues for rail freight does not consider ethanol. One additional key difference is that unlike the 1980s, the transportation system has less ability to adjust because it is already running near capacity (Denifcoff, 2007).

Given the concerns about transportation capacity, the focus of this paper is to consider how the sudden increase in ethanol production affects demands on transportation modes

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[2] U.S. Class I Railroads are line haul freight railroads with 2006 operating revenue in excess of $346.8 million (Association of American Railroads, 2008).

and infrastructure for grain, ethanol, and DDGS. The paper is organized into five sections. First, historic modal splits for grain transportation are reviewed. Second, demands for grain transportation are considered in light of the expansion in ethanol production since 2004. Next, a transportation flow model is constructed to portray adjustments facing the transportation system. After considering the implications of these adjustments for corn, ethanol, and DDGS, the paper ends with a prognosis.

Historical Modal Splits for Grain Transportation

Every six years, the USDA publishes a modal report for grain movements (Marathon, VanWechel, and Vachal, 2006). Data from various sources are reconciled to estimate tonnage movements by mode for export and domestic markets for corn, wheat, soybeans, sorghum, and barley. The modes are the final movements by rail, barge, and truck.

Total U.S. grains transported increased from 327 million tons in 1991 to 393 million tons in 2004 (Marathon, VanWechel, and Vachal, 2006). Around 70 percent of the total tonnage is shipped to domestic markets, with the remaining grain shipped to export markets. Virtually all of the growth over this 14 year period was in domestic traffic. Most of this growth was captured by truck, as the modal share for truck transportation grew from 40 to 50 percent (Figure 1). Truck transportation is especially important for domestic movements of grain. Overall rail moves 33 percent of all grain movements, while barge accounts for the remaining 18 percent of grain movements. Rail tonnage is up slightly from 1991 to 2004, from 128 to 136 million tons, while barge tonnage slightly declined, from 70 to 67 million tons.

Corn accounted for 61 percent of all grain movements in 2004, at 242 million tons (Marathon, VanWechel, and Vachal, 2006). Modal splits for corn are similar for all grains, with truck gaining in importance over time. Approximately 20 percent of the corn is exported each year, moving to ports by barge (68 percent) and rail (30 percent). The production of corn has greater transportation requirements than other grains simply because the yield per acre is much higher. For example, in 2007, the average yield of corn was 151 bushels per acre compared to yields of 74, 60, 60, and 41 bushels per acre for sorghum, barley, soybeans, and wheat respectively (USDA-NASS, 2008). The higher yield per acre means there is much more grain to be hauled when raising corn as opposed to other grains. An acre of corn has twice the volume of grain compared to sorghum, 2.5 times the volume of barley and soybeans, and 3.7 times the volume of wheat. Thus, changes in corn production lead to much greater impacts on transportation requirements than other grains simply because of volume.

From 2004 to 2008, utilization of U.S. grain rose around 15 percent, from 16.6 billion bushels to almost 19 billion bushels (Figure 2). The increase has arisen almost exclusively from a growth of 1.8 billion bushels in domestic corn utilization. Growth in domestic and export utilization of other grains (wheat, soybeans, sorghum, and barley), as well as export corn, has been relatively flat. The surge in grain utilization

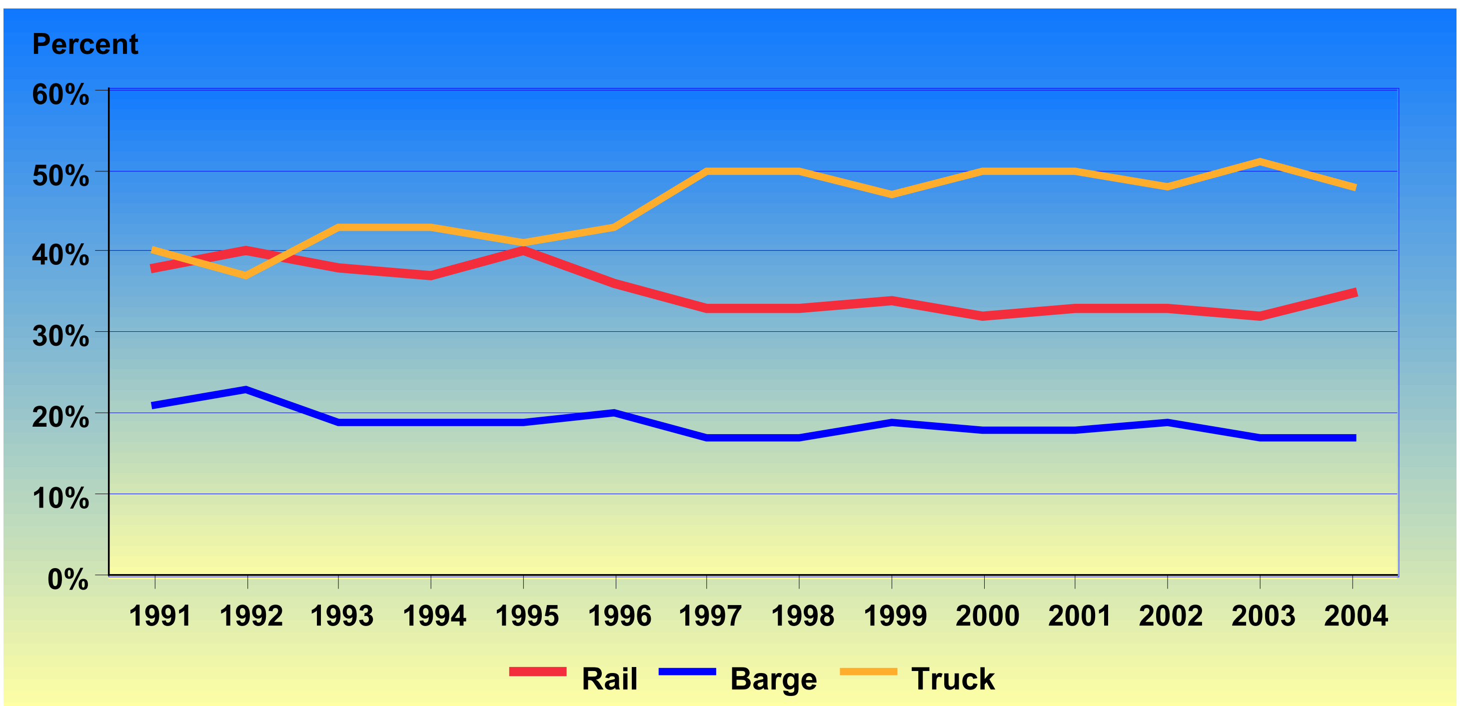

Figure 1. Modal Shares for U.S. Grains, 1991-2004
Source: Marathon, VanWechel, and Vachal, 2006

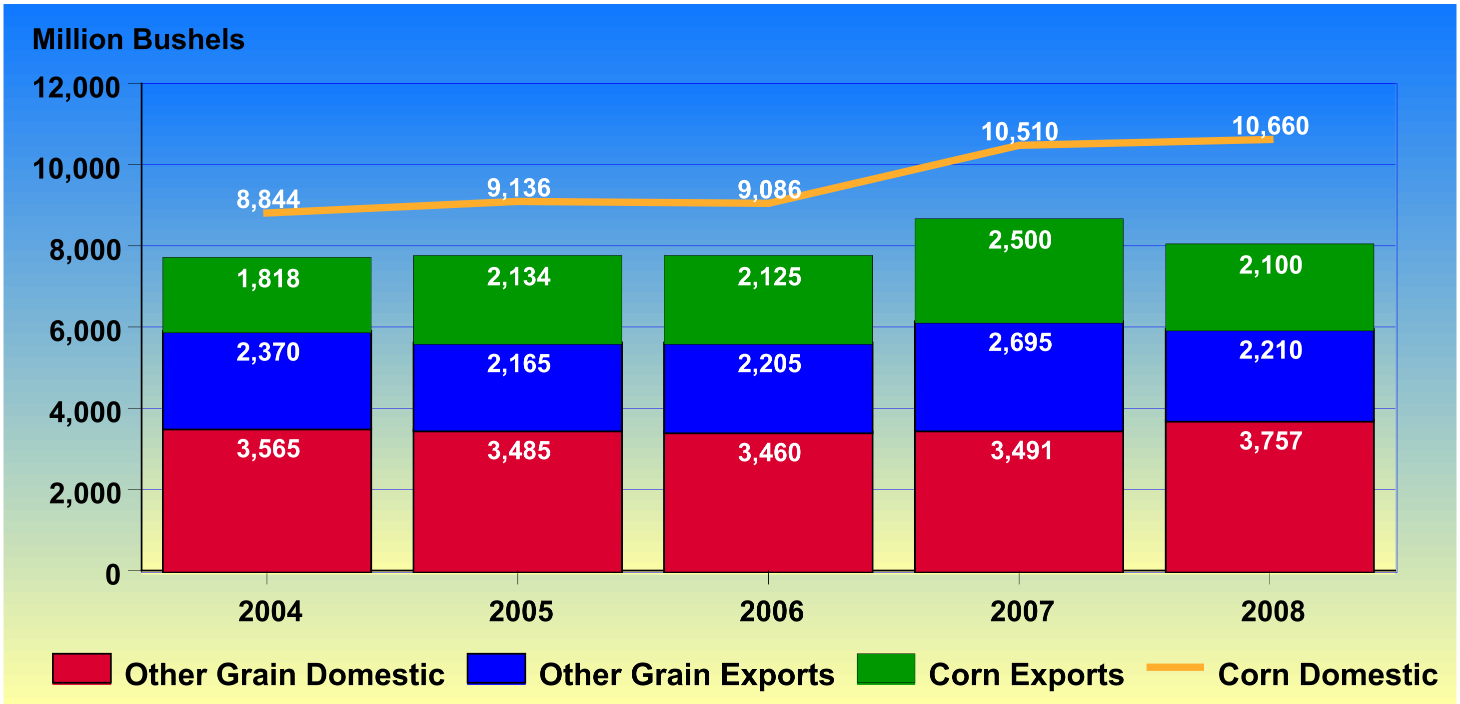

Figure 2. Utilization of U.S. Grain, 2004 to 2008
Source: Economic Research Service, 2008a, 2008b, and 2008c

since 2004 in turn has increased grain transportation requirements.

The four main uses of U.S. corn are for livestock feed, food products (such as high-fructose corn syrup, dextrose, glucose, starch, beverage alcohol, or cereals), exports, and ethanol. Except for ethanol, all of these uses have been relatively stable since 1991 (Figure 3). Feed use has fallen from 2007 to 2008, in part because of higher corn prices and the increased availability of DDGS as a substitute in feed rations. Thus, the increased usage of corn can be largely attributed to the emergence of the ethanol industry.

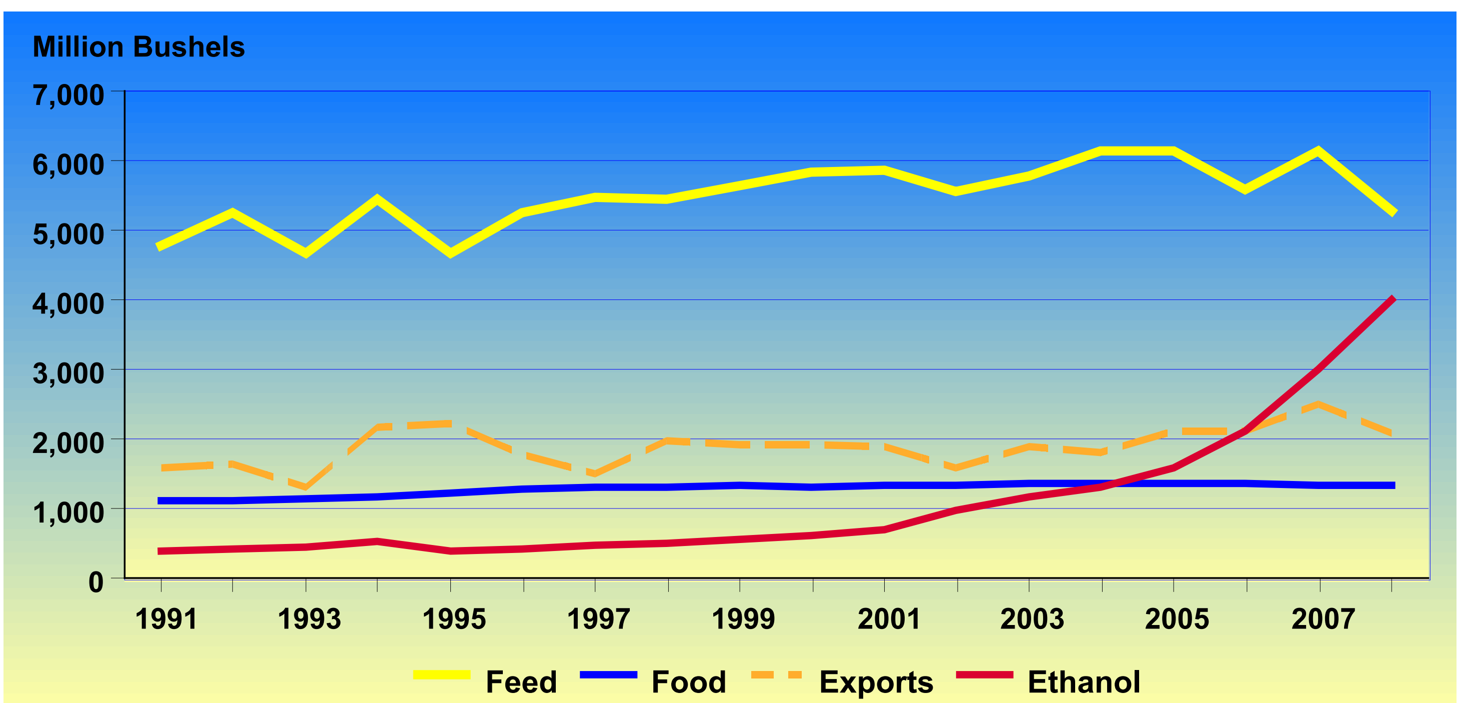

Figure 3. Corn Utilization for Feed, Food, Exports, and Ethanol, 1991-2008
Source: Economic Research Service, 2008a

The 1.8 billion bushels is equivalent to 50.8 million tons of additional corn utilized in domestic markets, or a level almost equal to total annual barge shipments of grain. In 2004, the modal splits for domestic corn shipments were 66.4, 31.8, and 1.8 percent for truck, rail, and barge respectively (Marathon, VanWechel, and Vachal, 2006). The capacity of a truck, rail hopper rail car, and barge are 26, 100, and 1,500 tons respectively (Denicoff, 2007). If the traditional modal split holds, this expansion in corn utilization has generated new traffic of 1.3 million truckloads, 160,000 rail carloads, and 588 barges. In addition, new ethanol and DDGS traffic is generated.

Yet it is suggested that traditional flows will be altered and most corn will be shipped to ethanol plants by truck (Denicoff, 2007). In addition, the United States may be more dependent on truck to move ethanol and DDGS to final markets because of capacity constraints for rail and barge traffic (Pentland, 2008). However, to date, rail appears to be the most important carrier for ethanol, while truck is of greater importance for DDGS (Table 1).

Modeling Transportation Flows

Unfortunately, the next USDA modal split analysis will not be published until sometime in 2012. This information is of great value as industry and governmental planners consider investments in equipment and infrastructure. Thus, a model is developed to provide some initial perspective about the shifts in corn, ethanol, and DDGS movements. The model does not compare in complexity to the intricate and detailed mathematical programming models built prior to rail deregulation. Nevertheless, it does consider the magnitude of the new traffic upon the existing network, as well as providing an initial consideration as to the geographic locations for corn, ethanol, and DDGS production and consumption. In turn, effects on transportation requirements are inferred based upon whether the consumption is within a state's borders. Corn, DDGS, and ethanol produced and consumed within a state are assumed to move by truck, while surplus production from a state is assumed to move by rail or barge.

The model captures the flow of corn to two end uses, as ethanol and livestock feed (Figure 4). Two separate flows

Table 1. Estimated Modal Shares for Ethanol and DDGS, 2005 and 2007

Product	Ethanol		DDGS	
	2005[a]	2007[b]	2005[a]	2007[b]
Truck	30%	25.0 to 26.3%	84%	43.5%
Rail	60%	66.0 to 73.7%	14%	56.5%
Barge	10%	0 to 9.0%	2%	0%
Total	100%	100%	100%	100%

Sources: [a]Denicoff (2007) and [b]Wu (2008).

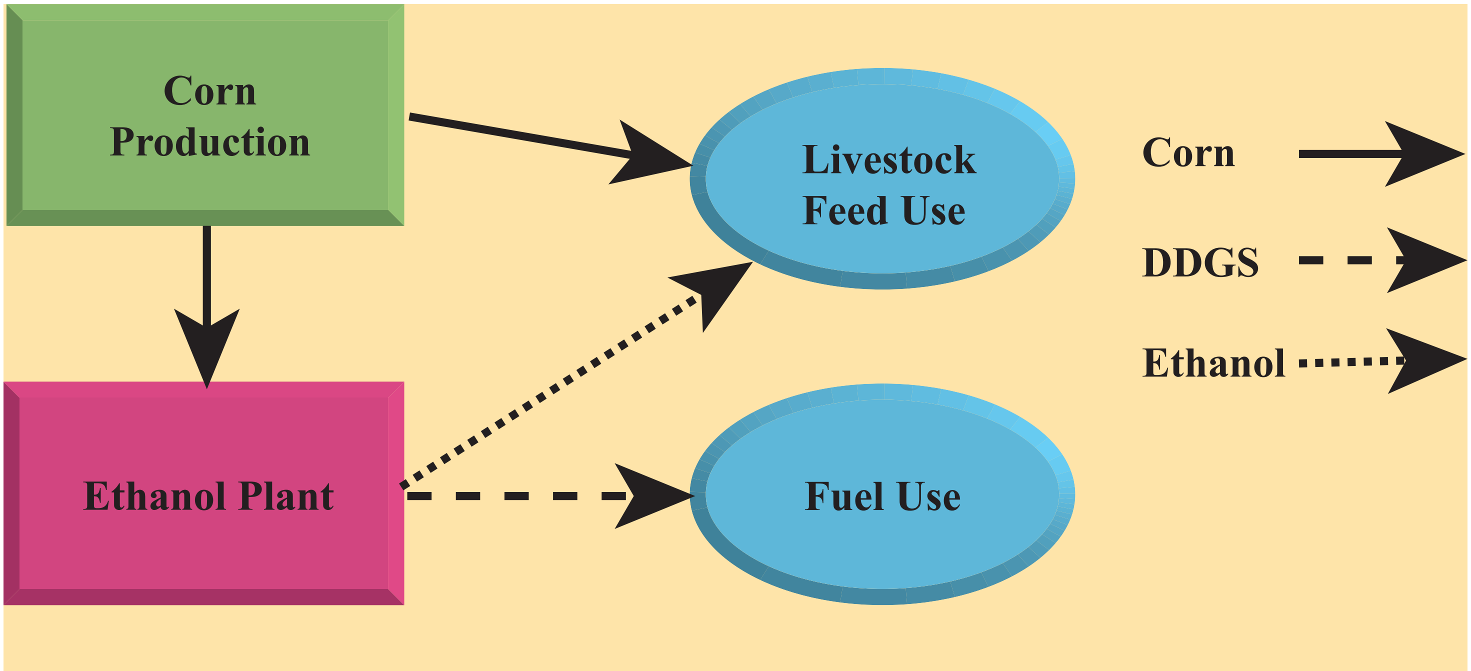

Figure 4. Flows of Corn, Ethanol, and DDGS

are tracked from the ethanol plant, first, as ethanol to terminal blenders, and second, as DDGS to feed livestock. Secondary data represent state level activity, with snapshots presenting flows for 2004, 2007, and 2010. The 2004 model provides a baseline consistent with the last USDA transportation modal analysis report and also reflects the market before the recent expansion in ethanol. The 2007 model captures the effect of first wave of ethanol construction and the growth in corn production. The 2010 model anticipates the further expansion of ethanol capacity, and ethanol demand encountering the "blending wall" associated with a usage of a 10 percent blend of ethanol in gasoline.

Corn production data are from the Economic Research Service (ERS) (2008a) of the USDA. Data for 2004 are the average corn production from crop years 2003 and 2004, and for 2007 are the average from crop years 2006 and 2007. The forecast for 2010 is based on the USDA projections for 2009 and 2010. State level values from 2007 are inflated proportionally to reach the estimated U.S. total production for 2010. Assumed total production is 10.9, 11.8, and 13.4 billion bushels for 2004, 2007, and 2010 respectively (Table 2). Corn production is heavily concentrated in the Midwest states, with Census Regions 3 and 4 accounting for 87.5 percent of all corn production. Five states - Illinois, Indiana, Iowa, Minnesota, and Nebraska - account for 65 percent of U.S. corn production.

Plant capacities, locations, and year of entry are obtained from *Ethanol Producer Magazine* (2008). In 2004, 66 plants operated 4.1 billion gallons of capacity. At the end of 2007, 137 plants were in operation with 8.2 billion gallons of capacity. By 2010, 195 plants will operate 13.2 billion gallons of production capacity. Over 90 percent of the ethanol produc-

Table 2. Assumed Corn Production and Region Share, by Year

Census Region	States	2004	2007	2010	Region Share
		000 bushels			
1	CT, MA, ME, NH, RI, VT	0	0	0	0.0%
2	NJ, NY, PA	185,490	196,418	222,843	1.7%
3	IL, IN, MI, OH, WI	3,912,425	4,184,035	4,746,940	35.5%
4	IA, KS, MN, MO, ND, NE, SD	5,684,025	6,141,190	6,967,404	52.0%
5	DE, FL, GA, MD, NC, SC, VA, WV	273,157	294,256	333,844	2.5%
6	AL, KY, MS, TN	333,558	341,870	387,864	2.9%
7	AR, LA, OK, TX	348,010	410,075	465,245	3.4%
8	AZ, CO, ID, MT, NM, NV, UT, WY	164,910	182,964	207,579	1.5%
9	CA, OR, WA	46,580	53,573	60,780	0.4%
	USA	10,948,154	11,804,381	13,392,500	100.0%

Source: USDA, Economic Research Service, (2008a)

Table 3. Assumed Ethanol Production and Region Share, by Year

Census Region	States	2004	2007	2010	Region Share
		000 gallons			
1	CT, MA, ME, NH, RI, VT	0	0	0	0.0%
2	NJ, NY, PA	0	0	150,000	0.6%
3	IL, IN, MI, OH, WI	1,037,000	2,132,000	3,401,000	25.8%
4	IA, KS, MN, MO, ND, NE, SD	3,023,500	5,475,500	8,246,000	65.8%
5	DE, FL, GA, MD, NC, SC, VA, WV	0	0	160,000	0.6%
6	AL, KY, MS, TN	33,000	93,000	193,000	1.3%
7	AR, LA, OK, TX	0	100,000	340,000	1.7%
8	AZ, CO, ID, MT, NM, NV, UT, WY	0	202,000	262,000	1.8%
9	CA, OR, WA	0	203,000	415,000	2.4%
	USA	4,093,500	8,205,500	13,167,000	100.0%

Source: *Ethanol Produceer Magazine*, (2008) tive capacity is found in Census Regions 3 and 4 (Table 3). Iowa and Nebraska alone account for 40 percent of industry capacity. Plants were found in 12, 20, and 26 states in 2004, 2007, and 2010 respectively.

Thus, ethanol plants can be described as origin mills as production capacity is heavily concentrated in the same geographic area as the feedstock. Each bushel of corn is assumed to produce 2.79 gallons of denatured ethanol and 17.5 pounds of DDGS. Thus, ethanol plants consume 1.5, 2.9, and 4.7 billion bushels of corn, while producing 12.8, 25.7, and 41.2 million tons of DDGS in 2004, 2007, and 2010 respectively.

To estimate livestock demand, state level animal populations were obtained from the 2002 Census of Agriculture for 10 classes of animals (cattle on feed, beef cows, milk cows, other cattle, breeding swine, market swine, layers, pullets, turkeys, and broilers) (USDA-NASS, 2002). USDA projections assume that beef cattle and dairy consume around 90 percent of DDGS, while hogs and chickens account for around 5 percent each (USDA-IAPC, 2007). Annual feed consumption rates per head per species are adapted from N'Guessan (2007) for corn and DDGS. Animal numbers are assumed to remain constant over the three time periods. Southern states in Census Regions 5, 6, and 7 host most of the nation's poultry and hogs, while cattle production is concentrated in the Plains states in Regions 4 and 7 (Table 4).

Consumption of ethanol is based on gasoline consumption by state, which is assumed to be constant over time. Gasoline consumption is dispersed across the United States (Table 5). State level consumption of ethanol for 2004 was obtained from the Energy Information Administration (USDA-EIA, 2008a). Total U.S. ethanol consumption in 2004 was 3.5 billion gallons (USDA-EIA, 2008b). For 2010, it is assumed that state level consumption in each state will reach 13.8 billion gallons, or the blending wall of 10 percent of expected gasoline consumption. According to the EIA, U.S consump-

Table 4. Distribution of Cattle, Hogs, and Chickens, and Feed, by Census Region

Census Region	States	Region % of Cattle	Region % of Hogs & Poultry	Region % of U.S. Feed Use
1	CT, MA, ME, NH, RI, VT	0.5%	0.0%	0.6%
2	NJ, NY, PA	3.0%	1.9%	4.4%
3	IL, IN, MI, OH, WI	8.1%	2.2%	11.3%
4	IA, KS, MN, MO, ND, NE, SD	32.3%	5.1%	30.8%
5	DE, FL, GA, MD, NC, SC, VA, WV	6.1%	36.9%	11.9%
6	AL, KY, MS, TN	6.5%	25.2%	6.6%
7	AR, LA, OK, TX	22.8%	24.6%	17.2%
8	AZ, CO, ID, MT, NM, NV, UT, WY	12.9%	0.1%	9.1%
9	CA, OR, WA	7.7%	3.9%	8.2%
	USA	100.0%	100.0%	100.0%

Source: United States Department of Agriculture, 2004

Table 5. Distribution of Gasoline Demand and Ethanol Blend Rates, by Census Region

Census Region	States	Region Share of U.S. Gasoline Market	Ethanol Blend Rate 2004	Ethanol Blend Rate 2007
1	CT, MA, ME, NH, RI, VT	4.8%	2.6%	5.3%
2	NJ, NY, PA	11.0%	2.6%	4.5%
3	IL, IN, MI, OH, WI	15.1%	4.8%	10.0%
4	IA, KS, MN, MO, ND, NE, SD	7.3%	5.5%	10.2%
5	DE, FL, GA, MD, NC, SC, VA, WV	20.7%	0.7%	3.8%
6	AL, KY, MS, TN	6.9%	0.9%	3.8%
7	AR, LA, OK, TX	12.7%	0.4%	3.8%
8	AZ, CO, ID, MT, NM, NV, UT, WY	6.9%	1.0%	4.0%
9	CA, OR, WA	14.6%	4.6%	5.4%
	USA	100.0%	2.5%	5.6%

Source: Energy Information Administration, (2008a,b) tion of ethanol for 2007 was expected to total 7.7 billion gallons. States in Census Regions 3 and 4 were assumed to use a 10 percent blend of ethanol, while states in the rest of the country used ethanol at the either the maximum of the state level blend rate in 2004 or 3.8 percent (Table 5).

After all data calculations were completed, state level consumption was subtracted from state level production for corn, ethanol, and DDGS, for each year. This determines whether a state has a surplus or deficit of corn, ethanol, or DDGS. The changes are compared over time to identify the effects of shifts in corn utilization and ethanol production.

Model Results

Corn Movements

In 2004, the 48 contiguous states produced 10.9 billion bushels of corn (Table 2). Of this total, 5.9 and 1.5 billion bushels were used for feeding livestock and ethanol production respectively. To determine corn flows, Net Corn is defined:

$$\textit{Net Corn}_{i,t} = \textit{Corn Production}_{i,t} - \textit{Corn for Livestock}_{i,t} - \textit{Corn for Ethanol}_{i,t}$$

where i is a state among the 48 continental U.S. states and t is time period (2004, 2007, or 2010). If Net Corn is greater than zero, the state has a surplus of corn that can be shipped to states with a deficit, used for food production, or exported. In contrast, states with a negative Net Corn balance must import corn to meet livestock and ethanol corn demands.

Nationwide, the United States had a net corn surplus of 3.5 billion bushels of corn in 2004 (Tables 6 and 7). However, this calculation ignores U.S. utilization of corn for food processing and exports, which have been as high as 3.5 billion bushels in recent years (Figure 3). Sixteen states ran a corn surplus in 2004, with Illinois, Iowa, Indiana, and Minnesota accounting for most of the surplus. The 16 corn surplus states produced 9.6 billion bushels of corn, using 2.3 billion bushels to feed livestock, 1.4 billion bushels for ethanol.

The 32 corn deficit states in 2004 produced 1.3 billion bushels of corn, but consumed 3.6 billion bushels to feed livestock and 31 million bushels for ethanol production (Table 7). Most likely the locally produced and consumed corn moved by truck, while most of the 2.3 billion bushels of imported corn moved by rail or barge. The largest importing states in 2004 were Texas, California, and Oklahoma.

From 2004 to 2007, total U.S. corn production increased from 10.9 to 11.8 billion bushels (Table 2). Although corn production is growing across the United States, the growth in production is concentrated in the Corn Belt states of the Midwest. While total production grew, the nationwide corn surplus fell by 219 million bushels (Table 7). The number of surplus states fell to 15, as Tennessee moved to a corn deficit. The 15 surplus states produced 10.2 billion bushels, while consuming 2.1 and 2.6 billion bushels for livestock and ethanol. Thus, 5.6 billion bushels were available for shipment from the surplus states. The pattern for the 33 corn deficit states was similar to 2004, with the deficit states running a shortage of 2.2 billion bushels. States with the largest surpluses remained the same as in 2004, while Georgia replaced Oklahoma as having the third largest corn deficit.

The change in corn utilization will likely follow a similar path from 2007 to 2010. Corn production will reach 13.4 billion bushels in 2010 (Table 2). The net corn balance will return to 3.5 billion bushels by 2010 (Table 6). Thus, given the corn used for food processing and historic levels of exports, the United States will use virtually all of its corn in the near future.

In 2010, 18 states run a corn surplus, producing 11.9 billion bushels, while consuming 2.2 and 4.0 billion bushels for livestock and ethanol (Table 7). Over 5.6 billion bushels remain available for shipment from the surplus states. The corn deficit falls for the 30 corn deficit states. While the consumption of corn for ethanol in deficit states grows from 319 to 694 million bushels, this is offset as less corn is fed to livestock due to as increased DDGS utilization in animal diets.

DDGS Movements

As a coproduct of ethanol production, DDGS production tracks the expansion in ethanol production. In 2004, the 12 states with ethanol plants produced 12.8 million tons of DDGS (Table 9). With the expansion of ethanol production to 20 and 26 states in 2007 and 2010, respectively, DDGS production increases to 22.9 and 35.2 million tons. Thus, over time DDGS will become more geographically disperse, thereby reducing the distance for DDGS transportation from surplus to deficit states.

In 2004, the seven DDGS surplus states consumed 5.1 million tons and shipped 7.4 million tons of DDGS elsewhere, of which 868,000 tons was exported (Table 9). The 41 DDGS deficit states only produced 270,000 tons of DDGS. By 2007, U.S. consumption of DDGS grew to 23.1 million tons. Consumption is expected to grow to 34.9 million tons by 2010, when U.S. markets will be close to the saturation point. The level of exports is expected to reach 2.6 and 6.4 million tons in 2007 and 2010 respectively.

States with the greatest surplus of DDGS mirror states with the greatest ethanol production. In 2010, Iowa, Nebraska, and Illinois, will account for over 60 percent of the nationwide surplus in DDGS (see Table 9). States with the largest deficits in 2010 are Texas, Oklahoma, and California.

Shipment of DDGS via rail or barge initially encountered difficulties related to flowability, a factor related to the moisture content. Unless the moisture content of DDGS is un-

Table 6. Net Corn Position, by Census Region and Year

Census Region	States in Census Region	Net Corn Position 2004	2007	2010
		000 bushels		
1	CT, MA, ME, NH, RI, VT	-36,247	-31,819	-22,900
2	NJ, NY, PA	-80,119	-42,775	-56,780
3	IL, IN, MI, OH, WI	2,866,907	2,782,524	2,903,132
4	IA, KS, MN, MO, ND, NE, SD	2,784,589	2,459,460	2,336,688
5	DE, FL, GA, MD, NC, SC, VA, WV	-466,522	-416,622	-404,661
6	AL, KY, MS, TN	-84,102	-83,697	-38,091
7	AR, LA, OK, TX	-675,062	-553,336	-445,477
8	AZ, CO, ID, MT, NM, NV, UT, WY	-365,040	-369,930	-262,676
9	CA, OR, WA	-436,085	-454,292	-488,180
	USA Surplus for Food and Exports	3,508,319	3,289,512	3,521,054

Table 7. Information on States in Surplus or Deficit Net Corn Position, by Year

Item	Net Corn Position 2004	2007	2010
Number of Corn Surplus States	16	15	18
Number of Corn Deficit States	32	33	30
	000 bushels		
Information from States with Surplus:			
Corn Production	9,602,227	10,200,751	11,850,069
Corn for Livestock	2,320,700	2,136,494	2,337,764
Corn for Ethanol	1,436,380	2,621,685	4,024,731
Available for Out of State Shipment	6,160,650	5,645,410	5,631,144
Information from States with Deficit:			
Corn Production	1,345,927	1,603,630	1,542,431
Corn for Livestock	3,651,931	3,437,335	2,814,327
Corn for Ethanol	30,824	319,355	694,624
Imported Corn	-2,336,828	-2,153,060	-1,966,520
Largest Three Surplus States (04, 07, 10)			
IL, IL, IL	1,576,412	1,658,991	1,809,424
IA, IA, IA	1,176,719	1,010,598	850,830
IN, IN, MN	702,847	649,107	661,010
Largest Three Deficit States (04, 07, 10)			
OK, GA, GA	-163,237	-150,110	-181,108
CA, CA, TX	-339,849	-325,224	-326,144
TX, TX, CA	-406,237	-353,353	-346,273

der 11 percent, DDGS can cake or solidify during shipment (Shurson, 2005). Because of these problems, the BNSF and Union Pacific require that DDGS be shipped in hopper cars owned or leased by the shipper. Yet both carriers anticipate additional growth in DDGS traffic, as unit train rates have been implemented from ethanol plants in the Midwest to feed lots in Texas, New Mexico, and other locations.

Ethanol Movements

Net surpluses and deficits for ethanol display much greater variability over time because both production and consump-

Table 8. Net DDGS Position, by Census Region and Year

Census Region	States in Census Region	Net DDGS Position 2004	2007	2010
		000 tons		
1	CT, MA, ME, NH, RI, VT	-87	-211	-461
2	NJ, NY, PA	-520	-1,260	-1,163
3	IL, IN, MI, OH, WI	1,887	4,300	7,929
4	IA, KS, MN, MO, ND, NE, SD	5,141	10,128	17,584
5	DE, FL, GA, MD, NC, SC, VA, WV	-567	-1,374	-1,704
6	AL, KY, MS, TN	-308	-501	-1,180
7	AR, LA, OK, TX	-2,121	-4,482	-7,613
8	AZ, CO, ID, MT, NM, NV, UT, WY	-1,459	-2,210	-4,938
9	CA, OR, WA	-1,097	-1,792	-2,104
	Available to Export from the USA	868	2,598	6,350

Table 9. Information on States in Surplus or Deficit Net DDGS Position, by Year

Item	Net DDGS Position 2004	2007	2010
Number of DDGS Surplus States	7	9	13
Number of DDGS Deficit States	41	39	35
	000 tons		
Information from States with Surplus:			
DDGS Production	12,568	22,940	35,216
DDGS for Livestock	5,147	8,587	12,119
Available for Out of State Shipment	7,421	14,353	23,097
Information from States with Deficit:			
DDGS Production	270	2,794	6,078
DDGS for Livestock	6,822	14,549	22,825
Imported DDGS	-6,553	-11,755	-16,748
Largest Three Surplus States (04, 07, 10)			
IA, IA, IA	2,725	5,516	9,514
NE, IL, NE	1,830	1,931	3,346
IL, NE, IL	1,774	1,753	3,028
Largest Three Deficit States (04, 07, 10)			
KS, OK, CA	-629	-905	-1,940
CA, CA, OK	-801	-1,548	-1,976
TX, TX, TX	-1,562	-3,127	-4,657

tion are experiencing dramatic change. Ethanol capacity has grown from 4.0 to 8.2 to 13.2 billion gallons in 2004, 2007, and 2010, respectively, as the number of states with ethanol plants grew from 12 to 20 to 26 (see Table 3). However, even with plants across the country, ethanol production is heavily concentrated in the Corn Belt states. With respect to consumption, the blend rate of ethanol in gasoline has grown from 2.5 percent in 2004 to 5.6 percent in 2007 to 10 percent in 2010 (see Table 5) as blenders have sought to replace MTBE as an oxygenate and oil prices have risen in price.

Nationwide, the United States had ethanol surpluses of 594 million gallons in 2004 and 526 million gallons in 2007 (Table 10). A deficit of 587 million gallons is anticipated in 2010. However, imports are not included as part of the available ethanol stock. Thus, the nation is on track to reach sufficient productive capacity to meet the blending wall by 2010.

Table 10. Net Ethanol Position, by Census Region and Year

Census Region	States in Census Region	Net Ethanol Position 2004	2007	2010
		000 gallons		
1	CT, MA, ME, NH, RI, VT	-171,318	-349,873	-654,603
2	NJ, NY, PA	-395,472	-681,308	-1,362,934
3	IL, IN, MI, OH, WI	38,324	60,208	1,329,208
4	IA, KS, MN, MO, ND, NE, SD	2,470,528	4,450,795	7,237,736
5	DE, FL, GA, MD, NC, SC, VA, WV	-199,794	-1,074,775	-2,688,557
6	AL, KY, MS, TN	-49,110	-264,727	-755,111
7	AR, LA, OK, TX	-76,608	-559,440	-1,407,764
8	AZ, CO, ID, MT, NM, NV, UT, WY	-97,692	-179,821	-690,278
9	CA, OR, WA	-925,092	-875,559	-1,594,814
	USA exports or imports	593,766	525,500	-587,117

Table 11. Information on States in Surplus or Deficit Net Ethanol Position, by Year

Item	Net Ethanol Position 2004	2007	2010
Number of Ethanol Surplus States	8	12	10
Number of Ethanol Deficit States	40	36	38
	000 gallons		
Information from States with Surplus:			
Ethanol Production	4,007,500	7,314,500	11,229,000
Ethanol for Blenders	1,654,086	3,414,356	5,054,728
Available for out of state shipment	2,353,414	3,900,144	6,174,272
Information from States with Deficit:			
Ethanol Production	86,000	891,000	1,938,000
Ethanol for Blenders	1,845,648	4,265,644	8,699,390
Imported Ethanol	-1,759,648	-3,374,644	-6,761,390
Largest Three Surplus States (04, 07, 10)			
IA, IA, IA	1,191,558	2,038,056	3,313,056
NE, NE, NE	595,838	1,220,150	1,728,150
SD, SD, SD	523,774	637,689	847,689
Largest Three Deficit States (04, 07, 10)			
OH, TX, TX	-186,228	-342,340	-832,368
NY, OH, FL	-299,208	-396,173	-868,081
CA, CA, CA	-874,146	-858,288	-1,368,037

In 2004, the 8 ethanol surplus states consumed 1.7 billion gallons of the 4.0 billion gallons produced in those states (Table 11). In contrast, the 40 ethanol deficit states consumed 1.8 billion gallons while only producing 86 million gallons. Over time, Iowa, Nebraska, and South Dakota have run the largest surpluses of ethanol. The largest deficits have been observed in the populous states of California, New York, Florida, Ohio, and Texas.

Since 2004, ethanol capacity has rapidly expanded. In 2007, the 12 ethanol surplus states will consume 3.4 billion gallons of the 7.3 billion gallons produced (Table 11). Production in 2007 for the deficit states rose to 891 million gallons, but consumption rose to 4.3 billion gallons. Assuming that the blending wall is reached in 2010, the 10 ethanol surplus states will produce 11.2 billion gallons of ethanol, consuming 5.1 billion gallons of that production. The other

Table 12. Modal Shares and Loads Generated for Corn, DDGS, and Ethanol, by Year

Product/Mode/Loads	2004	2007	2010
Corn			
Truck Modal Share	47%	54%	59%
Rail Modal Share	53%	46%	41%
Total Corn Volume (000 bu)	10,948,154	11,804,381	13,392,500
DDGS			
Truck Modal Share	42%	44%	44%
Rail Modal Share	58%	56%	56%
Total DDGS Volume (000 tons)	12,838	25,734	41,294
Ethanol			
Truck Modal Share	43%	52%	53%
Rail Modal Share	57%	48%	47%
Total Ethanol Volume (000 gal)	4,093,500	8,205,500	13,167,000
Truck Loads (000)			
Corn	5,608	6,991	8,687
DDGS	208	438	700
Ethanol	221	547	889
Total Truck Loads (000)	6,037	7,976	10,276
Rail Carloads (000)			
Corn	1,670	1,555	1,568
DDGS	74	144	231
Ethanol	78	129	204
Total Rail Loads (000)	1,822	1,828	2,003

38 states will increase production to 1.9 billion gallons, as consumption rises to 8.7 billion gallons.

Modal Shares

The results for corn, DDGS, and ethanol from Tables 6 through 11 can be used to generate rough estimates of modal shares for truck versus rail, as well as the number of truckloads and rail carloads generated. All corn, DDGS, or ethanol produced and consumed within the boundaries of a particular state is assumed to be a truck movement. All production available for export from the Net Corn, DDGS, or Ethanol Surplus states is assumed to be shipped by rail. Corn, DDGS, and ethanol are measured in bushels, tons, and gallons respectively. Truckload capacities are 910 bushels, 26 tons, and 7,865 gallons, while railcar capacities are 3,500 bushels, 100 tons, and 32,240 gallons (Denicoff, 2007). While values are reported as rail modal share or carloads, barge would be competitive for many of the rail movements, in large part because much of the production originates from states found along the Mississippi River system.

Transportation requirements are greatest for corn because the flows reflect both ethanol and livestock consumption. Over time, the truck modal share is expected to grow from 47 percent in 2004 to 54 percent in 2007 to 59 percent in 2010 (Table 12). This shift is driven by two factors. First, the volume of corn shipped is much larger, growing by 2.4 billion bushels. Second, most ethanol plants will draw corn from local truck markets. The number truckloads of corn will increase from 5.6 to 8.7 million from 2004 to 2010, while rail carloads will slightly decline, from 1.7 to 1.6 million. It is likely that corn used for food processing will continue to largely move by truck, while corn shipped to export markets will move by rail or barge.

The truck modal share for DDGS is expected to be constant ranging from 42 to 44 percent from 2004 to 2010. This is consistent with the values reported by Denicoff (2007) and Wu (2008) in Table 1. While modal splits are stable, traffic will increase because of the much greater production of DDGS over time. Truckloads climb from 208,000 to 700,000, while rail shipments increase from 74,000 to 231,000 carloads.

Finally, truck modal share for ethanol starts at 43 percent in 2004, before rising to 53 percent in 2010. This estimate of truck share is around 10 percent higher than Denicoff (2007) and Wu (2008). In terms of truckloads, ethanol increases fourfold from 2004 to 2010, from 221,000 to 889,000 loads. Rail carloads rise from 78,000 in 2004 to 204,000 in 2010. Truck gains more relative to rail because ethanol productive capacity is found in 26 states in 2010 compared to only 12 in 2004. However, it may be necessary to rail corn to ethanol plants in Arizona, California, Colorado, Georgia, Idaho, Kentucky, Michigan, Missouri, North Carolina, New Mexico, New York, Oregon, Tennessee, Texas, Washington, and Wyoming. An additional factor constraining rail shipment is that only 10 percent of the terminal blenders have rail receiving capacity (Quear, 2008). Furthermore, only a handful of the blenders in the country, probably less ten, can receive unit train shipments of ethanol (Knight, 2007).

Overall transportation requirements will increase for both trucks and rail because of the influx of ethanol production and consumption. Total truck loads will rise from 6.0 million in 2004 to 10.3 million in 2010, while railcar shipments climb from 1.8 million to 2.0 million (see Table 12). The 9.9 percent increase in railroad traffic encompasses a reduction in corn traffic offset by increases in DDGS and ethanol. The railroads seemingly have the ability to manage this change. On its face, the 77.7 percent increase in truck traffic will likely create greater equipment and infrastructure challenges, especially at the local level.

Prognosis

After 15 years of relative calm, transportation is once again emerging as an issue of concern for agricultural shippers and receivers, transportation firms, and public policy makers. The pace of change caused by the growth in ethanol is rapid. Five observations are made.

First, the effects of ethanol and related products on transportation equipment and infrastructure are large in magnitude. In the short run, ethanol firms, truckers, and railroads are experiencing order backlogs for new hopper and tanker cars or difficulties in shipping DDGS. While challenging, these likely reflect short term adjustments as opposed to long term concerns.

Second, the effects of increased truck traffic are felt most in the communities and surrounding areas with the new ethanol plants. A 100 million gallon per year ethanol plant requires 110 truckloads of corn per day, while generating 35 truckloads each of ethanol and DDGS. While the economic development associated with new ethanol plants is welcome in rural communities, the increase in truck traffic may be straining local highway maintenance budgets. The problem may be more serious in regions with bridges in poor condition.

Third, compared to the traditional grain sector, many ethanol plants have relatively little storage for corn and outputs. With as little as 10 days to 2 weeks of storage capacity, these plants are reliant on dependable providers of transportation service. As a corollary, railroads might increase their equipment utilization when shipping ethanol and DDGS as compared to grain. The predictable, steady nature of shipments from ethanol plants stands in sharp contrast to the seasonality associated with shipping grain.

Fourth, once 13.4 billion gallons of ethanol capacity is reached, the industry will face the blending wall. Yet the Renewable Fuels Standards mandate consumption of 35 billion gallons of ethanol by 2022. The pathway to achieving this is only beginning to be contemplated, but likely involves investment in infrastructure to supply E85, a blend of 85 percent ethanol with gasoline. E85 requires an entirely different system of pumps and alternative fuel vehicles.

Finally, while transportation challenges in expanding ethanol production certainly exist, there are also several examples of innovative responses to the challenges by entrepreneurs. For example, a train loading ethanol terminal, Manly Terminal, opened in December 2007 in Manly, Iowa. Gateway Terminals LLC in Sauget, Illinois is set to open in the summer of 2008, with the capability to load either unit trains or barges of ethanol. In Florida, Kinder Morgan is retrofitting a 102 mile pipeline to ship ethanol. Finally, in Kankakee, Illinois and elsewhere, shippers are loading DDGS in containers for shipment to Asia.

Overall, the prognosis for ethanol is seemingly positive. As an industry in the midst of rapid expansion, uncertainty is high. Additional investment in transportation infrastructure and equipment will be required, especially for trucks and local highways. It may also be wise to consider a comprehensive analysis of the grain transportation and marketing system. The research done during the last major restructuring of the grain industry in the 1970s provided important insights for industry and government. A better understanding of the transition related to ethanol would likely lead to better planning in the current environment as well.

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