TRANSITION TO A BIO ECONOMY

Environmental and Rural Development Impacts

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Transition to the Bioeconomy: Impacts on Rural Development and the Environment

Conference Proceedings

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Executive Summary

Biofuels have gained considerable attention as a strategy for reducing dependence on foreign oil, enhancing energy security, supporting rural economic development, and mitigating greenhouse gas emissions associated with fossil fuels. The emerging bioeconomy offers the potential for creating jobs, new sources of income, and investment opportunities that can revitalize rural America while reducing the need for migration of the labor force to urban areas. The reliance on corn-based ethanol, however, has created considerable controversy about its impact on food prices and its environmental benefits. Specifically, scientists have questioned its potential to reduce greenhouse gas (GHG) emissions when forests in other countries are converted to agricultural land, releasing carbon stocks as the world replaces the food diverted to U.S. biofuels.

Concerns have also been raised about the water requirements for growing biofuel crops and for biorefineries as well as about the impacts of expanding fertilizer-intensive corn production on nitrate run-off, soil erosion, and water quality in the Mississippi River. These concerns have stimulated interest in next-generation cellulosic biofuels, using crop residues and perennial grasses that have the potential to mitigate the competition for land between food and fuel and achieve larger reductions in GHG emissions than corn-based ethanol. The use of cellulosic feedstocks is not devoid of concerns either. The collection of corn stover for biofuel production has implications for soil quality and soil erosion, and monocultures of perennial grasses can impact wildlife habitats and biodiversity.

In October 2008, researchers and policy makers participated in the third in a five-conference series, *Transition to a Bioeconomy*. This conference focused on environmental and rural development impacts of biofuels. The conference was held on October 15 and 16, 2008, in St. Louis, Missouri. Conference participants examined the GHG emissions, water quality, and domestic and global land use implications of biofuels. Other sessions focused on the impacts of the bioeconomy on jobs and rural economic development and the role of public policies and green technologies in helping to meet our energy and economic development needs sustainably. Session topics included: The Bioeconomy and the Environment; Rural Development in the Bioeconomy; Resource Impacts of the Bioeconomy; Lifecycle Carbon Footprint of Biofuels; Green Technologies for Rural Regions; and, Local Opportunities and Challenges: The Next Decade.

In the opening session, Bill Hohenstein, USDA Global Change Program Office, discussed the direct and indirect GHG emissions associated with biofuels, and technological and policy strategies for reducing those emissions. Considerable variation in the lifecycle GHG emissions associated with ethanol occurs due to the fuel used for biofuel production and the feedstock used. Emissions reduction, relative to gasoline, range from 20% with corn ethanol produced using coal, to 90% with cellulosic ethanol. Emissions due to indirect land use changes could be substantial if biofuel production in the United States leads to an expansion of crop production through deforestation in other countries. This could be countered through yield-increasing innovation, policies to restrict deforestation, and rehabilitation of degraded lands.

John Reilly, of Massachusetts Institute of Technology, continued the discussion on the effects of land use on climate change, focusing on the role that cellulosic ethanol may play in reducing emissions and the threat to food security. Reilly also emphasized the need for intensification of agriculture, increasing yields from each acre in order to meet growing demand for both food and energy. Based on his analysis, he concluded that supplying domestic fuel needs with biofuels would likely lead the United States to become a significant net food importer, and that either climate policy or high oil prices would be needed to make cellulosic biofuels competitive.

Robert Larson, of the U.S. Environmental Protection Agency, described the EPA's efforts at implementing the Renewable Fuels Standard (RFS). The RFS requires that by 2022, 60% of the 36 billion gallons in renewable fuels must come from “advanced biofuels,” such as cellulosic ethanol, which should reduce GHG emissions by at least 50%. He discussed the boundaries being used to estimate direct and indirect GHG emissions associated with biofuels from alternative feedstocks, and described the use of several economic models to establish consistent parameters for these estimations.

Jimmy Daukas, of American Farmland Trust, discussed using water quality trading to create incentives for adopting improved land management practices. He emphasized how such incentives may also address other environmental problems, such as GHG mitigation, through practices that store carbon in the soil. Daukas noted the agricultural sector should view these incentive-based solutions to environmental problems as an economic opportunity and get involved in their development as a way to pre-empt increased public pressure for regulation.

The second session examined the impact of the bioeconomy on jobs and the rural economy and strategies to enhance those benefits. The bioeconomy, as explained by Andrew Isserman of the University of Illinois, goes far beyond traditional agriculture, and includes the biotechnology and biosciences industries. According to Isserman's data, jobs in the bioeconomy have grown at a rate of 5.7% since 2001, compared with 3.1% overall, and received an average salary of $71,000 in 2006 compared to $42,000 in the private sector overall. However, only 23% of these jobs are in rural areas. Moreover, biosciences jobs in food and agriculture, the “Green Bioeconomy,” have decreased by 25,000 since 1998; other sectors of the bioeconomy have added more than 500,000 jobs during this time. For rural areas to capitalize on the opportunities offered in this new bioeconomy, governments and citizens in rural regions will have to work to entice businesses to their areas.

Thomas Dorr, Under Secretary for Rural Development, USDA, and Mark Drabenstott, of the RUPRI Center for Regional Competitiveness, University of Missouri, highlighted the need for the government to provide incentives for businesses to set up shop in rural areas, and for education that would ensure these businesses have a pool of talented potential employees from which to draw. Drabenstott reiterated Isserman's point that rural communities can succeed in the new bioeconomy if they think beyond traditional agriculture and seek new partnerships to increase employment through different kinds of job creation. Wind energy and "Farmaceuticals" are two innovative examples of industries in the bioeconomy with potential for new investments, rural wealth, and job creation through regional partnerships.

Sara Wyant, of Agri-Pulse Communications, gave the rural perspective in her speech at lunch on "Public Perceptions of the Bioeconomy." Too often, agricultural activities are seen as causing negative impacts on ecosystems, with some suggesting a decrease in area devoted to farmland in favor of purposes such as recreational preserves. But as Jimmy Daukas and others pointed out, sound agricultural practices can produce food and provide environmental benefits. The next session of the conference continued this message in looking at the resource impacts of the bioeconomy.

The third session of the day focused on the bioeconomy's impacts on the use of land and other resources vital for the agricultural sector. Noel Gollehon of USDA's Natural Resources Conservation Service estimated that 15% of current ethanol capacity is in counties where more than 50% of the corn is irrigated, while another 11% is in counties where more than 85% of the corn is irrigated. While it is unclear how much of the corn for ethanol is produced using irrigation, constraints on ground water availability in many locations will limit the extent to which irrigated crop production can be used to expand biofuel production.

Madhu Khanna, Energy Biosciences Institute (EBI) at the University of Illinois, examined the economic potential and land use implications of cellulosic biofuels from perennial grasses, switchgrass and miscanthus; and crop residues, corn stover. While these are currently estimated to be more expensive than corn ethanol, their economic viability differs across feedstocks and across locations depending on yields per acre and the opportunity cost of land. Khanna showed that existing biofuel targets are likely to lead to a trade-off between reduced GHG emissions and increased nitrogen use due to expansion of corn production. Steve Del Grosso of Colorado State University continued that discussion by noting that these environmental impacts depend on the type of land use prior to conversion to biofuel crop production. For example, conversion of Conservation Reserve Program (CRP) land to corn for ethanol production could result in little net GHG savings compared to gasoline, greatly increase nitrate leaching, and constrain other benefits of CRP land such as wildlife habitat.

The conference offered two sessions of selected papers, which are included in their entirety in these proceedings. One session focused on the effects of biofuel production and policies on land use and lifecycle GHG emissions. James Kaufman, University of Missouri-Columbia, showed that significant benefits may be possible from corn yield increases and reductions in energy use for corn and ethanol production with biotechnology. However, the realization of these benefits will depend on government policies and market structure. The next three papers examined the GHG effects of biofuels. According to Wyatt Thompson, also of the

University of Missouri-Columbia, the indirect land use expansion effects in Brazil of biofuel production in the United States may be tempered by the likely reallocation of existing cropland in Brazil among crops and by the change in ethanol consumption in Brazil; factors that were underestimated in the widely cited paper by Searchinger et al (2008). Deepak Rajagopal, EBI, University of California, Berkeley, discussed methodologies for estimating the GHG emissions associated with biofuels while accounting for direct and indirect land use changes. Using historical estimates of the acreage elasticity with respect to agricultural production, he concluded that Searchinger et al (2008) are likely to have overestimated the indirect land use effects caused by US biofuel production. Christine Lasco, EBI, University of Illinois, showed that existing biofuel policies in the United States that provide a tax credit and import tariff for ethanol, result in negligible GHG savings and high economy-wide costs, because they cause substitution towards the relatively carbon-intensive and costly domestic corn ethanol and away from imported sugarcane ethanol. Subbu Kumarappan, Michigan State University, offered possible strategies for integrating biofuels within a GHG trading program by using life cycle analysis to estimate emissions credits and by granting GHG property and trading rights to biofuel producers. His estimates indicate considerable revenue generating potential of these carbon credits for biofuel producers.

Other presentations centered on more localized impacts of biofuels: on water quality, jobs and community development. Scott Malcolm, USDA Economic Research Service, illustrated the trade-offs associated with the use of crop residues from corn for biofuel production. While these residues can help meet the mandate for cellulosic biofuels, their removal will require more fertilizer to maintain soil health and productivity with negative implications for water quality and the carbon footprint of biofuels. The use of perennial grasses instead of corn for biofuels has the potential to reduce soil erosion and phosphorus run-off as discussed by Silvia Secchi, Southern Illinois University. However, considerably high prices would be needed to induce a substantial switch to switchgrass production in the Midwest. Unlike the Midwest, Michael Popp, University of Arkansas, showed that considerable acreage could be devoted to switchgrass and sorghum in Arkansas due to their relatively lower cost of production in that state relative to the Midwest. Larry Leistritz and Nancy Hodur of North Dakota State University, estimate the economic impacts of cellulosic ethanol with those associated with corn ethanol production. They find that the former will have economic impacts that are three times larger and employment effects that are two times larger than those of corn ethanol. Jurgen Scheffran, EBI, University of Illinois, showed that the optimal location of cellulosic biorefineries in Illinois is likely to be close to feedstock production sources and their economically viable size is expected to be larger than that of corn ethanol plants due to their high capital costs.

The second day of the conference focused on emerging biofuels technologies that may help development in rural regions. Steve Moose, EBI, University of Illinois, discussed the potential for biotechnology to produce sustainable, carbon-positive systems for agricultural biomass. He described a new hybrid feedstock, sugarcorn that can provide sugar yields similar to U.S. sugar beets and be grown without supplemental nitrogen. Doug Lamond, Sanimax Energy, described innovations occurring in his company as it makes a transition from rendering to producing biodiesel and biogas.

David Laird, of USDA's National Soil Tilth Laboratory, raised concerns about the negative impacts of removing crop residues from the field for soil quality, future crop yields, and water quality. A potential solution would be to return the residues from the pyrolysis process, called "char," to the soil to maintain soil structure and possibly reduce the need for chemical fertilizers. This session illustrated the technological challenges to be overcome to provide usable renewable energy in a sustainable manner.

The Honorable Ed Schafer, U.S. Secretary of Agriculture, addressed the group, discussing efforts of the federal government to aid in the transition to a bioeconomy.

The final session of the conference centered on local opportunities and challenges. The 2007 RFS has stimulated substantial research and investment in cellulosic ethanol development, but more is still needed to ensure that emerging technologies become practical applications. Cole Gustafson, North Dakota State University, echoed contentions made earlier in the conference that the more local the ownership of ethanol refineries, the more local jobs are created. He described the challenges facing the biofuel industry in the United States due to lack of capital, concerns regarding future prospects of the industry, and general uncertainty in U.S. financial markets. At the same time, foreign competitors in Brazil and Mexico are positioning themselves to meet U.S. mandates for advanced biofuels.

Joe Black, of Southern Financial Partners, discussed the overall mission of his company to invest directly in rural communities and the use of biofuel enterprises as one tool in long-term economic development in southern Arkansas. Harry Baumes, of the USDA Office of Energy Policy and New Uses, closed the conference by discussing what is known and what needs to be known about biofuels. He re-emphasized the need for investment in research and development to provide the infrastructure and technologies needed to ensure a successful and sustainable transition to a bioeconomy.

Biofuels and Land Use Change

John Reilly, Angelo Gurgel, Sergey Paltsev.[1]

Abstract: Biofuels may make a substantial contribution to meeting the world's energy needs. That contribution may come sooner and be greater if there is a strong climate policy to reduce greenhouse gases and biofuels can be produced in a way that minimizes greenhouse gas emissions. We investigate the land use implications of biofuels under different policy conditions using a computable general equilibrium model of the world economy that has been adapted to explicitly consider land use change. We find that to meet a substantial portion of the worlds liquid fuel needs a global area approximately equal to that of today's cropland would be needed. As much as two-thirds of the land could come from intensification of existing land, especially pastureland. Conversion of forests and the loss of natural ecosystems and carbon dioxide emissions associated with land use change present a substantial risk. We also find that comparative advantage in biofuels likely rests in the tropics despite belief in the US that biofuels could be a domestic source of energy, freeing us from imports. An attempt to meet US fuel needs through a domestic biofuels program would likely mean the US would become a major food importer and would contribute to higher land and food prices in the US.

Energy from biofuels has a mixed record. On one hand, it is often seen as a renewable source of clean energy, a substitute for fossil fuels people fear are growing scarcer, offering energy security for countries without other domestic resources, and a source of income for farmers. On the other hand, current production methods often involve the use of fossil fuels so that the CO_2 benefits are minimal; they rely on crops such as maize, rapeseed, or oil palms where the potential to supply significant energy is limited; and through competition for these crops, land, and water, they significantly affect food prices and create additional pressure for deforestation. The US and Europe have proposed major initiatives to expand biofuel use in the past couple of years. But even before these programs were fully realized, expansion of the industry has revealed what analysts have long understood—there would be environmental consequences even for an industry that is supplying no more than a few percent of, for example, US gasoline use (e.g. Searchinger et al., 2008). The US industry has been seen as responsible for recent rises in world maize prices, with consequences for poorer consumers worldwide (Mitchell, 2008). European blending requirements and the demand for biodiesel, if met through expanding oil palm plantations would lead to deforestation in Indonesia (e.g., Fargione et al., 2008). The promise of improving farm income has been realized as commodity prices have risen sharply but that success also spells the limits of the technology in terms of providing a substantial domestic supply of energy.

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Advocates for the development of cellulosic conversion methods believe such a second generation technology avoids many of these consequences. It is able to use crops such as switchgrass or waste such as corn stover so the technology does not directly compete for food. Perennial grasses would have less environmental impacts than row crop agriculture, and per hectare energy yield could be several times that of maize because the entire plant can be converted to fuel (Heaton et al., 2008). In this article we try to address the following questions: Does the cellulosic technology offer a biofuels option that avoids some of the negative consequences we have seen with current technologies? What is the potential size of a cellulosic biofuels industry? What are the limitations in terms of land availability and the impacts on natural environments? If this technology matures, where and when will biomass production occur? How would development affect land cover, food and land prices, and energy markets? Would greenhouse gas (GHG) mitigation policies create greater demand for biofuels?

The article is organized in the following way. In the next section we provide cost estimates for the second generation biofuels. Section 3 provides some scenarios of bioenergy use depending on the level of climate stabilization. Section 4 discusses land use implications and in Section 5 agricultural and land prices are considered. Section 6 offers conclusions.

2. Cost Estimates

Current biomass production processes in the USA (e.g., ethanol from corn) often use fossil energy thus releasing nearly as much CO_2 as is offset when the ethanol is used to replace gasoline. Potential production from these sources is too limited ever to play a role much beyond that of producing enough ethanol to serve as an oxygenating additive to gasoline in the USA. Even though the U.S. Energy Independence and Security Act (EISA) of 2007 requires fuel producers to use at least 36 billion gallons of biofuel by 2022, including 16 billion gallons of cellulosic biofuels, the United States Energy Information Administration projects that available quantities of cellulosic biofuels will be insufficient to meet EISA targets. The European Union has set a goal of replacing 5.75% of all transport fossil fuels (petrol and diesel) with biofuels by 2010 and by 2020 this target is set to 10%. In 2008 the EU has announced that it is rethinking its biofuels program due to environmental and social concerns such as rising food prices and deforestation.

Our focus is thus to discuss advanced technologies that can make use of a broader biomass feedstock, thereby achieving levels of production that can make a more substantial contribution to energy needs. We considered early estimates of global resource potential and economics (Edmonds and Reilly, 1985) and recent reviews of potential (Moreira, 2004) and the economics of liquid fuels (Hamelinck et al., 2005) and bio-electricity (International Energy Agency, 1997). Regarding cost, Hamelinck et al. (2005) estimate costs of lignocellusic conversion of ethanol of 9 to 13 €/Gigajoule (GJ) compared with 8 to 12 and eventually 5 to 7 €/GJ for methanol production from biomass. They compare these to before tax costs of gasoline production of 4 to 6 €/GJ. The IMF

(2007) reports that the current cost of ethanol from cellulosic waste is $0.71 per liter, which is 2.1 times higher than the cost of gasoline production. IEA (2006) estimates that lignocellulosic production costs for ethanol could fall to $0.40 per liter of gasoline equivalent and for biodiesel to $0.70-0.80 per liter using the Fischer-Tropsch synthesis.

Energy yield from different biomass sources can vary substantially. Vegetable oil crops have relatively low energy yields (40-80 gigajoules (GJ) per hectare (ha) per year) compared with crops grown for cellulose or starch/sugar (200-300 GJ/ha/yr). According to IPCC (2001), high yielding short rotation forest crops or C4 plants (e.g., sugar cane or sorghum) can give stored energy equivalent of over 400 GJ/ha/yr.

Woody crops are another alternative. The IPCC (2001) reports a commercial plot in Sweden with a yield of 4.2 oven-dry tonnes(odt) per ha per year, and anticipates that with better technologies, management and experience the yield from woody crops can be up to 10 odt/ha/year. Using the number for a higher heating value (20 GJ/odt) that Smeets and Faaij (2007) used in their study of bioenergy potential from forestry, we can estimate a potential of 84-200 GJ/ha/yr yield for woody biomass.

Hybrid poplar, willow, and bamboo are some of the quick-growing trees and grasses that may serve as the fuel source for a biomass power plant, because of the high amount of lignins, a glue-like binder, present in their structures, which are largely composed of cellulose. Such so-called “lignocellulose” biomass sources can potentially be converted into ethanol via fermentation or into a liquid fuel via a high-temperature process.

Table 1 provides a summary of recent estimates of energy output per unit of land, energy content of dry biomass and conversion efficiency of dry biomass into liquid fuels. Current energy output per unit of land varies from 6.5 odt/ha for corn to 30 odt/ha for sugar cane. The highest estimates of future energy output per hectare of land are just over 60 odt/ha for sugar cane. Expected efficiency of converting biomass into liquid fuels also varies with most estimates around 30-45%. In the following sections we provide some results from the MIT analysis using the Emissions Prediction and Policy Analysis (EPPA) model (Paltsev et al., 2005). Table 1 reports assumptions used in the model for 2020, 2050, and 2100 for a second-generation biomass. The EPPA model is less optimistic than the maximum potential numbers as it represents an average for land of different quality as it varies among regions.

Land that is needed to grow energy crops competes with land used for food and wood production unless surplus land is available. For example, Smeets and Faaij (2007) estimate a global theoretical potential of biomass from forestry in 2050 as 112 EJ/year. They reduce this number to 71 EJ/year after considering demand for wood production for uses other than bioenergy. The number is decreased further to 15 EJ/year when economic considerations, such as profitability, are included into their analysis.

In the study of biodiesel use in Europe, Frondel and Peters (2007) found that to meet the EU target for biofuels of 5.75% by 2010, 11.2 Mha are required in 2010, which is 13.6% of total arable land in the EU-25. These analyses, while providing useful benchmarks, typically take market conditions as given, whereas prices and markets will change in the future and will depend on, for example, the existence of greenhouse gas mitigation policies that could create additional incentives for biofuels production.

Table 1. Estimates of the potential for energy from biomass

Biomass source	Odt/ha	GJ/odt	Dry biomass energy yield (GJ/ha)	Conversion efficiency	Liquid biomass energy yield (GJ/ha)
Grain corn[a]	6.5	21	136.5	16%	21.8
Grain corn *(future)*	6.5[a]	21	136.5	45%[b]	61.4
Sugar cane[c]	30	21.5	650	40%	260.0
Sugar cane *(future)*	63	21.5	1350[c]	45%[d]	607.5
Eucalyptus[c]	23	20	450	43%[f]	193.5
Eucalyptus *(future)*	50	20	1000[c]	68%[g]	680.0
Poplar	20[h]	20	400	51%[e]	204.0
Switch-grass fuel pellets[a]	10	18.5	185	88%	162.8
Switch-grass			430[c]	51%[e]	219.3
EPPA Model estimates (2020) [i]	6 – 16	20	120 – 320	40%	48 – 128
EPPA Model estimates (2050) [i]	11 – 18	20	210 – 360	40%	84 – 144
EPPA Model estimates (2100) [i]	18 – 30	20	358 – 600	40%	144 – 240

[a] Samson *et al.* (2000).
[b] Novem/ADL (1999), cited by Fulton and Howes (2004).
[c] Moreira (2006).
[d] Assumption based on Moreira (2006) considering all solid biomass primary energy will be converted in final energy through cogeneration plants and 40% of the sugar cane residues is left in the field to protect soil.
[e] Assumption based on Novem/ADL (1999), cited by Fulton and Howes (2004) for ethanol production from poplar through enzymatic hydrolysis.
[f] Assumption based on Novem/ADL (1999), cited by Fulton and Howes (2004) for diesel production from gasification / Fischer-Tropsch.
[g] Assumption based on Novem/ADL (1999), cited by Fulton and Howes (2004) for diesel production from hydrothermal upgrading (HTU) biocrude.
[h] Luger (2007).
[i] Values are region-specific.

Table 2 provides a rough estimate of a global potential for energy from biomass based on the total land area. IPCC (2001) used an average energy yield of 300 GJ/ha/year for its projection of a technical energy potential from biomass by 2050. The area not suitable for cultivation is about half of the total Earth land area of 15.12 Gigahectares (Gha) and it includes tropical savannas, deserts and semideserts, tundra, and wetlands. Using the numbers for converting area in hectares into energy yield, we estimate the global potential of around 2100 EJ/year from biomass. One can increase or decrease this estimate by including or excluding different land types from the calculation. Assuming a conversion efficiency of 40 percent from biomass to the final liquid energy product, we estimate a potential of 840 EJ/year of liquid energy product from biomass.

Table 2. World land area and a potential for energy from biomass

	Area, Gha	Max dry bioenergy, EJ	Max liquid bioenergy, EJ
Tropical Forests	1.76	528	211
Temperate Forests	1.04	312	125
Boreal forests	1.37	411	164
Tropical Savannas	2.25	0	0
Temperate grassland	1.25	375	150
Deserts and Semideserts	4.55	0	0
Tundra	0.95	0	0
Wetlands	0.35	0	0
Croplands	1.60	480	192
Total	15.12	2106	842

Source: area (IPCC, 2000); assumptions about area to energy conversion – 15 odt/ha/year and 20 GJ/odt (IPCC, 2001); conversion efficiency from biomass to liquid – 40%.

Table 3 presents a similar calculation for the U.S., where a potential for dry bioenergy is about 200 EJ/year, and potential for a liquid fuel from biomass is about 80 EJ/year. These are maximum potential estimates that assume all land that is currently used for food, livestock, and wood production would be used for biomass production. A recent study by the U.S. Government (CCSP, 2007) projects an increase in the global energy use from about 400 EJ/year in 2000 to 700-1000 EJ/year in 2050, and to 1275-1500 EJ/year in 2100. The corresponding numbers for the U.S. are about 100 EJ/year in 2000, 120-170 EJ/year in 2050, and 110-220 EJ/year in 2100. These numbers suggest that energy from biomass alone would not be able to satisfy global needs even if all land is converted to biomass production, unless a major breakthrough in technology occurs.

Table 3. U.S. land area and a potential for energy from biomass

	Area, Gha	Area, billion acres	Max dry bioenergy, EJ	Max liq. Bioenergy, EJ
Cropland	0.177	0.442	53.0	21.2
Grassland	0.235	0.587	70.4	28.2
Forest	0.260	0.651	78.1	31.2
Parks, etc	0.119	0.297	0	0
Urban	0.024	0.060	0	0
Deserts, Wetland, etc	0.091	0.228	0	0
Total	0.906	2.265	201.6	80.6

Source: area (USDA, 2005); assumptions about area to energy conversion – 15 odt/ha/year and 20 GJ/odt (IPCC, 2001); assumption for conversion efficiency from biomass to liquid energy product – 40%.

Concerns about national energy security and mitigation of CO_2 have generated much interest in biofuels, although a recent cost-benefit study (Hill et al., 2006) has found that even if all of the U.S. production of corn and soybean is dedicated to biofuels, this supply would meet only 12% and 6% of the U. S. demand for gasoline and diesel, respectively. Other work has shown that the climate benefit of this fuel, using current production techniques, is limited because of the fossil fuel used in the production of the crop and processing of biomass (Brinkman et al., 2006).

Advanced synfuel hydrocarbons or cellulosic ethanol produced from biomass could provide much greater supplies of fuel and environmental benefits than current technologies.

In this article we therefore consider a second generation biofuel based on an estimated cost structure of production, assuming some further advance and demonstration of the technology. We do not specify in detail the technological process but it is expected to be a "cellulosic" or "lingocellulosic" conversion because the cellulosic resources, such as grasses and fast-growing trees, are widespread and abundant. Some analysts also consider that genetically modified microorganisms could be an efficient way to produce biofuels. While it is an important topic for the future research, here we do not attempt to include in our analysis considerations on possible consumer reaction against genetically modified products and that highly regulated frameworks for production and international trade of genetically modified products may affect the expansion of the biofuels industry.

3. Scenarios

To illustrate the potential role of biomass as an energy supply, we draw on recent applications of the Emissions Prediction and Policy Analysis (EPPA) model (Paltsev et al., 2005) developed by Massachusetts Institute of Technology's Joint Program on the Science and Policy of Global Change. The first of these applications involves scenarios of atmospheric stabilization of greenhouse gases (GHG's). The second study involves investigation of USA GHG mitigation policies that have been proposed in recent Congressional legislation and some additional assumptions about developed countries doing their share in reducing GHG's from present levels to 50% below 1990 levels by 2050 (Paltsev et al., 2007). These applications allow us to focus both on the global bioenergy potential and on some specific issues with regard to USA bioenergy.

Reference Scenario: No Climate Policy

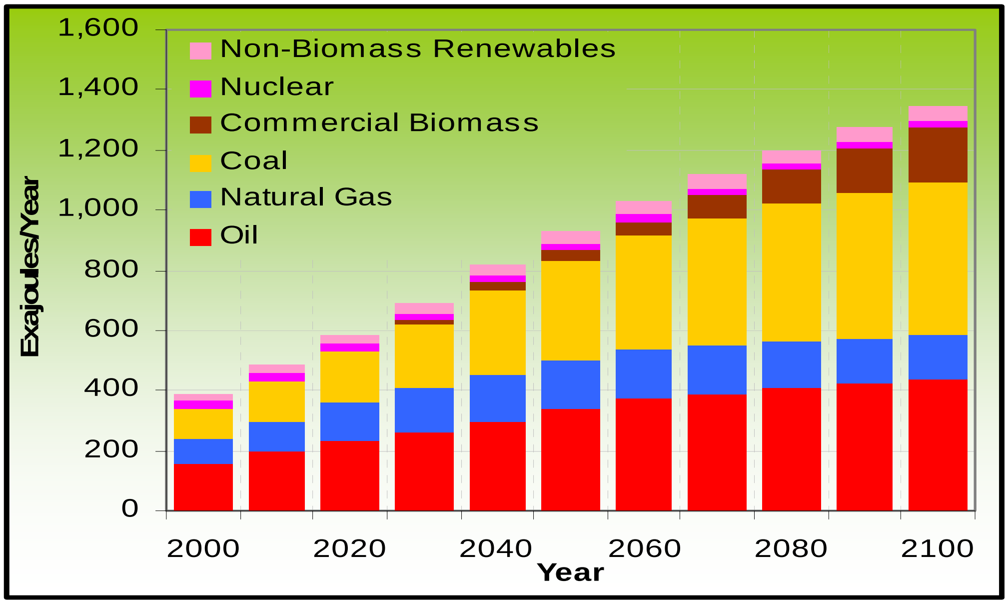
To make a proper comparison, we start with a scenario of "what would have happened otherwise," i.e., we need to establish a reference scenario, where no climate policy is introduced. This would enable us to make a proper comparison in terms of economic costs and performance of biomass industry when some climate policy is in place. Obviously, the world is already committed to climate-related actions such as the European Union Emissions Trading Scheme and the Kyoto Protocol but they are only fully specified for the next decade or so. In the future, it is expected that climate policy will have broader coverage in terms of participating countries and the degree of emissions reduction.

Figure 1 shows the composition of global primary energy in the reference scenario developed for the recent U.S. Climate Change Science Program study (CCSP, 2007). The reference scenario exhibits strong growth in the production of cellulosic biofuels beginning after the year 2020 based on relative economics.

Deployment is driven primarily by a world oil price that in the year 2100 is over 4.5 times the price in the year 2000, but down somewhat from the high oil prices of 2008.

Dwindling supplies of high grade crude oil drive up the oil price to make cellulosic ethanol competitive. By 2040, the total global biofuels production (in terms of liquid fuel output) reaches about 30 EJ/year, which is a drastic increase compared with 2005 output of 0.8 EJ/year. By 2100 bioenergy production reaches about 180 EJ/year, which is about the same amount of energy as derived from the global oil consumption in 2000. Even with these huge increases in bioenergy production, it still counts only to about 5% in 2040 and about 15% in 2100 of the global primary energy use.

Figure 1. Global primary energy consumption, Reference Scenario



Climate Policy: Atmospheric Stabilization of Greenhouse Gases
To illustrate how bioenergy technologies perform when climate-related constraints are introduced, we use four stabilization scenarios employed in the CCSP study (CCSP, 2007). The stabilization levels are defined in terms of the total long-term effect on the Earth's heat balance of the combined effect of GHGs. The constraints were formulated as radiative forcing levels that allowed some additional increase in other greenhouse gases, and were set at no more than 3.4 Watts per square meter (W/m^2) for Level 1, 4.7 W/m^2 for Level 2, 5.8 W/m^2 for Level 3, and 6.7 W/m^2 for Level 4. These levels were defined as increases above the preindustrial level, so they include the roughly 2.2 W/m^2 increase that had occurred through the year 2000. The levels were chosen so that the associated CO_2 concentrations would be roughly 450, 550, 650, and 750 parts per million by volume (ppmv), stabilization levels widely discussed in policy circles. To meet these targets, an idealized cap-and-trade system was implemented beginning in 2015 in which the whole world participated.

The numbers for biomass represent only the production of biomass energy from the advanced technologies represented in EPPA and do not include, for example, the own-use of wood wastes for energy in the forest products industry or non-commercial biomass used in developing countries. In addition, existing use of corn and sugar ethanol, about 16.0 billion gallons in 2007 (1.5 EJ - less than ½ of 1%), is not explicitly modeled.

These sources are implicit in the underlying input-output data to the extent the forest product industry uses its own waste for energy, it purchases less commercial energy or where agricultural/processing industries show sales to refinery or service station sectors where ethanol is blended with gasoline. Similarly, to the extent that traditional biomass energy is a substantial source of energy in developing countries it implies less purchase of commercial energy.

Figure 2. Global biomass production, CCSP Scenarios

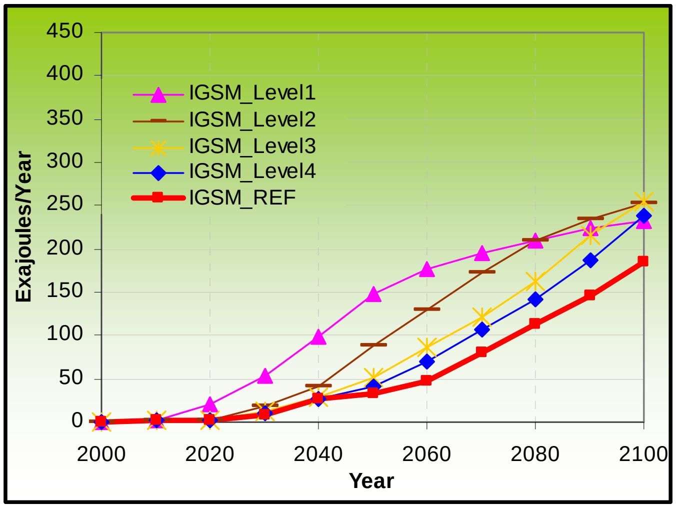


Figure 2 presents "advanced" biomass production for the world across the scenarios. In the stabilization scenarios, global biomass production reaches 250 EJ/year, in comparison to 180 EJ/year in the reference scenario. Tighter emissions constraints lead to an earlier increase in the bioenergy production but the maximum potential of bioenergy is not very different by 2100 in the stabilization scenarios due to a limiting factor of land availability.

Figure 3. Global primary energy, Level 1 Scenario

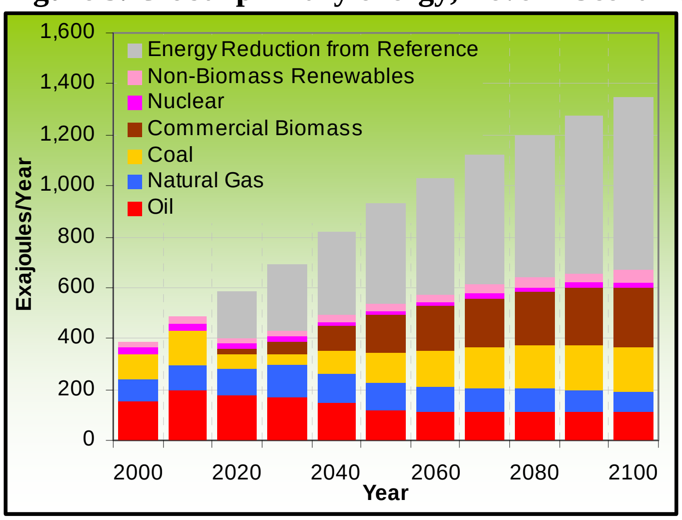
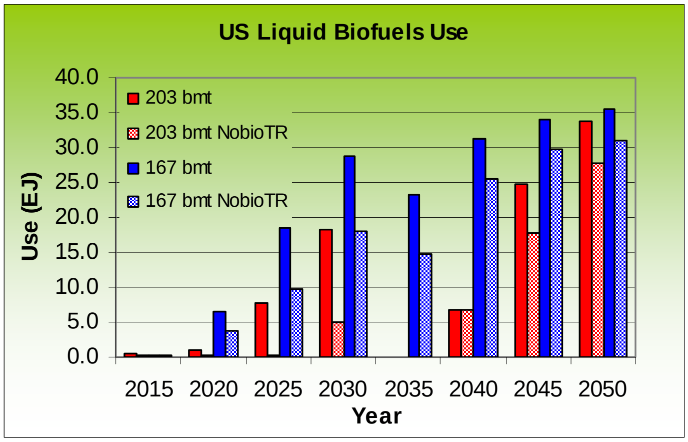


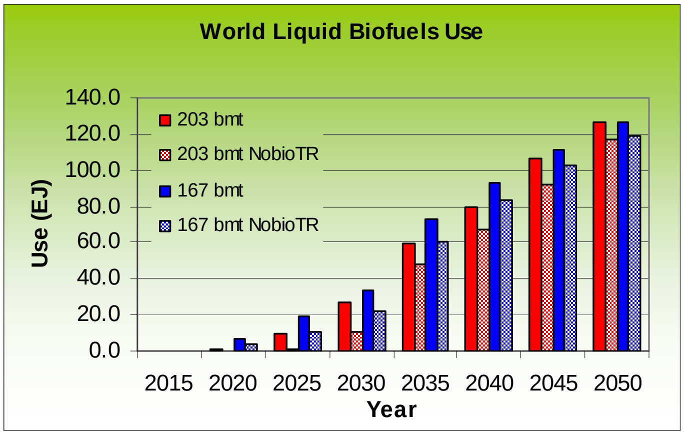
Figure 3 shows the composition of global primary energy for the Level 1 scenario. This level of stabilization requires a rapid and fairly complete shift away from fossil fuels with biomass energy playing a major role. The CO_2 prices required to meet this constraint significantly increases the full cost of delivered energy which results in a large reduction in energy use. Not shown are similar figures for Levels 2-4. The overall pattern of change is quite similar across the different scenarios with the successively less constrained scenarios allowing a slower transition to non-fossil alternatives and less reduction in demand.

The Potential Role of Bioenergy in US GHG Policy

Interest in GHG mitigation legislation in the U.S. Congress has grown substantially and in 2008 there were several proposals for cap and trade systems in USA. Some of these bills envisioned emissions in the USA as low as 80% below present levels by 2050. Such a steep reduction cannot avoid making significant cuts from CO_2 emissions from transportation which currently accounts for about 33% of USA CO_2 emissions related to fossil fuel combustion (EIA, 2006). While improved efficiency of the vehicle fleet might contribute to reductions, it is hard to imagine sufficient improvements in that regard. Of the contending alternative fuels—hydrogen, electric vehicles, biofuels—the biofuel option appears closest to being technologically ready for commercialization.

Figure 4. Biofuel use. US: top panel; World: bottom panel





Paltsev et al. (2007) considered a number of reduction scenarios that bracketed leading Senate proposals. Here we focus on the role of bioenergy under two of the mitigation scenarios they analyzed. For the two scenarios, the initial allowance level was set in 2012 to the estimated USA GHG emissions in 2008 and the annual allowance allocation followed a linear path through 2050 to (1) 50% below 2008; and (2) 80% below 2008. Over the 2012 to 2050 period the cumulative allowance allocations under these scenarios are 203 and 167 billion metric tons (bmt), of carbon dioxide equivalent (CO_2-e) emissions. The GHG scenarios are designated with the shorthand labels *203 bmt*, and *167 bmt*. The banking of GHG allowances in the US is simulated by meeting the target with a CO_2-e price path that rises at the rate of interest, assumed to be 4%. Other developed countries are assumed to pursue a policy whereby their emissions fall to 50% below 1990 levels by 2050, and a policy whereby all other regions return to the projected 2015 level of emissions in 2025, holding at that level until 2035 when the emissions cap drops to their year 2000 level of GHG emissions. The economy-wide trading among greenhouse gases at their Global Warming Potential (GWP) value is simulated. All prices are thus CO_2-equivalent prices (CO_2-e). The carbon dioxide prices required to meet these policy targets in the initial projection year (2015) are \$41, and \$53/t CO_2-e for the *203* and *167 bmt* cases, respectively. While the unrestricted biofuels trade scenario suggests that foreign dependence would be shifted from oil to biofuels, the restricted trade scenario allows consideration of what would happen if the US indeed depended on domestic resources.

Figure 4 presents the core cases and the scenarios with restricted trade in biofuels (denoted by the extension *NobioTR*).The USA biofuel use is substantial in all cases, rising to 30 and to 35 EJ in 2050 unrestricted biofuel trade cases. The restricted trade cases drop biofuel use by about 5 EJ from the comparable trade cases because reliance on domestic sources drives up the biofuel price. World biofuel use is also substantial in both cases, reaching 100 to 120 EJ, because the rest of the world is pursuing a strong GHG policy as well. Under the scenarios biofuels account for nearly 55% of all liquid fuels and thus have substantially displaced petroleum products in the US.

To focus on biofuels, each of these two scenarios are then simulated with unrestricted trade in biofuels and with the requirement that the US (and all other regions) biofuel demand is met domestically. Absent the trade restriction, significant amounts of biofuel are used in the USA but nearly all of it is imported. There are currently tariffs on biofuel import into the USA, and one of the reasons biomass is of interest in the USA is because it is viewed a domestic energy source that would reduce foreign dependence.

Regional Biofuel Production

In order to estimate regional biofuel production, the above discussed *203bmt* scenario is extended to 2100 to limit global cumulative GHG emissions to about 1,490 billion metric tons (bmt) from 2012 to 2050 and 2,834 bmt from 2012 to 2100. Those numbers are equivalent to 60% of the emissions in the reference scenario in the period from 2012 to 2050, and 40% over the full period. The cumulative level of GHG emissions is approximately consistent with a 550 ppmv CO_2 stabilization goal, discussed in Section 3. The policy is implemented as a cap and trade policy in each region, which limits the amount of fossil fuel that can be used, and thus provides economic incentive for biofuel and other low carbon energy sources.

Table 4. Regional biomass production (EJ/year)

	USA	Mexico	Australia and New Zealand	Latin America	Africa	Other regions	Global
2010	0	0	0	0	0	0	0
2020	0	0	0	0	2	0	2
2030	1	0	1	4	19	0	25
2040	4	2	2	26	30	5	69
2050	13	4	4	54	41	6	122
2060	17	4	6	71	48	6	152
2070	20	5	8	87	58	7	185
2080	24	6	11	107	71	10	229
2090	28	7	13	127	85	13	273
2100	33	8	16	147	98	18	320

Table 4 presents the bioenergy production in selected world regions, with other regions aggregated based on a version of the EPPA model that applies an elasticity of land supply and which is referred to as Observed Land Supply Response (OLSR) version of the model (Gurgel et al., 2007). Latin America and Africa are the two most important regions supplying biomass. In both regions land availability is crucial to achieving these production levels. The greater land productivity in biomass crops allows Latin America to supply between 45% and 60% of world production for most of the model horizon. The US is the third largest world producer, supplying between 33 and 36

EJ of biomass in 2100 in the policy case. Mexico, Australia and New Zealand, and the aggregate of the rest of the world, which includes several countries in tropical areas of South Asia, are also able to produce large amounts of biomass in the policy scenario. The contribution to biomass production from others is very small (~1% of world production). This reflects the existence of large areas of natural forest and pasture in those countries and regions, and the fact that biomass is more productive in tropical areas.

China and India are, not surprisingly, exceptions to this overall pattern. Key aspects of the model that drive this result are growth of food demand and modeling of trade in biofuels and agicultural goods. Both India and China have increasing demand for food. The combination of strong growth of domestic food demand favors dedication of land to agricultural production to supply domestic food needs, and if necessary the importation of biofuels to meet a carbon dioxide reduction target.

Clearly, policies that block or distort trade will change where biomass is produced, and as shown previously, such policies can then have implications for trade in other agricultural products. In the case of unrestricted trade in bioenergy, the main producers would be Latin America, Africa, Australia, New Zealand, and Mexico. The amount of bioenergy exports is around 80 EJ/year by 2050 and around 200 EJ/year by 2100. In the case of restricted trade in bioenergy, almost all regions of the world would produce bioenergy, with main producers being Latin America, USA, Africa, and Europe. The level of global bioenergy production is lower by 30-40 EJ/year in 2050 and by 70-110 EJ/year in 2100 in comparison to unrestricted trade.

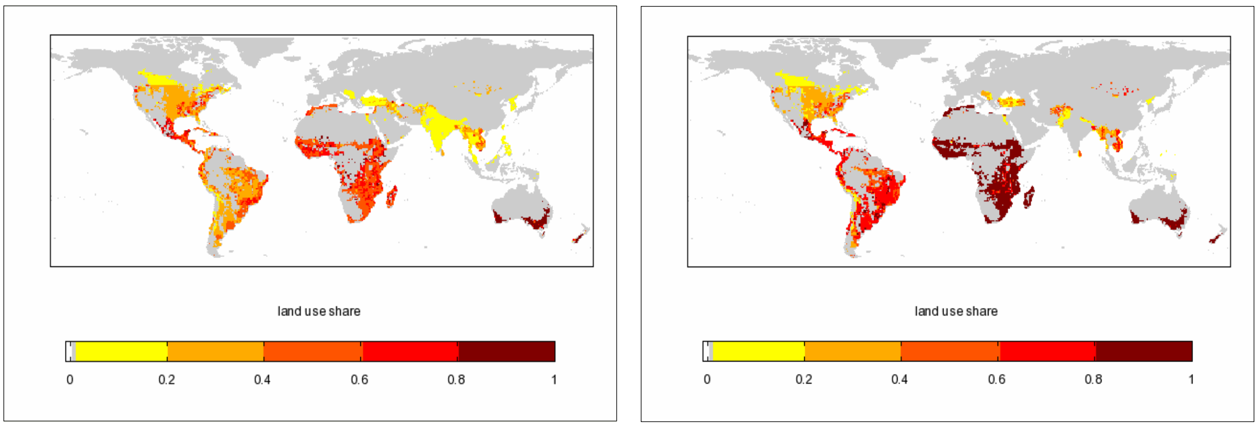
The energy from biomass is projected to be an important component of world energy consumption, but even in the policy case with unrestricted trade, biofuels account for about 30% of the global energy consumption. The larger share of biomass in the policy case is due to the replacement of the oil production, since bio-fuels are low carbon alternative in transportation.

4. Land Use Implications

As mentioned in the previous section, the large amount of biomass energy has significant implications for global land use. Figure 5 presents a share of land devoted to biomass production in a policy scenario in 2050 and 2100, where the darkest shading denotes regions with 80-100% shares. Most of these regions are located in Latin America, Africa, Australia, New Zealand and USA. An important factor driving the regional results is that unrestricted trade of biofuels, a homogeneous good, is allowed, which tends to lead to specialization of production in Latin America and Africa where the land input is least costly.

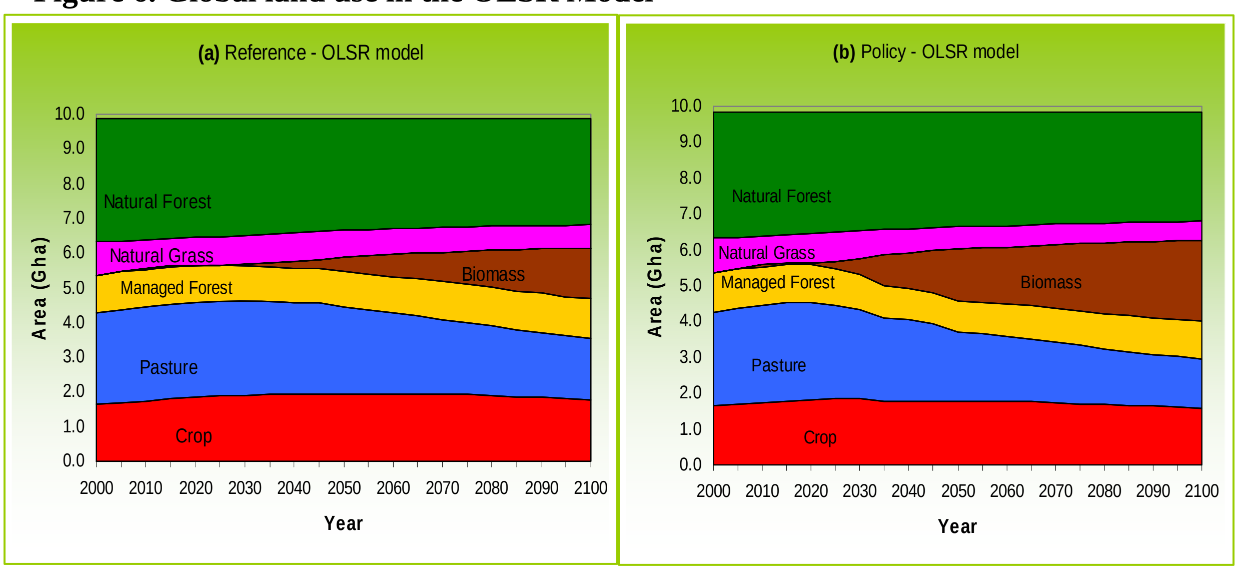
Figure 6 shows a competition among land uses. Gurgel *et al*. (2007) discuss two possibilities for land supply representation in the EPPA model. One approach allows unrestricted conversion of natural forest and grass land (as long as conversion costs are covered by returns), which is labeled as the Pure Conversion Cost Response (PCCR) model. Another approach is to parameterize the model to represent observed land supply response. This version of the EPPA model is labeled as the Observed Land Supply Response (OLSR) model. We focus here on the results from the OLSR version as it is based more closely observed response, limiting the amount of deforestation.

Figure 5. Share of land devoted to biomass production in a policy case
Panel a: 2050 **Panel b: 2100**



In total the land area in five land types is 9.8 Gha, but the use of this land changes considerably from 2000 to 2100. The area covered by biomass in 2050 ranges from 0.42 to 0.47 Gha in the reference scenario, and from 1.46 Gha to 1.67 Gha under the policy case. In 2100 biomass production covers between 1.44 and 1.74 Gha in the reference, and from 2.24 to 2.52 Gha in the policy case. This compares with 1.6 Gha currently in cropland.

Figure 6. Global land use in the OLSR Model

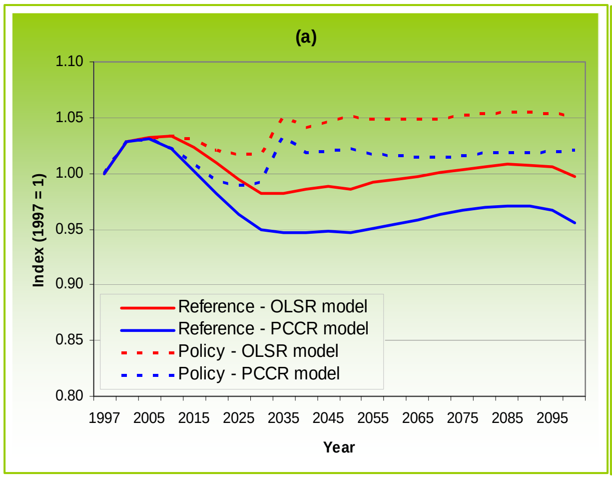


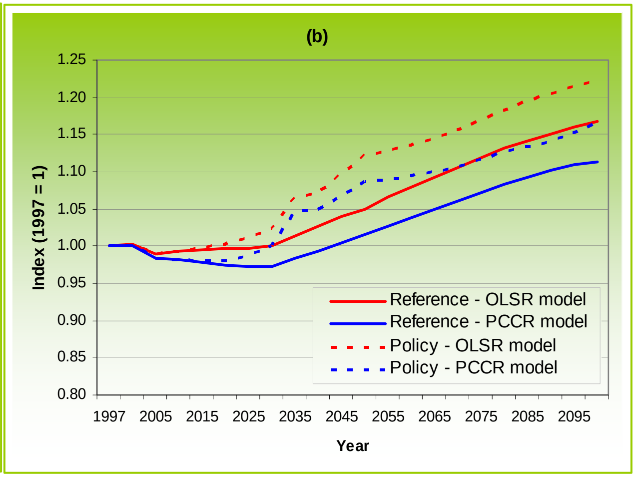
Biofuels production at this level thus has major consequences for land use on a global scale. Natural forests are affected in all scenarios and under both model assumptions, but, as expected, much more conversion occurs under the PCCR model. In this case, natural forests are reduced from its original 3.7 Gha to 2.2 Gha in the reference scenario, and to only 2.0 Gha in the policy case, a 40% reduction in natural forest area. In contrast, the OLSR model shows much less reduction in natural forest area with a bigger reduction in pasture land. Thus, this version of the model makes room for biofuels production by intensifying production on existing agricultural land, especially pasture land. In both model versions natural forest and pasture land are the land types most reduced to make room for biofuels, with land in crops, managed forest, and natural grassland showing smaller net changes.

5. Long-term Effects on Agricultural Prices and Land Rents

The impacts on global agricultural and industrialized food prices are shown in Figure 7. To simplify the presentation and to show the average effect on world prices we compute global price indices using the Walsh index, as described in IMF (2004). The simulated price levels reflect the combination of increasing demand for food, fiber, and forestry products as GDP and population grow with our assumption of the increasing productivity of land. In the reference scenario we observe price increases in forestry and livestock products, while crop prices are little changed through the century. Forestry and livestock price increases likely reflect the competition for this land from biofuels that develops over the century and more rapid growth in demand for these products than for crops. With the climate scenario we see an increase in crops and food prices of about 5% and for livestock of 15 to 20%. This corresponds to the time when biofuels production expands in the climate policy scenario, and thus is likely attributable to the biofuels competition for land. The OLSR version of the model shows price increases of 2 to 3 percentage points more than the PCCR model, as a consequence of lower flexibility in the land transformation from natural areas to agricultural use. The relative changes in prices of crops, livestock, and forestry reflect the share of land in the production of each and the fact that livestock are affected both by the increase in the pasture land rent and by the increase in crop prices.

Figure 7 World agricultural and food price indexes





The impact of the biofuels industry on food and commodity prices is projected to be relatively small compared to recent price increases in corn that have at least been casually attributed to expansion of ethanol production in the US. There are several important aspects of this comparison. One is that the EPPA model projection is for all crops and the potential impact on single crop can be greater. The modeling also reflects longer run elasticities that give time for the sector to adjust, and over the longer term agriculture has proven very responsive to increasing demand. In fact, the current run-up in corn prices has led to a rapid response by farmers in planting more corn, and with more supply the price may retreat. We also expect less direct effect on crop prices because corn-based ethanol directly affects the corn market whereas cellulosic crops would only indirectly affect crops through the land rent effect. In this regard, the EPPA model simulations suggest that it is possible to integrate a substantial ethanol industry into the agricultural system over time without having dramatic effects on food and crop prices.

6. Conclusions

A second generation "cellulosic" technology would increase the potential for biofuels in terms of energy output per unit of land area. To realize its full potential the technology still needs further improvements. In terms of cost, we have based our estimates on costs of conversion that would require sustained gasoline prices of more than $4.00 per gallon of gasoline (retail) to make the fuel competitive. This takes into account the lower energy content of ethanol, retail-wholesale price spreads, and assuming that over the longer run biofuels would be subject to fuel taxes in the US that support the highway trust fund. Of course, estimates about the future costs vary: the IEA has by 2030 a cost for cellulosic ethanol close to that from sugar cane which is currently competitive. Similarly, there are a range of estimates of potential land productivity in terms of energy output. We included a 1% per year improvement in productivity in our estimates, reflecting potential improvements in biomass crops through selection, conventional crop breeding, or biotechnology.

While competition for land (which would lead to an increase in agriculture, land and food prices) still exists, we find it to have less impact on prices than the current "first-generation" technology, especially if there is time for the agriculture system to adjust to increased demand. While climate policy could spur bioenergy production, rising oil prices could be enough eventually to bring along second generation technology even if production costs do not fall. Analyses presented in this article project that the second-generation biomass may produce around 30-40 EJ/year by 2050 and around 180-260 EJ/year by 2100. As a comparison, the 2005 global bioenergy production was less that 1 EJ and the 2005 global oil consumption was 190 EJ. However, because energy use is growing, these large increases in bioenergy production still account only for 15% of global primary energy use in 2100.

Carbon policy increases demand for carbon-free fuels making bioenergy competitive earlier, but the entry depends on the relative price of fossil fuels and biofuels. A climate policy targeting 550 ppmv stabilization of CO_2 concentrations could lead to bioenergy production of 90-130 EJ/year by 2050 and 250-370 EJ/year by 2100. This amounts to about 30% of global energy use derived from bioenergy, with the percentage as high as it is in part because such a policy, by raising energy prices, not only encourages alternatives but also reduces energy use.

The global area required to grow biomass crops by the end of the century in the reference scenario is about 1.5 to 1.7 Gha, similar to the amount of land area used for crops today. Under the policy scenario, the land required for biomass production reaches 2.2 to 2.5 Gha in 2100. Global prices for food, agriculture and forestry products increase relative to the reference case as a result of more rapid expansion of biofuels when there is a strong climate policy but these price increases are relatively modest. Thus, it appears to be possible to introduce a large cellulosic biofuels industry without dramatically upsetting agricultural markets if there is time for the agricultural system to respond to this increased demand. However, the expansion of the industry could result in substantial deforestation and unintended release of carbon emissions.

References

Brinkman, N., M. Wang, T. Weber, T. Darlington. 2006. *Well to Wheels Analysis of Transportation Fuel Alternatives*, Argonne National Lab. Available at: http://www.transportation.anl.gov/pdfs/TA/339.pdf

Climate Change Science Program (CCSP). 2007. *CCSP Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*, US Climate Change Science Program, Department of Energy, Washington, DC.

Edmonds, J.A. and J. Reilly. 1985. *Global Energy: Assessing the Future*, New York: Oxford University Press.

Energy Information Administration (EIA). 2006. *Emissions of Greenhouse Gases in the United States 2005*, Energy Information Administration, US Department of Energy, Washington DC.

Energy Information Administration (EIA). 2008. *Statement of Guy Caruso, Administrator of Energy Information Administration before the Committee on Energy and Natural Resources of The United States Senate on March 4, 2008*, Energy Information Administration, US Department of Energy, Washington DC.

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. “Land Clearing and the Biofuel Carbon Debt,” *Science* 319: 1235-1237.

Fulton, L. and T. Howes. 2004. *Biofuels for Transport: An International Perspective*, IEA/EET.

Frondel, M. and J. Peters, 2007. “Biodiesel: A New Oildorado?” *Energy Policy*, 35: 1675-1684.

Gurgel, A., J. Reilly and S. Paltsev. 2007. *Potential Land Use Implications of a Global Biofuels Industry*. MIT Joint Program on the Science and Policy of Global Change, Report 155, Cambridge, Massachusetts. Available at: http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt155.pdf

Hamelinck, C., G. van Hooijdonk, and A. Faaij. 2005. "Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle-, and long-term." *Biomass and Bioenergy*, 28(4):384-410.

Heaton, E.A., F. G. Dohleman and S. P. Long. 2008. "Meeting US biofuel goals with less land: the potential of Miscanthus." *Global Change Biology* 14: 2000–2014, doi: 10.1111/j.1365-2486.2008.01662.x

Hill, J., E. Nelson, D. Tilman, S. Polasky and D. Tiffany. 2006. "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels." *Proc. Natl. Acad. Sci. USA*, 103:11206-11210.

International Energy Agency (IEA). 1997. *Renewable Energy Policy in IEA countries, Volume II: Country reports*, OECD/IEA, Paris.

International Monetary Fund (IMF). 2004. *Producer Price Index Manual: Theory and Practice*. Washington, DC.

International Monetary Fund (IMF). 2007. *World Economic Outlook 2007*. Washington, DC.

IPCC. 2000. *Land-Use, Land-Use Change, and Forestry*, Special Report of the Intergovernmental Panel on Climate Change, R. Watson *et al* (eds.), Cambridge, UK: Cambridge University Press.

IPCC. 2001. *Climate Change 2001: Mitigation*, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, B. Metz *et al* (eds.), Cambridge, UK: Cambridge University Press.

Luger, E. 2007. *Energy Crop Species in Europe*, BLT Wieselburg, Austria. Available at: http://www.blt.bmlf.gv.at/vero/artikel/artik013/Energy_crop_species+.pdf

Mitchell, D. 2008. A Note on Rising Food Prices, Policy Research Working Paper 4682, The World Bank Development Prospects Group (July), Washinton DC.

Moreira, J.R. 2004. "Global Biomass Energy Potential." Paper presented at the Expert Workshop on Greenhouse Gas Emissions and Abrupt Climate Change, Paris 30 Sept.-1 Oct., manuscript, Brazilian Reference Center on Biomass, Rua Francisco Dias Vlho, 814-04581.001, Sao Paulo, Brazil

Moreira, J. R. 2006. “Global Biomass Energy Potential”, *Mitigation and Adaptation Strategies for Global Change*, 11:313-342.

Novem/ADL. 1999. Analysis and Evaluation of GAVE Chains, Vol. 1-3, GAVE analysis programme, http://www.novem.nl/default.asp?menuId=10&documentId=699

Paltsev, S., J. Reilly, H. Jacoby, R. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian, and M. Babiker. 2005. *The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4*, MIT Joint Program on the Science and Policy of Global Change, Report 125, Cambridge, Massachusetts. Available at: http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt125.pdf

Paltsev, S., J. Reilly, H. Jacoby, A. Gurgel, G. Metcalf, A. Sokolov and J. Holak. 2007. *Assessment of US Cap-and-Trade Proposals*, MIT Joint Program on the Science and Policy of Global Change, Report 146, Cambridge, Massachusetts. Available at: http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt146.pdf

Reilly, J. and S. Paltsev. 2007. *Biomass Energy and Competition for Land*. MIT Joint Program on the Science and Policy of Global Change, Report 145, Cambridge, Massachusetts. Available at http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt145.pdf

Samson, R., M. Drisdelle, L. Mulkins, C. Lapointe and P. Duxbury. 2000. *The Use of Switchgrass Biofuel Pellets as a Greenhouse Gas Offset Strategy*. Resource Efficient Agricultural Production (REAP) – Canada, REAP Report.

Searchinger, T., R. Heimlich, R. A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, T-H. Yu. 2008. “Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change.” *Science* 319:1238-1240

Smeets, E. and A. Faaij. 2007. “Bioenergy Potentials from Forestry in 2050: An Assessment of the Drivers that Determine the Potentials.” *Climatic Change*, 81: 353-390.

Meeting Biofuels Targets: Implications for Land Use, Greenhouse Gas Emissions and Nitrogen Use in Illinois

Madhu Khanna, Hayri Önal, Xiaoguang Chen and Haixiao Huang[1]

Abstract: This article develops a dynamic micro-economic land use model to identify the cost-effective allocation of cropland for traditional row crops and perennial grasses and the mix of cellulosic feedstocks needed to meet pre-determined biofuel targets over the 2007-2022 period. Yields of perennial grasses are obtained from a biophysical model and together with county level data on costs of production for Illinois are used to examine the implications of these targets for crop and biofuel costs, greenhouse gas emissions, and nitrogen use. The economic viability of cellulosic feedstocks is found to depend on their yields per acre and the opportunity cost of land. The mix of viable cellulosic feedstocks varies spatially and temporally with corn stover and miscanthus co-existing in the state; corn stover is viable mainly in central and northern Illinois while miscanthus acres are primarily located in southern Illinois. Biofuel targets lead to a significant shift in acreage from soybeans and pasture to corn and a change in crop rotation and tillage practices. The biofuel targets assumed here lead to a reduction in greenhouse gas emissions but an increase in nitrogen use.

Biofuels are increasingly being viewed as the center piece in any strategy for energy independence, stable energy prices, and greenhouse gas (GHG) mitigation in the U.S. A key challenge to the expansion of biofuel production is the allocation of limited agricultural land between crops and biomass to meet the needs for food, feed and fuel and its potential to raise the prices of food/feed crops. The share of corn being used for ethanol production has increased from 10% to 28% between 2004/2005 and 2007/2008 , and despite an unprecedented increase by 15% in the acreage under corn in 2007 relative to 2005, corn prices reached record high levels in 2007 that were twice as high as those in 2005.

Energy policy in the U.S. initially sought to promote production and use of first-generation biofuels, corn ethanol, through mandates and tax credits; this has changed due to concerns about the implications of expanding demands for corn ethanol for food prices as well as the greater potential of cellulosic biofuels to mitigate climate change. The recently enacted Energy Independence and Security Act of 2007 places greater emphasis on the next generation of biofuels and mandates that 21 of the 36 billion gallons of ethanol be advanced biofuels that reduce GHG emissions by at least 50% relative to baseline levels.

Unlike the current generation of biofuels based on a single feedstock, that is corn, cellulosic biofuels can be produced from several different feedstocks including crop residues, woody biomass, and perennial grasses. Crop residues, being by-products of crop production do not create a food-fuel competition for land. However, currently available corn stover would meet only about a third of the advanced biofuels mandate for 2022 in the U.S. necessitating reliance

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on other sources, such as perennial grasses (Perlack et al., 2005). The latter also offer the potential for various environmental benefits compared to row crops they may displace and to corn-based ethanol.

Two perennial grasses, switchgrass (*Panicum virgatum*) and miscanthus (*Miscanthus x giganteus*), have been identified in particular as among the best choices as dedicated energy crops in the U.S. (Heaton et al., 2004; Lewandowski et al., 2003). These grasses have higher yields than others, provide high nutrient use efficiency, and require growing conditions and equipment similar to those for corn, making them compatible with conventional crop cultivation. They can provide a larger volume of biofuels per acre and lower life cycle GHG emissions per gallon of fuel than corn ethanol and thus alleviate the competition for land. Moreover, unlike corn, switchgrass and miscanthus can be grown on marginal lands and have the potential to reduce soil erosion and chemical run-off due to low chemical input needs and root structure[2].

This article develops a dynamic micro-economic land use allocation model that determines the profit maximizing land use choices to meet a targeted level of corn ethanol and cellulosic ethanol (from corn stover, miscanthus and switchgrass) over the 2007-2022 horizon while taking into account the spatial heterogeneity in yields, costs of production, and land availability within a region. Spatially heterogeneous yields of switchgrass and miscanthus are obtained from a biophysical crop growth model and used to examine the heterogeneity in the viability of biofuels from alternative feedstocks across geographical locations and the mix of feedstocks that is likely to be economically viable. A second purpose of this article is to examine the impact of these biofuel targets for the price of food crops that will be displaced from cropland and for the cost of producing biofuels to meet given mandates. The diversion of corn needed to meet the target for corn ethanol is expected to raise the prices of both corn and other competing commodities, and thus the cost of production of corn ethanol. Rising corn prices would also raise the opportunity costs of land to be converted to energy crops and thus the costs of producing cellulosic biofuels.

This article also investigates the effects of biofuel targets on nitrogen use and lifecycle GHG emissions. Biofuels from different feedstocks differ in their nitrogen requirements, energy-balance, and life-cycle emissions. While corn-ethanol reduces GHG emissions relative to gasoline, the production of corn is nitrogen and carbon intensive compared to perennial grasses. Reliance on current-generation biofuels, therefore, poses a trade-off between reducing GHG emissions and potentially increasing nitrate run-off and causing water quality problems.

The model is operationalized using county-specific data for Illinois to examine the economic and environmental implications of biofuels targets over the period 2007-2022. Illinois produces 17% of corn and 19% of the ethanol in the U.S. and has the climatic and soil conditions conducive to the production of herbaceous perennials that can be used as feedstocks for cellulosic biofuels. Estimates of nitrogen use and life-cycle GHG emissions associated with biofuels from different feedstocks are based on county-specific production practices in Illinois.

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[2] There have been some concerns that miscanthus, as an introduced species, might be an invasive plant. However, most varieties used for biofuel production (like *Miscanthus x Giganteus*) are sterile hybrids and do not produce seed.

The next section describes the related literature. The economic model is described in Section 3 followed by a description of the dedicated energy crops being considered here and the data and assumptions underlying the numerical simulation. Results of the numerical simulation are presented in Section 5 followed by conclusions in Section 6.

2. Related Literature

The dynamics of agricultural land use changes have been examined by several studies. Foremost among these are the studies based on the Forest and Agricultural Sector Optimization Model (FASOM) which is a multi-period, price endogenous, spatial market equilibrium model of land allocation between agricultural crops and forests. The model is run on a decadal time step. Biophysical relationships that quantify the growth of timber and the sequestration of carbon in forests and land are included. Alig et al. (1997) apply this model to investigate the allocation of land among 39 crop and livestock activities and forests across five regions in the U.S. to achieve given carbon sequestration targets, while Alig et al. (2000) examine the land use implications of producing hardwood short rotation woody crops on cropland for the US pulp and paper sector and its impact on the agricultural and forest sectors in the U.S.

McCarl et al. (2000) apply FASOM to examine the competitiveness of electric power generation using bioenergy from milling residues, whole trees, logging residues, switch grass, and short-rotation woody crops instead of coal while disaggregating the U.S. into eleven homogenous regions. McCarl and Schneider (2001) expand this model into the ASMGHG model to investigate competitiveness of various carbon mitigation strategies that include soil sequestration, biofuel crops, and afforestation at alternative carbon prices across 63 regions in the U.S. They find that at low carbon prices, soil carbon sequestration through a change in cropping practices is competitive while at high carbon prices, abatements are achieved mainly through use of biomass for power generation and conversion of land to forests.

Another dynamic agricultural sector model used to analyze allocation of cropland in the U.S. is POLYSYS (Ugarte et al., 2003). The model includes various traditional and energy crops and investigates land use impacts of exogenously set bioenergy prices. It is more regionally disaggregated than FASOM with 305 agricultural statistical districts as defined by the USDA and provides annual estimates of changes in economic outcomes. Walsh et al. (2003) apply POLYSYS to examine the potential for using CRP land to produce bioenergy crops at various bioenergy prices and find that switchgrass is more competitive than woody bioenergy crops and that annual farm income and crop prices would increase due to bioenergy crop production.

A few studies examine the environmental effects of the ethanol mandate. English et al. (2008) apply POLYSYS to show that the corn ethanol mandate will lead to major increases in corn production in the Corn Belt, shifting soybeans and wheat production to the southeast and shifting cotton westward over the period 2007-2016 (assuming that cellulosic biofuels are not feasible over this period). Fertilizer use and soil erosion will increase significantly while soil carbon sequestration will decline. Malcolm (2008) uses Regional Environment and Agriculture Programming Model (REAP), a partial-equilibrium model of the U.S. agricultural sector consisting of 50 regions to quantify the extent to which substitution of crop-residue based cellulosic ethanol for corn ethanol reduces soil erosion and nutrient deposition.

The dynamic land use allocation model developed here differs from the models used in studies mentioned above in that spatial and temporal heterogeneity in returns to land are incorporated at county level rather than much broader regions considered in these studies, and the optimal mix of competing cellulosic feedstocks—corn stover, miscanthus and switchgrass—is examined to meet the ethanol mandates. Due to the perennial nature of miscanthus and switchgrass, we use a multi-period dynamic rolling horizon model. The model generates a time path of the costs of meeting the biofuel mandate and examines its sensitivity to assumptions about the costs of producing cellulosic feedstocks. A biophysical model of energy crop yields and life cycle analysis of carbon emissions is integrated with the land use model to examine the environmental implications of land use changes to meet the specified targets.

3. The Model

A dynamic spatial optimization model is developed to analyze market prices, socially optimal land use strategies, and production and consumption of various row crops and perennial crops while meeting specific targets for ethanol production in Illinois over the 16-year planning horizon of 2007-2022. The annual crops considered here are corn, soybean, wheat, and sorghum, while the perennial crops considered are alfalfa, switchgrass and miscanthus. Since Illinois is a major producer of corn and soybeans, a significant change in the crop pattern in this region is likely to alter the market prices of these two commodities. Therefore, when determining the optimum resource allocation the model incorporates market equilibrium prices for corn and soybeans as endogenous variables. This is done by using a conventional approach where the sum of consumers' and producers' surplus is maximized subject to demand-supply balances, resource availability constraints, and technical constraints underlying production possibilities in Illinois (see, McCarl and Spreen, 1980; Takayama and Judge, 1971) for a rigorous presentation of this methodology and a review of studies that used this approach). Consumers' behavior is represented by constant elasticity demand curves for soybeans and for traditional (non-ethanol) uses of corn, both specified regionally, while the prices of wheat, sorghum and alfalfa are fixed at their base year levels. The parameters of the regional constant elasticity demand curves for corn and soybeans are computed based on national demand elasticity estimates of these commodities and their the base year consumption levels (quantities sold at the farmgate) using the method in Kutcher (1972). When computing the producers' surplus, returns from commodity sales and the costs associated with production of row crops and perennial crops, costs of land conversion between perennial and row crops, and the processing costs of both corn ethanol and cellulosic ethanol are incorporated in the objective function of the model. In addition, returns from the sales of co-products of biofuel production (such as Distiller's Dried Grains with Solubles (DDGS) and electricity, a byproduct of cellulosic biofuel production) are included in the producers' surplus, with the price of DDGS linked to the price of corn. The production costs of row crops vary with alternative management practices (rotations and tillage choices) while the costs and the yields of perennials vary with the age of the perennials.

The model determines optimal allocation of agricultural land simultaneously in all of the 102 counties in Illinois that are heterogeneous in their crop productivity and related costs, including the costs of producing biofuels (due to differences in feedstock costs), across various crops, rotations and management practices while satisfying the county-level land availability constraints, policy constraints (ethanol targets), and various technical constraints underlying the row crop rotation choices and dynamics of perennial crop production. The annual targets for corn ethanol and cellulosic ethanol for Illinois are assumed to be proportional to those set by the renewable fuels mandate, based on the current share of Illinois in national ethanol production.

The perennial nature of switchgrass and miscanthus requires consideration of year-to-year changes in crop yields and costs, thus multi-year production plans. For this we use a 10-year planning horizon assuming that farmers make long-term production plans based on anticipated prices in each year, the dynamics of crop yields and costs, and the demands for corn and biomass that are consistent with the ethanol targets. Due to the steady increase in ethanol production targets the demand for agricultural land would also increase and some marginal lands currently not being utilized may be converted to crop land, the extent of conversion would depend on the variations in crop prices over time. Therefore, in our analysis we treat the agricultural land supply as 'semi-endogenous' using a 'rolling horizon' approach. Specifically, we solve a 10-year market equilibrium model for each year of the 2007-2022 period assuming a fixed land supply in each run (differing by county), but the county land availability is varied between successive runs based on estimated land supply elasticities and an expected crop price index. Out of the resulting multi-year solution we take the first-year values of the crop production, consumption, and price variables and assume that they are 'realized' while the rest corresponding to a long-term optimal plan may be altered in subsequent runs. We use the endogenous first-year prices for all crops to determine the overall price index and incorporate this information to adjust the land availability in the subsequent runs. In this iterative procedure we first solve the model using the base-year (2007) land availability and ethanol targets for 2007-2022. Then, using the 2007 prices determined endogenously and observed prices prior to 2007 we compute the expected crop price index for 2008, update the land availability accordingly, and solve the model again considering the ethanol targets for the next 16 years (i.e. 2008-2023). This is repeated for each year of the planning horizon with the ethanol targets beyond 2022 being set at their levels in 2022.

Another salient feature of the model used here is the limited flexibility for changes in optimal crop patterns. To prevent unrealistic changes in land use, we incorporate a combination of historical and hypothetical acreage patterns into the land allocation for each row crop. Observed historical acreages can be used under 'normal' conditions to guide the potential planting behavior for row crops as in McCarl (1982) and Önal and McCarl (1991). Since we are considering further increases in the production of corn and planting new bioenergy crops in order to meet mandatory cellulosic ethanol targets, unprecedented land use patterns are likely to occur in the near future. To ensure that the model can generate results which are consistent with farmers' planting history and potential future trends, we incorporate both historical and hypothetical acreage pattern (crop mixes, each mix being a vector of crop acreages) in the model. The hypothetical crop mixes included in the model are generated *a priori* based on estimated acreage supply elasticities (both own price and cross price elasticities) and considering a set of price vectors in which crop prices (for corn, soybeans, and wheat only) are varied systematically. In addition, we impose a constraint that governs the dynamics of land conversion between perennials and row crops. These constraints are partly imposed by the allowable crop rotation possibilities and partly by limits imposed on the extent to which land can be converted from conventional to conservation tillage and from row crops to perennial grasses.

4. Data

We estimate rotation and tillage specific costs of production in 2007 prices for four row crops—corn, soybeans, wheat and sorghum—and three perennial grasses—alfalfa, switchgrass and miscanthus. The three perennial grasses have lifetimes of 5, 10 and 20 years, respectively. Application rates for nitrogen, potassium, phosphorus and seed for the four row crops and for alfalfa vary with yields per acre (University of Illinois Extension, 2002), as do the costs of drying and storage of crops (FBFM, 2003). Costs of producing row crops and alfalfa are obtained from the Farm Business and Farm Management data (FBFM, 2007). County-specific, five year (2002-2006) historical average yield per acre for each row crop is obtained from National Agricultural Statistics Service (USDA/NASS, 2008a) and used to construct these costs for each of the 102 counties in Illinois. Observed yields per acre are assumed to be those under a corn-soybean rotation, which is the dominant rotation practiced in Illinois. Corn yield per acre under a continuous corn rotation is assumed to be 12% lower than under a corn-soybean rotation. Costs of machinery operation, depreciation, and interest vary across the northern, central, and southern regions of Illinois and are obtained from the FBFM data for various years (FBFM, 2003; FBFM, 2007; FBFM, 2008). The per acre costs of labor, building repair and depreciation, and overhead (such as farm insurance and utilities) are excluded from these costs of production since they are likely to be the same for all crops and would not affect the relative profitability of crops. These are, therefore, part of the opportunity costs of using existing farm land, labor, and capital to produce bioenergy crops.

Corn stover yield for each county and each rotation is obtained from corn yields assuming a 1:1 ratio of dry matter of corn grain to dry matter of corn stover and 15% moisture content in the grain (Sheehan et al., 2003). Corn stover yields range from a low of 2.25 t dm per acre (metric tons of dry matter per acre) in southern Illinois to a high of 4 t dm per acre in northern and central Illinois. In the absence of long term observed yields for switchgrass and miscanthus, a crop productivity model MISCANMOD is used to simulate these yields in Illinois using GIS data on climate, soil moisture, solar radiation and growing degree days, as described in Khanna et al. (2008). Harvestable yields of miscanthus and switchgrass are estimated to be lower in northern Illinois (9.8 t dm per acre and 4.4 t dm per acre, respectively) than in southern Illinois (12.1 t dm per acre and 5.8 t dm per acre, respectively). This pattern of yield is in contrast to that observed for corn and corn stover. This is because solar radiation and growing degree days which are more abundant in southern Illinois are critical determinants of biomass yield while soil quality is more important for corn yields.

Agronomic data indicate that miscanthus does not yield harvestable biomass in the first year; it provides 50% of its maximum yield in the second year, and 100% of yields from the third year onwards for its remaining life. For switchgrass, we assume that 50% of the maximum yield can be harvested in the first year and full yield can be obtained in the second year and onwards. We also assume that 33% of the peak yield is lost during harvest of miscanthus, but there are no harvest losses for switchgrass (unlike Khanna, 2008; Khanna et al., 2008). Harvested switchgrass and miscanthus have moisture contents of 15% and 20%, respectively.

In estimating the costs of producing miscanthus and switchgrass, we rely on agronomic assumptions about fertilizer, seed, and pesticide application rates for switchgrass and miscanthus described in Khanna et al. (2008), while updating the costs of inputs using 2007 prices.

Miscanthus is planted using rhizomes and planting costs are estimated at $1000 per acre. Costs of harvesting switchgrass and miscanthus (i.e., mowing, raking, baling and staging) are obtained from the FBFM data (FBFM, 2007; FBFM, 2008) and from Duffy (2007). Costs of mowing/conditioning and raking in Illinois are $14.2 and $4.5 per acre, respectively, while the cost of staging is $2.75 per bale (with a weight of 950 lbs). Baling costs for switchgrass and miscanthus are based on current estimates of the cost of baling hay. The cost of baling hay with a yield of 1.18 metric tons per acre is estimated to be $20.5 per acre in Illinois. We consider a high cost scenario in which baling costs of switchgrass and miscanthus increase proportionately with yield. In the low cost scenario the fixed costs of baling (tractor and implement overhead) are estimated to be $14.3 per acre and to be invariant with yield. The variable costs of baling include costs of fuel, lube, and labor which depend on the biomass yield to be baled. These are estimated to be $5.25 per metric ton (FBFM, 2008). We also consider a high and a low cost scenario for storage of biomass; the former with storage in an enclosed building and the latter with storage in the open field on crushed rock covered by tarp. Storage costs are estimated to be $18.37 per metric ton in the former case (Duffy, 2007) and $3.22 per metric ton in the latter case (Brummer et al., 2000). Loss of biomass is assumed to be 2% and 7% in the high and low cost scenarios, respectively.

The costs of producing corn stover include the cost of fertilizer that needs to be applied to replace the loss of nutrients and soil organic matter due to removal of residue from the soil. The costs of replacement fertilizer are obtained by assuming that removal rates of N, P, and K are 7.72, 1.76 and 16.76 pounds, respectively, per dry metric ton of stover removed as estimated by Sheehan et al. (2003). In addition, corn stover collection will involve a second pass through the field using commercial equipment after harvesting the corn grain. The costs of mowing, raking, baling, and staging are determined for a high cost and low cost case using similar assumptions as described above. Similar to Malcolm (2008), we assume that 50% of the residue can be removed from fields if corn is produced using no-till continuous corn rotation and 30% can be removed if conventional till was practiced. These estimates are more conservative than those in Khanna (2008). In addition, we consider a scenario of high stover yield, in which 70% of residue can be removed from fields if corn is produced using no-till continuous corn rotation and 50% can be removed using conventional till while other cost items remain the same as in the low cost scenario.

The estimates of breakeven cost of production of cellulosic feedstocks under average yield conditions in Illinois are shown in Table 1. The opportunity costs of land are the foregone profits from a corn-soybean rotation on that land. In the case of corn stover, the opportunity cost of land is estimated under the assumption that demand for corn stover leads to a switch from a corn-soybean rotation to continuous corn with 12% lower corn yields and 40 lbs per acre greater fertilizer applications in the absence of nitrogen fixation by soybeans (University of Illinois Extension, 2002). The costs of producing these feedstocks vary considerably due to spatial differences in their yields as well as differences in the costs of land. The costs of corn and corn stover are lower in the northern and central regions of Illinois, while the lowest costs for miscanthus prevail in the southwestern and southern regions of Illinois. The per unit cost of producing switchgrass in Illinois is extremely high compared to miscanthus.

Table 1. Farmgate Costs of Production of Cellulosic Feedstocks in Illinois

Cost Items ($/Acre)	Switchgrass		Miscanthus		Corn Stover		
Scenario	High Cost	Low Cost	High Cost	Low Cost	High Cost	Low Cost	High Yield
Fertilizer	66.7	66.7	29.8	29.8	11.85	11.85	16.59
Chemicals	7.7	7.7	0.5	0.5	-	-	-
Seed	7.0	7.0	70.8	70.8	-	-	-
Interest on operating inputs	5.7	5.7	7.1	7.1	0.83	0.83	1.16
Preharvest Machinery	14.1	14.1	11.0	11.0	-	-	-
Harvesting	117.4	82.5	277.5	151.6	55.0	52.3	60.15
Storage	77.3	14.6	199.3	37.6	29.8	5.6	7.86
Annualized Total Operating Cost ($/acre)	**296.3**	**198.3**	**595.9**	**308.4**	**97.5**	**70.6**	**85.8**
Annualized deliverable yield (t dm/acre)[a]	3.5	3.3	8.5	8.1	1.4	1.3	1.79
Breakeven cost ($/t dm)	**84.5**	**59.6**	**70.1**	**38.2**	**70.2**	**55.1**	**47.91**
Opportunity cost of land ($/ t dm)[b]	125.8	132.6	51.9	54.7	61.5	64.8	46.26
Breakeven cost inc. land ($/t dm)	**210.3**	**192.2**	**122.0**	**92.9**	**133.6**	**119.9**	**94.03**

[a] Deliverable yield at the farmgate estimated after including losses during harvest and storage. Yield losses during storage are assumed to be 7% in the low cost scenarios and 2% in the high cost scenario.
[b] Opportunity cost of land is estimated assuming a price of $5 per bushel for corn and $12 per bushel for soybeans and a yield of 145 bushels/acre for corn and 50 bushels/acre for soybeans with a corn-soybean rotation.

Ethanol yield from corn grain is 2.8 gallons of denatured ethanol per bushel of corn. Based on pilot demonstrations cellulosic biofuel yield from a nth-generation stand alone plant is estimated as 87.3 gallons per metric t dm of biomass (Wallace et al., 2005). Because of its high deliverable yield (average annualized value of 8.5 t dm per acre), miscanthus produces 86% more ethanol than corn per unit of land (with a yield of 145 bu/acre under a corn-soybean rotation), more than twice as much as switchgrass and five times as much as corn stover.

The cost of conversion of corn grain to ethanol is obtained from a dry mill ethanol plant simulator developed by Ellinger (2008), which simulates the performance of a 100 million gallon capacity plant over a seven-year period. The cost is estimated to be $0.69/gallon in 2007 prices with adjustments based on Wu (2008). A co-product credit for DDGS is included assuming that 17.75 lbs of DDGS is produced per bushel of corn used for ethanol. The non feedstock costs of producing cellulosic ethanol are estimated to be $1.46 per gallon for a 25 million gallon capacity plant operating 330 days a year in 2007 prices (Wallace et al., 2005).

The costs of biofuel production from alternative feedstocks are reported in Table 2. Ignoring the opportunity cost of land, corn ethanol has the highest feedstock cost while ethanol from miscanthus has the lowest. When the opportunity cost of land is included, miscanthus is still the cheapest feedstock at farmgate but switchgrass becomes the most expensive. Under average conditions, the cost of ethanol production from corn is estimated as $1.99/gal while the cost of cellulosic ethanol varies between $2.61/gal and $3.96/gal, with miscanthus ethanol being the cheapest and switchgrass ethanol the most expensive.

Table 2. Cost of production of biofuels from alternative feedstocks (in \$/gallon)[a]

Feedstock	Feedstock cost[b]		Opportunity cost of land		Non feedstock cost	Co-product credit	Total cost		Feedstock cost at farmgate[c]	
	High cost	Low cost	High cost	Low cost			High cost	Low cost	High cost	Low cost
Corn	1.78	1.78	-	-	0.69	0.48	1.99	1.99	1.78	1.78
Corn stover	1.03	0.84	0.70	0.74	1.46	0.12	3.08	2.92	1.53	1.37
Switchgrass	1.18	0.89	1.44	1.52	1.46	0.12	3.96	3.71	2.41	2.20
Miscanthus	1.01	0.65	0.59	0.63	1.46	0.12	2.95	2.61	1.40	1.06

[a] Due to space limitations, costs of biofuel from corn stover in the high yield scenario are not reported in this table. These costs are: feedstock cost, \$0.55/gal; opportunity cost of land, \$0.53/gal; total cost, \$2.42/gal; and feedstock cost at farmgate, \$0.87/gal.
[b] This cost includes transportation cost but excludes opportunity cost of land.
[c] This cost excludes transportation cost but includes opportunity cost of land.

To obtain the demand functions for corn and soybeans faced by Illinois producers, we use short-run national demand and supply price elasticities estimated by various sources. For corn, we use the demand elasticity of -0.16 (OECD, 2001) and supply elasticity of 0.2 (Gardner, 1976). The corresponding estimates for soybeans are -0.594 (USDA/ERS, 2007) and 0.45 (Gardner, 1988), respectively. The share of Illinois in the U.S. corn and soybean production in 2007 is 17.1% and 14.9%, respectively (USDA/NASS, 2008a). The commodity prices and production quantity in 2007 (excluding the amount of corn used for ethanol) are used to estimate the parameters of the demand functions for corn and soybeans. For wheat, sorghum and alfalfa, the farmgate prices are assumed to be exogeneous and remain constant throughout the planning horizon at their 2007 values observed in Illinois (USDA/NASS, 2008b).

We use the data on total planted acres by county and state-level prices for corn, soybeans, sorghum, wheat and alfalfa for 1995-2007 to estimate the relationship between cropland acreage and the lagged value of the Laspeyres crop price index for each county (with 1995 as the base year). We determine the elasticity of crop specific acreage responses with respect to own and cross prices for corn and soybeans for each of the nine crop reporting districts (CRD) in Illinois. In the estimation procedure, we incorporate the current and lagged regional acreages, the lagged state level crop prices, a time trend, and the national commodity stock levels in December of the previous year. The crop acreage response elasticities estimated thereby for each CRD are then used for determining the land supply in the counties belonging to that CRD.

We consider six most commonly practiced rotation choices in Illinois and two tillage choices for the row crops. Methods used to determine the costs of production of each crop under conservation tillage are described in Dhungana (2007). County-specific historical acres under each crop (crop mixes) for the period 1995-2007 are obtained from (USDA/NASS, 2008b) and used to set bounds for the allocation of land among crops in each county. We also use simulated (hypothetical) crop mixes for each county, which are generated by assuming different combinations of crop prices increased by 50% and 100% over their 2007 levels and by using the estimated crop specific elasticities mentioned above.

We conduct a life cycle analysis of the above ground CO_2 equivalent emissions (CO_2e) generated from biofuels production using different feedstocks; emissions of the major GHGs are converted to equivalent levels based on their 100-year global warming potential (IPCC, 2001). We include the CO_2e generated not only from various inputs and machinery used on the farm in the production of each feedstock and the energy used to produce and transport those inputs to the farm, but also from the energy used to transport the feedstock to a biorefinery and the energy used to convert the feedstock to biofuel. Specifically, inputs for feedstock production include fertilizers (e.g., nitrogen, phosphorous and potassium), herbicides, and insecticides. Energy used in the production of biofuel feedstock includes the direct consumption of gasoline, diesel, liquefied petroleum gas, and electricity, and the indirect consumption of energy embodied in farm equipment such as tractors and plows. Similarly, CO_2e generated during the biorefinery phase accounts for the energy used to convert the feedstock to fuel and the energy embodied in buildings and equipment in the biorefinery. CO_2e is obtained by aggregating the CO_2 emissions from the energy used and the GHG emissions induced from the use of the inputs such as nitrogen and lime. For more details regarding the assumptions and parameters used in our life cycle analysis for biofuel feedstock production, see Dhungana (2007); for biofuel conversion, see Farrell et al. (2006). CO_2e from corn stover ethanol is estimated using an incremental emissions approach as described in Wu et al.(2006). Specifically, life cycle emissions arising from stover harvesting and additional chemical application as a result of stover removal are evaluated. If demand for corn stover, miscanthus, or switchgrass leads to a switch away from the baseline corn-soybean rotation to alternative land uses, the change in emissions due to this change is also incorporated.

Finally, the annual corn and cellulosic biofuel production targets for Illinois are assumed to be 20% of their respective annual national ethanol mandates. These targets are specified for each year of the planning horizon (e.g., for 2022 the respective mandates are 3 billion and 4.2 billion gallons).

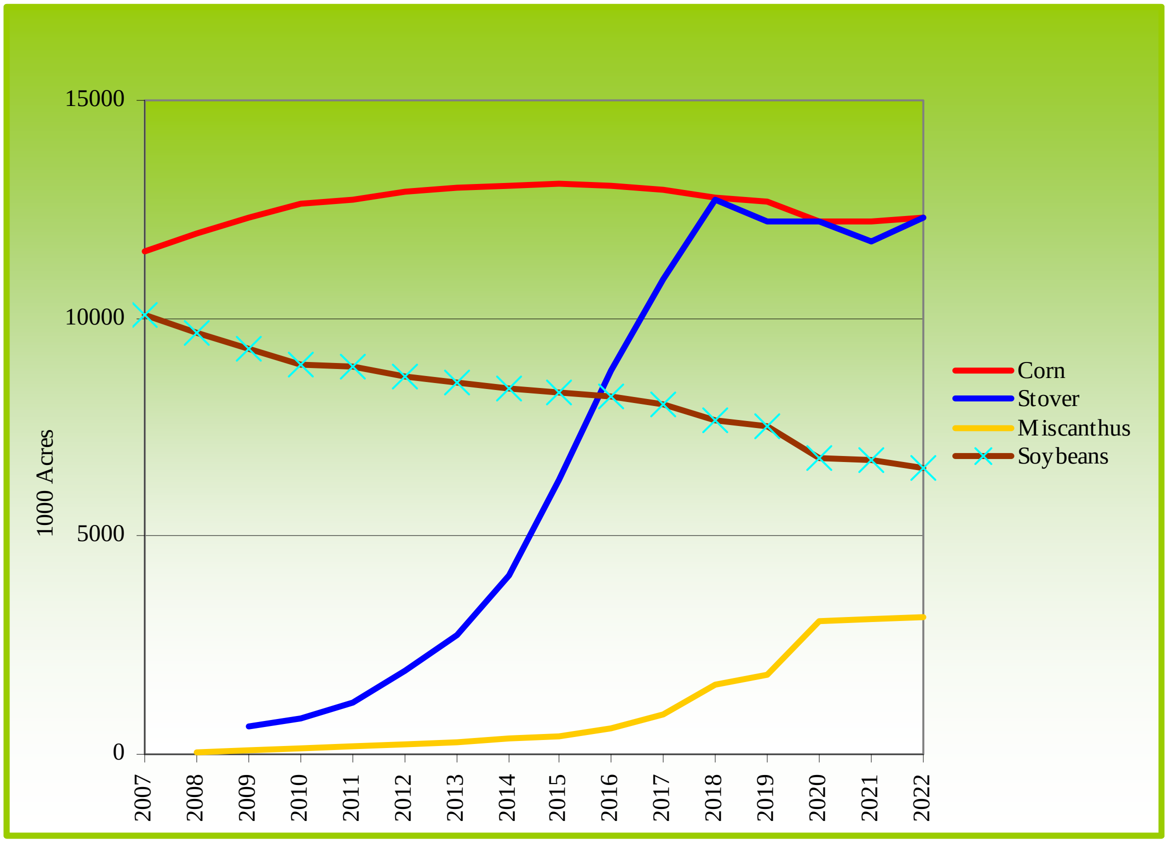
5. Results

We simulate land use decisions in Illinois between 2007 and 2022 under four scenarios: no biofuel targets (baseline), biofuel targets with high costs of feedstock production (high cost), biofuel targets with low costs of feedstock production (low cost) and biofuel mandates with high corn stover removal rates and low costs of feedstock production (high stover yield) (see Table 3). Imposing biofuel targets has three types of effects on land use. First and foremost, it increases the demand for land, which in turn increases the cropland brought into production relative to the baseline. Second, the mandate leads to a conversion of land from food crops to biofuel crops. Third, the biofuel targets and the resulting demand for corn stover lead to a significant change in the tillage and rotation choices for crop production. More specific results are given below.

Under all three scenarios with biofuel targets, we find that the total land use increases by about 5% by 2022. The results also show an increase in the percentage of land under corn (from 47% to 53%-55%), a decrease in the percentage of land under soybeans (from 45% to 29%), wheat (15% reduction) and pasture (44% reduction). Of the total corn produced, 56% would be used to produce ethanol and 14% of the cropland would be diverted to produce miscanthus by 2022 under the high cost and low cost scenarios. The land under miscanthus would be lower but still significant (10% of the total cropland) under the high stover yield scenario. Switchgrass would not be produced under any of the scenarios we analyzed because of its yield and cost disadvantage compared with miscanthus. The biofuels target results in the use of 100% of the available corn stover for cellulosic biofuel production in 2022 under all scenarios.

The trends in acreage under corn, stover, and miscanthus under the low cost scenario are shown in Figure 1.We find that miscanthus and corn stover would be used conjunctively to produce biofuels. Specifically, 36% of the cellulosic target in 2022 would be produced from corn stover. Assumptions about corn stover removal rates have a significant impact on the trends in allocation of acreage among cellulosic feedstocks. In this case, stover production begins in 2010 and is used to meet 83% the cellulosic target in 2015 and 53% of the cellulosic ethanol in 2022.

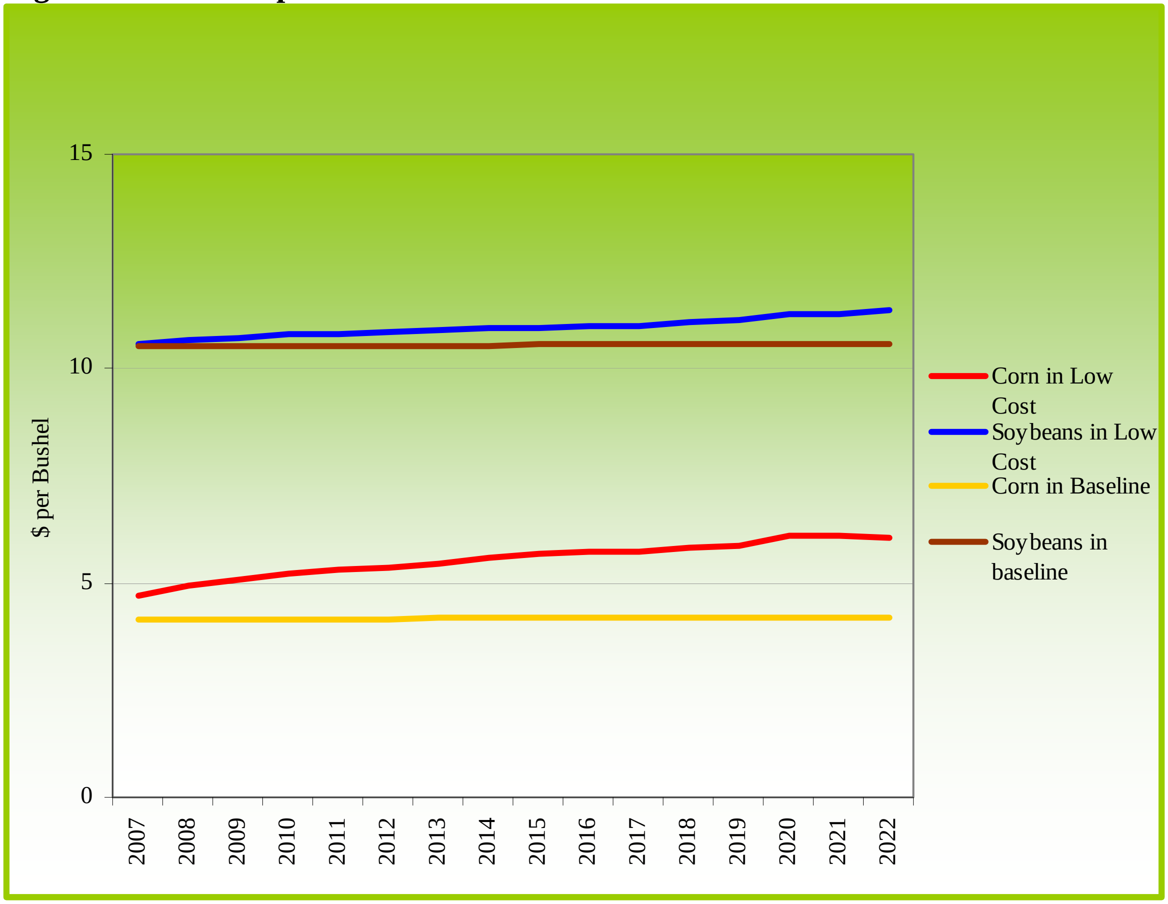
Figure 1. Trends in acreage in low cost scenario



The diversion of land to biofuel production affects the prices of both corn and soybeans because of the reduced acreage and production of these commodities for food and feed uses, as shown in Figure 2. As compared to the baseline, biofuel targets lead to an increase in total production of corn from 1.7 billion bushels in the baseline to about 1.9 billion bushels, a decrease in food and feed uses by about 50% for corn and 36% for soybeans, an increase in corn prices from $4.22 to $6.09 per bushel (by 44%) and an increase in the price of soybeans by 7% from $10.60 to $11.40 per bushel. Corn and soybean price in the high stover yield scenario are very similar to those in the other scenarios. The cost of producing cellulosic biofuels differs in the three scenarios due to differences in the share of biofuels from corn stover vs. miscanthus.

For instance, the cost of corn ethanol in 2022 is $2.17 per gallon and that of cellulosic ethanol is $2.99 per gallon in the low cost scenario and $4.08 per gallon in the high cost scenario. With the high stover yield, the costs of producing corn ethanol and cellulosic ethanol are lower, $2.09 and $2.54 per gallon, respectively.

Figure 2. Trends in prices in baseline and low cost scenario



The cropland under corn-soybean rotation decreases from 80% to 29% in the low cost scenario, and 27% in the high cost or the high stover yield scenarios, while the land under continuous corn increases from 7% to 36%, 37% and 37% in the low cost, high cost and the high stover yield scenarios, respectively. We also see an increase in the land under conservation tillage which allows a larger percentage of corn stover to be collected, from 28% in the baseline to about 59% in both the low and high cost scenarios with the mandate in 2022. The land under conservation tillage increases from 27% to 61% in the high stover yield scenario, leading to a reduction in the land allocated to miscanthus compared to the other two scenarios.

We find considerable spatial variability in the acres devoted to cellulosic feedstocks across counties and over time. Under the low cost scenario, in 2015, 90% of the corn acreage would be in the central and northern counties while corn stover would be collected in 73 of 102 counties (6.3 million acres). In contrast, by 2022, the land under corn is reduced in 33 southern counties (by 884 thousand acres) due to the increase in the cellulosic biofuel target which in turn increases the acreage of miscanthus in that region, as shown in Figure 3. Under the high stover yield scenario, in 2015, corn stover would be collected from 4.6 million corn acres in 52 central and northern Illinois counties. Under all three scenarios, corn stover is collected from the entire corn acreage in 2022. Under the low cost scenario, towards the end of the planning horizon 67 of the 102 Illinois counties would allocate about 14% of their total cropland to miscanthus production, which expands primarily in the southern counties, from 1.3 million acres in 2015 to 2.5 million acres in 2022.

Finally, we estimate that the cumulative GHG emissions (2007-2022) from production of corn and soybeans and the use of energy equivalent gasoline in the absence of biofuel targets is about 0.84 million metric tons. The total emissions over the same period with biofuel targets are estimated as 0.39 million metric tons, 54% lower than the baseline. This reduction is generated primarily by the displacement of gasoline by ethanol which more than offsets the increase in emissions due to greater corn production. The flip side of this environmental benefit is the increased use of nitrogen in agricultural production, which may have adverse implications for water quality. While the total GHG emissions are halved, nitrogen use would be increased by 25% relative to the baseline level because of several reasons, including: i) the expansion of corn acres, ii) conversion of land from corn-soybean rotation with conventional tillage to the more carbon intensive continuous corn, and iii) removal of corn stover that has to be compensated by increased use of nitrogen fertilizers. Expansion of perennial crop acreage to meet the biomass demand of the cellulosic ethanol industry adds very little to nitrogen use due to its low requirements for nitrogen.

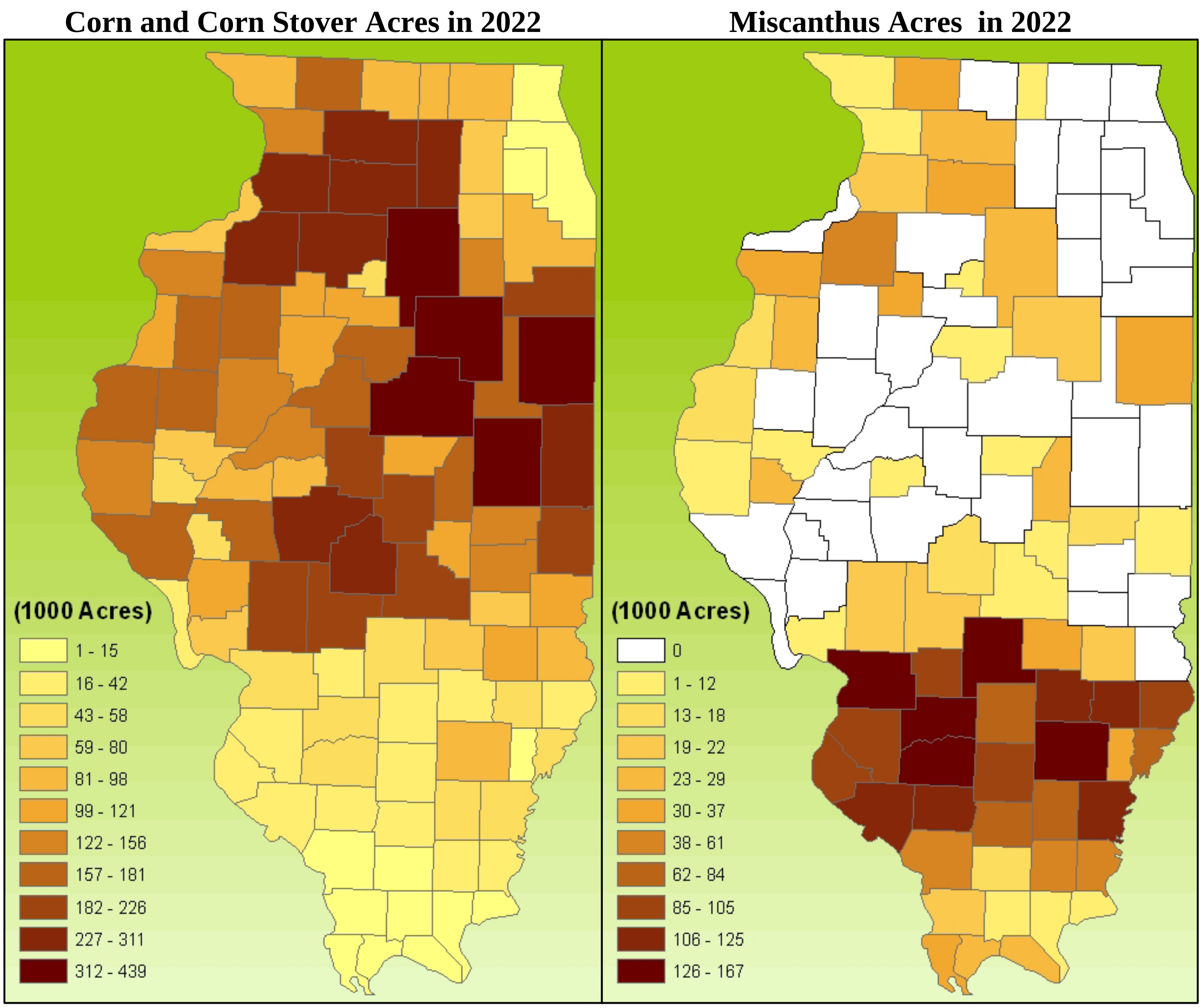
6. Conclusions

This article examines the implications of biofuel production targets up to 2022, mandated by the Energy Independence and Security Act, for the allocation of land among food and fuel crops and the resulting impacts on crop prices. Although the study has a somewhat narrow regional focus, the main conclusions are likely to be valid for U.S. agriculture as a whole, commodity markets, and environmental costs/benefits. We find that biofuel targets lead to a significant shift in the acreage from soybean, wheat and pasture to corn, and a change in crop rotation and tillage practices. Despite an increase in corn production by 12%, the biofuel targets considered here result in significantly higher corn and soybean prices due to the diversion of about 56% of the corn produced to ethanol production. Among cellulosic feedstocks, we find that corn stover is likely to play an important role in meeting the cellulosic biofuel targets in Illinois mainly due to its relatively low cost of production and high yields in this region. All of the available corn stover that can be sustainably harvested is, however, insufficient to meet the biofuel target; this creates demand for miscanthus as an inevitable alternative source of bioenergy. There is considerable spatial variability in the allocation of land to food and fuel crops across Illinois, with much of the corn stover production occurring in central and northern Illinois while miscanthus production occurs mostly in southwestern Illinois. Finally, our analysis highlights the trade-offs involved in relying on biofuels, particularly the current generation of biofuels, in terms of climate change mitigation and water quality improvements. Increased biofuel production reduces GHGs by 54%, but it increases nitrogen use by 25% relative to the baseline. In contrast, cellulosic biofuels from grasses, such as miscanthus, offer the potential for carbon emissions reduction with minimal increases in nitrogen applications.

Table 3. Effect of biofuel targets on land use, crop production and the environment

	Variables (Values calculated for 2022)	**Non-ethanol baseline**	**High Cost**	**Low Cost**	**High Stover Yield**
Land use	Total land (M Acres)	22.04	23.10	23.09	23.13
	Land under corn (%)	47.83	53.46	53.32	55.27
	Land under soybeans (%)	45.42	28.32	28.50	29.37
	Land under wheat(%)	3.34	2.89	2.83	3.24
	Land under pasture(%)	3.09	1.74	1.74	1.84
	Land under stover (%)		53.46	53.32	55.27
	Land under miscanthus (%)		13.50	13.53	10.18
	Land under conservation tillage(%)	27.55	58.96	58.61	61.49
	Land under corn-soybean rotation (%)	80.05	27.02	29.48	30.58
	Land under corn-corn rotation (%)	7.21	37.25	35.95	36.96
Crop Production, Consumption (M Bushels)	Corn Production	1709.24	1927.1	1923.61	1983.11
	Corn Consumption (non ethanol use)	1709.24	855.67	852.18	911.68
	Soybeans	449.83	283.71	285.69	292.44
Prices in 2022 (in 2007 dollars)	Corn ($/Bu)	4.22	6.04	6.09	5.85
	Soybean ($/Bu)	10.59	11.35	11.35	11.31
	Corn ethanol($/gallon)		2.16	2.17	2.09
	Cellulosic ethanol ($/gallon)		4.08	2.99	2.54
Volume of ethanol	Corn (B gallons)		3.00	3.00	3.00
	Stover (B gallons)		1.53	1.53	2.21
	Miscanthus (B gallons)		2.67	2.67	1.99
Environmental Effects	**Greenhouse Gas Emissions (M tons)**	**0.84**	**0.39**	**0.39**	**0.38**
	Energy Equivalent Fuel Emissions	0.76	0.26	0.26	0.26
	Corn Production	0.08	0.10	0.11	0.11
	Stover Production		0.007	0.007	0.015
	Miscanthus Production		0.008	0.008	0.005
	Nitrogen Use (1000 tons)	**13.39**	**16.76**	**16.75**	**16.91**
	Corn Production	12.99	15.79	15.78	15.88
	Stover Production		0.39	0.39	0.49
	Miscanthus Production		0.20	0.20	0.15

Figure 3. Spatial heterogeneity in land use with biofuel targets in low cost scenario



References

Alig, R., D. Adams, B. McCarl, J. M. Callaway, and S. Winnett. 1997. "Assessing Effects of Mitigation Strategies for Global Climate Change with an Intertemporal Model of the U.S. Forest and Agriculture Sectors." *Environmental And Resource Economics* 9: 259-274.

Alig, R., M. Adams, B. McCarl, and P. J. Ince. 2000. "Economics Potential of Short-Rotation Woody Crops on Agricultural Land for Pulp Fiber Production in the United States." *Forest Products Journal* 50 (5): 67-74.

Bange, G. A. 2007. "The Situation and Outlook for World Corn, Soybean, and Cotton Markets." Presentation to National Grain and Oils Information Center, Beijing, China.

Brummer, E., C. Burras, M. Duffy, and K. Moore. 2000. "Switchgrass Production in Iowa: Economic Analysis, Soil Suitability, and Varietal Performance." Ames, Iowa: Iowa State University, Prepared for Bioenergy Feedstock Development Program, Oak Ridge National Laboratory, Oak ridge, TN

Dhungana, B. R. 2007. "Economic Modeling of Bioenergy Crop Production and Carbon Emission Reduction in Illinois." PhD Dissertation, University of Illinois.

Duffy, M. 2007. "Estimated Costs for Production, Storage, and Transportation of Switchgrass." Dept. Agr Econ, Iowa State University, Ames, Iowa.

Ellinger, P. 2008. Ethanol Plant Simulator. Dept. Agr Econ, University of Illinois at Urbana-Champaign, Urbana, IL.

English, B., D. G. Ugarte, R. Menard, and T. West. 2008. "Economic and Environmental Impacts of Biofuel Expansion: The Role of Cellulosic Ethanol." Paper presented at the Integration of Agricultural and Energy Systems Conference, Atlanta, GA.

Farrell, A. E., R. J. Plevin, B. T. Turner, A. D. Jones, M. O'Hare, and D. M. Kammen. 2006. "Ethanol Can Contribute to Energy and Environmental Goals." *Science* 311 (27): 506-509.

FBFM. 2003. "Farm Economics Facts and Opinions." *Farm Business and Farm Management* Newsletters. Department of Agricultural Economics, University of Illinois at Urbana-Champaign.

FBFM. 2007. "Farm Economics Facts and Opinions." *Farm Business and Farm Management* Newsletters. Department of Agricultural Economics, University of Illinois at Urbana-Champaign.

FBFM. 2008. "Farm Economics Facts and Opinions." *Farm Business and Farm Management* Newsletters. Department of Agricultural Economics, University of Illinois at Urbana-Champaign.

Gardner, B. 1988 *Economics of Agricultural Policies*. New York: Macmillan Publishing company.

Gardner, B. L. 1976. "Futures Prices in Supply Analysis." *American Journal of Agricultural Economics* 58 (1): 81-84.

Heaton, E. A., J. Clifton-Brown, T. Voigt, M. B. Jones, and S. P. Long. 2004. "Miscanthus for Renewable Energy Generation: European Union Experience and Projections for Illinois." *Mitigation and Adaptation Strategies for Global Change* 9: 433-451.

IPCC. 2001 "Climate Change 2001: The Scientific Basis." Third Assessment report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press.

Khanna, M. 2008. "Cellulosic Biofuels: Are They Economically Viable and Environmentally Sustainable?" *Choices*, 3rd Quarter 23, (3): 16-21.

Khanna, M., B. Dhungana, and J. Clifton-Brown. 2008. "Costs of Producing Miscanthus and Switchgrass for Bioenergy in Illinois." *Biomass and Bioenergy* 32 (6): 482-493.

Kutcher, G. P. 1972. "Agricultural Planning at the Regional Level: A Programming Model of Mexico's Pacific Northwest." Ph. D dissertation, University of Maryland.

Lewandowski, I., J. M. O. Scurlock, E. Lindvall, and M. Christou. 2003. "The Development and Current Status of Perennial Rhizomatous Grasses as Energy Crops in the U.S. And Europe." *Biomass and Bioenergy* 25 (4): 335-361.

Malcolm, S. 2008. "Weaning Off Corn: Crop Residues and the Transition to Cellulosic Ethanol." Paper Presented at the Transition to A BioEconomy: Environmental and Rural Development Impact, Farm Foundation, St. Louis, MO.

McCarl, B., and U. Schneider. 2001. "The Cost of Greenhouse Gas Mitigation in U.S. Agriculture and Forestry." *Science* 294: 2481-2482.

McCarl, B. A. 1982. "Cropping Activities in Agricultural Sector Models: A Methodological Approach." *American Journal of Agricultural Economics* 64 (4): 768-772.

McCarl, B. A., D. M. Adams, R. J. Alig, and T. C. John. 2000. "Analysis of Biomass Fueled Electrical Power Plants: Implications in the Agricultural and Forestry Sectors." *Annals of Operations Research* 94: 37-55.

McCarl, B. A., and T. H. Spreen. 1980. "Price Endogenous Mathematical Programming as a Tool for Policy Analysis." *American Journal of Agricultural Economics* (62): 87-102.

OECD. 2001 "Market Effectsof Crop Support Measures."

Onal, H., and B. A. McCarl. 1991. "Exact Aggregation in Mathematical Programming Sector Models." *Canadian Journal of Agricultural Economics* 39: 319-334.

Perlack, R. D., L. L. Wright, R.L.Graham, B. J. Stokes, and D. C. Erbach. 2005. "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply." DOE/GO-102005-2135, ORNL/TM-2005/66, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Sheehan, J., A. Aden, K. Paustian, K. Killian, J. Brenner, M. Walsh, and R. Nelson. 2003. "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol." *Journal of Industrial Ecology* 7: 117-146.

Takayama, T., and G. G. Judge. 1971. *Spatially and Temporal Price and Allocation Models*. Amsterdam: North Holland Publishing Co.

Ugarte, D. G., M. E. Walsh, H. Shapouri, and S. P. Slinsky. 2003. "The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture." U.S. Department of Agriculture.

University of Illinois Extension. 2002. "Illinois Agronomy Handbook, 23rd Edition." University of Illinois, College of Agricultural, Consumer and Environmental Sciences, Cooperative Extension Service.

USDA/ERS. 2007. Commodity and Food Elasticities: Demand Elasticities from Literature, http://www.ers.usda.gov/Data/Elasticities/query.aspx.

USDA/NASS. 2008a. U.S. & All States County Data - Crops, http://www.nass.usda.gov/QuickStats/Create_County_All.jsp.

USDA/NASS. 2008b. U.S. & All States Data - Crops, http://www.nass.usda.gov/QuickStats/Create_Federal_All.jsp.

Wallace, R., K. Ibsen, A. McAloon, and W. Yee. 2005. "Feasibility Study for Co-Locating and Integrating Ethanol Production Plants from Corn Starch and Lignocellulogic Feedstocks." NREL/TP-510-37092 Revised January Edition: USDA/USDOE/NREL.

Walsh, M. E., D. G. d. l. T. Ugarte, H. Shapouri, and S. P. Slinsky. 2003. " Bioenergy Crop Production in the United States: Potential Quantities, Land Use Changes, and Economic Impacts on the Agricultural Sector." *Environmental and Resource Economics* 24 (4): 313-333.

Wu, M. 2008. "Analysis of the Efficiency of the U.S. Ethanol Industry 2007." Argonne National Laboratory, Report Delivered to Renewable fuels Association.

Wu, M., M. Wang, and H. Huo. 2006. "Fuel-Cycle Assessment of Selected Bioethanol Production Pathways in the United States." Argonne National Laboratory Report, ANL/ESD/06-7.

Potential for Uncertainty about Indirect Effects of Ethanol on Land Use in the Case of Brazil

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

Abstract: The indirect effects of ethanol on land are a focus of recent US biofuel literature and policy. The experiments presented here highlight the sensitivity of land use changes to assumptions about the ability of land to be converted from one use to another and the ease with which decision makers can make these conversions. By varying parameters governing land use in a simulation model, indirect effects on land use can be varied no less widely. Extending this result, there is an inverse relationship between the responsiveness of land allocation, which is a key element of overall supply response in the medium-term, and the magnitude of price effects: for a given shock, greater land response dampens the scale of price changes and lower land response is associated with greater price effects. Moving beyond agricultural commodity markets alone, Brazilian ethanol markets may be as sensitive to prices as US markets are sometimes believed to be. If so, then changes in Brazilian trade may represent a substantial part of the market response to changes in US ethanol consumption at least over certain ranges. With uncertainties about area and ethanol market effects taken into account, a particular path of US imports may be associated with any number of land use effects.

The carbon footprint of biofuels is argued to be highly dependent on the indirect effects of biofuels on land use and, in particular, on deforestation. The potential for carbon emissions generated through land use change, raised by Searchinger et al. (2008a, 2008b) invites further consideration given the magnitude of land use effects. Here, the parameters associated with indirect effects of biofuel policies in the US on land allocation elsewhere are explored.

Supply and demand responses to price signals are at the heart of indirect effects of US policies on land use. US biofuel policies themselves do not directly affect or dictate how land is used in the US, let alone in other countries. The principal tools of the current US biofuel policy regime are mandated minimum levels of biofuel use, tax credits per gallon of biofuel blended, and tariffs on imports, none of which dictates land use directly. In each case, the line of causality from US biofuel policy to land use must go through markets. Policies to encourage biofuel use lead to greater demand for biofuels to the extent they affect consumer behavior. Rising biofuel demand tends to raise biofuel prices. Higher prices bring about greater production, which requires more feedstock purchases. As biofuel processors buy more feedstocks, such as corn or vegetable oil, competition among users will tend to bid up prices of these goods which in turn will encourage more supply. Agricultural commodity producers will attempt to increase supply by allocating more land to the crops with the higher returns and converting land from other uses than crop production if it is profitable to do so. For land use in other countries, interactions through trade must be added to these links, as quantities of net exports from the US are reduced

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by the feedstock purchases of biofuel processors, leading to rising world prices which may be transmitted into other countries, leading to changes in land use outside the US.

Each stage along this path depends on behavior by producers, consumers, and traders. We briefly explore the implications of different assumptions about responsiveness of land use in Brazil to price signals. Brazil is widely seen as a potential or even likely source of more agricultural area in response to higher prices.

2. Indirect Land Use Effects of Ethanol

Searchinger et al. (2008a, 2008b) extrapolate from an estimate of biofuel effects on markets to changes in land use which they claim to have dramatic effects on the carbon footprint of biofuel. The authors state, "We calculated that an ethanol increase of 56 billion liters [or 14.8 billion gallons], diverting corn from 12.8 million ha of US cropland, would in turn bring 10.8 million ha of additional land into cultivation. Locations would include 2.8 million ha in Brazil, 2.3 million ha in China and India, and 2.2 million ha in the United States" (2008a). The market results are based on a model that is a modified version of the FAPRI-MU models for the United States agricultural commodity and biofuel markets plus reduced-form trade equations to represent the rest of the world (2008b, footnote 9). Authors infer the land conversion implicit in the model of greenhouse gas emissions that they use (GREET). But they judge the basic model results to be implausible as regards land effects: first, the amount of corn area diverted to ethanol is considered to be too low and, second, the land converted to crop use in the basic model results is drawn from pasture and unused crop area (2008b). Authors approach the question of land conversion by using data about total land use in the 1990s to infer the bilateral conversions, such as from forest to crops, and applying these changes to area results from a partial equilibrium model (2008b).

The response of land use to prices is a topic of current research. Much of the research is being undertaken by researchers working on variants of the GTAP global general equilibrium model with a representation of biofuel markets and detailed land data. For example, Birur, Hertel, and Tyner (2007, 2008) use such a variant, GTAP-E, that includes biofuels in the energy sector and agro-ecological zones (AEZs) for land use. Base data represent 2001, and these are updated in part to 2006 to help calibrate biofuel equations before the effects of US and EU mandates are explored. Land allocation within each AEZ is simulated in a series of stages, with the highest stage separating land among pasture, crop, and forest uses and a second stage to allocate cropland to different crops. Ranges of change in broad land use categories due to biofuel-related factors from 2001 to 2006 vary for each region in size and even in direction, but in Brazil cropland rises by 2.8%, forest area falls by 0.5%, and pasture are also falls by 0.4% (Birur, Hertel, and Tyner, 2008).

Golub, Hertel, and Sohngen (2007) describe the land allocation system characteristic of these efforts based on GTAP in some detail, noting an iterative process between GTAP and a timber model based on Sohngen and Mendelsohn (2006). Authors go further to explore various representations of land allocation within each AEZ: (1) homogeneous and mobile, (2) heterogeneous or of limited mobility using a constant elasticity of transformation (CET) specification, and (3) heterogeneous or of limited mobility using a set of nested decisions, first between agricultural and forestry and then agricultural land use is divided into cropland and pasture uses, both using CETs. Authors also introduce a land supply curve based on a land conversion cost that is asymptotic with respect to total land. The FASOM model (Adams et al, 1996) is a basis for forestry-to-cropland conversion elasticities in many GTAP-based studies, as well as Schneider and McCarl (2005), and the FARM model is also a key input for many GE studies, such as Ahammad and Mi (2005). Two specifications of land allocation are investigated by Gurgel, Reilly, and Paltsev (2007), who question constant elasticity specifications.

General equilibrium studies, such as those listed above, typically assume heterogeneity of goods based on country of origin. This assumption is not the basis of many partial equilibrium models such as the FAPRI model system. In this representation, agricultural goods are typically modeled at a level of detail that may defy the assumption of differences based on country of origin. Banse, van Meijl, and Woltjer (2008) observe that at least several “existing studies treat land exogenously” (p 4). This claim perhaps over-states the problem in that land devoted to crops is almost certainly endogenous in most models of agricultural commodities. But the broader point holds that the area response to prices as represented in partial equilibrium models might be reviewed in light of recent successes with the staged tree approach of recent general equilibrium model experiments.

This line of discussion leads to a question. If land allocation is decomposed into a series of behavioral equations in a partial equilibrium model, how sensitive are biofuel analysis results to varying assumptions about parameters that represent responsiveness to price signals?

3. Methods

We address this question using the FAPRI-MU model of key US agricultural commodity and biofuel markets and a stylized representation of world agricultural and biofuel markets. The first of these models is related to the biofuel and agricultural market representation used by Searchinger et al. (2008b). Those authors adapted an earlier version of this model. The model used here incorporates US bioenergy policies as set out by law passed in late 2007 and updates market representations for recent events. Another difference is that some equations intended to give detailed regional results within the US are aggregated into single equations. A fundamental difference with respect to Searchinger et al. is that those authors assumed very elastic ethanol demand and supply. The potential for US biofuel expansion in the model used here is limited by the potential of ethanol in particular to overcome hurdles of distribution and adoption, as well as delays in building production capacity, as described in FAPRI-MU (2008).

The representation of world commodity markets is a stylized model of wheat, rice, corn, other coarse grain, sugar, soybean, rapeseed, sunflower, palm, vegetable oil, oilseed meal, beef, pork, and poultry markets. Argentina, Brazil, Canada, China, India, Indonesia, the European Union, and Mexico are identified separately, and reduced form net trade equations are used to represent the rest of world. The Brazilian ethanol market is also represented separately. For purposes of responses to shocks in US markets, each country or region responds to changing world prices depending on price transmission of world prices to domestic markets and then on to consumer and producer prices. For the US, price transmission is typically unity because US border prices are indicator world prices in most cases. In the case of Brazil, a greater-than-proportionate price transmission of 1.2 is assumed for sugar, ethanol, and the oilseed complex, and unitary price transmission for most other crops. If there is a partly fixed margin between world and local prices of relevant crops and crop products that are exported from Brazil, then a 1% change in the world price could lead to greater than a 1% change in domestic prices. Then, producers and consumers respond to these price signals. Consumer response is dictated by cross-price elasticities that are based on a common Hicksian demand matrix for each of three sets of countries, with these categories established based on level of per capita income. The Slutsky equation is used to calculate Marshallian elasticities that represent the conditions of each country, so local differences manifested in varying expenditure shares are reflected in the applied elasticities. The Brazilian ethanol market follows in style the US model, but is simpler in its representation. Ethanol demand is responsive to relative gasoline-to-ethanol prices, particularly around the point of energy equivalence, with some delays. Ethanol production responds with greater delays to net returns to sugar-based ethanol production but, over time, continues to respond to any sustained change in net returns. Apart from the US and Brazil, the small ethanol net trade of the rest of the world ethanol market is reduced to a single equation with price elasticity of -1, and the world price balances trade among these two countries and this aggregate. Oilseeds are converted into vegetable oil and meal equivalents, which are both price-clearing markets, and oilseed prices are functions of these prices.

The links between livestock and crop markets are represented through feed markets, as well as in pasture area as described below. Supplies of livestock products depend on output prices and input cost indices, with these cost indices reflecting feed costs. Feed demand for grains and oilseed meal are tied to livestock product output.

Crop supply in partial equilibrium models is often represented as the product of yield and area allocated to the crop, and this model is no exception. Yields are driven largely by estimated trends that are bound to a plausible range, but do also respond to prices to some extent and with delays to reflect the impacts of price signals through research and development. USDA Foreign Agriculture Service (FAS) Production, Supply, and Distribution (PSD) data serve as the basis for crop and livestock product supply and use data. World indicator prices of the FAPRI-MU model and exchange rates determine domestic national price levels.

Broad land allocation rests largely on FAO land use data. Land allocation is simulated in a nested tree approach. Constant elasticities to regulate shifts in land among crops uses at the lowest stage are calibrated based on the assumption that a 1% change in relative prices will lead to 0.1% of total crop land being reallocated, which leads to larger area elasticities for individual crops, with cross-effects calibrated to maintain adding up in the base data. A fixed-weight index of crop prices multiplied by yields represents the value of land allocated to these uses in the next higher stage. In that stage, the uses are land to these annual crops, pasture, palm, sugar, and permanent crops or groves. Thus, the crop revenue index is compared to (1) the price of land in pasture which is tied to the beef price; (2) the price of land used for palm which depends, through the palm oil price, on the vegetable oil price; (3) revenues from sugar; and (4) the price of permanent crops or groves which is determined by macroeconomic variables in the absence of corresponding commodity models. In each case, the ratio of land allocated to an alternative use relative to land allocated to annual crop use is a function of the relative land use price to the crop land price index. At the next higher stage, land is allocated to these agricultural uses or forest based on relative prices or price indices. Other land use is assumed to increase with the ratio of a price linked to GDP growth (that is exogenous in these experiments) relative to the average price of land allocated to forest or agricultural uses. Total land of a country or region is held constant.

This nested representation is quite similar to methods being applied in the context of GTAP work in overall structure, albeit without the distinction of AEZs within country. The partial equilibrium model has other limits. While prices of permanent crops and forestry are not exogenous, they will not respond in the scenarios that follow. Any broader economic effects that may be increasingly relevant in poorer countries are ignored. Parameters are not estimated, although parameters are tested in simulation and judged to be plausible. Uncertainty about parameters relating to land allocation is the subject of the next section.

4. Results

The purpose of the experiment is to see how changes in US markets affect world land use under alternative assumptions of behavioral response. The experiment is an increase in the petroleum price from $125 to $160 per barrel, but only the direct effects on US markets are introduced. The direct effects of the petroleum price change on biofuel markets and agricultural supplies in all other countries, including Brazil, are ignored, even though they could be quite important. The effects of the higher petroleum price in the US are (1) increased demand for substitute sources of motor fuel, ethanol and biodiesel, and (2) increased agricultural production costs. Thus, as observed in recent years, the higher petroleum price will have a two-fold effect on US agricultural markets, namely demand shifts outward and supply shifts backward, both of which will cause prices to rise.

Additional effects, such as on transportation costs or on the wider economy, are not included. These omissions are by no means unimportant, and preclude extrapolating on the basis of this study the effects of petroleum prices on the sector, much less to the specific case of recent price increases in petroleum and agricultural commodity prices. The economic effects are presumably mixed, but would dampen income at least in countries that import petroleum and likely decrease their food demand while at the same time contributing to inflation. The effects of higher transportation costs also depend on a countries' position as exporter or importer and on relative transportation costs. Rising transportation costs would lower prices for at least some agricultural commodity exporters, such as Brazil and the US, but could also lead to a reallocation of trade flows that actually favor some exporters so the effect on any particular exporting country is ambiguous.

By way of motivation, this analysis is intended to highlight uncertainty about land use effects of biofuel expansion. A less theoretical motivating explanation is a hypothetical tax on petroleum of some sort, such as one to offset carbon emissions or to recognize some other externality, imposed only by the US. Even in this case, any number of important complications is ignored.

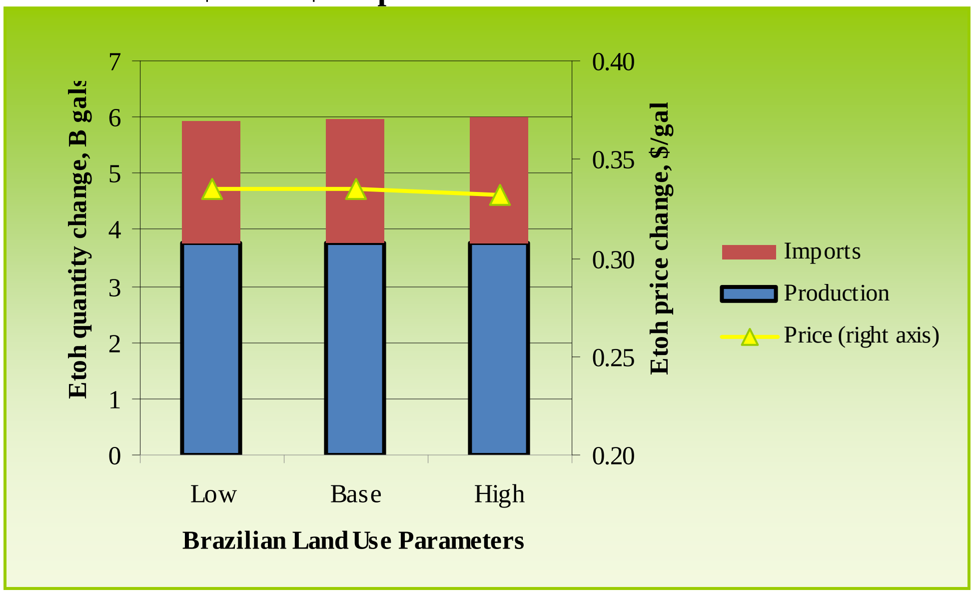
The implications of these two effects on Brazilian area allocation are investigated under alternating assumptions of sensitivity. The parameters governing Brazilian area allocation noted in passing above are set at each of three levels: (the "Base" case) 0.05 for the other land class elasticity, 0.10 for the parameter governing the trade-off between forest and agricultural uses, and 0.15 for the second-stage substitution between annual crop, palm, permanent crop, pasture, and sugar; ("Low" case) with no land use changes at the highest level, among agriculture, forest, and other land classes, and the parameter governing substitution at the next stage reduced by half relative to the base case, to 0.075; or ("High" case) increased to 1 for the trade-off between forest and agricultural uses and also to unity for substitution among second-stage agricultural uses, as well as an elasticity of other land classes increased to 0.1. The elasticities governing trade-offs among the annual crops are not changed. In each case, the model is first calibrated to a baseline for 2008 to 2017, and the effects of a scenario are calculated by comparing the simulated results with the change in petroleum price to the simulation results without the change.

The effects of $35 per barrel higher petroleum price on the US ethanol market are similar in all three cases (Figure 1). This reflects the sensitivity of ethanol consumption to relative prices. The change in ethanol consumption is an increase of approximately 6 billion gallons following a $35 increase in the petroleum price in average use over the period from 2010 to 2017. This increase of about 25% contrasts sharply with the doubling of ethanol use for an increase in the petroleum price by $10 per barrel found by Searchinger et al (2008b). The model used here assumes limits to ethanol expansion owing to the costs of greater E85 distribution and consumer adoption delays that are more relevant as ethanol use grows and approaches these limits. Another important assumption is that, despite this price signal, fuels other than E-85 with more than 10% ethanol, such as E20, do not become widely used. Thus, there would be more expansion for a given increase in the petroleum price starting from a lower initial petroleum price relative to the present experiment and there could be greater expansion if limiting factors were overcome more easily than assumed here. Nevertheless, the constraints to rapid expansion in ethanol use could still prove limiting at some point, but greater use of blends with more than 10% ethanol would lead to greater quantity effects and smaller price shift. As it is, the ethanol price increases 13%. The pattern of effects reflects the short-term constraints of the model in that the price effect is larger at first and the quantity change is smaller, whereas the quantity effect tends to grow over time as more adjustments take place and the price effects become smaller.

There are two implications of these ethanol market impacts on Brazil. First, the higher ethanol price leads to higher ethanol imports, almost all of which come from Brazil. Second, the higher price also encourages processors to produce and sell more ethanol, which indirectly drives corn and other commodity prices higher. This demand-induced price effect, plus the backward shift in US supplies owing to higher energy and fuel prices associated with the petroleum price increase, leads to higher crop prices in international markets. The prices are transmitted to Brazil, a leading agricultural commodity exporter.

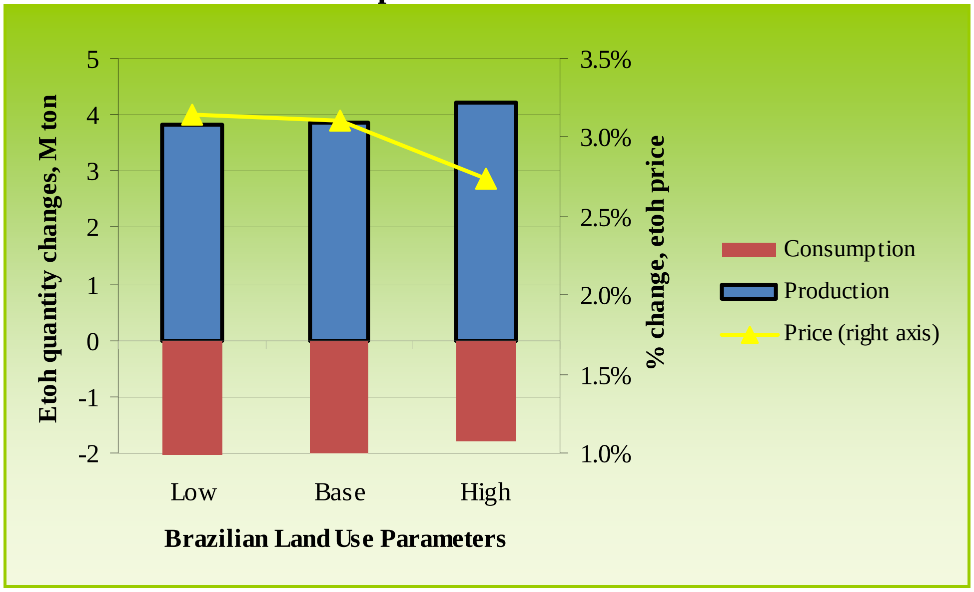
In these experiments, however, US imports of ethanol vary little, despite the changes in land allocation parameters for Brazil. This reflects the expectation that Brazilian ethanol demand is about as sensitive to relative prices as is US ethanol demand. An increase in US ethanol import demand is likely to be met by increasing production in Brazil or decreasing Brazilian use for even a narrow range of simulated price changes (Figure 2). The change in Brazilian exports is just under 6 million tons in all three cases, but the composition of supply and demand quantity changes depends on the extent to which land use changes. Given that yield response is less than 1% on average from 2010-2017 in any of these cases, supply response over this time period depends on the ability of producers to reallocate area among crops and to bring new area into agricultural use at the expense of other land classes.

Figure 1. Average 2010-17 effects on US ethanol market of petroleum price increase from $125 to $160 per barrel



Source: model simulation results, as described in text

Figure 2. Average 2010-17 effects on Brazilian ethanol market of petroleum price increase from $125 to $160 per barrel



Source: model simulation results, as described in text

The effects of changes in US markets brought about by an increase in the petroleum price and related costs of production on land use in Brazil depend on the chosen land use parameters, as well as on market signals. The first-round effects of the higher petroleum price on the US are higher ethanol demand and higher costs of agricultural production, leading to higher prices overall but the most pronounced price effects are on ethanol and corn markets.

For Brazil, the corn price effect is large, but so too is the effect on the sugar market as demand for sugar to convert into ethanol increases. Area is reallocated accordingly (Table 1). Area is pulled into sugar and corn production, but only to a limited extent as all crop prices tend to increase. Moreover, the substitution between sugar and other uses is assumed to be limited as compared to the case of corn, so the increase in sugar area is proportionally less than the increase in corn area even though the price increases are of the same order of magnitude. Land is pulled into crop uses from other purposes, such as perennials. In practice, falling perennial area would lead to price effects that would dampen some of this initial impact, but this effect is not included here. Offsetting effects limit the impact on palm and pasture area because in both cases the rising value of land maintained in these uses, as determined by the roughly 4.5% increase in vegetable oil price and approximately 1.5% higher beef prices, counteracts some part of the greater value of land shifted into crops.

Table 1. Average 2010-17 Brazilian land use changes from increase in petroleum price from $125 to $165 per barrel

Land use class	Parameters governing Brazilian land use					
Changes in absolute	Low		Base		High	
or relative terms	thou ha	percent	thou ha	percent	thou ha	percent
Top Levels						
Other Land Classes	0.0	0.00%	-29.9	-0.03%	-54.9	-0.05%
Forest	0.0	0.00%	-77.1	-0.02%	-819.2	-0.18%
Agriculture	0.0	0.00%	106.9	0.04%	874.1	0.30%
Agriculture Land Uses						
Annual Crops	86.2	0.11%	204.1	0.27%	1683.6	2.20%
Pasture	-87.6	-0.04%	-104.4	-0.05%	-846.2	-0.43%
Perennial Crops	-9.2	-0.12%	-15.5	-0.21%	-87.1	-1.16%
Palm Groves	0.1	0.16%	0.2	0.36%	1.4	2.47%
Sugar	10.5	0.18%	22.5	0.39%	122.5	2.12%
Annual Crops						
Wheat	-10.7	-0.60%	-7.7	-0.43%	29.4	1.64%
Corn	121.8	0.83%	146.2	0.99%	447.9	3.04%
Other Grains	-4.2	-0.37%	-2.3	-0.20%	21.5	1.86%
Soybeans	-34.9	-0.16%	-2.4	-0.01%	400.7	1.84%
Rapeseed	0.0	-0.86%	0.0	-0.70%	0.0	1.23%
Sunflower	-0.4	-0.57%	-0.3	-0.41%	1.1	1.55%
Rice	-13.6	-0.46%	-8.7	-0.29%	52.7	1.76%
Other Crops	28.3	0.08%	79.3	0.23%	730.2	2.14%

Source: model simulation results, as described in text

Land is drawn from forest and other classes into agriculture. The results for broad land uses do vary with parameters, as expected, with as much as several hundred thousand hectares shifting in the case of higher elasticities selected for this illustrative example. Of course, at the low end of the parameter values there is far little movement in area, and consequently less potential to increase area in sugar, corn, and other agricultural activities. This implies a lower supply response in Brazil overall and comparing the proportional price changes in the low and high parameter cases implies that the change in prices of sugar and soybeans could be at least one-quarter higher with the lower area response parameters.

Table 2. Average 2010-17 Brazilian land use changes from decrease in petroleum price from $125 to $90 per barrel

Land use class	Parameters governing Brazilian land use					
Changes in absolute	Low		Base		High	
or relative terms	thou ha	percent	thou ha	percent	thou ha	percent
Top Levels						
Other Land Classes	0.0	0.00%	32.8	0.03%	61.2	0.06%
Forest	0.0	0.00%	85.1	0.02%	916.9	0.20%
Agriculture	0.0	0.00%	-117.9	-0.04%	-978.1	-0.34%
Agriculture Land Uses						
Annual Crops	-92.3	-0.12%	-218.9	-0.29%	-1787.7	-2.33%
Pasture	85.3	0.04%	92.4	0.05%	759.8	0.39%
Perennial Crops	10.2	0.14%	17.2	0.23%	99.5	1.32%
Palm Groves	0.0	-0.05%	-0.1	-0.15%	-0.6	-1.03%
Sugar	-3.2	-0.06%	-8.5	-0.15%	-49.2	-0.85%
Annual Crops						
Wheat	8.0	0.44%	4.8	0.27%	-34.5	-1.92%
Corn	-236.0	-1.61%	-261.0	-1.78%	-567.2	-3.86%
Other Grains	1.4	0.12%	-0.6	-0.05%	-25.7	-2.22%
Soybeans	95.9	0.44%	61.4	0.28%	-365.1	-1.67%
Rapeseed	0.0	1.01%	0.0	0.84%	0.0	-1.22%
Sunflower	0.6	0.85%	0.5	0.68%	-1.0	-1.39%
Rice	8.5	0.29%	3.3	0.11%	-61.5	-2.05%
Other Crops	29.4	0.09%	-27.2	-0.08%	-732.7	-2.15%

Source: model simulation results, as described in text

To explore the sensitivity of the experiment to the levels of petroleum prices, a second set of experiments is conducted for a reduction in petroleum price, from $125 per barrel to $90, which is repeated again for each of the three sets of parameter values. There are reasons to expect asymmetry in the response. Ethanol production capacity is unlikely to be destroyed once it has been built, biofuel use mandates and regulatory uses of ethanol that are inelastic with respect to price, US ethanol imports will not be negative, and consumers' willingness to substitute one fuel for another may be very sensitive to the precise price ratio at which one fuel is cheaper than another. Nevertheless, at least for these price ranges and over a ten-year interval these results suggest responses that are only somewhat non-symmetrical. US ethanol price effects are greater in part because ethanol import reductions are limited. Less change in direct exports of ethanol from Brazil allow indirect effects to take a larger role in determining land reallocation, generating small effects on sugar area, and larger proportional changes in sugar and corn area than in the case of a rising petroleum price.

5. Summary

This illustrative experiment focuses on the uncertainties about behavioral responses of one country, Brazil, and of one type, land allocation. This uncertainty weighs on estimates of the indirect effects of biofuel demand on land use changes. The case explored here uses a stylized model that represents land use following a nested structure, with parameters governing broader categories varied over a range. The scenario is an increase in the petroleum price from $125 to $160 per barrel implemented on the basis of its effects on only US biofuel demand and agricultural costs of production. This could be motivated as a simulation of a US-only tax on petroleum use, but only by omitting important factors, and so is better considered as a mechanism to highlight indirect effects of US market events associated with petroleum price changes on land use in Brazil.

The ethanol market is judged to be extremely responsive to changes in relative prices at least at the levels explored in experiments. Higher motor fuel prices lead to increasing quantities demanded in the US, but also to a rapid decrease in ethanol use in Brazil if US importers bid up ethanol prices. Rising agricultural commodity prices for Brazilian agriculture add pressure to use land to produce these goods. It is nearly tautological to observe that the responsiveness of land use decision making to relative prices controls the magnitude of change, but ranging parameters over a wide range that seems broadly plausible as regards responsiveness in the coming years yields a similarly wide range of results.

Uncertainty about how to represent these fundamental characteristics of market participants' behavior might be manifested in differences among research results, with different analysts producing a range of results. While likely true in the case of the effects of US biofuel use on area in other countries, some part of this uncertainty may be obscured by differences in experiment design. For example, the results here are not fully comparable with Searchinger et al. (2008a), who allow a large increase in ethanol use over a 10-year period and consequently suggest that US ethanol use doubles with an increase in the petroleum price from $54 to $64 per barrel. They find that millions of hectares of new land would be brought into crop production in Brazil as an indirect consequence of a $10 increase in petroleum. In contrast, larger increases in petroleum prices to even higher levels explored here result in far less dramatic changes in ethanol use as some constraints are imposed. The simulations here suggest that indirect effects of a $35 change in petroleum price through petroleum-ethanol substitution in the US are first and foremost reallocation of land already used for crops. Moreover, the more direct effects on ethanol exports from Brazil and, consequently, on sugar prices, can play an important role alongside indirect effects through corn and soybean markets.

The changes in US ethanol markets are largely invariant with respect to changes in Brazilian area in these stylized experiments. Brazilian exports meet US requirements by some combination of consumption and production changes in this representation. If true, then an expansion of US ethanol use can, within some limits at least, be met by changing ethanol use in Brazil as much as by changing land use.

Another result from this analysis relates to the interaction of price and area effects. The larger the area effect in Brazil and the more additional land brought into production, the smaller the market price changes will be over time. On the other hand, the smaller the reallocation of area to agricultural uses in Brazil, the larger the price effects. An implication is that concerns about land effects and agricultural commodity price increases should reflect the fact that these two possible outcomes of increasing biofuel production are mutually offsetting to some extent.

Finally, some limitations of this experiment are reiterated. The petroleum price increase effects were only imposed on the US, so Brazilian ethanol demand did not shift out. While this might be taken as a simulation of a US-only tax on petroleum use, it is not and is more clearly viewed as an experiment to highlight indirect effects. The equilibrium also does not extend to gasoline and crude oil markets, so changes in ethanol use have no effect on gasoline and petroleum markets. Finally, although it is not certain that parameters based only on events of the past or the recent run-up on commodity prices would be better, the parameter ranges used here are illustrative rather than carefully calculated to reflect expected land use sensitivity to relative prices in the next ten years.

References

Adams, D. M., R. J. Alig, J. M. Callaway, B. A. McCarl, and S. M. Winnett. 1996. *The Forest and Agricultural Sector Optimizing Model (FASOM): Model Structure and Policy Applications*. Washington, DC: U.S. Department of Agriculture, Forest Service. PNW-RP-495.

Ahammad, H., and R. Mi. 2005. "Land Use Change Modeling in GTEM: Accounting for Forest Sinks." Australian Bureau of Agricultural and Resource Economics. Paper presented at EMF22: Climate Change Control Scenarios, Stanford University, California.

Banse, M., H. van Meijl, and G. Woltjer. 2008. "The Impact of First and Second Generation Biofuels on Global Agricultural Production, Trade and Land Use." Paper presented at the 11th Annual GTAP Conference, Helsinki, Finland.

Birur, D., T. Hertel, and W. Tyner. 2007. "The Biofuel Boom: Implications for World Food Markets." Paper presented at the Food Economy Conference Sponsored by the Dutch Ministry of Agriculture, The Hague, The Netherlands.

Birur, D., T. Hertel, and W. Tyner. 2008. "Impact of Biofuel Production on World Agricultural Markets: a Computable General Equilibrium Analysis." Working Paper, GTAP, Purdue University.

Food and Agricultural Policy Research Institute at the University of Missouri–Columbia (FAPRI-MU). 2008. "FAPRI–MU model of the United States Ethanol Market." FAPRI-MU Report #07-08.

Gurgel, A., J. Reilly, and S. Paltsev. 2007. “Potential Land Use Implications of a Global Biofuels Industry.” *Journal of Agricultural and Food Industrial Organization*. The Berkeley Electronic Press.

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T. Yu. 2008a. “Use of US Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change” *Science* 319 (5867): 1238-1240.

______. 2008b. “Use of US Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change. Supporting Online Material.” *Science*. Accessed online May 2008 at www.sciencemag.org/cgi/content/full/1151861/DC1.

Schneider, U. A., and B. A. McCarl. 2005. “Implications of a Carbon –Based Energy Tax for US Agriculture.” *Agricultural and Resource Economics Review* 34(2):265-279.

The Impact of Ethanol Policy on Social Welfare and GHG Emissions

Christine Lasco and Madhu Khanna[1]

Abstract: We develop a stylized model of fuel markets in an open economy to analyze the impact of ethanol policy on social welfare and greenhouse gas (GHG) emissions. The policies considered here include the $0.51 per gallon blender's subsidy for ethanol and the import tariff of $0.54 per gallon on sugarcane ethanol. Our analysis shows that the combined subsidy and tariff policy decreases welfare by about $3.6 billion relative to a non intervention policy. Furthermore, there are no GHG mitigation benefits since GHG emissions show a slight increase (0.08%) when both policies are in place.

Concerns about energy security and climate change have led to the rapid increase in demand for alternative fuels, particularly ethanol which uses corn as feedstock. The growth of the ethanol industry in the US not only impacts agriculture and energy markets but also environmental quality, primarily through its impact on greenhouse gas emissions from the use of fuel. Policies that regulate the ethanol market have direct implications for social welfare and GHG emissions. Energy policy in the US supports the domestic production of ethanol through several policies including mandates on the use of renewable fuels, a subsidy for blending ethanol with gasoline and a tariff on ethanol imports, notably from Brazil which produces ethanol from sugarcane at a lower marginal cost.

The purpose of this paper is to examine the effects of the $0.51 subsidy on blending ethanol and the $0.54 tariff on imported ethanol on social welfare and GHG emissions. Life-Cycle Analysis (LCA) is a useful tool for measuring GHG emissions from the production and use of different fuel types. We use estimates of GHG emissions of gasoline, corn ethanol and sugarcane ethanol from various LCA studies and use these to differentiate the environmental impact of each fuel type.

Other studies have analyzed the effect of existing biofuel policies on fuel prices, quantities consumed, and social welfare. Gallagher et al. (2003) used a partial equilibrium simulation model to analyze the implication of the national MTBE ban and the implementation of a renewable fuel standard (RFS) on demand for ethanol. They found that the MTBE ban increases the share of ethanol in the additives market, and implementing an RFS with the MTBE ban further increases demand for ethanol. Both policies lead to losses in social surplus, but also improve air quality by decreasing air pollutants. De Gorter and Just (2007a, b) analyzed the implications of the ethanol tax credit and import tariff with and without a binding ethanol mandate for prices and quantities consumed of domestic and imported ethanol and gasoline. They show that under a non-binding mandate, the tax credit for ethanol is a subsidy to producers and that removal of the import tariff would increase imports by 94%. Elobeid and Tokgoz (2006) analyzed the effects of trade liberalization and removal of the tax credit for the prices and quantities of domestic and imported ethanol. Results show that the removal of trade distortions

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and the tax credit decreases US ethanol price and increases the world price relative to non-intervention. This leads to a doubling of imports, all of which come from Brazil.

Our paper differs from the existing literature analyzing the impacts of ethanol policy in several important aspects. First, we specify a constant elasticity of substitution production function for miles driven from which ethanol and gasoline demands are derived. Most studies have assumed that ethanol and gasoline are either perfect substitutes (De Gorter and Just, 2007, 2008) or have dominant complementarity (Elobeid and Tokgoz, 2008). The prevailing market condition has features of both substitutability and complementarity. When used as an additive and in E10 fuels, ethanol and gasoline are complements. However, with the advent of E85, ethanol is potentially becoming a substitute for gasoline. Since it is too constraining to impose perfect substitutability or complementarity for gasoline and ethanol, we model gasoline and ethanol as imperfect substitutes with a low elasticity of substitution that recognizes that there are costs and constraints to substituting one fuel for the other. The framework developed here allows us to analyze the effects of changing this elasticity on the market impacts of ethanol policies.

Secondly, in measuring welfare impacts, we take into account environmental damages associated with the production and use of fuels. Although some studies (Gallagher et al., 2003) report impacts on environmental quality, the social costs of these impacts have not been incorporated into welfare measurement. There are a few studies that have addressed this issue. Vedenov and Wetzstein (2008) derive the optimal ethanol subsidy taking into account policy impacts on energy security and GHG emissions. Khanna et al. (2008) also looked at the effect of the ethanol subsidy considering its environmental impacts. Our study extends the analysis in the studies mentioned above by examining the effect of the ethanol subsidy as well as the tariff on imported ethanol. We differentiate between ethanol from Brazil and the US based on their environmental impacts and analyze the impact of trade restrictions on welfare and GHG emissions.

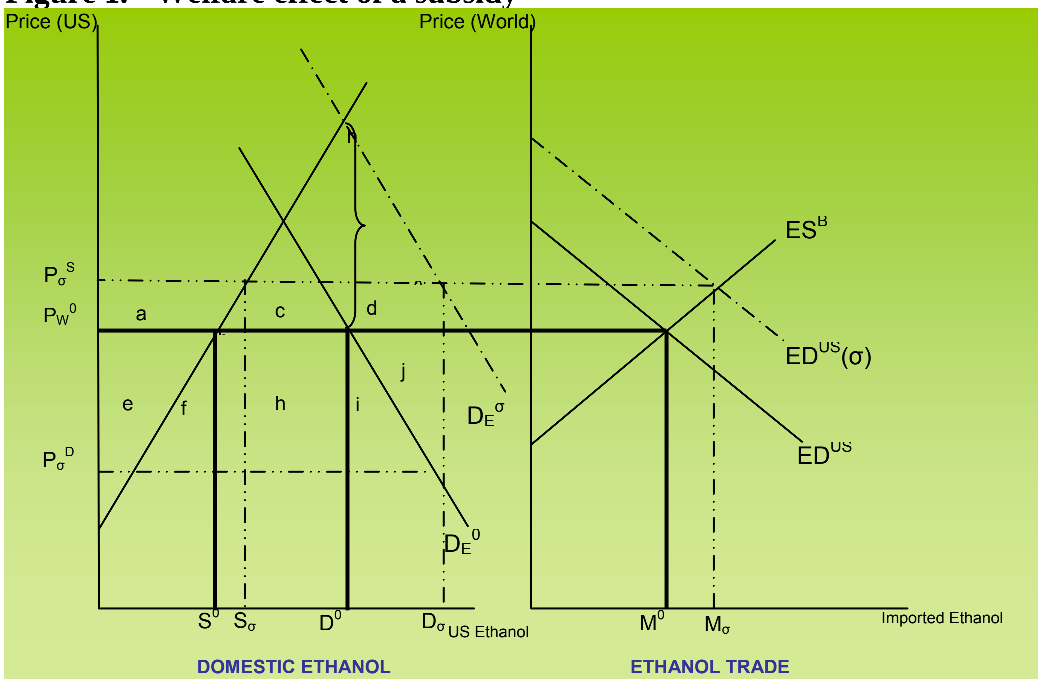
2. Theoretical Framework

In this section we discuss the welfare and GHG emissions effects of a subsidy, a tariff and a combined subsidy and tariff, which is the status quo policy relative to non intervention. We illustrate the deadweight loss associated with policy intervention, starting with the effect of a subsidy which is shown in Figure 1. To keep the discussion tractable, we exclude welfare loss from increased GHG emissions, as well as welfare changes in the gasoline and miles markets.

Subsidy

A subsidy benefits consumers through decreased prices and benefits ethanol producers by decreasing the marginal cost of ethanol production. However, this is at the expense of government expenditures. In Figure 1, the domestic ethanol market is on the left panel and ethanol trade with Brazil (representing all foreign produced ethanol) is on the right panel. We assume that world excess demand for ethanol is the excess demand of the US. In the non-intervention scenario, ethanol price in the domestic and world market is P_W^0. Domestic supply is S_0, demand is D_0 and imports are M_0. Suppose the government provides a subsidy of σ per gallon of ethanol consumed. Initially, this would shift the domestic demand to the right by the size of the subsidy. This decreases the consumer price to (P_σ^D) and increases the producer price to (P_σ^S), with the difference in P_σ^D and P_σ^S being σ. The shift in the demand curve also shifts the excess

Figure 1. Welfare effect of a subsidy



demand curve to $ED^{US}_{(\sigma)}$ although the vertical rise of ED^{US} is less than σ because the increase in ethanol price also increases domestic production. The shift in excess demand increases ethanol price in the world market to P_σ^S which increases imports to M_σ. This implies that importers are also benefited by the domestic subsidy.

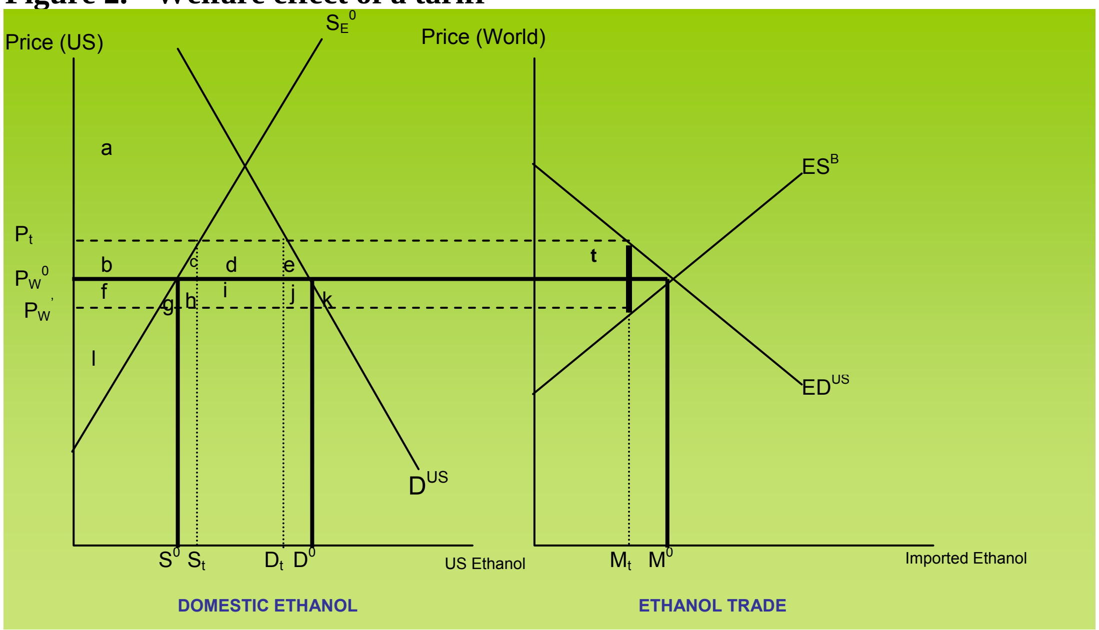
The welfare effect of a subsidy is clearly negative. Consumers gain area (e + f + g + h + i) and producers gain area a. However, the government incurs a cost of area (a + b + c + d + e + f + g + h + i + j) to subsidize all ethanol consumption leading to a net welfare loss of (b + c + d + j). Area b is the loss in social welfare due to the distortion caused by the increase in domestic production at a marginal cost that is higher than the world price P_W^0. Area (c + d) is the loss in social welfare for the US due to subsidy payments on the imported quantity of ethanol M_σ and area j is the loss in social welfare due to a distortion caused by the increase in consumption as the subsidy causes the domestic price to fall below the non-intervention level.

The subsidy makes ethanol relatively cheaper than gasoline, which induces substitution of ethanol for gasoline. Since ethanol is less GHG intensive than gasoline, this substitution of ethanol for gasoline could reduce carbon emissions. However the subsidy also lowers fuel prices which could lead to higher miles consumption, thereby increasing GHG emissions through higher fuel consumption. Thus, the net effect on emissions is unclear since disutility from increased consumption of miles may or may not offset benefits from reduced carbon emissions (see Khanna, et al., 2008; Vedenov and Wetzstein, 2008).

Tariff

The tariff drives a wedge between the excess supply curve of Brazil (ES^B) and the excess demand curve of the US (ED^{US}) (Figure 2). This restricts imports and supports domestic ethanol production by increasing the domestic price of ethanol. Since the US is assumed to be a large buyer in the ethanol market it faces an upward sloping excess supply curve of Brazil. The tariff lowers the world price of ethanol to $P_W^{'}$ and raises domestic price of ethanol in the US to P_t. Domestic supply increases to S_t but imports (M_t) and overall demand (D_t) decrease. The welfare effect of this tariff is ambiguous since the tariff lowers the world price of ethanol. The improvement in terms of trade for the US creates welfare gains that offset some of the loss in welfare caused by the tariff-induced increase in domestic price and loss in domestic consumer surplus. Consumers lose area (b+c+d+e) due to the price increase while producers gain area b. The government gets tax revenues equal to (d+i) which means that net welfare is positive if $i-c-e > 0$ and negative otherwise.

Figure 2. Welfare effect of a tariff

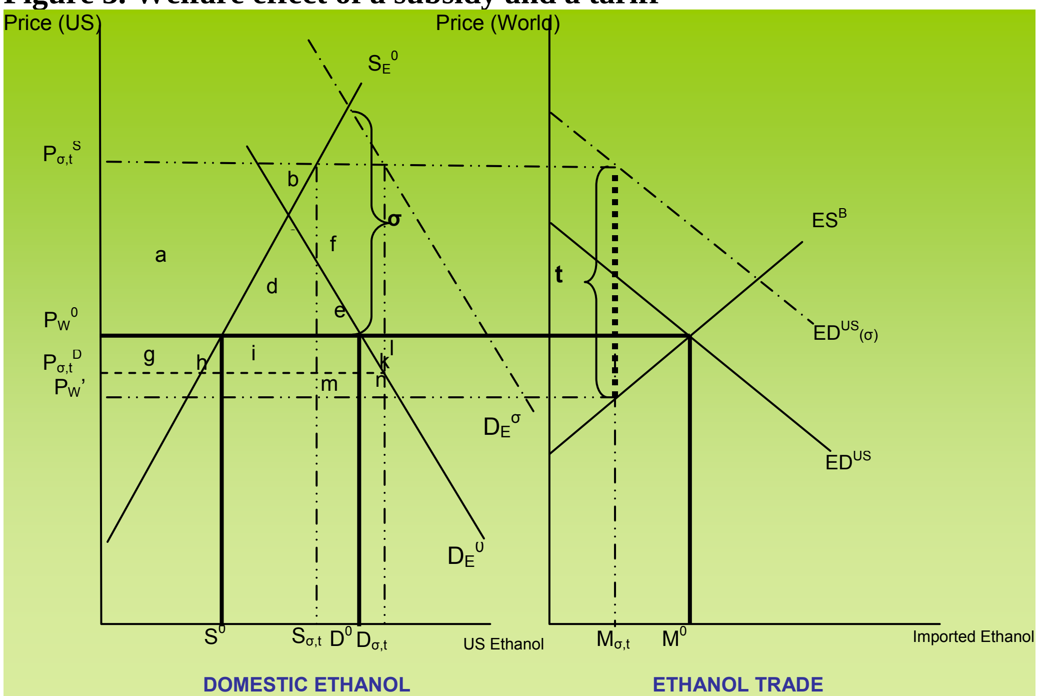


The tariff biases consumption against imported sugarcane ethanol in favor of domestic corn ethanol and gasoline which are both more carbon intensive. Furthermore, the tariff increases overall ethanol price which leads to more gasoline consumption. These two effects increase GHG emissions relative to the non intervention level as well as relative to the case where there is only a subsidy. Since a tariff could increase overall fuel price it could also lead to less miles consumption and therefore less demand for fuels. Thus, the net environmental impact of a tariff is ambiguous since it is not clear whether reduced emissions from lower miles consumption will offset increased GHG emissions from the substitution of gasoline for ethanol.

Status Quo

Current US policy gives a subsidy for blending ethanol with gasoline regardless of whether the ethanol is produced domestically or imported. However, a larger tariff is also imposed on sugarcane ethanol to keep foreign producers from benefiting from the subsidy. This lowers the marginal cost of corn ethanol while increasing the marginal cost of sugarcane ethanol. In Figure 3, with both a tariff and a subsidy in place, domestic demand and excess demand both shift to the right (D_E^{σ} and $ED^{US}_{(\sigma)}$ respectively), but there is a wedge the size of the tariff between $ED^{US}_{(\sigma)}$ and ES^B. Depending on the magnitude of the tariff and subsidy the resulting demand price in the US could be higher or lower than the non-intervention price (P_W^0). As shown, $P_{\sigma t}^D$, the domestic market price after a subsidy and tariff, is lower than P_W^0. Domestic producers receive $P_{\sigma t}^D + \sigma$ or $P_{\sigma t}^S$. This leads to an increase in domestic ethanol production from S^0 to $S_{\sigma,t}$, and an increase in ethanol demand to $D_{\sigma,t}$. Because of the tariff, ethanol exporters receive only $P_W{}'$ which decreases imports to ($M_{\sigma t}$).

Figure 3. Welfare effect of a subsidy and a tariff



We find that the welfare effect of a tariff and a subsidy in the US market is ambiguous. Consumers gain (g + h + i + j + k) and producers gain (a + b), respectively, from the price change while the government spends (a + b + c + d + e + f + g + h + i + j + k + l) on subsidies and gets a tariff revenue of (e + f + j + k + l + m + n). The net social surplus effect is positive if (j + k + l + m + n) −(d + c) > 0 and negative otherwise. For ethanol importers, the subsidy received (f + e) is less than tariff payments, which implies that the status quo policy is welfare decreasing to ethanol exporters. In the case where the non intervention price is lower than the domestic price with subsidy and tariff, this ambiguity in welfare effect remains, although as a result of the subsidy and tariff, consumers will lose from the price increase and producers will have greater gains in producer surplus. In terms of GHG emissions, the combined subsidy and tariff induces substitution towards corn ethanol away from gasoline and sugarcane ethanol. Since gasoline emits more GHG while sugarcane ethanol emits less GHG, the overall impact of the substitution effect is unclear. Depending on the overall effect on fuel prices, there could be an increase or decrease in miles consumption which will determine the impact on the total demand for fuels (and hence GHG emissions).

Since the welfare impacts of a subsidy and tariff are ambiguous, we use numerical simulation to quantify price, quantity, and welfare measures associated with the status quo and non-intervention, taking into account resulting changes in corn, gasoline and miles markets and the cost of changes in GHG emissions.

3. Empirical Model

We develop an empirical model to measure social welfare and environmental quality under non-intervention and status-quo. In non intervention, there are no tariffs or subsidies. In the Status Quo scenario, there is a $0.51 subsidy for blending ethanol with gasoline and a $0.54 tariff on imported ethanol.

In our analytical framework, we assume that consumers derive benefits from the consumption of miles and disutility from aggregate greenhouse gas emissions through its impact on air quality and global warming. The markets in our model are those for corn, domestic ethanol, imported ethanol, refined gasoline and miles. We include the corn market to account for the effects of changing feedstock price on ethanol supply, although we limit our welfare measurement in the miles and fuels markets. We use a constant elasticity of substitution (CES) production function for miles with gasoline and ethanol being imperfect substitutes but domestically produced ethanol and imported ethanol being perfect substitutes. The elasticity of substitution is set to 2 and the share and scale parameters are calibrated using 2006 market data. The level of GHG emissions is modeled as an additive function of marginal carbon emissions of each fuel multiplied by the level of use. Each unit of GHG emission has some cost which is parameterized using estimates from the literature. The miles supply function and the demands for domestic ethanol and gasoline are derived within the model. Imported ethanol demand is defined as the net demand in the domestic market. The rest of the supply and demand curves are assumed to have constant elasticity forms and are parameterized based on estimates available in the recent literature in this area and market data. We derive remaining unknown parameters by calibrating our model to data on relevant prices, quantities and elasticities.

Data and Parameters

We use elasticity estimates found in the literature. For corn supply, Lee and Helmberger (1985) estimated the supply price elasticity to be 0.25. Gallagher (2003) reported ethanol supply elasticity to be 1.5 while wholesale gasoline supply elasticity is 10. For the supply elasticity of imported ethanol, we use 2.7 as reported by De Gorter and Just (2007b). Corn demand elasticity is assumed to be -0.17, which is from the USDA elasticities database. The demand elasticity for miles is -0.40 (Parry and Small, 2005; Vedenov and Wetzstein, 2008).

Market data in 2006 is used to calibrate the model. The price of corn is $3 per bushel which is the weighted average farm price reported by the USDA (2008). Ethanol and gasoline prices are \$2.6 and \$1.9 per gallon respectively (Omaha wholesale free-on-board average rack price, Nebraska Ethanol Board (2007)). We add a markup of \$0.30 per gallon and taxes of \$0.38 per gallon to get the retail prices of ethanol and gasoline.

In 2006, 12.5 B bushels of corn were produced, 17% (2.1 B bushels) of which went into the production of 4.9 B gallons of ethanol (RFA, 2007; USDA, 2008). RFA also reports that total ethanol imports for the same year are 0.65 B gallons which brings total demand to 5.5 B gallons. According to the Department of Energy (2007), total gasoline input to motor fuels production was 112 B gallons. The US Federal Highway Authority (2007) also reported that miles driven in 2006 was 2966 B miles. To parameterize the environmental disutility functions, we set the marginal damage of a metric ton of carbon (mt C) emissions to be \$25 based on Parry and Small (2005). Emissions intensity from "well-to-wheel" of gasoline is 3.2 kg C per gallon, while for corn the value is 1.7 kg C/gallon (Farrell et al., 2006). Macedo et al. (2008) report that "seed to factory gate" emissions of sugarcane ethanol are 0.44 kg C per gallon. Based on this, we assume that transportation adds 0.16 kg C per gallon which gives sugarcane ethanol a "well-to-wheel" emissions intensity of 0.60 kg C/gallon. These intensities imply that for equal energy content, the use of corn ethanol emits 18% less carbon than gasoline while sugarcane ethanol emits 67% less.

4. Results

Table 1 summarizes the results of our numerical simulation. The deadweight loss associated with the subsidy and tariff compared to non-intervention is \$3.6 billion. The deadweight loss associated with the combined subsidy and tariff is \$3.2 billion, while the cost of increased GHG emissions is \$450 million.

The combined effect of the subsidy and the tariff lowers fuel prices by 0.34% and 3% for gasoline and ethanol respectively. Because of decreased fuel prices, driving miles become less expensive, thus increasing miles consumption in the status quo by 0.19% from 2960 to 2966 B miles. Most of the increase in fuel use comes from ethanol rather than gasoline. Ethanol demand increases by 6% while gasoline demand decreases by 0.09%. Most of the increase in demand is met by domestic production which increases by 9% while imports are reduced by 11%.

GHG emissions are higher in the status quo by 0.08% relative to non-intervention. Even though ethanol has increased its fuel share (by 1%), the increase in driving brought about by lower fuel prices increases overall fuel use. Thus, the benefits of reduced GHG emissions due to the substitution of corn ethanol for gasoline appear to be more than offset by increased GHG emissions that results from the rise in miles and fuels consumption, as well as the decrease in the use of sugarcane ethanol.

We conducted sensitivity analysis to key parameter assumptions and found that the elasticity of substitution (φ) between ethanol and gasoline in the miles production function affected the magnitude of responses in the ethanol market. A high elasticity of substitution implies that the cost of substituting one fuel for the other is low, while a low elasticity of substitution implies a higher cost. Thus, given a policy change that decreases the price of ethanol, the increase in ethanol demand will be greater if the elasticity of substitution is high. On the other hand, the response in the ethanol market is constrained if the elasticity of substitution is low. When we set φ = 10, ethanol demand increased by 8% from non intervention to the status quo, while when φ = 0.1, the increase in demand is only 1%. Despite the varying impacts in the ethanol market, however, the impact on gasoline and miles markets, as well as on the overall welfare outcome, is modest. The primary reason for this is that ethanol has a small share in fuel consumption such that a change in the ethanol market may not greatly affect the market for gasoline and miles.

Table 1. Welfare, price and quantity for alternative policies

	Unit	Non Intervention	Status Quo
Welfare Change	B$		-3.6
Quantity			
Miles	B miles	2960	2966
			(0.19)
Gasoline	B gallons	112.1	112
			(-0.09)
Ethanol			
Domestic Supply	B gallons	4.5	4.9
			(9)
Imports	B gallons	0.73	0.65
			(-11)
Total Demand	B gallons	5.2	5.5
			(6)
GHG Emissions	B mT C	0.37	0.37
			(0.08)
Consumer Price			
Ethanol	$/ gallon	2.8	2.7
			(-3)
Gasoline	$/ gallon	2.6	2.6
			(-0.34)

Note: Numbers in parentheses are % change from Non Intervention to Status Quo.

5. Conclusions

Our findings show that a combined subsidy and tariff increases ethanol demand and domestic production, while restricting the ethanol imports from Brazil. Energy security and climate change mitigation have been cited as reasons for the current ethanol policy which uses both the subsidy and the tariff. Our study shows that this causes deadweight loss in the economy and does not help mitigate climate change, since GHG emissions are increased, relative to non intervention. Thus, a serious reconsideration of current policy is warranted if the goal of ethanol policy is to increase welfare and environmental quality.

References

De Gorter, H., and D. Just, 2007. "The Economics of a Biofuel Consumption Mandate and Excise-Tax Exemption: An Empirical Example of US Ethanol Policy." Working Paper, Department of Applied Economics and Management, Cornell University.

—2008 "The Economics of the U.S. Ethanol Import Tariff with a Blend Mandate and Tax Credit" *Journal of Agricultural & Food Industrial Organization*, 6(2), December.

Department of Energy, 2007. Department of energy webpage. Website accessed July 2007. http://www.eia.doe.gov/emeu/mer/petro.html

Elobeid, A., and S. Tokgoz. 2008. "Removing distortions in the US ethanol market: What does it imply for the United States and Brazil?" *American Journal of Agricultural Economics* 90: 918-932

Farrell, A., R. Plevin, B. Turner, A. Jones, M. O'Hare, and D. Kammen, 2006. "Ethanol Can Contribute to Energy and Environmental Goals." *Science* 311:506-08.

Federal Highway Authority. 2008. Highway Statistics 2006. Website accessed July 2007. http://www.fhwa.dot.gov/policy/ohpi/qftravel.cfm.

Gallagher, P., H. Shapouri, J. Price, G. Schamel, and H. Brubaker, 2003. "Some long-run effects of growing markets and renewable fuel standards on additives markets and the US ethanol industry." *Journal of Policy Modeling* 25 (6-7): 585–608.

Lee, D., and P. Helmberger, 1985. "Estimating Supply Response in the Presence of Farm Programs." *American Journal of Agricultural Economics* 67 (2): 193–203.

Macedo, I. C., J. E. Seabra, and J. E. Silva, 2008. "Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and prediction for 2020." *Biomass and Bioenergy* 32: 582–595.

Nebraska Ethanol Board. Ethanol and Unleaded Gasoline Average Rack Prices. Website accessed July 2007. http://www.neo.state.ne.us/statshtml/66.html

Parry, I., and K. Small. 2005. "Does Britain or the United States Have the Right Gasoline Tax?" *American Economic Review* 95 (4), 1276–1289.

RFA, 2007. Renewable Fuels Association Ethanol Industry Overview. Website accessed July 2007. URL http://www.ethanolrfa.org

USDA, 2008. USDA Feed Grains Database. Website accessed July 2007. http://www.ers.usda.gov/Data/FeedGrains/

Vedenov, D., and M. Wetzstein. 2008. "Toward an Optimal US Ethanol Fuel Subsidy." *Energy Economics* 30:2073–2090.

Impacts of Land Conversion for Biofuel Cropping on Soil Organic Matter and Greenhouse Gas Emissions

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Abstract: To assess the value of biofuels, the environmental costs of their production must be compared with the benefits of displacing fossil fuel. This article focuses on the environmental impacts of biofuel cropping systems and calculates net greenhouse gas (GHG) emissions using life cycle analysis. The impacts of corn and switchgrass cropping for ethanol production were calculated for three states in the US (Iowa, Illinois, and Indiana) assuming three previous land use scenarios: Conservation Reserve Program (CRP) land, pasture land, and land already used for cropping. Although the results were different for the 3 states considered, the impacts of previous land use and cropping system were more important than location. Conversion of CRP lands to corn ethanol production would result in little net GHG savings compared to burning fossil fuel, greatly increase NO_3 leaching, and constrain other benefits of CRP land such as wildlife habitat. Conversion of pasture and crop land to corn ethanol cropping show GHG benefits, reductions in leaching for previously cropped systems, and increases in leaching for lands previously in pasture. Converting CRP land to switchgrass cropping would lessen the rate at which these soils store SOC, increase N_2O emissions, and have little impact on NO_3 leaching. Converting pasture and crop land to switchgrass cropping would increase SOC storage, decrease N_2O emissions, and decrease NO_3 leaching. We conclude that current land management (cropping system, tillage intensity, and fertilizer application), as well as previous land use, must both be considered to quantify the environmental impacts of biofuel cropping systems.

Biofuels are a growing alternative energy source, but there are environmental impacts associated with growing and processing biomass for fuel production. Impacts include greenhouse gas emissions (GHG), nitrogen oxides, and ammonia (NH_3) emissions, and nitrate (NO_3) leaching, The sources of these impacts can be placed into four categories; 1) producing and transporting farm inputs (fertilizers, pesticides, etc.), 2) operating farm equipment (tractors, harvesters, etc.), 3) cropping soils used to produce biomass, and 4) transporting and refining biomass to fuel. In this article we emphasize the impacts of biofuel production on soil carbon (C) and nitrogen (N) fluxes, but also perform complete life cycle analyses for GHG emissions in Iowa from all four sources, as well as account for the GHG benefits from displacing fossil fuel combustion.

Converting land to biofuel production affects soil organic matter levels, nitrogen (N) gas emissions, and NO_3 loss rates. Plowing soils typically leads to loss of C and N stored in soil organic matter. As soil organic matter decreases, GHG emissions tend to increase while soil fertility decreases. N additions from fertilizer increase N gas emissions and NO_3 leaching. Important N gases emitted from soils are nitrous oxide

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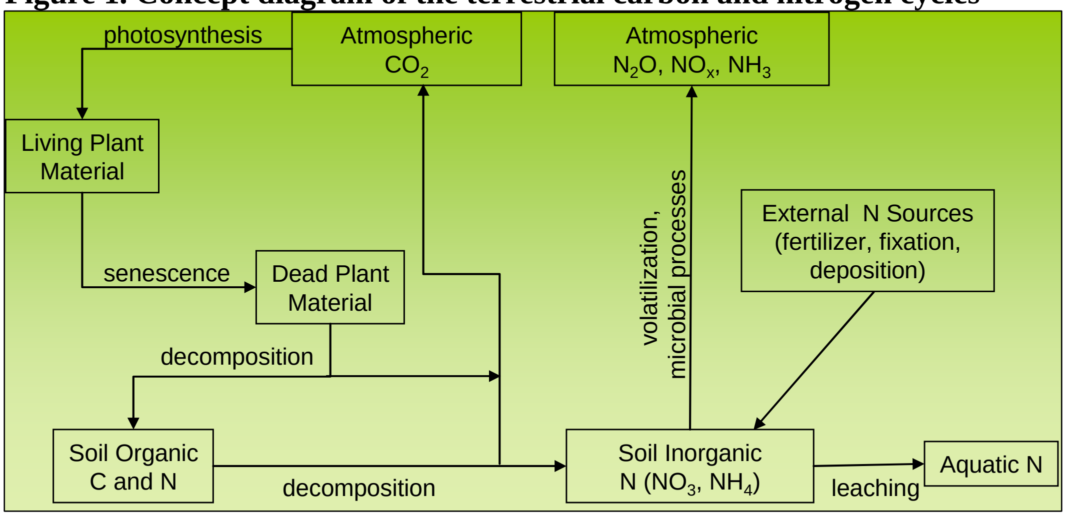
(N_2O), nitric oxide and nitrogen dioxide (NO_x), and ammonia (NH_3). N_2O is a potent GHG that also affects stratospheric ozone levels and agricultural soils are the primary anthropogenic source. NO_x is a source of ground-level ozone and contributes to acid rain. NH_3 also contributes to acid rain and eutrophication.

Soils are both a source and a sink of atmospheric carbon dioxide (CO_2) (Figure 1). CO_2 fixed from photosynthesis is transferred to surface litter pools when leaves and other above ground plant components die (i.e. senesce) and to soil litter pools when roots senesce or secrete chemicals (i.e., root exudation). Decomposition of litter returns CO_2 to the atmosphere but a portion of the C in litter remains on the soil surface and in soil organic matter. If C inputs from senesced vegetation and root exudation exceed carbon losses from decomposition of litter and soil organic matter, then soils are a net CO_2 sink. But if gaseous C losses exceed inputs, then soil becomes a net source of atmospheric CO_2. Factors influencing soil C balance include previous and current land use, soil properties such as texture, and weather.

Figure 1. Concept diagram of the terrestrial carbon and nitrogen cycles



In addition to C, soils are also a source and sink of N (Figure 1). Plant residues contribute organic N to soil litter pools which is converted to the inorganic form during decomposition. But, as with soil C, a portion of the N remains in soil organic matter. Besides decomposition, inorganic N can be added to soils via fertilizer/manure amendments, biological fixation, and atmospheric deposition of N compounds. N can be lost from soils in gaseous form and can be leached into groundwater or lost via overland water flow. The major pathways for gaseous N losses from soils are ammonia volatilization and microbial processes.

Nitrification and denitrification are two of the most important processes that contribute to N losses from soils (Firestone and Davidson, 1989). Nitrification is the aerobic oxidation of ammonium (NH_4) to NO_3. A portion of the transformed N is lost as N_2O and NO_x. Once N is in the NO_3 form, it is vulnerable to leaching because NO_3 is more soluble than NH_4, and can also be denitrified. Denitrification occurs when oxygen is limited and anaerobic microbes use NO_3 as an electron acceptor, resulting in the reduction of NO_3 to N_2O and N_2. As with soil C fluxes, land use practices, soil physical properties, and weather interact to control soil N losses. In particular, N gas emissions and NO_3 leaching tend to be correlated with external N inputs from fertilizer and organic matter additions, as well as N fixation from legume cropping.

The Energy Independence and Security Act of 2007 (EISA) mandates that 36 billion gallons of biofuel be produced in the US by 2022. For comparison, about 7 billion gallons of biofuel (ethanol plus biodiesel) were produced in 2007 in the US. To address the GHG emissions associated with biofuel production discussed above, the 2007 Energy Bill includes standards such that total emissions from grain-based ethanol must be at least 20% lower than using fossil fuel to generate an equivalent energy yield, grain-based biodiesel emissions must be at least 50% lower, and cellulosic-based fuel emissions at least 60% lower.

Our objectives were to investigate how current and previous land uses interact to control net GHG emissions and NO_3 leaching for different biofuel cropping systems in Iowa, Indiana, and Illinois. Approximately 40% of the corn used to produce ethanol in the US is expected to be grown in these states by 2010 according to Forest and Agricultural Sector Optimization Model (FASOM) projections (McCarl, 2008).

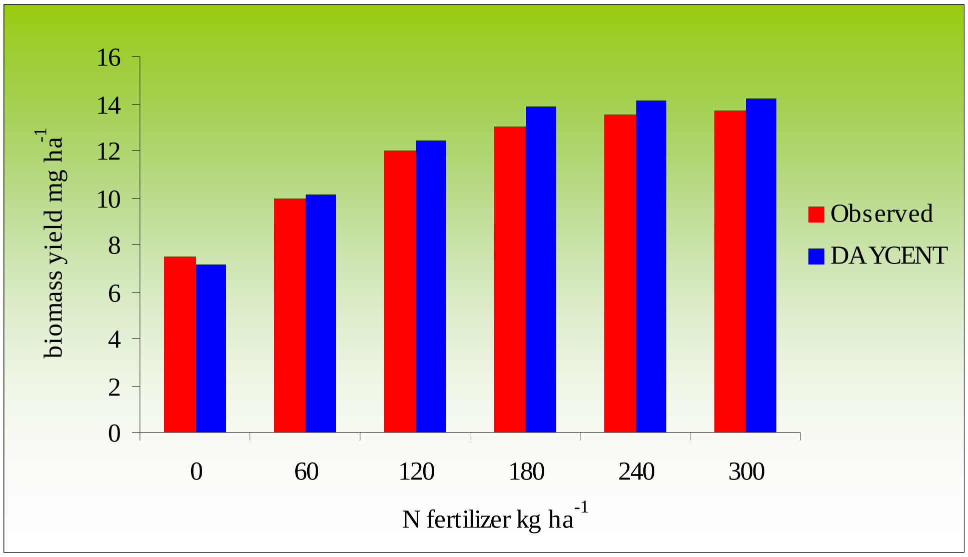
2. Methods

Soil Emissions and Crop Yields

The DAYCENT ecosystem model was used to estimate soil C and N losses from gaseous emissions and NO_3 leaching, as well as biomass yields. Daycent (Del Grosso et al., 2001; Parton et al., 1998) is a process-based model of intermediate complexity. DAYCENT simulates exchanges of carbon, nutrients, and trace gases among the atmosphere, soil, and plants as well as events and management practices such as fire, grazing, cultivation, and organic matter or fertilizer additions. To run DAYCENT for a particular site, soil texture, current and historical land use, and daily maximum/minimum temperature and precipitation data are required. DAYCENT includes submodels for plant growth and senescence of biomass; microbial decomposition of dead plant material and soil organic matter; water, nutrient and temperature flows through soil; evaporation and transpiration of soil water; and other processes. DAYCENT was selected by the EPA (EPA, 2008) to quantify N_2O emissions from major cropped and grazed systems in the US because model results generally compare favorably with measurements (Del Grosso et al., 2005) and the inputs required to run the model (weather, soil type, crop management, soil class) are available nationwide for the vast majority of agricultural land in the US.

The ability of DAYCENT to simulate grain yields form annual crops such as corn, wheat, and soybean has been previously confirmed (Del Grosso et al., 2005) but model generated yields for perennial biofuel crops, such as switchgrass, have only recently been validated. The current version of DAYCENT was tested using biomass yield data collected during two growing seasons near Ames, IA, from switchgrass plots receiving 6 levels of N fertilizer addition (Vogel et al., 2002). Both the DAYCENT model and observations showed a strong yields response as N increased up to 120 kg per ha but little response above 180 kg per ha (Figure 2).

Figure 2. Observed and DAYCENT simulated switchgrass biomass yields from plots near Ames, IA



GHG Life Cycle Analysis

As mentioned above, the DAYCENT model was used to estimate soil CO_2 and N gas emissions as well as NO_3 leaching losses. To fully account for soil N_2O emissions, direct, as well as indirect, N_2O emissions were considered. Direct N_2O is emitted from soil during nitrification and denitrification. Indirect N_2O results from the transformation of N that left the farm in a form other than N_2O. There are two pathways that produce indirect N_2O Emissions: 1) Volatilized N in the form of NO_x or NH_3 that is deposited and converted to N_2O off-site and 2) NO_3 leached into waterways that is converted to N_2O via aquatic denitrification. To estimate indirect N_2O, we used the default IPCC (2006) emission factors and assumed that 1% of volatilized N and 0.75% of leached NO_3-N are converted to N_2O. To convert total N_2O emissions to CO_2 equivalents we used a global warming potential of 310 (Forster et al., 2007). CO_2 emissions from fossil fuel used to manufacture and transport farm inputs were from West and Marland (2002), emissions from farm machinery operation were estimated using the IFSM model (Rotz, 2004), emissions from converting feedstock to ethanol (including transportation of biomass) and avoided emissions from displaced fossil fuel were calculated from crop yields and Sheehan et al. (2004), and avoided CO_2 emissions from co-products of biomass conversion were based on Ferrell et al. (2006). To summarize, total greenhouse gas emission calculations included 8 components: soil CO_2, direct soil N_2O, indirect soil N_2O, farm inputs, farm operations, feedstock conversion, displaced fossil fuel, and co-products.

Scenarios Simulated

We considered three previous land uses before conversion to biofuel cropping: existing cropping (i.e., 2 year corn/soybean rotation), Conservation Reserve Program (CRP), and pasture. The biofuel cropping systems considered were corn ethanol and switchgrass. To simulate corn ethanol we assumed a 5 year rotation with 4 years of corn followed by 1 year of soybean. N additions to corn, based on state averages, were 171, 162, and 144 kg per ha in IL, IN, and IA, respectively. N additions for switchgrass were 66, 63, and 56 kg per ha in IL, IN, and IA, respectively. Soybeans received no N fertilizer. Weather and soils data for each state were from randomly selected agricultural counties. Corn grain was harvested but no residue was removed and 85% of above ground biomass was harvested for switchgrass. We assumed reduced tillage cultivation. Land use conversion was assumed to occur in 2007 and results are presented as 10-year annual means for 2007-2016.

3. Results

Productivity, Soil GHG Fluxes, and NO_3 Leaching

Above ground net primary productivity (ANPP) was highest for corn/soy cropping, intermediate for pasture, and lowest for CRP (Figure 3a). Conversion to corn ethanol increased ANPP for all previous land uses (Figure 3b-d), even cropping, because soybeans were only grown once every 5 years in the corn ethanol rotation compared to every other year with the corn/soybean rotation, and corn produces more biomass than soybeans.

Figure 3. Above ground net primary productivity (ANPP) for crop (corn/soybean), pasture, and CRP lands in three states (a) and ANPP for land converted from crop, pasture, and CRP to corn ethanol and switchgrass in Iowa (b), Indiana (c) and Illinois (d). Results are 10-year means

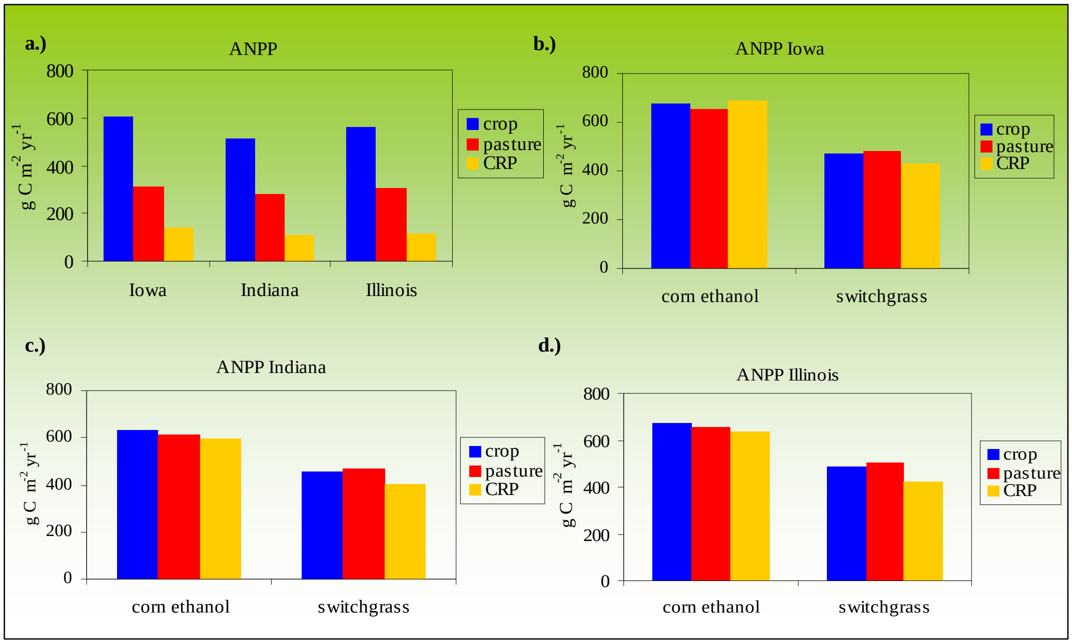
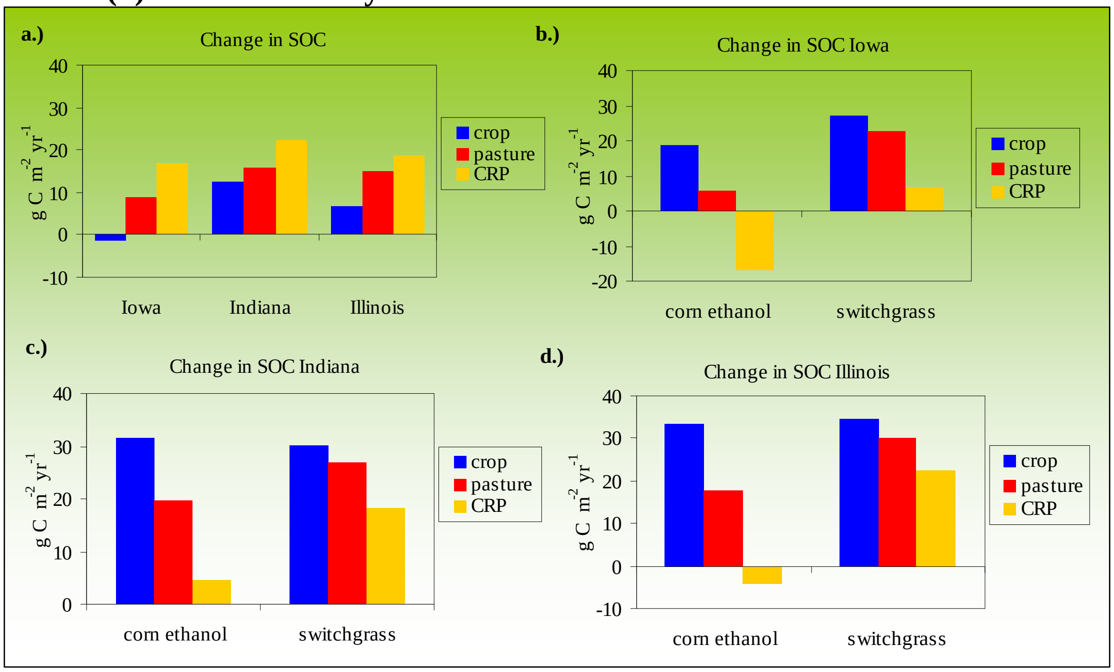


Figure 4. Changes in soil organic carbon (SOC) for crop (corn/soybean), pasture, and CRP lands in three states (a) and SOC changes for land converted from crop, pasture, and CRP to corn ethanol and switchgrass in Iowa (b), Indiana (c), and Illinois (d). Results are 10-year means.



Conversion to switchgrass reduced ANPP for croplands, but increased for pasture and CRP (Figure 3b-d), likely a result of switchgrass having lower N inputs than corn/soybean cropping, but higher N inputs than pasture or CRP. Soil organic carbon changes are close to neutral for corn/soy cropland in Iowa and positive for Indiana and Illinois, while pasture and CRP land stored soil organic carbon (SOC) in all 3 states (Figure 4a). Converting cropland or pasture to corn ethanol or switchgrass cropping led to gains in SOC, but converting CRP land to corn ethanol resulted in SOC losses in Iowa and Illinois (Figure 4b-d). N_2O emissions are highest for corn/soy cropping, intermediate for pastures, and lowest for CRP lands (Figure 5a). Conversion to corn ethanol cropping had little impact on N_2O emissions for land already cropped, but resulted in increased emissions for land that was previously in pasture or CRP (Figures 5b-d). Conversion of cropland and pasture to switchgrass decreased N_2O emissions but conversion from CRP to switchgrass increased N_2O (Figures 5b-d). Similar to N_2O, NO_3 leached was highest for corn/soy cropping, intermediate for pastures, and lowest for CRP lands (Figure 6a) and conversion to corn ethanol cropping had little impact for land already cropped, but resulted in increased leaching for land that was previously in pasture or CRP (Figures 6b-d). Conversion of cropland and pasture to switch grass decreased leaching but conversion from CRP to switchgrass increased leaching (Figures 6b-d). NO_3 leached tended to be higher if the previous land use was pasture and lower if the previous land was CRP upon conversion to corn ethanol, but previous land use has little impact if land was converted to switchgrass.

Figure 5. N_2O emissions for crop (corn/soybean), pasture, and CRP lands in three states (a) and emissions for land converted from crop, pasture, and CRP to corn ethanol and switchgrass in Iowa (b), Indiana (c), and Illinois (d). Results are 10-year means.

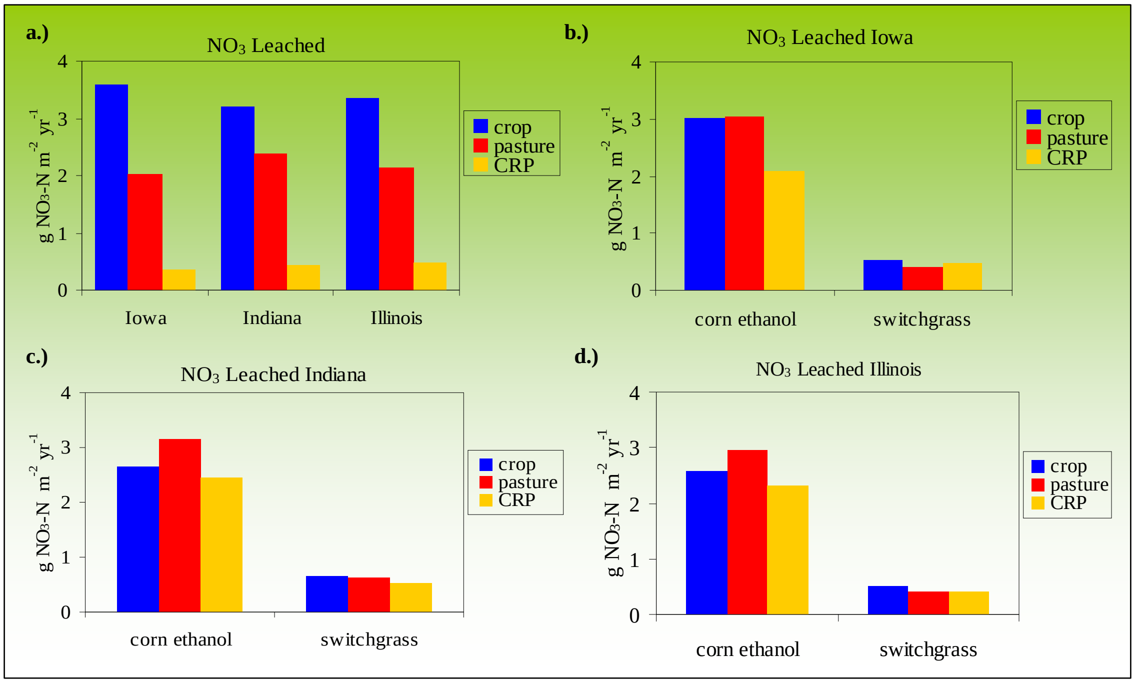
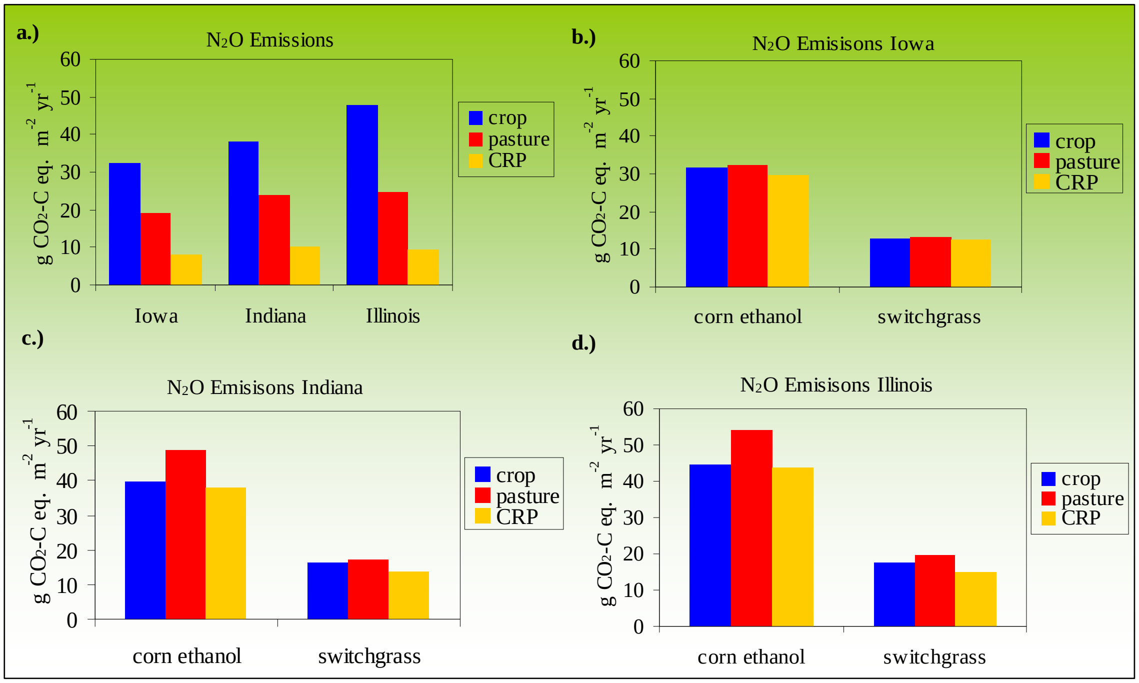


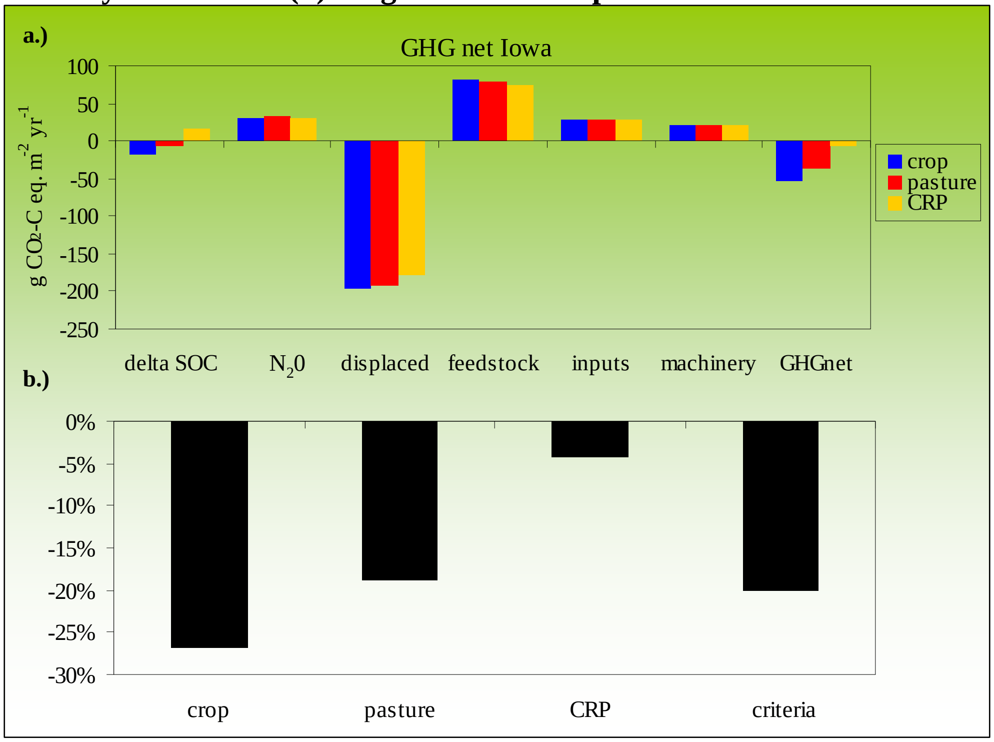
Figure 6. NO_3 leaching for crop (corn/soybean), pasture, and CRP lands in three states (a) and leaching for land converted from crop, pasture, and CRP to corn ethanol and switchgrass in Iowa (b), Indiana (c), and Illinois (d). Results are 10-year means.



Life Cycle Analyses for Total GHG Emissions

Feedstock conversion was the major GHG source and displaced fossil fuel was the main sink (Figure 7a). However, previous land use had an impact on soil CO_2 fluxes such that CRP lands converted lost SOC, while land that was in pasture or already cropped gained SOC. Of the three land use change options considered, cropland conversion exceeded the 20% reduction criteria, pasture conversion came close, and CRP conversion showed little net GHG reduction (Figure 7b).

Figure 7. Components of net greenhouse gas fluxes (GHG) from life cycle analysis of crop (corn/soybean), pasture, and CRP land converted to corn ethanol cropping in Iowa (a) and the reduction in GHG compared to burning fossil fuel for an equivalent amount of energy and the minimum GHG reduction for grain based ethanol from the Energy Independence and Security Act of 2007 (b). Negative values represent GHG sinks.



Limitations

This analysis has several limitations. The DAYCENT model results were from point simulations so variability in weather, soils, and land management within the states of Iowa, Indiana, and Illinois were not represented. We did not include leakage. That is, conversion of previously cropped land to biofuel production in the US is likely to be at least partially compensated by increasing cropped land areas in other parts of the world. A more complete accounting would include the GHG impacts of land use change in other countries resulting from biofuel cropping in the US. We assumed reduce tillage but did not include other improved land management practices such as nitrification inhibitors, which are expected to reduce both N gas emissions and NO_3 leaching. Lastly, the feasibility of ethanol production from cellulosic crops such as switchgrass has yet to be demonstrated on large scales.

4. Conclusions

Conversion of CRP lands to corn ethanol production would result in little net GHG savings compared to burning fossil fuel, greatly increase NO_3 leaching, and constrain other benefits of CRP land such as wildlife habitat. Conversion of pasture and crop land to corn ethanol cropping show GHG benefits, reductions in leaching for previously cropped systems, and increases in leaching for lands previously in pasture. Converting CRP land to switchgrass cropping would lessen the rate at which these soils store SOC, increase N_2O emissions, and have little impact on NO_3 leaching. Converting pasture and crop land to switchgrass cropping would increase SOC storage, decrease N_2O emissions, and decrease NO_3 leaching. These results highlight the importance of considering how current and previous land use interact to control soil storage and fluxes of C and N compounds.

References

Del Grosso, S.J., W.J. Parton, A.R. Mosier, M.D. Hartman, J. Brenner, D.S. Ojima, and D.S., Schimel. 2001. “Simulated Interaction of Carbon Dynamics and Nitrogen Trace Gas Fluxes Using the DAYCENT Model.” In M. Schaffer, et al. eds. *Modeling Carbon and Nitrogen Dynamics for Soil Management*, Boca Raton, Florida, USA, CRC Press. 303-332.

Del Grosso, S.J., A.R. Mosier, W.J. Parton, and D.S. Ojima. 2005. “DAYCENT Model Analysis of Past and Contemporary Soil N_2O and Net Greenhouse Gas Flux for Major Crops in the USA.” *Soil Tillage & Research* 83:9-24.

EPA. 2008. “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006.” http://www.epa.gov/globalwarming/publications/emissions, U.S. Environmental Protection Agency, Washington, D.C.

Farrell, A.E., R.J. Plevin, B.T. Turner, A.D. Jones, M. O’Hare, and D.M. Kammen. 2006. “Ethanol Can Contribute to Energy and Environmental Goals.” *Science* 311:506-508.

Firestone, M.K., and E.A. Davidson. 1989. “Microbial Basis of NO and N_2O Production and Consumption in Soils.” In M.O. Andreae and D.S. Schimel, eds. *Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere*, New York: John Wiley, 7-21.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, and R. Van Dorland. 2007. "Changes in Atmospheric Constituents and in Radiative Forcing." In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, eds. *Climate Change 2007: The Physical Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 129-234.

IPCC. 2006. "IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4: Agriculture, Forestry and Other Land Use." C. De Klein, R.S.A. Nova, S. Ogle, K.A. Smith, P. Rochette, T.C. Wirth, B.G. McConkey, A. Mosier, and K. Rypdal (authors). 11.1-11.54.

McCarl, 2008. Personal communication

Parton, W. J., M. Hartman, D. Ojima, and D. Schimel. 1998. "DAYCENT and its Land Surface Submodel: Description and Testing." *Global and Planetary Change* 19:35-48.

Rotz, C.A. 2004. "The Integrated Farm System Model: A Tool for Developing More Economically and Environmentally Sustainable Farming Systems for the Northeast NABEC-04-0022." St. Joseph, Michigan, USA, American Society of Agricultural Engineers.

Sheehan, J., A. Aden, K. Paustian, K. Killian, J. Brenner, M. Walsh, and R. Nelson. 2004. "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol." *Journal of Industrial Ecology* 7:117-146.

Vogel, K.P., J.J. Brejda, D.T. Walters, and D.R. Buxton. 2002. "Switchgrass Biomass Production in the Midwest USA: Harvest and Nitrogen Management." *Agronomy Journal* 94:413-420.

West, T. O., and G. Marland. 2002. "A Synthesis of Carbon Sequestration, Carbon Emissions, and Net Carbon Flux in Agriculture: Comparing Tillage Practices in the United States." *Agriculture, Ecosystems, and Environment* 91:217-232.

Regulation of GHG Emissions from Biofuel Blended Energy

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Abstract: Regulatory agencies are planning to implement policies targeted at mitigating greenhouse gas emissions (GHG)—e.g., low carbon fuel standards and carbon trading. Biofuels are viewed as a path to achieve these goals. Biofuels, however, pose challenges to regulators because their GHG emissions are site-specific (there are regional differences, as well as technical differences) and uncertain. In this article, we propose methodological improvements to existing methods that yield better estimates for biofuel GHG emissions, and reduce uncertainty. We propose to break the net emissions caused by a regulated site, such as an oil refinery, into two parts: direct and indirect emissions. Direct emissions arise both at and away from the final regulated site, but are directly attributable to the final output. Indirect emissions, on the other hand, are comprised of emissions not traceable to a single entity, but which can be computed from aggregate supply and demand, e.g., indirect land use change (ILUC) emissions due to agricultural expansion. The sum of the site-specific direct emissions and the average indirect emissions is, then, compared to the standard, which is constructed given uncertainty. Such a framework can be implemented in practice given existing data and yet allows flexibility given heterogeneity and uncertainty.

Economic forces, as well as demand for energy security, no doubt are providing incentives for producing and blending biofuels as substitute fuel. At the same time in order to tackle global warming, governments are beginning to regulate emissions attributed to energy production and consumption. Biofuels, which are part of the energy production sector, pose additional challenges to regulators, because their GHG emissions not only vary between regions and between the technologies used, but are also uncertain. Biofuels can be produced from a diverse set of feedstock (e.g., corn, sugarcane, cassava) using a diverse set of production technologies; a set of technologies that varies with location and with time. The cultivation and processing of each type of feedstock can be carried out in a variety of ways with widely varying carbon intensities.

The challenge of regulating biofuel is then augmented by uncertainty; primarily, from indirect emissions. Biofuels increase demand for agricultural land, which induces land use changes in regions that substantially affect global carbon sequestration (regions that are also efficient in producing biofuel crops). Furthermore, trade causes land use changes to occur in regions different from the place of production and/or consumption of biofuels. Therefore, regulating biofuels should account for the indirect emissions, if indeed the regulators' goal is to lower, or at least mitigate, carbon emissions.

In this article, we clearly categorize GHG emissions into direct and indirect emissions. We then suggest a site-specific methodology for regulating GHG emissions, a methodology which extends current methods by introducing heterogeneity, as well as accounting for uncertainty and market forces. Specifically, we propose a site-specific method for measuring GHG emissions, and introduce, albeit briefly, a conceptual framework for regulating biofuels using the proposed measures.

2. Calculating emissions

We classify emissions into two categories: Direct and Indirect.

Direct Emissions

Direct emissions comprise all emissions directly related to production of final output (e.g., gasoline or biofuel or a blend). Direct emissions are classified into two sub-categories; namely,

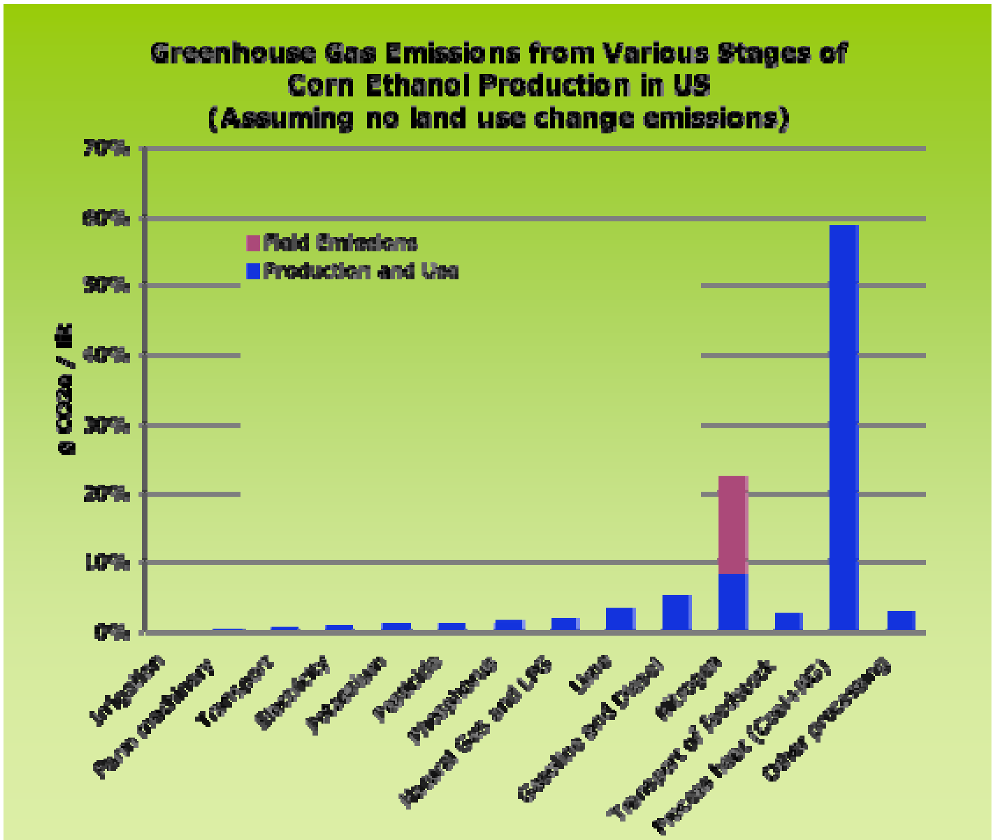
Direct on-site emissions: These are emissions at the regulated site, which are directly related to the production of the final product. For example, if the regulated site is an ethanol biorefinery, then these are emissions from combustion of coal or natural gas used in converting corn or sugarcane to ethanol. Suppose, for instance, that the regulated site is a biorefinery. For US ethanol corn production, direct on-site emissions comprise 55% of total direct emissions (see Fig. 1). Although soil carbon emissions from farming are not included in the figure they are relevant and should be taken into account. This is a source of uncertainty that should be addressed in a regulatory framework.

Direct off-site emissions: These are emissions emanating off-site that are directly attributed to intermediate inputs used to produce the final good. For instance, ethanol producers use crops. Crops use fertilizers, which are a large source of emissions both at the farm site and at the fertilizer production site. From Figure 1 we can see that 45% of the direct emissions are off-site, with fertilizer production and use accounting for a large share of total emissions.

Several studies calculate direct emissions from biofuels, which include both combustion and production. A detailed review of this literature can be found in Rajagopal and Zilberman (2007). Most of these studies use an LCA approach and report a single number. For example, Farrell et al. (2006) calculated that corn ethanol emits 77 grams of carbon-dioxide equivalent emissions (gCO2e) per megajoule (MJ) of energy, while gasoline emits 94 gCO2e per MJ.

Measuring direct emissions using LCA has its strength and weakness. The strength is that LCA allows for comprehensive accounting of all direct on-site and off-site emissions. The weakness is that it reports a number, which represents the emission intensity for a particular combination of inputs (usually assumed equal to the industry's average). For instance, Farrell et al. (2006) assume the ethanol refinery uses a mix of 40 percent coal and 60 percent natural gas to produce the energy required for production of ethanol from corn; the direct on-site emissions are, therefore, appropriately weighted by the average carbon intensity of coal and natural gas. Now an increase in the price of natural gas relative to coal leads the marginal producer to switch to coal, which would increase the fraction of coal and increase GHG emissions. Therefore, current LCA may provide a good description of the present or the past, but have limited ability to predict what happens when economic conditions change. Modeling lifecycle indicators as functions of economic and policy parameters can overcome this limitation. A detailed discussion of price-responsive lifecycle indicators can be found in Rajagopal and Zilberman (2008a). They show that depending on whether an ethanol refinery uses coal instead of natural gas for its energy needs, ceteris paribus, the total direct emissions for corn ethanol equals 91% of net GHG emissions from gasoline (as opposed to 58% when it uses natural gas).

Figure 1: **Lifecycle GHG emissions for us corn ethanol based on ebamm model**



Indirect Emissions

When food or cropland is diverted to biofuel production it will have two types of effects, namely, extensive and intensive effects. GHG emissions that accompany such changes are referred to as indirect emissions. For instance, demand for biofuel raises the price of agricultural commodities, which raises the rent to land, thereby allowing marginal land to enter production, i.e., the extensive effect. Emissions due to the extensive effects arise from (i) conversion of non-agricultural land into farmland (for example, emissions from clearing trees and pastures), and (ii) cultivation on converted land (for example, emissions from use of inputs like fertilizer). On the other hand, higher output prices result in more intensive use of inputs like fertilizers and irrigation on existing farmland, i.e., the intensive effect.

Different from direct emissions, indirect emissions arise from the interaction of aggregate supply and demand, and therefore are not site-specific. Analogous to the idea of a price taking producer, we propose the indirect emissions allocated to a regulated facility equal the average amount of indirect emissions. The average is the total amount of indirect emissions calculated using a multi-market or general equilibrium model, divided by total amount of biofuel produced. The indirect emissions allocated to each site equal this number times the amount of biofuel produced. Given an estimate of indirect land use changes (ILUC) a simple model for calculating total and average indirect emissions is described in the appendix.

The current approach to calculate ILUC is to model the impact of a shock in the form of a biofuel mandate on the demand and supply of land in a partial or general equilibrium framework. Searchinger et al. (2008), using the FAPRI partial equilibrium model of the agricultural sector in conjunction with the global GTAP land database, calculated that producing 56 billion liters of corn ethanol (requiring 140 million tonnes of corn at a corn to ethanol conversion rate of 2.7 gallons of ethanol per bushel of corn) in the US would cause global agricultural acreage to expand by 10.8 million hectares. By allocating this acreage across difference types of land with differing stocks of carbon, they calculate indirect emission from land use change as 106.4 gCO_2e per MJ of ethanol. Similarly, Hertel et al. (2008) use the GTAP general equilibrium model of the world economy to calculate ILUC resulting from the US and EU's biofuel mandates for 2015. Irrespective of whether a partial or general equilibrium model is used, the calculations should accord with empirical evidence. We believe that Searchinger et al.'s (2007) estimates of ILUC are high.

To this end, let $\varepsilon_{L/Q}$ denote the elasticity of acreage with respect to agricultural production, $\Delta L/L$, the percentage change in acreage, and $\Delta Q/Q$, the percentage change in agricultural output, then, $\varepsilon_{L/Q} = \frac{\Delta L/L}{\Delta Q/Q}$. Rearranging we get $\Delta L = \varepsilon_{L/Q} \cdot \Delta Q \cdot L/Q$. Between 1950 and 1998, global agricultural output increased 150% while harvested acreage increased only 13%. This implies $\varepsilon_{L/Q}$ is 0.09. In the year 2006 the combined global acreage of the three major food grains, namely rice, wheat, and corn, was about 510 million hectares, i.e., *L,* while combined global production was 1950 million tones, i.e., *Q*. Given these values for $\varepsilon_{L/Q}$, *L* and *Q*, if corn production were to increase by 140 million tonnes (i.e, ΔQ =140) in order to offset the quantity diverted for ethanol (according to equation (1) above, corn acreage will increase 3.3 million hectares. This estimate is conservative, given that we assume the quantity of corn allocated to ethanol is entirely replaced by new supply so that consumption of corn as food remains unchanged. This is unlikely because demand for food is not inelastic and will adjust to higher corn prices. Yet we find that Searchinger et al.'s estimate is more than three times higher[4].

Low elasticity of acreage implies intensification involving greater input use (fertilizer, water) and adoption of new technologies (better seeds, pesticides, irrigation), which contributed the lion's share of the increase in output in the 20th century. Obviously historical trends may change, but they can be affected by policies, market conditions, and biophysical developments. For example, future agricultural expansion may occur on marginal lands with low yield.

Although the current approach for calculating ILUC is to use equilibrium models, an econometric model can be employed. Given the wide variation in the historical acreage response, point estimates of ILUC do not present a complete picture and a sensitivity analysis of ILUC to various assumptions about prices, technologies and policies in the future should be undertaken.

3. A Target Number and a Framework for Regulation

Current regulations, such as the maximum allowable emission in mechanisms like the low carbon fuel standard (LCFS), aim to establish an upper bound for GHG emissions per unit of biofuel. Searchinger (2007) suggested that the measure of biofuel emissions should include both a direct and indirect effect. Let $\bar{f}$ be the upper bound, which is compared to the emission measure of each site.

For illustration purposes, consider the LCFS, where $\bar{f}$ is the standard, e.g., 94 gCO_2e per MJ. This is the number reported by Farrell et al. for gasoline. Let f_D denote the direct site-specific emissions per unit output and f_I denote the average indirect effect. The sum $f_D + f_I$ represents the overall emissions per unit of biofuel from a given site. To reiterate, f_D is computed using an LCA style approach, whereas f_I is computed using economic equilibrium models.

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[4] Our estimate of ILUC is sensitive to the value of the elasticity of acreage with respect to output $\varepsilon_{L/Q}$. We do acknowledge that our estimate $\varepsilon_{L/Q}$ based on total change in acreage and production between 1950 and 1998 may be optimistic. Disaggregating the data for total acreage and total output for some of the major crops (corn, wheat, rice, soybean, wheat and cotton) shows high variability in $\varepsilon_{L/Q}$ for different crops during different periods. For example, low elasticity (<0.1) for wheat during the green revolution and for cotton after the introduction of biotech but high elasticity (>0.5) at other times when little new innovation was introduced. Furthermore future agricultural expansion may occur on marginal lands where yields may be lower and therefore exhibit $\varepsilon_{L/Q}$. At the same time new technological breakthroughs may deliver higher rate of yield growth. The National Corn Growers Association expects corn yield in the US would increase 20% and reach 175 bushels per acre by 2015. Our aim in any case is not to present a new number for the GHG balance or the land use change but only to point out that there is heterogeneity across locations, feedstocks and technologies and that both direct and indirect effects can be influenced by regulation and economic incentives.

Table 1: Comparison of emissions in different scenarios

	Comparison of gasoline and ethanol*	Direct emissions gCO2e/MJ	Indirect emissionsgCO2e/MJ	Total gCO2e/MJ	% Emissions relative to standard***
	Maximum level of emissions set equal to emissions from marginal gasoline from conventional oil (Farrell et al)	94		94	-
1	US Corn Ethanol today (Direct emissions from Farrell et al. and indirect emissions from Searchinger et al.)	77	106	183	195%
	Corn ethanol scenarios				
2	Corn processing using only coal and Indirect emissions 1/3 rd of Searchinger's estimate**	88	35	123	131%
3	Processing based using only gas and Indirect emissions 1/3 rd of Searchinger's estimate**	61	35	96	103%
	Cellulosic Ethanol scenarios				
4	Direct emissions from Farrel et al. and Indirect emissions from Searchinger et al	11	106	117	125%
5	Direct emissions from Farrel et al. and Indirect emissions 1/3 rd of Searchinger's estimate**	11	35	46	49%

*- comparison is with respect to emissions from marginal gasoline which is assumed to be conventional oil. If marginal gasoline is derived from heavy oil and tar sands then benefits from ethanol increase

** - Scenarios use the assumption that indirect emissions are 1/3rd of Searchinger's estimate

**** - A value greater than one implies total biofuel emissions exceed the standard and a value less than one implies it is below the standard and hence results in GHG savings

Depending on the regulatory framework, the regulated site may have to provide certification showing, $f_D + f_I \le \bar{f}$ to get a permit. Alternatively, the regulator may need to inspect the site and show that $f_D + f_I > \bar{f}$ to close the site. Since the site takes f_I as given, this effectively requires ensuring that the direct emissions f_D satisfies the constraint, $f_d < \bar{f} - f_I$.

In Table 1 we show emissions from ethanol produced under various scenarios of direct and indirect emissions relative to emissions from gasoline. Current estimates for direct emissions (Farrell et al., 2006) and indirect emissions (Searchinger et al., 2008) imply ethanol is more polluting than gasoline. More interestingly, it suggests that, even if indirect emissions decrease to $1/3^{rd}$ the amount estimated by Searchinger et al. (2008), corn ethanol still under performs gasoline. Scenarios with indirect emissions equaling $1/3^{rd}$ of Searchinger et al.'s estimate were chosen because as we explained earlier we expect their estimate of induced land use change to be more than three times larger compared to ours (See Section 2.2). Finally, a scenario involving cellulosic ethanol and low indirect emissions can potentially reduce carbon emissions by 50 percent relative to gasoline (scenario 5).

We now briefly discuss the data required to implement this framework. As regards the setting of an upper bound on emissions from biofuel, one option is to set this relative to the emissions from gasoline, for example, no higher than net GHG emissions from gasoline and reliable estimates of this exist today. As regards on site and offsite direct emissions from biofuel, these can be estimated using the type of data that was used by Farrell et al. (2006) in determining the direct emissions from corn ethanol. Calculation of indirect emissions among other things requires data on the quantity and type of lands that were converted from non-farm use to farm use world-wide and the net change in carbon stored on those parcels of land due to such conversion and these can be obtained from literature. Again this can be calculated using data from GIS based models. It is worth emphasizing that the most accurate estimate we can obtain is total land use change between two points in time. The most challenging aspect however is in ascribing a share of this total change to biofuels after controlling for changes in land use due to other factors such as economic growth and weather shocks.

4. Policy

If the goal is to produce biofuel efficiently, and to minimize carbon emissions and damage to the environment, then the first best policy is a carbon tax and payment for environmental services. Levying a carbon tax shifts production from fossil fuel to biofuel and induces greater supply of clean fuel. It, however, brings on land conversion and a loss of biodiversity. Therefore, a policy to price clean air should be paired with a policy to price environmental services (Hochman et al., 2008). Politically, a carbon tax may not be a viable option. It may not be feasible to levy a tax on a global public bad. A second best policy is the next possibility.

A fuel tax based on LCA is currently proposed by some state and national governments. They are easy to impose because fuel consumption is observable. Different from existing fuel taxes, a second best fuel tax should vary according to fuel types--with dirtier fuels taxed more heavily. LCA could then be used to classify fuels according to their carbon emissions. Such a tax may also account for other local externalities such as traffic congestion. This policy also has a problem of double counting.

An alternative second best solution, which bans biofuel production if it has limited environmental benefit, is LCA thresholds or certification standards. Only biofuels that have sufficient small life cycle emissions can be used. Governments may account toward mandate or offer subsidies only to those biofuels that are certified to meet the desired standards (e.g., the number used to compare the direct and indirect site specific emissions). Note that standards might be different between countries, because local environmental amenities are different. Standards are currently used in the United States.

Because carbon emissions are a global public bad, policy ought to be coordinated between all countries. More specifically, international environmental agreements should account for the cost of deforestation (e.g., destruction of rain forests in Brazil). Landowners do not capture all the benefit from their efforts to preserve the environment. The benefit, in terms of biodiversity and carbon sequestration, accrues to people around the world. Therefore, landowners should be paid for the environmental services their land provides. To this end, an international agreement, which will internalize the negative externalities from fuel production and consumption, needs to be established.

5. Conclusion

Even if a first best GHG tax is imposed on all GHG emitting fuels, so long as there is no tax on emissions from land use, biofuels can result in leakage, i.e., effective GHG emissions due to a blend may be above the level accepted by the regulator. In the absence of carbon tax, the implementation of second best mechanisms such as carbon standards or emission trading will inevitably require calculation of all direct and indirect emissions associated with final output. With this in mind we have outlined a framework that can be applied to the regulation of GHG emissions from energy production. Ours is a hybrid approach that suggests a process LCA type approach for calculation of direct emissions and a market equilibrium approach for calculation of indirect effects. But significant improvements in the methodology for calculating ILUC, as well as ILUC emissions, is required before it is used in regulation. Our framework however is generic and given data on direct and indirect emissions can be implemented in practice and can account for heterogeneity and uncertainty. It can also be extended to the regulation of non-greenhouse gas externalities. An obvious exclusion in this article is a discussion of the monitoring mechanisms for tracing and certifying emissions, the information gaps, and the transaction costs associated with implementing this framework. We hope to address this in future work.

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References

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. “Land Clearing and the Biofuel Carbon Debt,” *Science* 319(5867): 1235-1238.

Farrell, A.E., R.J. Plevin, B.T. Turner, A.D. Jones, M. O’Hare, and D.M. Kammen. 2006. “Ethanol can Contribute to Energy and Environmental Goals.” *Science* 310(5760):506-508.

Hertel, T. W., W. E. Tyner, and D. K. Birur. 2008. “Biofuels for all? Understanding the Global Impacts of Multinational Mandates.” GTAP Working Paper 51, Center for Global Trade Analysis, Purdue University, West Lafayette, IN.

Rajagopal, D., and D. Zilberman. 2007. "Review of Enironmental, Economic and Policy Literature on Biofuels", *World Bank Working Paper Series* #4341, World Bank.

Rajagopal, D., and D. Zilberman. 2008a. "Prices, Policies and Environmental Life Cycle Analysis of Energy, *Farm Foundation conference Lifecycle Footprint of Biofuels*, Washington DC.

Rajagopal, D., and D. Zilberman. 2008b. "Life cycle performance is function of prices and policies." Working paper, Department of Agriculture and Resource Eonomics, UC Berkeley.

Searchinger, T., R. Heimlich, R. A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgov, D. Hayes, and T. H. Yu. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change," *Science* 319(5867): 1238-1240.

Tilman, D., J. Hill, and C. Lehman. 2006. "Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass," *Science* 314(5805): 1598-1600.

Appendix: Mathematical model for calculation of indirect emissions

$\Delta\gamma$ To present this notion more precisely, let Q denote the total agricultural output before biofuel, ΔQ_b the quantity of crop allocated for biofuel production, and ΔQ the total increase in output after biofuel[5]. Let, L_0 denote the total land under cultivation before introduction of biofuel, ΔL_0 the change in land under cultivation after introduction of biofuel (i.e., the extensive effect)[6], and ΔL_b the land required to produce the quantity ΔQ_b of biofuel. Let Z_0 and Z_1 denote the change in emissions from agriculture with and without biofuel production and ΔZ denote the total change in agricultural emissions due to introduction of biofuel. ΔZ is broken down into two components, F_D the change in direct agricultural emissions due to production of biofuel and F_I the change in indirect agricultural emissions due to production of biofuel. Let δ denote the average GHG coefficient of new land, γ_0 the average GHG coefficient of farming before biofuel, the change in the average pollution due to farming activities. With this notation, the mathematical model is described below.

Agricultural emissions before biofuel $Z_0 = \gamma_0 L_0$

Agricultural emissions after biofuel, $Z_1 = \gamma_1 L_1 = \delta\Delta L_0 + (\gamma_0 + \Delta\gamma_0)(L_0 + \Delta L_0)$

Change in agricultural emissions, $\Delta Z = Z_1 - Z_0 = \delta\Delta L_0 + \gamma_0\Delta L_0 + L_0\Delta\gamma_0$

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[5] ΔQ_b is likely to be greater than ΔQ because of the following reasons: (1) Higher prices due to biofuel will depress demand and hence a portion of the diverted crop is never replaced and (2) in certain cases new crops do not have to replace the entire amount because of co-products that can substitute main crop. The gap between ΔQ and ΔQ_b is larger the less elastic the supply of corn and more elastic the demand for food.

[6] This is a function of the price elasticity of supply and demand, price elasticity of productivity and the quantity of biofuel produced.

Breaking down the total change in agricultural emission into direct and indirect changes we write, $\Delta Z = F_D(X_D, \beta_D, \varepsilon_D) + F_I(X_I, \beta_I, \varepsilon_I)$

We write F_D as a function of X_D - a vector denoting the level of technologies and inputs used to produce the final product, β_D - a policy parameter that can be thought of as affecting incentives, and ε_D - a random disturbance term. And so is F_I

The change in direct agricultural emission due to biofuel is $F_D(X_D, \beta_D, \varepsilon_D) = \gamma_0 \Delta L_b$

Therefore, the indirect emissions due to biofuel is then written as $F_I(X_I, \beta_I, \varepsilon_I) = \Delta Z - F_D(X_D, \beta_D, \varepsilon_D) = \delta \Delta L_0 + \gamma_0(\Delta L_0 - \Delta L_b) + L_0 \Delta \gamma_0$

Allocating these total indirect emissions across the total biofuel production, say V, the average indirect land emission per unit of biofuel f_I, is then written as

$$f_I(X_I, \beta_I, \varepsilon_I) = \frac{F_I(X_I, \beta_I, \varepsilon_I)}{V}$$

If we look closely the indirect emissions is comprised of,

$\delta \Delta L_0$ - emissions due to land conversion only (this is what Searchinger et al. and Fargione et al. calculate)

$\gamma_0 \Delta L_0$ - emissions from farming on the newly converted land

$\gamma_0 \Delta L_b$ - emissions during cultivation of the biofuel crop

$L_0 \Delta \gamma_0$ - emissions due to changes in farming practices on pre-existing farm land after the introduction of biofuel

GHG Trading Framework for the U.S. Biofuels Sector

Subbu Kumarappan and Satish Joshi[1]

Abstract: Substitution of petroleum fuels with biofuels such as ethanol and biodiesel has been shown to reduce greenhouse gas (GHG) emissions. These GHG reductions can be traded in the emerging carbon markets, and methodologies for quantifying and trading are still being developed. The main challenges in developing such GHG trading framework are analyzed. An outline of such a framework is presented that depends on the life cycle assessment of GHG reductions, along with a combination of project specific and regional standard performance measures. The advantages of assigning GHG property and trading rights to biofuel producers are discussed. At carbon prices of $10 per metric ton, estimated additional revenues to biofuel producers range from $ 17 to 64 million dollars per billion gallons of corn ethanol and cellulosic ethanol respectively.

Biofuels for transport applications are considered attractive because of their potential contribution to improving energy security, reducing greenhouse gas (GHG) emissions, and increasing rural incomes. Substituting biofuels such as ethanol from corn and biodiesel from vegetable oils for gasoline and diesel can reduce GHG emissions by 20%- 40% on an average. The second generation biofuels derived from cellulosic materials are considered even more promising because of their significantly higher GHG reductions which range from 60% to 120%. (Moomaw and Johnston, 2007; Wang, et al., 2007). Development of GHG markets enables monetizing and trading the environmental attributes of biofuels, specifically the reductions in GHG emissions (Gururaja, 2005). Considering the high volumes of liquid fuels used and the growing amount of biofuel use in US transportation, the GHG market implications of biofuel use are 'potentially very large' (Capoor and Ambrosi, 2007). For example, corn ethanol use in transportation in the US has increased from 0.9 billion gallons in 1990 to 6.5 billion gallons in 2007 and expected to exceed 10 billion gallons by 2012 (RFA 2007). Simultaneously, the global trade in GHG permits increased from ten to sixty billion dollars between 2005 and 2007, and carbon prices were as high as $45 per metric ton in the EU markets (Capoor and Ambrosi, 2007; Point Carbon, 2007).

Efforts are ongoing in the EU to develop a GHG trading framework and approved methodologies for biofuels. The GHG credits created from biofuel use can also potentially be traded under the system created by the Chicago Climate Exchange® (CCX®) in the US (CCX, 2007a; Gardner, 2007). Under the CCX trading platform carbon credits are generated from various types of projects in agriculture (e.g. reduced tillage), forestry, methane digesters, renewable energy projects and fuel switching. These carbon credits are then certified under CCX protocols, the certified GHG credits can then be sold to other members who are required to meet their mandated levels of GHG reductions. Using liquid biofuels in transportation can potentially be eligible for CCX GHG credits because it would be a form of fuel switching, from fossil fuels to renewable fuels. Some projects that are eligible under EU emissions trading scheme are said to

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be eligible under CCX (CCX, 2007b). However trading GHG benefits from biofuels is likely to be more challenging in the absence of an appropriate trading framework that establishes property rights over such GHG benefits and then help quantify the tradable GHG benefits. A GHG Trading Framework (GTF) for biofuels needs to address the following questions.

1. What is the appropriate method for quantifying the GHG benefits from biofuel use? How to handle the potentially large variations in GHG emissions because of variations in feedstocks, feedstock production practices, final biofuel products, conversion technologies, and vehicle technologies?
2. What quantities of GHG reductions below the baseline qualify for trading in the emissions market? In other words, what proportion of the GHG benefits satisfies the 'additionality' principle?
3. Who gets the property/trading rights to reductions in GHG from biofuel use?
4. How to design verification and monitoring mechanisms for measuring GHG reductions as well as leakages?
5. How to design incentive mechanisms that are compatible with relative contribution of various participants in the life cycle of biofuels?

These issues are discussed briefly before outlining a proposed GTF for the US biofuels sector. The proposed GTF directly addresses the first four questions, but depends on market mechanisms to allocate the monetized GHG benefits among various participants in the biofuel life cycle, namely feedstock producers, fuel producers, blenders, and final consumers. The proposed GHG trading framework is consistent with the methodologies used under the Clean Development Mechanism (CDM - supervised by United Nations Framework Convention on Climate Change) in the EU and other methodologies followed by CCX in the US (CDM, 2007a, 2007b; UNFCCC, 2007; WBCSD, 2007; WRI, 2007). The key question is 'what constitutes ownership of GHG credits in the US biofuels sector'? A property rights structure that would suit the US biofuels industry is proposed (Kumarappan and Joshi, 2008; Sims, 2003). While most of the following discussion uses ethanol to illustrate the proposed GHG trading framework, the analysis can easily be extended to other biofuels such as butanol, methanol, biodiesel, and biomass-Fisher-Tropsch liquids.

2. Issues in Creating Tradable GHG Credits from Biofuel Use in Transportation

What is the Appropriate Method for Quantifying the GHG Benefits from Biofuel Use?

Biofuels reduce the GHG emissions compared with gasoline and diesel, but do not eliminate all the emissions. GHG emissions from biofuels are less than that of fossil fuels on a life-cycle basis, because carbon dioxide is sequestered during the growth phase of the biomass (corn crop, cellulosic materials, algae) that is used to produce biofuels. However, additional GHG emissions occur from the use of fertilizers, pesticides, and machinery use in the feedstock production process, use of fossil energy in the biofuel conversion process and in the storage, transportation, and distribution of feedstocks and biofuels. Hence, the emission reductions from biofuel use should be quantified by comparing the life-cycle GHG emissions of biofuels with that of a baseline fuel (fossil fuel, such as gasoline). Life cycle methods have been used for biofuel policy making in most of the OECD countries including the US (OECD, 2008). For example, the

US Energy Independence and security Act of 2007 defines conventional and advanced biofuels based on their life cycle GHG reductions (BRDB, 2008; EISA, 2008).

While life cycle assessment (LCA) is relatively simple in concept, developing LCAs whose estimates are universally acceptable is very difficult. The challenges in LCA include choosing appropriate system boundaries, choice of representative processes and pathways to be modeled, accounting for input interdependencies, data representativeness and quality on inputs and outputs (including emissions), and evaluation of environmental impacts (Joshi, 2000). These issues get even more complex in the case of comparative LCAs of biofuels and fossil fuels because of multiplicity of pathways, products, interdependencies and co-products. A large number of feedstocks such as corn, sorghum, wheat, and cellulosic (herbaceous, woody, and waste) biomass can be used in biofuel production. The cultivation practices, types of inputs used and yield of these feedstocks vary significantly across geographical locations, depending on producer decisions, production process, relative input-output prices, soil quality and local climatic conditions. The feedstock to fuel conversion technologies (e.g. biochemical versus gasification of cellulosic biomass) use different levels of energy that contribute to different levels of GHG emissions. The energy sources at the biofuel production facility can range from coal and natural gas to biomass power; multiple energy sources could be used in the same facility as well. The production of various co-products needs to be accounted (e.g. lignin used for electricity production in cellulosic biorefineries). The vehicles that run on biofuels can vary in terms of their power-trains (e.g. conventional spark ignition vehicles, displacement on demand vehicles, hybrids, or flexible fuel vehicles) and biofuel blend levels (E10, E85, E100). Each combination of feedstock, biofuel production process and final vehicle use and underlying assumptions would lead to different levels of lifecycle GHG emissions. Hence, all types of ethanol do not yield the same level of GHG reductions; failure to recognize these differences might also lead to ‘leakage’ of GHG (increase in GHG emissions) elsewhere in the supply chain.

A large number of LCA models have been developed that compare life cycle GHG emissions for a number of these feedstock-fuel-vehicle combinations (MacLean and Lave, 2003; Wang, 2005). Among the various models, a model developed by Argonne National Laboratory (ANL), called ‘Greenhouse gases Regulated Emissions and Energy use in Transportation’ (GREET) is emerging as a generally accepted standard model that is being widely used by policy makers and industry in the U.S. (ANL, 2007; GM, 2001; GM, et al., 2002). GREET model is also being used by California Air Resources Board in developing its new low carbon fuel standards (CARB, 2008). Major advantages of the GREET model are that it is publicly available, free, comprehensive (i.e., it covers a large number of feedstock-fuel-vehicle pathways), well documented and transparent, flexible, and user friendly. Users can estimate changes in GHG emissions under different scenarios by changing specific parameters and input combinations relatively easily, and can also carry out uncertainty analyses using Monte-Carlo simulations (ANL, 2007; Wang, 2005). This model can accommodate the above said differences in feedstocks, production processes, blend levels, transportation and also indirect emissions due to land use changes.

Which GHG Reductions Qualify for Trading in the Market?

While substituting fossil fuels with biofuels can reduce GHG emissions, only that portion of GHG benefits that satisfy the 'additionality' criterion become eligible for trading in the GHG market under the CCX and CDM rules (CCX, 2007c; UNFCCC-CDM, 2007). That is, the GHG reduction achieved with biofuels should be over and above the baseline case or Business-As-Usual (BAU) case. The BAU needs to be defined both in terms of the quality (type of fuel used for baseline) as well as the baseline quantity of biofuel use.

In the case of ethanol, the identification of a baseline fuel becomes tricky due to existing renewable fuel mandates and fuel quality regulations that vary by region or state in the U.S. For example, certain US metropolitan areas afflicted by tropospheric ozone problems have mandated the use of reformulated gasoline (RFG) during summer months, which may contain ethanol (biofuel) or Ethyl tertiary butyl ether (ETBE) or methyl tertiary butyl ether (MTBE) as an oxygenate. Due to a recent ban on MTBE, ethanol is becoming the default fuel additive and oxygenate (EIA, 2003). Similarly areas that do not meet air quality standards for carbon monoxide have mandates to mix ethanol with gasoline to reduce carbon monoxide problems during winter months. Since different types of fuels are used to meet the mandates, any of these fuels—conventional gasoline, RFG with ethanol, or winter gasohol—can serve as the baseline fuel depending on the season and region. The provisions of EISA 2007 mandate renewable fuel use of 7.5 billion US gallons by the year 2012 increasing up to 36 billion gallons by 2022 (Ethanol – GEC, 2005). Various US states also have individual mandates causing variations in the mandated level of biofuels in a region. Further, Federal excise tax incentives ($ 0.54 per US gallon), and additional state tax incentives have resulted in increasing levels of ethanol blending in regular gasoline. Hence, it becomes very difficult to establish what would be a correct BAU baseline quantity for ethanol use (similarly for other biofuels).

Establishing the BAU baseline fuel and baseline quantity is necessary to differentiate the 'project' which generates tradable emission rights from the BAU case and quantify any 'additional' substitution of fossil fuels and the associated GHG emission reductions. The CDM procedures suggest the use of either (general) performance standards or project specific standard baselines, which need to be established on a case-by-case basis for the US biofuels sector (Atkinson, 2006; CCX, 2004).

Who Gets the Property/Trading Rights to Reductions in GHG from Biofuel Use?

The lifecycle emissions analysis of biofuels would include farm level feedstock production, conversion of feedstock into biofuels, storage, transportation, and distribution for blending, and final retail level combustion of biofuels in vehicles. At least four separate economic agents are involved in this process: feedstock growing farmers, ethanol producing plants, fuel blending intermediaries and individual consumers/vehicle owners. The net reduction in GHG is an overall result of their combined actions. This leads to the question of who should get the property rights and thus the trading rights to sell the GHG credits generated through the production and use of biofuels. CCX (2007b) notes that any participant (even feedstock producer or biofuel consumer) can claim the trading rights if ownership rights can be established; there is considerable ambiguity on how these property rights issues would be established unilaterally without regard to the actions of other life cycle participants.

Most of the GHG sequestration occurs during the production of agricultural feedstocks (Lynd and Wang, 2003). But the feedstock is produced by tens of thousands of farmers and their output has multiple potential uses ranging from food, animal feed, industrial raw material, to biofuel feedstock. It is very difficult to identify which specific farmer's, which portion of biomass output was used in biofuel production. This increases the transaction costs of assigning property rights to farmers.

Biofuel consumers can potentially claim the property rights to trade the GHG reductions from biofuel use because it is their ultimate fuel substitution that determines the GHG reduction. However assigning property rights to vehicle drivers is also problematic because there are millions of biofuel users, each of whom is responsible only for a tiny fraction of the GHG benefits, and accounting for and distributing GHG based revenues would almost be impossible. Moreover, both the farmers and consumers are unlikely to have the information about the intermediate steps in the lifecycle process and associated GHG emission benefits.

This leaves either the biofuel producer (e.g. ethanol plants) or the blender as feasible candidates from the perspective of reducing transactions costs and the availability of necessary information, to get the GHG credit trading rights. Traditionally, the US fuel ethanol subsidies have been paid to fuel blenders mainly because the tax credits were simply a function of ethanol blend levels and the blenders chose blend levels depending on the market conditions and local regulations (FHWA, 1998). However, as noted above, the amount of GHG credits generated is a complex function of feedstock composition, fuel sources, input use, and technology adopted in biofuel production, as well as the BAU baseline conditions. The blenders are unlikely to possess this type of information for ethanol that they may blend into gasoline.

Biofuel producers on the other hand are likely to have some of the key information. For example, biofuel producers have knowledge about the feedstock composition and sources, the conversion technology, and hence associated energy use and emissions, and the consumer markets they sell their product in. Hence assigning GHG trading rights to biofuel producers is likely to be feasible and optimal from a transaction costs and information costs perspective. A number of biofuel producers have submitted project proposals seeking trading rights under CDM using similar logic. For example, CDM has approved a methodology for biodiesel (BIOLUX project – AM0047) which "ensures that the CERs[2] can only be issued to the producer of the biodiesel and not to the consumer" (CDM, 2007b). Another project (Khon Kaen fuel ethanol) submitted to the CDM project, seeking the trading rights to be vested with the biofuel producers, notes that

> "A production-based approach to bio-fuel projects greatly assists monitoring. It is not really feasible to monitor individual motorists' actions, but monitoring the production of bio-fuels, and ensuring that only production that is used as a national transportation fuel qualifies for CERs, is an efficient and accurate method of ensuring integrity."
> (Agrinergy, 2004; CDM, 2007c - page 20)

[2] CER – Certified Emission Rights, an equivalent of GHG credits; 1 CER = 1 ton of carbon dioxide equivalent (CO_2e) mitigated

How to Design Verification and Monitoring Mechanisms for Measuring GHG Reductions as Well as Leakages?

The current carbon markets and associated GHG accounting, verification, certification, and monitoring mechanisms vary across countries and by agencies that have separate jurisdiction. However as GHG markets become increasingly global, consistent and comparable methodologies are necessary. The trading methodologies established under CDM for developing countries, under ETS in the EU and (possibly) under CCX in the US have to be consistent so that future global markets are based on common platforms and similar accounting methodologies across national borders and markets (Capoor and Ambrosi, 2007; EU-Environment, 2008; ICAP, 2008; IETA, 2007).

How to Design Incentive Mechanisms that are Compatible with Relative Contribution of Various Participants in the Life Cycle of Biofuels?

The assignment of property and trading rights with biofuel producers may sound optimal from a transaction and information cost perspective, but how the GHG revenues will be shared among the different participants along the value chain is not clear. In a market mechanism, the revenue sharing is based on the relative bargaining power of feedstock producers and consumers vis a vis biofuel producers, i.e., supply and demand elasticities. However the incentive properties of such market-based revenue sharing arrangements are not unambiguous. Alternatively, a governing body (e.g., renewable fuel association) may be designated to develop fiat-based revenue sharing formulae and oversee the distribution among the life-cycle participants, so that the benefits are shared according to their contributions. Even in this case, it would be optimal to retain the trading rights with the biofuel producers. Whether the optimal level of GHG reduction would be achieved under this kind of a trading scheme is an interesting question. Analyzing the tradeoffs and incentive effects on the market participants (quantitatively) is another important issue.

3. Current Global GHG Trading Schemes

Many biofuel projects that reduce GHG emissions have submitted methodologies to the CDM methodologies panel and Executive Board that evaluates and approves the GHG credits, e.g., BIOLUX biodiesel project, Agrinergy ethanol project (Atkinson, 2006; CDM, 2007b, 2007d). One of these project methodologies has been approved and could serve as a template for future biofuel related GHG credit requests (CDM, 2007b). Upon approval of these methodologies, these projects can sell GHG credits—termed as Emissions Reduction Units (ERU) and Certified Emissions Reduction (CER) for GHG credits generated in the developed and developing economies respectively—that are eligible for trading. The demand for GHG credits is generated within the CDM framework by requiring different emitters (e.g. power plants, cement manufacturing facilities) to reduce their GHG emissions levels; currently GHG emitters in EU countries that have ratified the Kyoto Protocol are engaged in trading GHG emission rights. There are private GHG trading exchanges such as GHGx, EUETS, and many over-the-counter (OTC) markets and exchanges serving the EU (EU-Environment, 2007; EUETS, 2007; GHGx, 2007; Point Carbon, 2007; UNFCCC - CDM Bazaar, 2008b). The trading of GHG's usually occurs in a price range of $7 to 15 per metric ton of carbon dioxide equivalent (t_{CO2e}) in organized exchange-based transactions whereas the prices in the OTC markets range from $20-40 per t_{CO2e} (or € 15-30 t_{CO2e}^{-1} at an exchange rate of € 1 = $1.30) (Capoor and Ambrosi, 2007; CCX, 2007a; Point Carbon, 2007).

In the US, since the GHG emissions are not regulated, participation in such markets is voluntary. CCX is one of the private firms that has established a trading platform for GHG trading within the US. The CCX Members commit to reduce their emission level which is legally binding. If they cannot reduce them below committed levels, they can buy offsetting GHG credits (also called carbon credits) from the members who are sellers within CCX; this creates the demand for GHG credits (CCX, 2007d). The GHG credits, called Carbon Financial Instruments® (CFI®), are supplied by offset projects and aggregators who are also members of CCX. These credits are generated in projects within North America, and ratified by CCX for its members through third party verification (CCX, 2007e). The GHG credits are generated by eligible projects such as in forestry, methane digestion, reduced tillage in agriculture, and production of electricity from renewable sources (CCX, 2007b). The projects eligible under CDM methodologies are also eligible under CCX. Since methodologies are being considered to trade the GHG emissions from biofuels in the CDM markets, such biofuel projects can become eligible for GHG credits in the US as well. In spite of their eligibility, there are no approved methodologies to quantify these GHG credits nor is there a GHG trading framework to trade the credits arising from biofuel projects. The next section discusses a possible GHG trading framework that may be appropriate for the US biofuel industry.

4. Proposed GHG Trading Framework for the US

Life Cycle Approach and a Combination of Standards

We propose that the system boundaries include the entire lifecycle and thus the activities of the feedstock producing farmers, manufacturing plants, blending intermediaries and the final consumers. However, quantifying the GHG benefits using LCAs tailored for various biofuel streams and plant locations can be difficult. A streamlined LCA using standard input processes and output (emissions) coefficients can help solve this problem. Such industry averages are known as 'standardized rules' in CCX ('performance standards' in CDM) and they are extensively used to quantify GHGs eligible for trading (CCX, 2004). However, using industry averages may not be appropriate when the project specific values are available or can be generated with relative ease. For example, information on the specific fuel mix (coal, natural gas) used at an individual ethanol plants is easily available and fuel-mix can significantly affect GHG performance. Hence, we propose a combination of standard and project-specific estimates, i.e., industry or regional level standardized rules for estimating emissions at the farm and final consumer level, and project-specific standards for estimates at biofuel manufacturing plant and blender levels as detailed below.

Feedstock production: We propose using region- and feedstock-specific averages for modeling GHG emissions from feedstock production stage of the lifecycle. This is necessary because there are thousands of farmers that supply multiple feedstocks for biofuel production and accounting for differences in input use and cultivation practices among individual farmers is very difficult.

Biofuel production: Project-specific information associated with feedstock mix (e.g., proportion of corn and cellulose in ethanol production), the technology used for conversion, input fuel mix and other process operations should be available with biofuel producers. Hence we recommend using project-specific data in quantifying the GHG emissions for this stage.

Blending and transportation: Similar to biofuel producers, the blending intermediaries also maintain project-specific data with regard to blend levels (e.g. gasoline-ethanol blends), modes of transportation and the extent of distribution (distance). Since this data is readily available, we recommend using project-specific data for this third stage.

Final use of biofuels in vehicles: Because final consumption of biofuels occurs in millions of vehicles of various makes and models, using a representative mix of vehicle-fleet and ‘performance standards’ to estimate tail pipe emissions becomes necessary. For an illustration of how to use the emission performance standards to calculate the emissions from a fleet of vehicles, see (CCAR, 2008).

We also recommend using the GREET model as a standard tool in evaluating life cycle performance since it is flexible, and can easily incorporate project-specific details and industry (or geographic) averages as necessary. Moreover, as discussed before, GREET is publicly available, widely accepted, and relatively transparent (ANL, 2007).

Definition of Baseline and Additionality

Defining the baseline, BAU case is crucial in GHG emissions trading to identify and quantify the GHG emission reduction from the ‘proposed project activity’ (i.e. biofuel substitution). As was discussed above, the definition of a BAU case for biofuel substitution can be tricky due to various types of fuels being used in the BAU case and the presence of multiple mandates that vary by seasons.

To illustrate, there are two types of regulatory requirements for ethanol use in the U.S. The first type is a quality mandate to meet air quality concerns (e.g., mandated reformulated gasoline or gasoline-ethanol blend)—since the ethanol used to meet these mandates would have been used due to regulations, it is not considered to be ‘additional;’ i.e., the ethanol project might have occurred even without the revenues from GHG credits. The second type of mandate is a quantity mandate. Various states require ethanol to be used in particular proportion to gasoline sold (e.g. 10 per cent of gasoline in Iowa, Kansas, and Hawaii (EPIC, 2008)). Since this ethanol would have been produced and consumed even without the particular project, the project under consideration may not be considered as ‘additional.’ Hence, the ethanol (or other biofuel) that is eligible for GHG credits should be the quantity that is produced and consumed over and above the mandates (both quantity and quality). For example, consider a case where the total US ethanol output is 20 billion US gallons in the year 2012; if 3 billion gallons were used to meet quality mandates (RFG mandates), and another 15 billion gallons were used to meet various quantity mandates, then only the remaining amount of 2 billion gallons can be considered as ‘additional’ due to project activities. Here, only 10 per cent of total ethanol production may be eligible for tradable GHG credits, according to this example—hence, the ethanol industry can stake a claim to GHG credits only for 10 per cent of its output during the year 2012. Since the mandates change over the years, the BAU case changes as well and thus the proportion of ethanol eligible for GHG credits needs to be recomputed periodically.

However, ambiguities arise when the quantity mandate also satisfies the quality mandate. In the above example, one can argue that the consumption of 15 billion gallons (under the quantity mandates) includes the 3 billion gallons used to meet the quality mandate as well—hence, the quantity of ethanol eligible for GHG credits is 5 billion gallons, or 25 per cent of the industry output in 2012. Many mandates specify the generic term 'biofuels' rather than one specific fuel (such as ethanol or butanol). If it is not explicitly stated or recognized in mandates, any particular biofuel may become eligible for GHG credits—this means that, in the above illustration, all industry output of 20 billion gallons of ethanol during 2012 may be eligible for GHG credits. Moreover, monetary incentives such as subsidies and tax rebates act indirectly as quantity mandates and the extent to which they affect the net BAU level of biofuel use is difficult to establish.

Given these realities, what proportion of biofuel produced in a particular plant (project) is eligible for GHG credit is not obvious. One option is to use the process described above: the proportion of biofuel output eligible for GHG credits can be calculated based on national mandates, adjusted to reflect the regional or state level mandates. For example, if 70 per cent of the total US ethanol output is required to meet federal mandates, only the remaining 30 per cent would be eligible for GHG credits. This 30 per cent could be uniformly applied to all ethanol plants. If any state requires more ethanol (than the federal mandates) in the form of a mandate, then the ethanol plants in those states alone can be assigned a different baseline level—i.e., if Iowa mandates make 80 per cent of its ethanol output to meet mandates while the federal mandates require only 70 per cent, then the higher of these two should be considered as the baseline (80 per cent in this example).

After establishing the baseline, the project-specific LCA using the GREET model can be used to compute the GHG credits. Table 1 presents selected scenarios where ethanol is produced from corn, using a wet or dry mill production process and used in gasoline or flex fuel vehicles (FFV). The estimates in Table 1 are from version 1.8a of the GREET model under current technology conditions (ANL, 2007). Based on these estimates, if an ethanol plant using corn as the feedstock, and employing dry-mill technology (with US average production techniques and fuel mix) produces 53 million gallons of corn ethanol, and 21 million gallons qualify as 'additional' then the GHG credits generated would be equal to 41.4 thousand tons CO_2e.

Trading Rights with Biofuel Producers

As explained above in section 3, assigning the property rights for trading GHG benefits credits to biofuel producers (e.g. ethanol manufacturing plants) is desirable to minimize transactions and information costs. Most project-specific data in terms of feedstock mix, technology, and energy sources used are available only with the biofuel producers. Table 2 depicts how the actions (energy source used) of the biofuel manufacturing facility affects the lifecycle (well-to-wheel) GHG emission reductions achieved in corn ethanol plants. Other manufacturing plant specific GHG reductions depend on the scale of operations (size) and the combination of feedstock (corn versus cellulosic materials). Further, biofuel manufacturing facilities may not be willing to divulge the specific details to farmers, blenders, or consumers, since much of this information can be of strategic importance in their operations. Hence, assigning the trading rights with any entity other than biofuel producers can lead to the use of incorrect information in the GHG markets. Biofuel producers have project specific information which they might be willing to share confidentially with certifying agencies such as CCX. Biofuel producers then require only

Table 1. Lifecycle GHG emissions per US gallon of ethanol (equivalent) used as automobile fuel

Fuel	**GHG[(a)] reduction compared with conventional gasoline (percent)**	**GHG[(a)] emissions (ethanol equivalent) kg per US gallon**	**GHG[(a)] emission credit of ethanol kg per US gallon.**
	Column A	***Column B*** = 7.61 * (1 – ***Column A***)	***Column C*** = 7.61 – ***Column B***
Conventional gasoline	0	7.61	
Corn ethanol, drymill[(b)] in gasoline vehicles(as E10)	26	5.64	1.97
Corn ethanol, wetmill[(b)] in gasoline vehicles(as E10)	17.8	6.25	1.36
Corn ethanol, drymill[(b)] in FFV (as E85)	29.2	5.37	2.23
Corn ethanol, wetmill[(b)] in FFV (as E85)	21.4	5.98	1.63
Cellulosic ethanol in gasoline vehicles (as E10)	85.1	1.14	6.47
Cellulosic ethanol in FFV (as E85)	85.5	1.10	6.51

Note:
[(a)] GHG refers to greenhouse gases as carbon dioxide equivalent (CO_2e)
[(b)] The terms ‘drymill’ and ‘wetmill’ refer to corn ethanol production processes
FFV refers to Flex Fuel Vehicles that can use gasohol with ethanol content up to 85 per cent
Adapted from Wang (2005)

industry averages (standardized rules or performance standards) for the farmer and consumer activities. If the biofuel producers desire more revenues through selling GHG credits, they have an incentive to source it from the farmers who follow better methods of feedstock cultivation. This indirectly creates a larger demand for feedstock that is produced with lesser GHG emissions. Using standards to quantify the micro emissions is a common practice in GHG accounting and it fits well with the farmers and consumers as prescribed here (CCAR, 2008). The biofuel manufacturing plants are relatively few in number (about 200) and dealing with fewer numbers of producers (who can quantify their project-specific emission levels) is an effective way to address this problem. Assigning the GHG property rights and trading rights to biofuel producers and following the above said framework is also an effective way to account for all biofuel eligible for GHG credits in a cost effective manner.

When the biofuel producers are assigned with the rights, they will be able to “demonstrate clear ownership rights to the environmental attributes associated” as required by CCX (CCX, 2007c, 2004). This can be done in the form of contracts: the contracts between biofuel manufacturing plant and blenders should specify that the ethanol manufacturing plant retains the GHG trading rights. Such a method has precedence in CCX where the forestry offset providers (tree growers) sell only the wooden logs to the timber industry but not the carbon credits associated with growing trees (CCX - Personal Communication).

Table 2: Impacts of different fuel sources on GHG emission reduction

Fuel used in corn ethanol conversion process	Well to Wheel GHG emission reduction of ethanol relative to RFG
Coal	3%
Coal and combined heat and power(CHP)	1%
Natural Gas	-28% to -39%
Distiller grains fueled boiler	-39%
Biomass fueled boiler	-52%

Note: RFG = Reformulated Gasoline; Adapted from Wang et al. (2007)

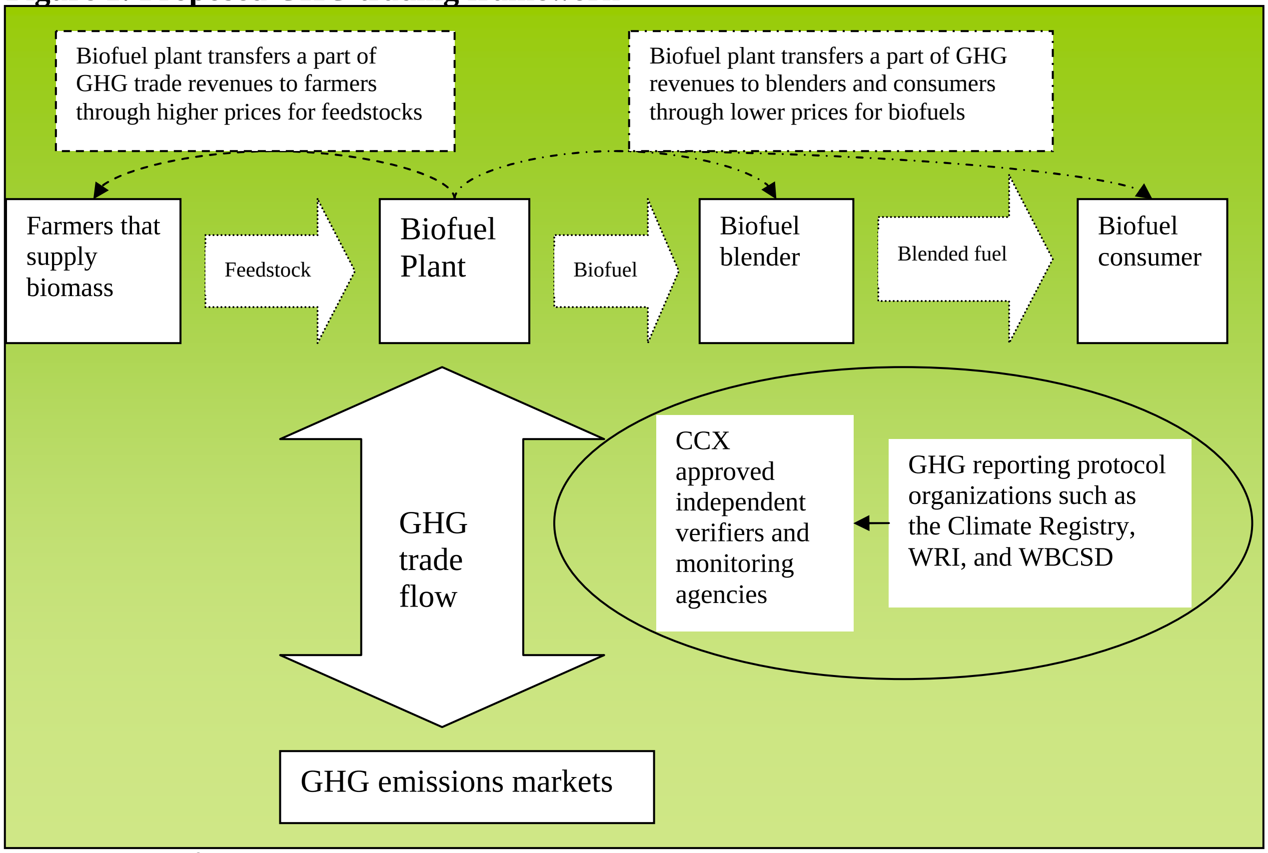
The consumers should understand that they are buying only the fuel properties of biofuel but not the GHG benefits associated with it—their share of revenues from GHG credits for choosing the biofuel over the pure fossil fuel would be passed on in the form of reduced biofuel prices compared with the situation where there are no revenues for GHG revenues. The contracts between feedstock-supplying farmers and ethanol production plants should explicitly state that the GHG reductions achieved from growing the biomass are transferred to the ethanol production plant. This could be contentious since most of the reductions occur at the farm level and the farmers might seek a claim to trade these GHG credits. But assigning the property and trading rights to farmers can lead to extensive leakage of GHG along the supply chain as mentioned below.

The trading framework described above requires approval and diligent acceptance of all the entities: farmers, biofuel industry, the certifying agencies (e.g. CCX), and government. Such coordination is necessary to help avoid the double counting problem (discussed below). The proposed GHG trading framework is depicted in Figure 1. The revenues from GHG trading are available with the biofuel production plants—the extent to which it would be shared with farmers (in the form of higher prices for feedstocks) and consumers (in the form of lower prices for biofuel) would be determined by their relative bargaining power and the demand elasticities for feedstocks and biofuels.

Other Issues

Aggregators: Many smaller biofuel production plants may not have enough GHG credits to trade on their own. These plants could use the services of independent aggregators to bundle the GHG credits of many smaller plants. Or, these plants can form GHG supply cooperatives that can greatly reduce the trading costs for all of them. The industry associations such as National Biodiesel Board or Ethanol RFA can work with the biofuel production plants to establish industry standards (Ethanol-RFA, 2007; NBB, 2007).

Figure 1: Proposed GHG trading framework



Source: Adapted from Kumarappan and Joshi (2008)

Independent verification and ratification: The achievement of GHG reduction through biofuels has to be verified by a third party. It can be done by carbon inventory agencies and registries such as Regional Greenhouse Gas Initiative (RGGI, 2007) or Climate Registry (Climate Registry, 2007; RGGI, 2007). This becomes necessary since there will be many more exchanges that trade in GHG in the US; NYMEX is planning to open one similar to that of CCX (Gardner, 2007). To facilitate easy movement and consistency across exchanges and trading methodologies, the ratification needs to be done by a neutral third party such as RGGI. Their functions would be similar to that of CDM which ratifies the methodologies, tools, and projects in the case of the Kyoto Protocol (Gardner, 2007).

Annual revision: The biofuel plants have to re-calculate the GHG credits that they are eligible to receive since the baseline case can change each year depending on the mandates. This will ensure the incorporation of latest developments and changes in the regulations.

Carbon reserve pools: Due to uncertainties in the estimated levels of GHG reduction, CCX tends to reserve 20 per cent of carbon credits in all the offset projects to create a reserve pool (CCX, 2004). Such rules will be applied for biofuels as well—this will reduce the amount of GHG credits issued to the biofuel producers. The credits in such reserve pools may be used to satisfy the biofuel plants' own 'Emission Reduction Commitments (ERC)' (CCX, 2007d). ERC are the mandatory levels of GHG reduction for CCX members; they can reduce the participation of many biofuel manufacturing plants which are already efficient without much scope for future reductions in their own internal emissions. The lifecycle analysis would partly reduce the burden imposed by ERC for the biofuel manufacturing plants.

Carbon leakage: There are other sources of GHG emissions such as clearing of land to open a biofuel production plant, or the changes in regional land use due to conversion of land from conservation programs to intensive biomass production purposes. These changes could lead to additional GHG emissions which are limited to one time period only. Any other long-term changes such as deforestation to grow biomass feedstock should also be included in the form of non-recurring leakage caused by the project (NEFA, 2008; Winters, 2008). The development and use of lifecycle based GHG emissions trading enables incorporating these types of indirect GHG leakages. In our proposed trading framework, we suggest using regional averages for computing GHG emissions during the feedstock production which will account for any major changes that occur within their feedstock catchment area. This also differentiates biofuels depending on which facility it was manufactured in and what region supplied the feedstock.

Limitations of the Proposed Framework

Our framework has no active mechanism to ensure the appropriate distribution of GHG revenues among all the life cycle participants. This is a common problem in all GHG trading methodologies that include lifecycle assessments but the trading rights are vested with only one agent (the biofuel producers in our case). The success of the proposed model and the reliance on market pricing mechanisms, where the biomass-supplying farmers get higher returns for their feedstock and consumers get biofuel blends at a lesser rate, are predicated upon the optimization behavior of the biofuel producer (Jolly, 2006).

Another issue is associated with Emissions Reduction Commitment (ERC) discussed above. When the biofuel producers are allocated the trading rights, they have more responsibility to reduce their internal emissions according to the rules of CCX. Since their operations require large amounts of fossil fuels, this can reduce their incentives for participating in GHG trading (CCX, 2007d). Under certain conditions, CCX can exempt the offset provider from meeting such ERC obligations; whether these exceptions are applicable in the case of biofuels is yet to be established.

Biofuel production and use also emits many other non-GHG emissions such as nitric oxides, carbon monoxide, particulate matter, and volatile organic compounds (Jacobson, 2007). The health impacts of these non-GHG emissions are not addressed by this study.

5. Implications for US Biofuel Producers and CCX

The revenues from trading GHG credits can be a significant source of revenue for biofuel manufacturing plants. If we assume that one third of the total US ethanol output is eligible for GHG credits (one third of industry output equals 2.2 billion US gallons in 2007), it would have generated \$ 37 million at a carbon price of \$10 per t_{CO2e}. Every billion gallons of ‘cellulosic ethanol’ eligible for GHG credits can generate \$64 million for the industry at a GHG price of \$10 per t_{CO2e}. The future expansion envisioned in the fuel ethanol industry in the US can bring revenues of up to $525 million as shown in Table 3. The actual revenues for an individual ethanol plant would however depend on the industry output, mandates, biomass feedstock used, production and energy input mix, storage, blend levels, transport, and the mix of automobiles that consume biofuels.

Table 3: Potential revenues from every one billion gallons of ethanol eligible for GHG credits (in dollars)

	GHG Price		
	$3 per Mg	**$10 per Mg**	**$20 per Mg**
Corn Ethanol 50% Cellulosic Ethanol 50%	$ 12 million	$ 41 million	$ 82 million
Corn Ethanol 80% Cellulosic ethanol 20%	$ 8 million	$ 26 million	$ 53 million
Corn Ethanol 100%	$ 5 million	$ 17 million	$ 34 million

Source: Adapted from Kumarappan and Joshi (2008) and Wang (2005)

Adopting such a trading framework and allowing the biofuel producers to trade the GHG credits have implications for CCX as well. Ethanol use in transportation alone can generate carbon credits of 1.7 and 6.4 million tons of GHG credit for one billion gallons of corn ethanol and cellulosic ethanol, respectively. With 5 to 7 billion gallons of ethanol (or other biofuels) eligible for GHG credits, over and above the quantity and quality mandates by the year 2022, the supply of GHG credits can range from 8 to 40 million tons. In the past 12 months (starting December 2007), CCX traded around 69 million tons of GHG credits. With a mandate to curb GHG emissions, the demand can increase considerably by the year 2022 and the above-mentioned GHG credits from biofuels might form a significant portion of supply in the GHG markets. Such a considerable increase in the supply of GHG credits from the biofuels sector can depress GHG prices in the US, if no other governmental regulations such as carbon caps can create a compensating demand for these credits. Hence, the proposed GHG trading framework has potentially large implications for the US GHG markets as well.

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References

Agrinergy. 2004. *Khon Kaen Fuel Ethanol Project*. Accessed July, 2006. Available at http://www.agrinergy.com/projects_sub_methods.htm.

ANL. 2007. *GREET Model*. Accessed November, 2007. Available at http://www.transportation.anl.gov/software/GREET/.

Atkinson, B. 2006. "The CDM, Kyoto Protocol and the Sugar, Ethanol and Bio-fuels Industry," *International Sugar Journal (1263) - World Ethanol Review*. Accessed August, 2006. Available at http://agrinergy.com/atkinson.pdf.

BRDB. 2008. "Sustainability - National Biofuels Action Plan." Accessed November, 2008. Available at http://www1.eere.energy.gov/biomass/pdfs/nbap.pdf.

Capoor, K., and P. Ambrosi. 2007. *State and Trends of the Carbon Market 2007*. Accessed November, 2007. Available at http://siteresources.worldbank.org/NEWS/MiscContent/21319781/StateCarbon.pdf.

CCAR. 2008. "California Climate Action Registry General Reporting Protocol - Version 3.0." Accessed October, 2008. Available at http://www.climateregistry.org/resources/docs/protocols/grp/GRP_V3_April2008_FINAL.pdf.

CCX. 2007a. *Chicago Climate Exchange*. Accessed November, 2007.Available at www.chicagoclimateexchange.com.

______. 2007b. *CCX Offsets Program*. Accessed November, 2007. Available at http://chicagoclimateexchange.com/content.jsf?id=23.

______. 2007c. *Offsets from Renewable Energy*. Accessed November, 2007. Available at http://chicagoclimateexchange.com/content.jsf?id=244.

______. 2007d. *Emission Reduction Commitment*. Accessed October, 2007. Available at http://chicagoclimateexchange.com/content.jsf?id=72.

______. 2007e. *Offset Project Verification*. Accessed November, 2007. Available at http://chicagoclimateexchange.com/content.jsf?id=102.

CCX - Personal Communication. 2006. CCX - Forestry Section, February 14, 2006.

CCX. 2004. *Rulebook - Chapter 9: CCX Exchange Offsets and Exchange Early Action Credits*. Accessed September, 2008. Available at http://chicagoclimateexchange.com/docs/offsets/CCX_Rulebook_Chapter09_OffsetsAndEarlyActionCredits.pdf, pp 9-28.

CDM. 2007a. *Clean Development Mechanism*. Accessed August, 2007. Available at http://cdm.unfccc.int.

______. 2007b. *F-CDM-NM0180: "BIOLUX Benji Biodiesel Beijing Project"*. Available at http://cdm.unfccc.int/UserManagement/FileStorage/CDMWF_AM_LSP8N2AV76VN489R6IUY72YJGTSJL9 Also See http://cdm.unfccc.int/UserManagement/FileStorage/CDMWF_IA2ZLSQWE05D01D2L4TYT9938LRDEQ (accessed November 2007).

______. 2007c. *Baseline methodology for the production of sugar cane based anhydrous bio-ethanol for transportation using LCA. Version 1*. Accessed October, 2007. Available at http://cdm.unfccc.int/UserManagement/FileStorage/UQKGKMUCPPWF3BQUIT02HYBO3EMI9B.

______. 2007d. *NM0142-rev: Palm Methyl Ester - Biodiesel Fuel (PME-BDF)*. Accessed November, 2007. Available at http://cdm.unfccc.int/UserManagement/FileStorage/CDMWF_0HIR3QLJ575AMHRC4PYXRCB726S18H.

Climate Registry. 2007. *California Climate Action Registry*. Accessed August, 2007. Available at http://www.climateregistry.org/ABOUTUS/.

EISA. 2008. *Energy Independence and Security Act of 2007 (H.R 6 - page 33)*. Accessed September, 2008. Available at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf.

EPIC. 2008. *State Mandates and Incentives*. Accessed September, 2008. Available at http://www.drivingethanol.org/ethanol_facts/public_state_mandates.aspx

Ethanol-RFA. 2007. *Ethanol Industry Outlook.* Accessed July, 2007. Available at http://ethanolrfa.org/resource/outlook/.

EU-Environment. 2008. *Emission Trading Scheme (EU ETS)*. Accessed July, 2008. Available at http://ec.europa.eu/environment/climat/emission/index_en.htm.

______. 2007. *Trading Allowances*. Accessed November, 2007. Available at http://ec.europa.eu/environment/climat/trading.htm.

EUETS. 2007. *the CO2 exchange for CEE*. Accessed November, 2007. Available at http://www.euets.com/.

Gardner, T. 2007. *NYMEX Considers Trading Greenhouse Emissions*. Accessed May, 2007. Available at http://www.reuters.com/article/environmentNews/idUSN0936779120070509.

GHGx. 2007. *Greenhouse Gas Exchange*. Accessed November, 2007. Available at http://www.ghgx.org/.

GM. 2001. "Well-to-Wheel Energy Use and Greenhouse Gas Emissions Analysis of Alternative Fuel/Vehicle Systems – North American Analysis." *TransForum* 3(2):47.

GM, et al. 2002. *Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems - A European Study*. Accessed September, 2006. Available at http://www.lbst.de/gm-wtw.

Gururaja, J. 2005. *Biofuels-issues, challenges and options*. Accessed November, 2007. Available at www.un.org/esa/sustdev/sdissues/energy/op/GFSE5_presentation_biofuels.pdf.

ICAP. 2008. *International Carbon Action Partnership*. Accessed September, 2008. Available at http://www.icapcarbonaction.com/

IETA. 2007. *Development of a global GHG market*. Accessed November, 2007. Available at http://www.ieta.org/ieta/www/pages/index.php?IdSiteTree=2.

Jacobson, M. Z. 2007. "Effects of Ethanol (E85) versus Gasoline Vehicles on Cancer and Mortality in the United States." *Environ. Sci. Technol.* 41(11):4150-4157.

Jolly, R. 2006. *A Firm Level Perspective on Ethanol Expansion*. Acessed December, 2006. Available at http://www.extension.iastate.edu/ag/JollyPresent.indd.pdf.

Joshi, S. 2000. "Product Environmental Life Cycle Assessment Using Input-Output Techniques." *Journal of Industrial Ecology* 3(2-3):95-120.

Kumarappan, S., and S. Joshi. 2008. "Trading greenhouse gas emission benefits from biofuel use in US transportation: Challenges and Opportunities." *Biomass and Bioenergy* Forthcoming.

MacLean, H. L., and L. B. Lave. 2003. "Life Cycle Assessment of Automobile/Fuel Options." *Environmental Science and Technology* 37(23):5445-5452.

Moomaw, W., and L. Johnston. 2007. "Emissions mitigation opportunities and practice in Northeastern United States." *Mitigation and Adaptation Strategies for Global Change* 13(5-6):615-642.

NBB. 2007. *National Biodiesel Board*. Accessed October, 2007. Available at http://www.biodiesel.org/.

NEFA. 2008. *New Fuels Alliance*. Accessed November, 2008. Available at http://www.newfuelsalliance.org/aboutus.html.

OECD. 2008. "Biofuel Support Policies: An Economic Assessment." Accessed November, 2008. Available at http://www.oecd.org/document/30/0,3343,en_2649_33785_41211998_1_1_1_37401,00.html.

Point Carbon. 2007. *Carbon Prices*. Accessed November, 2007. Available at http://pointcarbon.com/.

RGGI. 2007. *Regional Greenhouse Gas Initiative*. Accessed August, 2007. Available at http://www.rggi.org/about.htm

Sims, R. E. H. 2003. "Bioenergy to mitigate for climate change and meet the needs of society, the economy and the environment." *Mitigation and Adaptation Strategies for Global Change* 8(4):349-370.

UNFCCC-CDM. 2007. *Tool for the demonstration and assessment of additionality*. Accessed November, 2007. Available at http://cdm.unfccc.int/EB/029/eb29_repan05.pdf.

UNFCCC - CDM Bazaar. 2008b. *CDM Bazaar*. Accessed October, 2008. Available at http://www.cdmbazaar.net/about.asp.

UNFCCC. 2007. *Kyoto Protocol*. Accessed November, 2007. Available at http://unfccc.int/kyoto_protocol/items/2830.php.

Wang, M. 2005. *Updated Energy and Greenhouse Gas Emission Results of Fuel Ethanol*. Accessed November, 2007. Available at http://www.transportation.anl.gov/pdfs/TA/375.pdf.

Wang, M., M. Wu, and H. Huo. 2007. "Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types." *Environmental Research Letters* 2(024001):13.

WBCSD. 2007. *World Business Council for Sustainable Development*. Accessed August, 2007. Available at www.wbcsd.org.

Winters, P. 2008. *Environmental Groups Pressure EPA to Calculate Indirect Emissions*. Accessed November, 2008. Available at http://biofuelsandclimate.wordpress.com/2008/11/13/environmental-groups-pressure-epa-to-calculate-indirect-emissions/.

WRI. 2007. *World Resources Institute*. Accessed October, 2007. Available at http://www.wri.org/.

The Water Quality Effects of Corn Ethanol vs Switchgrass Based Biofuels in the Midwest

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Abstract: While biofuels may yield renewable fuel benefits, there could be downsides in terms of water quality and other environmental stressors, particularly if corn is relied upon exclusively as the feedstock. In this article, we describe a modeling system that links agricultural land use decisions in the Upper Mississippi River Basin (UMRB) to economic drivers. This modeling system is then used to assess several scenarios to identify the water quality effects of alternative land uses and the impacts of introducing on the landscape alternative feedstocks, such as switchgrass, to support renewable energy goals. Specifically, a scenario that assesses the water quality effects associated with an increase in corn acreage due to higher relative corn prices provides an estimate of the water quality effects that current biofuel policies may have in the UMRB. Since cellulosic alternatives such as switchgrass are not currently technologically feasible, we undertake two additional scenarios to assess the prices needed to induce switchgrass production in the watershed and the associated water quality changes. Switchgrass production has sizable benefits in terms of sediment and phosphorus losses, though targeting does little to improve sediment over the unrestricted location of switchgrass. Nitrate losses are still high, likely because of the high fertilization levels assumed. Our analysis can help evaluate the costs and environmental impacts associated with implementation strategies for the biofuel mandates of the new energy bill.

Unprecedented increases in biofuel production are occurring: the US now produces seven billion gallons of ethanol compared to less than two billion in 2002 (US EIA, 2008). Moreover, the latest energy bill, the Energy Independence and Security Act of 2007 (EISA 2007), mandates 36 billion gallons of ethanol by 2022 with only 15 billion coming from corn. The remaining 21 billion gallons are expected to come from second generation technologies which currently are not commercially viable, such as cellulosic ethanol.

In this article, we use an integrated economic and water quality modeling framework for the Upper Mississippi River Basin (UMRB) to conduct scenario analysis to shed light on potential water quality changes associated with ethanol production. We investigate the water quality changes associated with expanded corn based ethanol or cellulosic ethanol by using a calibrated watershed based water quality model to predict the water quality changes associated with spatially explicit land use changes. While cellulosic ethanol has a much higher net energy balance and it produces less greenhouse gases than corn-based ethanol, it is not currently commercially viable. Thus, assessing the land use and water quality changes associated with the production of ethanol via switchgrass requires the use of scenario analysis. Our modeling framework allows us to estimate the impacts of market forces through price effects and of policies based both on prices and/or environmental characteristics. The modeling system can

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be used to inform a wide range of future policies related to agricultural land use and conservation.

Two overarching questions motivate this research: 1) How much additional nutrients (N and P) are likely to end up in the rivers and streams of the UMRB as a result of the increases in the relative profitability of corn? and (2) How would those nutrient levels differ if switchgrass production in the UMRB became widespread in lieu of total reliance on corn-based ethanol?
We begin the article with a description of land use in the UMRB. Next we describe the key components of the integrated modeling framework; the data, models and assumptions used to generate a baseline are described. The baseline is then compared to several scenarios:

1. Commodity prices as forecast by the futures market and the latest Food and Agricultural Policy Research Institute (FAPRI) long term projections. The two sets of prices differ substantially both in terms of absolute and relative prices;

2. Switchgrass prices high enough to compete with traditional row crop production, and convert a sizable portion of the UMRB's cropland away from row crops, and

3. Switchgrass prices identical to scenario 2, but with production restricted to the most erodible land in the watershed. We then calculate the opportunity cost of producing switchgrass in the targeted areas, and the amount of subsidy necessary to implement the policy.

2. Landuse in the UMRB

We focus our analysis on the UMRB, a largely agricultural watershed that runs from the source of the Mississippi river in Minnesota to Cairo, Illinois. The total drainage area covers portions of seven states, but the main states included in the watershed are five. Nitrogen and phosphorous are the primary agricultural sources of nutrients in the UMRB and evidence suggests that both nitrate and phosphorous loads from the UMRB are linked to the hypoxic zone that occurs annually in the Gulf of Mexico (EPA Science Advisory Board). These nutrients also contribute to poor local water quality problems within many areas of the UMRB. In the most intensive agricultural portions of the Basin, well over 75% of the land is devoted to agricultural uses (USDA, 2000). Table 1 contains a summary of the acreage of key crops in the region. The major agricultural land use categories have remained relatively stable since the end of the 1990s, with the exception of a corn acreage increase in 2007, which is not expected to be maintained in 2008 (USDA NASS, 2008). However, beginning in 2006, there have been large and rapid changes of both absolute and relative prices for both corn and soybeans. Commodity and input prices are the most important drivers of farmers' choices. Therefore, it is very important to use reasonable forecasts to assess future land use changes, and their associated environmental impacts. In our model, farmers can choose between continuous corn, corn and soybean rotations, a corn-corn-soybean rotation and a five year corn alfalfa rotation, besides switchgrass. Farmers choose the most profitable rotation given their land characteristics (yields), their costs of production and the prices of the crops. Thus, the choice of rotation is heavily dependent on relative crop prices and input prices. We focus here on the relative crop price effects, but we are working on an extension that will include effects of input price changes (nitrogen and diesel).

The recent rises in prices have made forecasting long term equilibrium prices very complex. The latest FAPRI long term projections for the year 2018 forecast corn prices of $153.54 per metric ton (/mt) ($3.9/bushel) and soybean prices of $385.81/mt ($10.5/bushel) (FAPRI 2008). On the other hand, at the Chicago Board of Trade (CBOT) futures contracts for the Fall of 2010—the latest crop year for which both corn and soybean futures are available—are currently trading at $259.04/mt for corn ($6.58/bushel) and $540.13/mt for soybean ($14.7/bushel) (CBOT settlement June 19). The FAPRI predictions for 2010 are $152.36/mt ($3.87/bushel) for corn and $361.56/mt ($9.84/bushel) for soybeans (FAPRI, 2008). Thus, actual future market prices are diverging greatly from modeled forecasts.

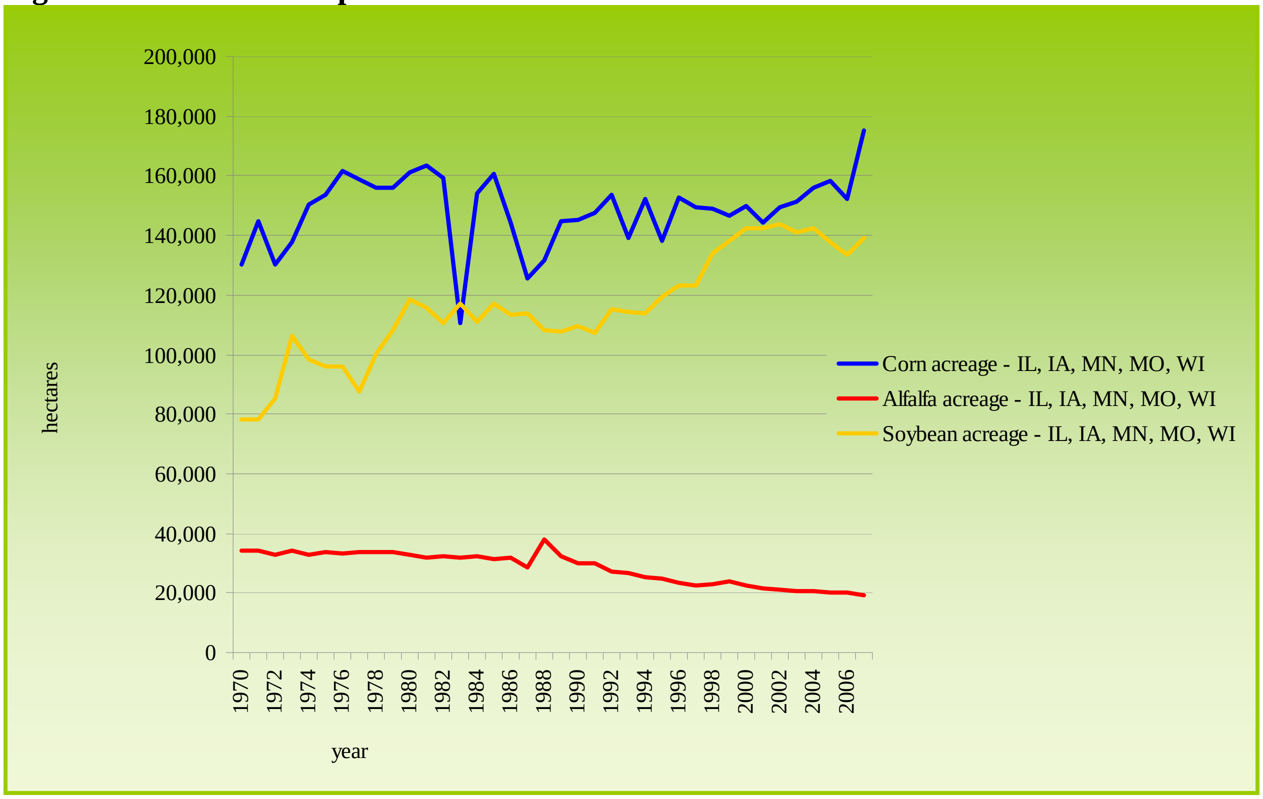
Table 1 – Land use changes in the Upper Mississippi River Basin (km^2)

	Corn area	Soybean area	Alfalfa area	CRP area	Switchgrass area
Baseline	119783	84618	22592	17344	0
FAPRI prices					
Without CRP	128281	99953	25623	0	0
With CRP	120371	95094	22572	17344	0
CBOT prices					
Without CRP	193612	36749	24204	0	0
With CRP	184402	33400	21014	17344	0
FAPRI prices					
With max net returns switchgrass	107264	83460	21099	17344	26952
With targeted switchgrass	110081	91618	15758	17344	23988
CBOT prices					
With max net returns switchgrass	170264	25642	19564	17344	24073
With targeted switchgrass	173102	31365	13912	17344	23988

Forecasting the price of feedstocks for cellulosic ethanol production is even more challenging, given that the technology is not commercially viable and the logistics and storage aspects of such a production systems are in their infancy. A recent study assumes costs ranging from $90 to $200 per ton (Toman et al., 2008). However, even though this is a very recent report, it assumes oil prices much lower than the current ones, as it is based on the 2006 Annual Energy Outlook projections.

The uncertainty in predicting absolute and relative prices of agricultural commodities and oil and natural gas translates into uncertainty in predicting farmers' choice of crop choice and rotations, and their consequent environmental impacts. A higher relative corn price means shifts into higher levels of corn production (as witnessed in 2007, when farmers, in response to high corn prices relative to soybeans, increased corn acreage by over 14% compared to the average acreage in the previous five years) (see Figure 1).

Figure 1 – Historical cropland levels in the five states of the UMRB



USDA NASS. 2008. Agricultural Statistics Data Base. URL: http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/

Another complicating factor is the fact that—particularly in the northern part of the UMRB—corn has been grown in rotation with alfalfa to be used for hay production. Because of transportation and storage costs due to hay's bulkiness, markets for hay tend to be local (Diersen, 2008). Therefore, demand for hay is highly inelastic for production levels higher than the levels that can be supported by the local livestock industry. Thus, price forecasts for hay at a national level, such as the one provided by FAPRI, have large margins of error when used to determine land use choices at a fine geographical scale. Indeed, the latest FAPRI Outlook states that "Hay markets are more fragmented than markets for most other agricultural commodities, so trends in national average prices may not be reflected at the local level" (FAPRI, 2008, p.110). For example, according to our analysis, if alfalfa prices in the UMRB were $128.55/metric ton ($116.62/ton) as forecast in FAPRI's long term projections for the year 2018, and the other crop prices followed FAPRI's projections, the alfalfa acreage would almost quadruple in the UMRB.

This suggests that the FAPRI forecast is likely overestimating the price of alfalfa in the watershed. Given that since the 1970s the alfalfa acreage in the five states of the watershed has been slowly declining (Figure 1), a more realistic alternative is to solve for the price of alfalfa that keeps the acreage constant. Thus, for both the FAPRI and CBOT prices we found the price of alfalfa the corresponded to an acreage close to the historical one and used that price.

The reasons behind these large changes in prices are currently the subject of intense debate which we do not attempt to resolve here, but most analysts point to rising energy prices, a low dollar, rising food demand from historically low income countries, trade policies in some parts of the world, and, most relevant for our discussion, ethanol policy which has raised the returns to corn production relative to other crops. Higher relative corn prices will alter crop planting decisions. In particular, the most likely expansion of corn production is likely to occur by shifting from corn-soybean, which is the historically dominant cropping rotation in the corn belt, to more use of continuous corn or corn-corn-soybean rotations.

In short, the combination of ethanol policy and subsidies with changing world conditions has lead to historically high crop prices. Farmers respond to prices by changing their cropping patterns, and this has the potential to reduce water quality in the region. Here we link two forecasted prices – which diverge in the predicted amount of land planted on corn - to changes to land use and cropping patterns in the Upper Mississippi River Basin and follow the impact of those land use changes onto their impacts on water quality. If degradation of water quality is occurring, as suggested by Simpson et al. (2008), it may be appropriate for government to consider implementation of policies that counteract these effects by supporting conservation actions that can offset this degradation (such as implementation of buffers, restoration of wetlands, or the elimination of fall fertilizer applications). Alternatively, it may be appropriate to re-configure the subsidies for ethanol production to favor an alternative feed stock, such as the perennial switchgrass.

3. The Integrated Modeling System

Our modeling system uses the 1997 Natural Resources Inventory (NRI) database. There are over 110,000 NRI "points" in the UMRB, each representing a combination of weather, soil characteristics, crop choices, rotations, and other agro-ecological conditions, thus allowing the model to represent the rich economic and environmental diversity of this spatially diverse, managed ecosystem. The economic model is linked to a watershed-level hydrological model, the Soil and Watershed Assessment Tool (SWAT) based again on the NRI.[4]

The SWAT model (Arnold and Fohrer, 2005; Gassman et al., 2007) is a conceptual, physically based, long-term, continuous watershed scale simulation model that operates on a daily time step. In SWAT, a watershed is divided into multiple subwatersheds, which are further subdivided into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics. Streamflow generation, sediment yield, and non-point-source loadings from each HRU are summed and the resulting loads are routed through channels,

[4] It is important to note that several other studies have integrated economic decision models with environmental process models to evaluate policies within the UMRB; notably Wu et al. (2004), Wu and Tanaka (2005), and Booth and Campbell (2007). For a discussion of similarities and differences in the modeling approaches see EPA, SAB (2007).

ponds, and/or reservoirs to the watershed outlet. Key components of SWAT include hydrology, plant growth, erosion, nutrient transport and transformation, and management practices. Outputs provided by SWAT include streamflow and in-stream loading or concentration estimates of sediment, organic nitrogen, nitrate, organic phosphorous, soluble phosphorus, and pesticides. Previous applications of SWAT for streamflow and/or pollutant loadings have compared favorably with measured data for a variety of watershed scales (Gassman et al., 2007). The UMRB SWAT simulation framework builds on the work of Arnold et al. (2000) and relies on numerous data sources to develop and execute the model. SWAT calibration and validation results for the entire UMRB or subregions are reported in Jha et al. (2006), Jha et al. (2003), Jha et al. (2007), Secchi et al. (2007).

The economic component of the modeling system assumes that farmers/landowners choose the crop and associated crop rotation for their land to maximize their net returns (profits) from farming. Thus, to predict the crop rotation and crop choice for an NRI point, we construct the costs of producing each crop under each rotation that is appropriate to that particular soil type, climate, and other physical characteristics. Of course, the profitability of a particular crop will also depend critically on the price of the commodity. The costs of production budgets are based on Iowa costs of production for 2008 (Duffy and Smith, 2008). We use state-based rates of fertilizer application, based on historical averages calculated by USDA ERS (USDA-ERS. 2007).

4. Scenario Analysis: Future Row Crop Landuse

To undertake policy relevant scenarios, we need to establish the likely cropping patterns and water quality in the UMRB in the absence of a perennial feedstock. As we noted above, this is complicated by the instability of the current price environment. Therefore, we use two price forecasts – the FAPRI ones, which correspond to a land use more closely aligned with the recent past, and the CBOT future prices, which would tilt the balance in favor of corn production. Once these scenarios are established, we can use the integrated modeling system just described to perform counterfactual scenario analysis. That is, we can imagine that positive returns to alternative crops, such as switchgrass, become reality to predict crop location across the region. With that altered cropping pattern, we run the calibrated SWAT model to predict pollutant loadings. Comparison with the row crop only scenarios allow us to indicate the degree to which water quality will be altered, for better or worse, due to the introduction of the new crop. Comparisons between the row crop only scenarios, on the other hand, illustrate the water quality impacts due to the relative increase in corn prices and the consequent increase in corn acreage.

As we noted above, an important agricultural land use in the region is enrollment in the Conservation Reserve Program (CRP), a government funded program that pays farmers to remove land from agricultural production. Over 17,000 km2 in the region were enrolled according to the NRI (Table 1). We assume that the land enrolled in CRP in 1997 remains in the CRP or returns to production. We will mostly focus here on the scenarios in which CRP remains constant in order to construct as much as possible a *ceteris paribus* analysis. Figure 2a illustrates how closely corn acreage would follow historical patterns if the FAPRI forecasts are realized. Most of the watershed was and would remain in corn – soybean rotations. In contrast, if the CBOT prices were to prevail, Iowa and Central Illinois would see tremendous increases in corn acreage, with consequent water quality effects as illustrated by Table 2.

Figure 2a. Location of corn area—no switchgrass scenarios

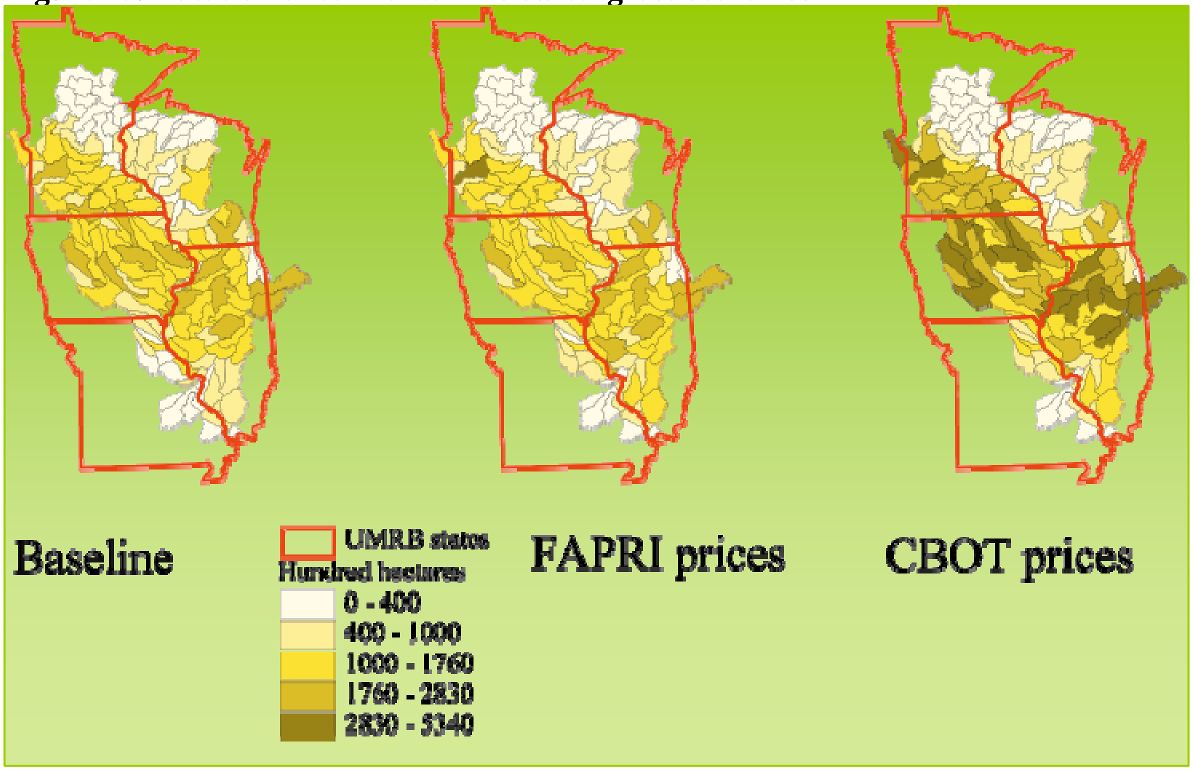


Figure 2b. Location of switchgrass area

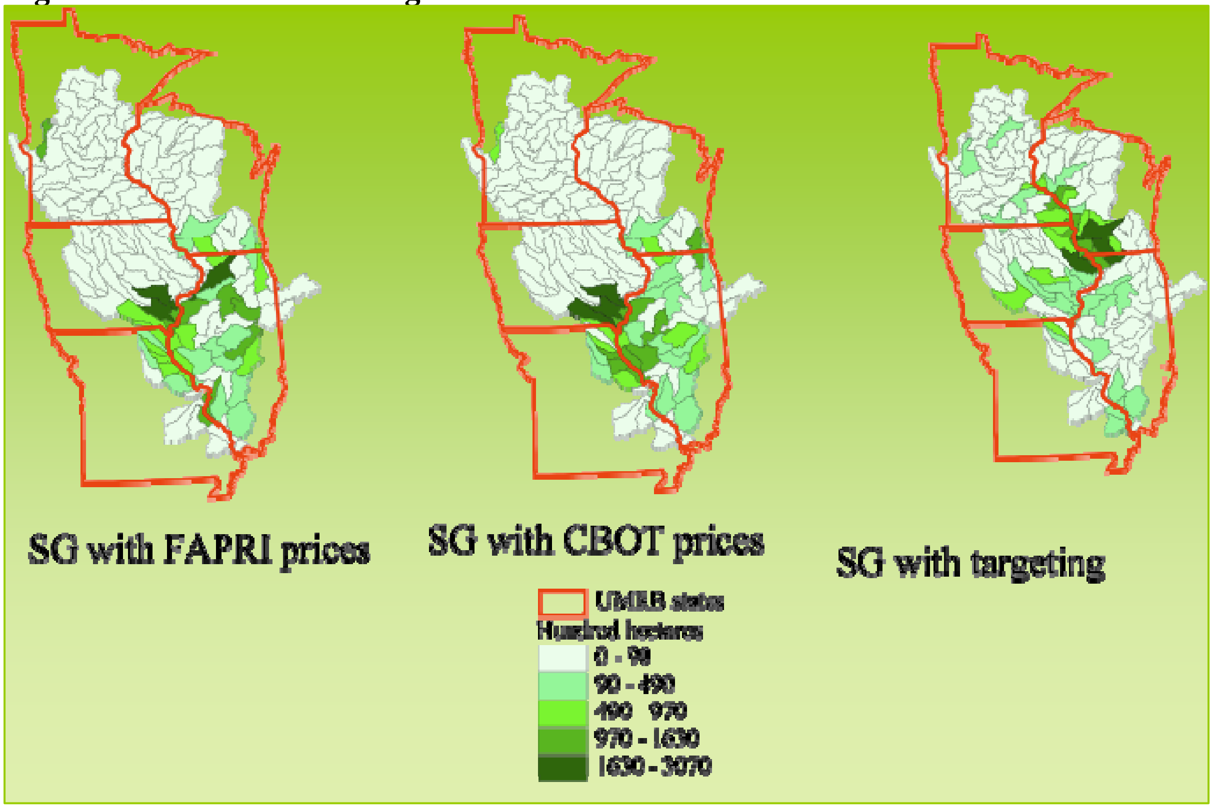


Table 2. SWAT results

	Avg Sediment Out Metric tons	Avg NO3 Out Kgs	Avg P Out Kgs
Baseline	23974833	329371667	25044750
FAPRI prices – No switchgrass	25412208	357808336	24912167
FAPRI prices – With switchgrass	22320875	363887503	22320708
FAPRI prices – With targeted switchgrass	21824958	411370837	22758375
CBOT prices – No switchgrass	24541375	346083335	27238500
CBOT prices – With switchgrass	20482083	353125001	24503250
CBOT prices – With targeted switchgrass	20263542	401183335	25009000

5. Scenario Analysis: Switchgrass

In addition to understanding the effect that higher corn prices could have on water quality in the region, it is also of interest to understand how water quality might change if an alternative feedstock were economically viable in the region.

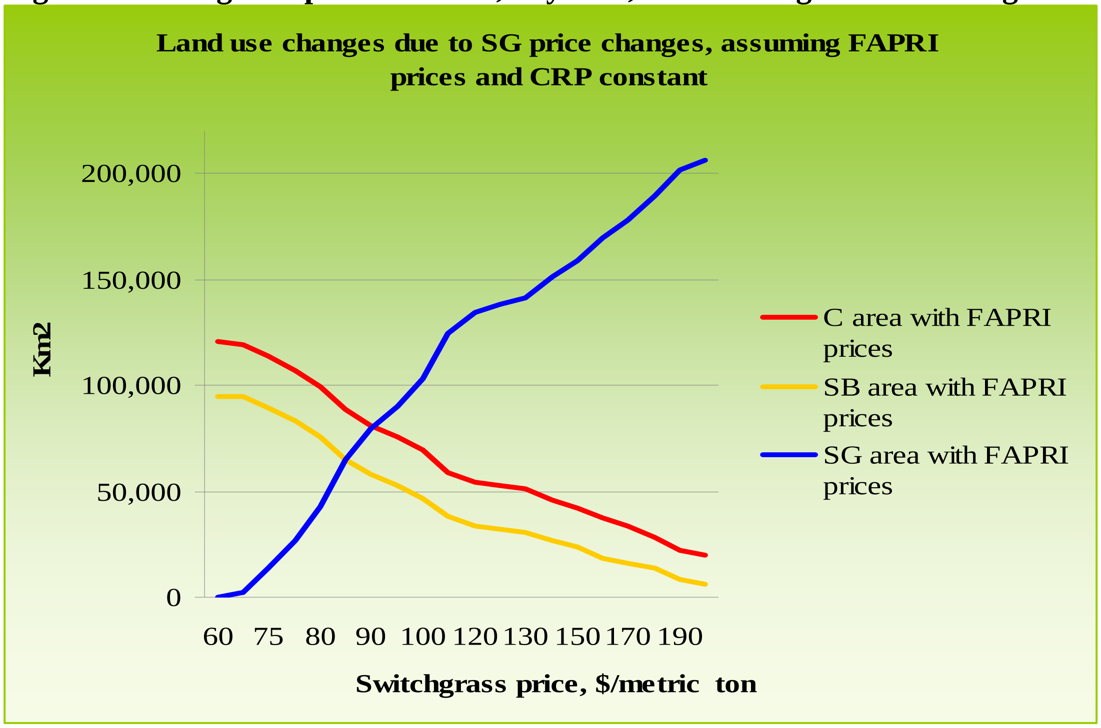
Switchgrass has been extensively evaluated as a biofuel crop throughout the US. Optimal fertilizer application rates have also been extensively investigated. Vogel et al. (2002) consider a wide range of nitrogen application rates and find that the optimal rate is 120 kg N ha^{-1}. There is consensus in the literature that higher rates of fertilization are needed in colder climate with a shorter growing season. McLaughlin and Adams Kszos (2005) and a recent extension publication (Barnhart et al., 2007) suggests higher rates would be optimal, at 157 kg N ha^{-1}. For our modeling purposes, we construct switchgrass net returns building upon Iowa State University's switchgrass budget cost assumptions (Duffy). The ISU budgets assume a fertilizer rate application of 112 kg ha^{-1}, but given the recent findings that higher rates may be optimal, we approximate a yield response function and identify optimal nitrogen application rate by using rates of 100, 120, 140 and 157 kg N ha^{-1} to compute yield and net returns from growing switchgrass throughout the UMRB. The optimal rates were determined by running the SWAT model at the rates mentioned above, finding the corresponding profit levels and choosing the highest possible profit level. Thus, our model is dependent on the SWAT model crop growth response function to nitrogen. We realize this crop growth may not be adequately representative of yield response functions. That is why we are working closely with agronomists and monitoring the published literature to make sure our assumptions are reasonable. Our annual costs of production for switchgrass are $34.6 per metric ton, constructed for a target yield of 15.38 tons ha^{-1}. It is important to note that these costs include only variable costs and only apply to land that is already cropped. Land of lesser quality and with lower rental rates may have lower opportunity costs than cropland. Note also that we are assuming the farmer would not incur any storage/transportation to storage costs. Because currently there are no substantial markets for switchgrass for ethanol production, the structure of such markets is largely a matter of speculation. The imputation of some of the costs related to processing could substantially alter net returns for farmers. Since we have assumed here that the processors would cover storage and transportation costs, our estimates could be considered to be on the low end of the spectrum. These costs may appear low compared to the switchgrass prices that we are using in the analysis. However, what needs to be considered are the opportunity costs – that is the returns from the production of alternative crops, in our case corn and soybeans. High prices in traditional row crop production mean that alternative crops will have to have relatively high prices to be grown.

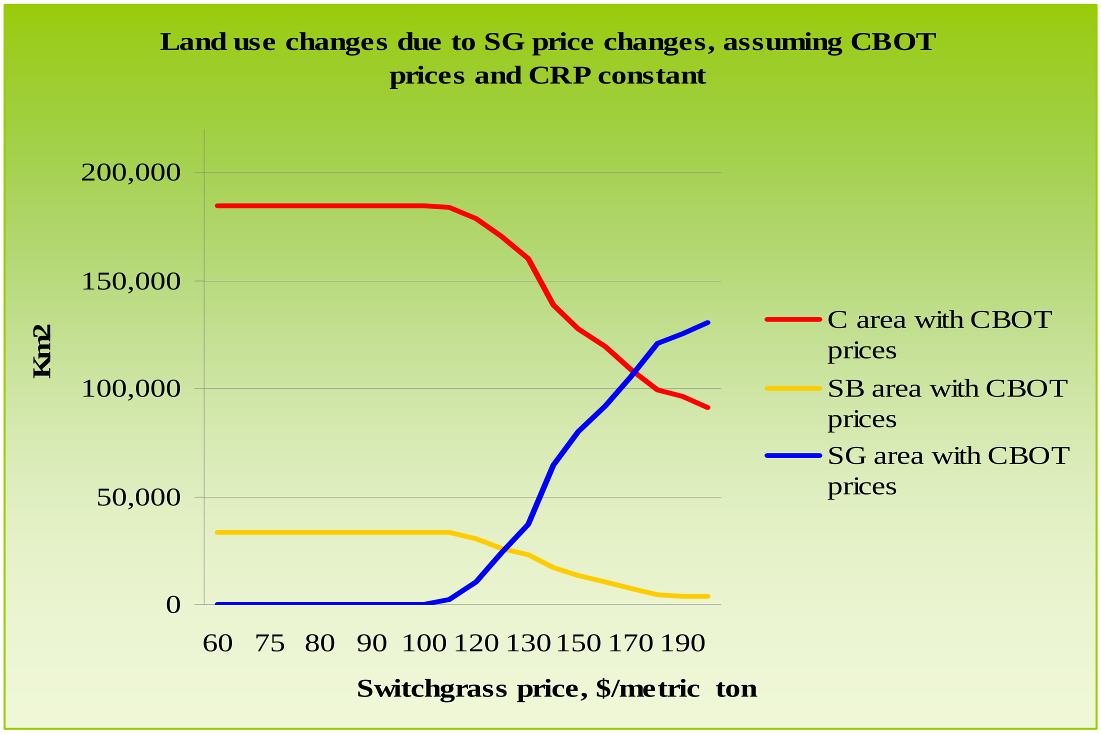
Using the full sets of budgets, we now use the full set of cost information on all crops to generate a switchgrass acreage response curve. As can be seen from Figure 3, the price that makes switchgrass economically competitive with corn and/or soybeans depends very much on the absolute level of row crop prices. Since most of the analysis forecasting cellulosic biomass prices is based on much lower than current oil and commodity prices (Toman et al., 2008; English et al., 2006), we decided to peg the determination of switchgrass' price level to the row crops to obtain around 10% cropland acreage in the watershed being planted in switchgrass. The reason for the – admittedly arbitrary – decision to look at a 10% conversion into switchgrass is that the Upper Mississippi includes some of the best corn producing land in the world. Thus, it is not likely that current cropland will all convert into perennials in the near future. As the following discussion shows, relatively high prices for switchgrass are needed to make the production of this crop more profitable than current row crop production and achieve a 10% land shift. Higher switchgrass prices still would be needed – given the current FAPRI and CBOT projections – to achieve higher switchgrass production in the basin. Note that our analysis could also be used to compute the amount of a subsidy for switchgrass production that would have to be paid to induce varying levels of acreage and production.

Figure 2b shows that the most profitable locations for growing switchgrass are in the southern part of the watershed, which has the longest growing season. The model could be extended to include other cultivars or species better suited for colder climates, and that would most likely affect the land use and water quality results. The figure also shows how the relative profitability of corn and soybean plays into the location of switchgrass acreage. With higher corn prices, in the CBOT scenario, some of the switchgrass leaves central Illinois, where corn production is more competitive, for southern Iowa and Missouri.

In addition to providing estimates of the water quality impact of switchgrass in the UMRB, the model can be used for policy analysis, for example to assess monetary outlays and water quality impacts of targeting policies. Here we undertake two such scenario simulations for illustrative purposes. Using both sets of prices, we assume that cultivation of switchgrass is restricted to the most erodible land in the watershed. The rationale is that erodible land would benefit the most from a perennial cover. Figure 2a shows that this would shift production to eastern Iowa and western Illinois. The acreage allocated to various crop rotations under the four switchgrass scenarios are provided in Table 1. The opportunity cost of the targeting scenario with FAPRI prices is almost $753 million per year, while the opportunity cost of targeting scenario with CBOT prices is much higher, over $1,319 million.

Figure 3. Acreage Response of Corn, Soybean, and Switchgrass to Switchgrass Prices





The water quality effects of these switchgrass scenarios are presented in Table 2. The model results show that switchgrass production has sizable benefits in terms of sediment losses, though targeting does little to improve sediment over the unrestricted location of switchgrass. This is largely due to the fact that we are measuring changes at the outlet of the watershed, and our targeting mechanism for switchgrass moves production further upstream, so that the impact at the outlet gets diluted by cumulative in-stream processes. The sum of upstream, local water quality impacts is likely higher with targeting, and we are conducting further analysis to ascertain this. The benefits of switchgrass in terms of sediment loads are highest under the CBOT scenario, because switchgrass takes the place of continuous corn more often. The model shows that the high level of fertilization for switchgrass we have assumed would result in worsening of the nitrate loads. This suggests that, since the switchgrass management practices that maximize returns to the farmer are most certainly not low input, incentives would have to be devised to limit fertilization of switchgrass.

The nitrite results are reversed in the case of phosphorus. Since there is no phosphorus fertilization on switchgrass, we would expect the highest losses in the scenario with CBOT prices without switchgrass, which has a lot of continuous corn, and the lowest in the scenario with FAPRI prices without switchgrass, which has the switchgrass and less corn/more beans. As in the case of sediment and nitrates, we would also expect losses to be higher in the targeted scenarios than in those with no targeting, because we are measuring loads at the outlet and targeting moves the switchgrass further up in the watershed.

6. Policy Implications and Conclusions

Simpson et al. (2008) conclude that the increase in corn acreage by about 15% seen from 2006 to 2007 could be expected to increase N loadings to the Gulf of Mexico by about 10% and P loadings by about 5%. Our findings are consistent with this prediction.

A number of important caveats should be noted. First, as discussed above, incomplete data on the location and land cover related to the Conservation Reserve Program have made accurate representation of its location on the landscape impossible. By representing the current CRP land to be in the same location as the land reported in 1997, we may be introducing substantive bias, though in which direction we cannot say. Further limitations include the fact that the model systematically underpredicts corn yields (1997-2006) by an average of 12% and soybeans by over 4%. Additionally, no yield drags for rotations are included in the model as no risk premia that farmers might require to plant a new crop, such as switchgrass, are included in the cost estimates. Moreover, our fertilizer levels for switchgrass are quite high. We are conducting further analysis to investigate the responses of the SWAT model to lower levels of nitrogen fertilizer application in switchgrass. However, our analysis points to the necessity of incorporating responses to economic incentives to environmental assessments. It is not realistic to just assume that farmers will limit themselves to low input production systems if higher input ones are more profitable. Most of the environmental analysis currently available simply assumes low levels of fertilizer application in biomass production systems, and this may not be the optimal behavior for farmers.

References

Barnhart S., L. Gibson, Bob Hartzler, M. Liebman, and K. Moore. 2007. *Switchgrass*. Extension Publication AG 200.

Booth, M.S., and C. Campbell. 2007. "Spring nitrate flux in the Mississippi River basin: A landscape model with conservation applications." *Environmental Science and Technology* 41 (15): 5410-5418.

Diersen, M. A. 2008. "Hay Price Forecasts at the State Level." Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. St. Louis, MO, April.

Duffy M., and D. Smith. 2008. "Estimated Costs of Crop Production in Iowa—2008." File A1-20. Iowa State University Extension, Ames, Iowa.

English, B., D. De La Torre, K. Jensen, C. Hellwinckel, J. Menard, B. Wilson, R. Roberts, and M. Walsh. 2006. "25% Renewable Energy for the United States by 2025: Agricultural and Economic Impacts." Department of Agricultural Economics, University of Tennessee, November.

US Environmental Protection Agency, Science Advisory Board, Hypoxia Advisory Panel. 2007. "Hypoxia in the Northern Gulf of Mexico: An Update by the EPA Science Advisory Board." EPA-SAB-08-003 Washington DC, December.

FAPRI Staff, 2008, FAPRI 2008 U.S. and World Agricultural Outlook [08-FSR1]. Food and Agricultural Policy Research Institute, Iowa State University and University of Missouri-Columbia, Ames, Iowa, January.

Gassman, P.W., M. Reyes, C.H. Green, and J.G. Arnold. 2007. "The Soil and Water Assessment Tool: Historical development, applications, and future directions." *Transactions of the ASABE* 50(4):1211-1250.

Jha, M., P.W. Gassman, and J.G. Arnold. 2007. "Water Quality Modeling for the Raccoon River Watershed using SWAT2000." *Transactions of the ASABE* 50(2):479-493.

Jha, M., P.W.Gassman, S. Secchi, and J. Arnold. 2003. "Configuration of SWAT for the Upper Mississippi River Basin: an application to two subwatersheds." Proceedings of the Total maximum Daily Load (TMDL) Environmental Regulations II, 8-12 November, Albuquerque, New Mexico. American Society of Agricultural Engineers, St. Joseph, MI. pp. 317-322.

—. 2006. "Upper Mississippi river basin modeling system part 2: baseline simulation results." In V.P. Singh and V.J. Xu eds., *Coastal Hydrology and Processes*. Water Resources Publications, Highlands Ranch, Colorado, pp. 117-126.

McLaughlin, S.B., and L. Adams Kszos. 2005. “Development of Switchgrass (Panicum vergatum) as a Bioenergy Feedstock in the US.” *Biomass and Bioenergy*, 28(6):515-535.

Simpson, T., A. Sharpley, R. Howarth, H. Paerl, and K. Mankin. 2008. “The New Gold Rush: Fueling Ethanol Production while Protecting Water Quality.” *Journal of Environmental Quality* 37(2): 318-324.

Toman M., J. Griffin, and R. J. Lempert. 2008. “Impacts on U.S. energy expenditures and greenhouse-gas emissions of increasing renewable-energy use.” RAND Technical report 384-1. Washington DC, June.

U.S. Department of Agriculture Economic Research Service. 2007. U.S. Fertilizer Use and Price.

U.S. Energy Information Administration. 2008. Annual Energy Outlook 2008. DOE/EIA-0383. Washington DC, June.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2000. Summary Report: 1997 National Resources Inventory, Washington, DC, and Statistical Laboratory, Iowa State University, Ames, Iowa, December.

U.S. Department of Agriculture National Agricultural Statistics Service. 2008. Crop Production Report 2-2 (10-08). Washington DC, October.

Vogel, K.P., J.J. Brejda, D.T. Walters, and D.R. Buxton. 2002. “Switchgrass biomass production in the Midwest USA: Harvest and nitrogen management.” *Agronomy Journal* 94(3):413–420.

Wu, J., R. Adams, C. Kling, and K. Tanaka. 2004. “Assessing the costs and environmental consequences of agricultural land use changes – A site-specific, policy-scale modeling approach.” *American Journal of Agricultural Economics*, 86(1): 26-42.

Wu, J. and K. Tanaka. 2005. “Reducing nitrogen runoff from the Upper Mississippi River basin to control hypoxia in the gulf of Mexico – Easements or taxes,” *Marine Resource Economics*, 20(2): 121-144.

The Impact of Biotech Corn Traits on Ethanol Production

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Abstract: The U.S. appears committed to the ongoing use of ethanol biofuels. In order to realize the desired benefits, ethanol production must continue to become more efficient. Although many technologies have emerged to improve efficiency this article focuses on the role that corn biotechnology might play. Biotechnology offers the potential to increase yields and lower input use as well as aid the conversion of corn to ethanol. This could have a meaningful impact on the energy balance and greenhouse gas emissions of ethanol production. This article finds those impacts to be significant, although likely to be eclipsed by cellulosic biofuels. However, the realization of any such benefits is conditioned by prevailing market and policy conditions. In a world where the market is less constrained by policy, increased yields afforded through biotechnology would increase corn production, which leads to lower corn price and larger ethanol production volume. When expected policies, most notably the Renewable Fuel Standard, are considered the impacts of biotechnology change. The Renewable Fuel Standard effectively limits the amount of corn based ethanol that is consumed as it shifts production towards cellulosic feedstocks. Despite the increase in corn production and reduced corn price there are only marginal increases in ethanol production volume. Accordingly, the RFSs support of competing biofuels might limit some dimensions of the ethanol industry including its ability to fully benefit from corn biotechnologies.

In the last decade biofuels have attracted increasing attention for their potential to reduce greenhouse gas emissions (GHG), provide sustainable energy supplies, and divert chronic agricultural commodity surpluses to new productive uses. In anticipation of the benefits many supporters have coalesced, making large investments in biofuels.

More recently, some of the benefits have been questioned amid rigorous debate. Corn ethanol, which comprises the vast majority of biofuels produced in the US, has been the focus of the scrutiny. Critics claim that corn ethanol is inefficient, using as much energy as it displaces. A comparison of ethanol life cycle analysis (LCA) studies (Farrell et al., 2006) explains the confusion by showing the diverse range of net energy ratios that have been derived, from negative (e.g., Patzek, 2004; Pimentel & Patzek, 2005) to significantly positive (Shapouri, Duffield, & Wang, 2002; Wang, 2001).

The debate over the environmental benefits of corn ethanol is equally ambiguous. Farrell et al. (2006) suggest that GHG emissions of ethanol are virtually on par with that of gasoline. Other studies (Fargione et al. 2008; McCarl et al., 2005; Searchinger et al., 2008) claim that when the increased land required to grow feedstocks is accounted for, GHG emissions may be significantly higher.

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The socio-economic impacts of corn ethanol production and policies have become perhaps the most hotly debated issue. While ethanol production has sought to create additional uses and demand for corn beyond its traditional food and feed markets, the recent spike in corn and other agricultural commodity prices has been viewed as an unfortunate consequence. Studies, both at the national (e.g., Tokgoz et al., 2007) and international (e.g., Hertel et al., 2008) level have linked the increasing use of corn for biofuel production with higher grain prices and, ultimately, somewhat higher food prices.

The ongoing debate suggests that the benefits of corn ethanol may not yet be clear cut. Given the early stage of development in corn ethanol production, technologies and policies should continue to evolve, improving the efficiency and balance of benefits. In this article we explore the potential contribution of coming technical advances on the development of the US corn ethanol market. Although different types of potential technological innovations exist, we focus on one, corn biotechnology, evaluating how it might influence corn ethanol's energy, environmental, and market impacts. We also examine how market structure and government policies could condition the influence of corn biotechnologies on ethanol production.

2. The Pipeline of Corn Biotechnology

Corn has been an attractive ethanol feedstock due, in large part, to an advanced and efficient system of breeding, production, and handling. In recent years, this system has been put to work to optimize corn for ethanol production. At the ethanol facility a number of improvements have been made to the process of converting corn to ethanol. Such advances have produced steady processing efficiency gains raising yields from 2.5 gallons per bushel (ga/bu) in 1980 to 2.8 in 2007 (Wu, 2008). During this same period the average corn yield rose from 104 to 150 bushels of corn per acre (bu/ac) in the U.S. (USDA, 2008). From these two types of improvements alone, the amount of ethanol that could be derived from an acre of corn grew 62%, with the lion's share of this increase coming from advances in corn production.

Improved corn productivity has come from the use of improved hybrids, precision agriculture, improved machinery, integrated pest management, reduced tillage and other innovations. One of the more recent additions to this arsenal is biotechnology. Corn hybrids improved through modern biotechnology have been found to lower production costs, increase yields and reduce the environmental footprint of corn production (Fernandez-Cornejo & Caswell, 2006; Kalaitzandonakes, 2003). Accordingly, since their introduction in 1996, biotech hybrids resistant to certain insect pests or some key broad spectrum herbicides have been commercialized and quickly adopted. In 2007, 3 out of 4 corn acres in the US were planted with such hybrids (USDA NASS, 2008). Continuing research and development has produced an increasingly robust pipeline of novel corn traits (Table 1). While the pipeline builds on the efficacy of the first generation offerings it also promises new traits such as drought resistance, increased nitrogen utilization and improved yield potential.

These agbiotech traits could impact ethanol production by (a) increasing corn yields; (b) modifying corn composition; (c) expanding corn acreage; (d) decreasing energy use in corn production; and (e) decreasing energy use in ethanol processing. Each trait may have more than one relevant impact. Drought tolerance, for instance, could increase corn yields, expand corn production to previously unsuitable lands, and decrease energy used for irrigation. Both the multifunctionality and the stackability of biotech traits hint at their promise. However, this multiplicity also makes *ex ante* impact analysis more difficult. In order to examine the potential impact of such new corn traits on ethanol production, we consider simplified scenarios that focus on the aggregate yield and input use effects of the biotech pipeline but ignore other potential impacts (e.g. decreased pesticide use, increased use of no till practices).

Table 1. The corn trait pipeline of key biotechnology firms

Syngenta	Expected Date	Monsanto	Expected Date	Dupont/Pioneer	Expected Date
VIP broad lep	2009	Drought tolerant corn	<2013	Stalk rot resistant	2009
Optimum GAT	2010	Drought tolerant corn II	<2015	Increased etoh 2&3	<2018
Corn rootworm II	2012	Nitrogen efficient corn	<2017	Corn rootworm II & III	<2018
Corn amylase	2009	High yielding corn	<2015	Corn borer II & III	<2018
Increased ethanol	2011	Yieldgard II (VT Pro)	2009	Drought tolerance	2013-15
		Yieldgard Rootworm III	<2017	Nitrogen efficiency	<2018
		High lysine corn	<2011	Increased yield	<2018
		High oil corn	<2017	Improved feed	2011-2013
		Increased etoh	current	High extractable starch	current

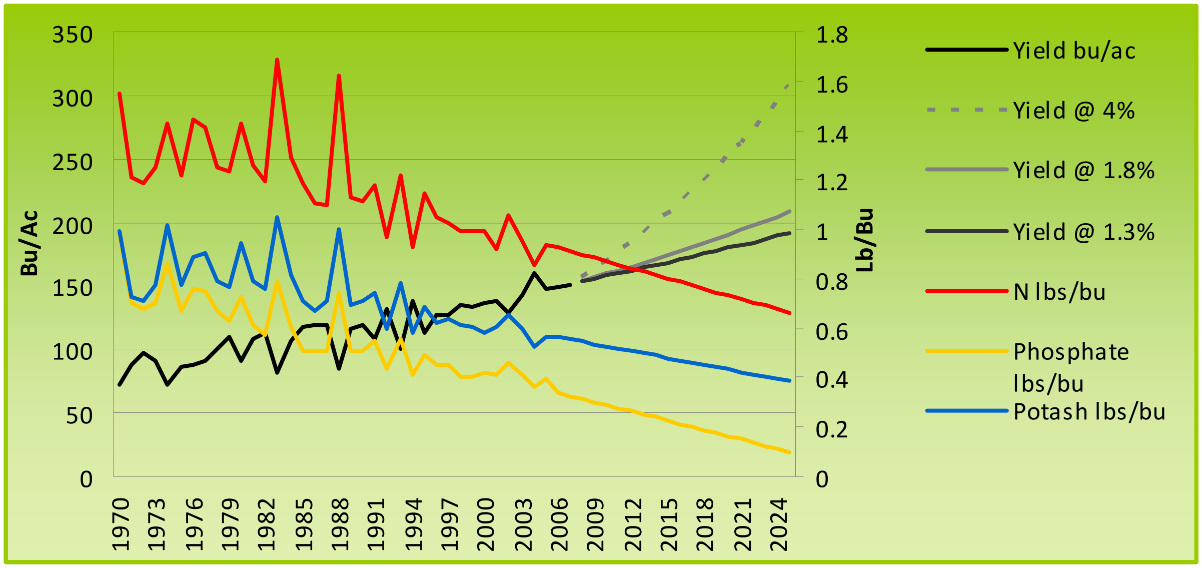
Source: company information

Prevailing long term trends show national corn yields have been growing at a rate of 1.3% per year over the last 20 years (USDA NASS, 2008). If such growth rate were carried forward, it would place the average yield of corn at approximately 175 bu/ac in 2018 and 192 bu/ac in 2025 (Figure 1). However, certain agbiotech developers have indicated that introduction of new biotech traits will accelerate the historical rate of yield growth in the near future. Monsanto, for example, anticipates that by 2030 average corn yields could be twice as large as those of today (Monsanto, n.d.).

Here we consider two possible scenarios of accelerating corn yields from novel biotech traits. First a 1.8% yield growth trend that is meant to reflect a more conservative scenario of continued adoption and evolution of first generation biotechnologies and gradual transition into second generation biotechnologies. Second, we consider an aggressive “upper bound” scenario of a 4% average yield growth rate, which slightly exceeds the projections of doubling the average corn yield in the next twenty years. These linear yield paths mean that by 2018 average corn yields in the US would grow to 184 bu/ac under the more conservative scenario and 233 bu/ac under the more aggressive scenario. Average yields would then further grow to 209 and 307 bu/ac respectively by 2025 (Figure 1).

These yield enhancements subsume the influence of a wide array of crop efficiencies targeted by the new biotech corn traits including resistance to drought and more efficient use of nutrients. Incremental improvements in such crop characteristics have been pursued through traditional corn breeding and other technologies for decades. As a result, between 1970 and 2005, while corn yield increased by 90%, the amount of nitrogen (N) fertilizer used per bushel declined by 36%, paralleled by reductions in phosphorous (P) and potassium (K) (USDA, 2007). In our analysis, we assume that new biotech corn traits can sustain these trends in input use. However, it is likely that these trends will ultimately be restricted by the nutrient removal of grain. Regardless, we assume that in 2025 a bushel of corn will require 0.66 lbs of Nitrogen, 0.1lbs of Phosphorous, and 0.39 lbs Potash (Figure 1).

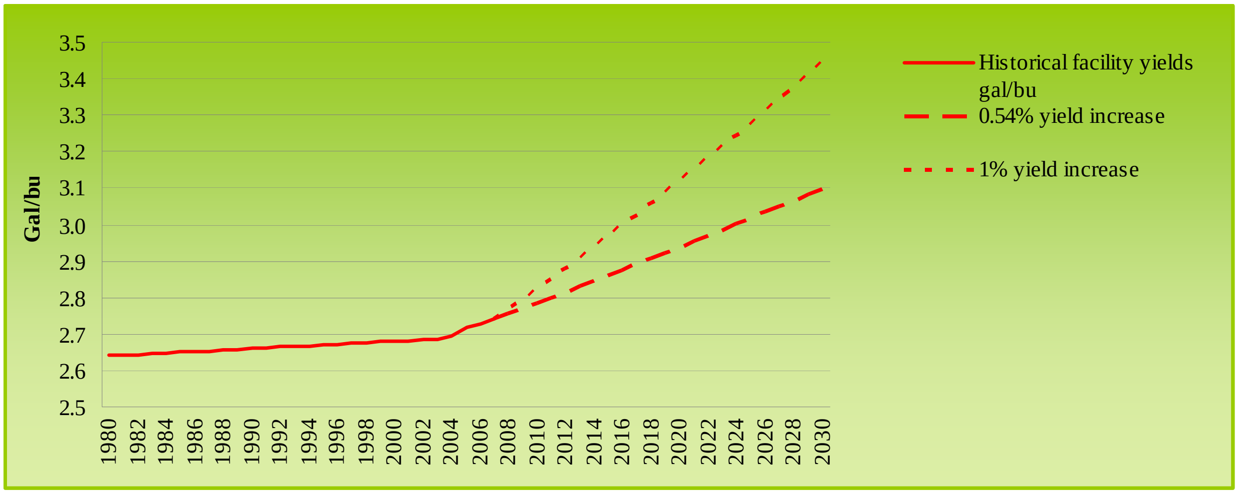
Figure 1. Historical and future trends in corn yields and fertilizer use



Agricultural biotechnology is also promising to positively impact ethanol processing efficiency—most notably with novel highly fermentable corn and high amylase corn hybrids. Existing highly fermentable corn hybrids have, on average, a 5% higher starch content which can result in a 2.7% increase in ethanol yield (Haefel et al., 2004). High amylase corn is promising to decrease the processing costs at the dry mill by essentially eliminating the liquefaction step—including much of the heat, water, tankage, sulfuric acid, and alpha-amylase associated with it (Urbanchuk, 2007). Other traits could further increase the amount of ethanol that can be extracted from a bushel of corn, facilitate the conversion process, or increase the value of co-products. Here we aggregate all such potential impacts of the agbiotech pipeline at the ethanol facility by considering scenarios of overall improved process efficiency. In the case of the LCA the efficiency is modeled as process energy reductions, and in the market analysis, the amount of ethanol yielded per bushel is used. In both cases these changes are assumed to occur at similar rates—a conservative annual rate of 0.54% and a more aggressive rate of 1% annually. Figure 2 shows the ethanol yield paths.

It is important to note that these yield growth rates are complicated by theoretical yield limits. The theoretical yield of ethanol from a bushel of corn containing 33.9 lbs of starch is 2.93 gallons. This theoretical maximum however, may be expanded as the starch profile of corn is increased and as cellulosic technology allows the fiber in corn to be converted to ethanol. The use of highly fermentable corn varieties has demonstrated the capability to increase ethanol yield by 2.7% (Haefele et al, 2004), potentially increasing the maximum to 3.01 gal/bu. The conversion of corn fiber would separately increase the theoretical maximum to 3.35 gal/bu (DOE EERE, 2008). Taken together this implies a theoretical maximum of corn at 3.44 gal/bu. Figure 2 shows the lower ethanol yield path crossing the theoretical starch yield limit in 2020 and the more aggressive in 2014. At which point it is assumed that either corn fiber is converted to ethanol and/or fermentable content of the kernel is otherwise increased.

Figure 2. Historical and future trends in ethanol conversion yields



3. Methods and Results

Given the diverse mode of action of the various new traits in the biotech pipeline, analysis of their potential impacts requires a system-wide approach. We use two types of analyses here: Life Cycle Analysis (LCA) and economic analysis using a partial equilibrium model of the US agricultural and biofuel economy. LCA allows us to examine whether the new corn biotechnologies could improve the environmental and energy profile of corn ethanol. The economic analysis allows us to determine whether these novel biotech traits could change the market fundamentals (e.g. demand, supply, prices) of corn ethanol and its feedstock while accounting for the interconnectedness of agricultural commodity markets and the influence of government policies.

Life Cycle Analysis

Many of the environmental benefits associated with biofuels (e.g., energy balance and GHG emissions) are best assessed using LCA. Energy balance is especially pertinent, as it provides insight on the relative efficiency changes that might be possible through biotech innovation. LCA evaluates the total “variable energy” use required to produce ethanol, including in corn production, ethanol manufacture, transport, and distribution. The energy analysis further includes losses in the individual processing steps, as well as losses associated with the extraction, refining, and distribution of the energy to the system. The “capital energy” contribution resulting from depreciation of equipment and machinery used to produce ethanol is also considered.

For our analysis we use the GREET model (Wang, 2008). In addition to its analytical advantages, the open source code adds to the transparency of the methodology and empirical results. Certain potential agronomic impacts of corn biotechnologies were directly incorporated into GREET in the form of yield increases and reductions in the per bushel fertilizer use (as illustrated in Figure 1). Other potential farm-level effects associated with increased corn yields required calculations exogenous to GREET. For this, simple assumptions were made using USDA ARMS data (2006) and the energy budget of Shapouri et al. (2002). Energy used for seed production, grain hauling, and drying was changed proportionately to the volume of grain produced. Conversely, energy used for field operations (tillage, harvest, spraying) and pesticide use was held proportionate to the area of land used per bushel of grain. The resulting energy budgets were applied to the GREET model and then compared to the baseline where yield growth rates and reductions in input usage are on par with historical trends.

All yield scenarios resulted in energy savings at the farm (Table 2). Staying on the historical yield and fertilizer use trends implies reductions in the gross energy consumption of 11% by 2017 and 25% by 2025. A shift in the annual yield growth to 1.8%, our more conservative yield scenario, offers moderate additional energy savings. Under the more aggressive scenario of 4% annual yield growth, however, energy savings are significantly higher—22% by 2017 and 36% by 2025.

Reductions in fertilizer use were responsible for a large portion of the energy savings. Only under the more aggressive scenario does yield begin to eclipse fertilizer use as the larger source of savings. This implies that biotechnology's ability to lower fertilizer use per bushel of corn produced could be important in achieving energy efficiency goals. Our empirical results also suggest that yield growth had a larger impact on petroleum use as machinery use decreased on a per bushel basis. Our analysis shows that the aggressive yield scenario reduces petroleum use dramatically when compared to a scenario of historical yields carried forward to 2025: 37% vs. 19%.

Table 2. GREET energy use changes associated with corn yield increases

	Baseline	Historical Yield Trend		Conservative Yield Growth Scenario		Aggressive Yield Growth Scenario	
Yield Path (annual % growth)	1.3	1.3	1.3	1.8	1.8	4	4
Year	2007	2017	2025	2017	2025	2017	2025
Yield bu/ac	151	172	191.6	180.6	208.5	224	306.84
N g/bu	413.7	351.1	301.1	351.1	301.1	351.1	301.1
P g/bu	148.2	91.0	45.2	91.0	45.2	91.0	45.2
K g/bu	251.9	209.2	175.0	209.2	175.0	209.2	175.0
Input/Impact Reductions							
Total energy		-14%	-25%	-16%	-27%	-22%	-36%
Petroleum		-10%	-19%	-14%	-22%	-24%	-37%
NOx		-14%	-26%	-17%	-29%	-24%	-40%
CO2		-11%	-21%	-13%	-22%	-18%	-30%
Input/Impact Reductions							
Total energy		-2%	-3%	-2%	-3%	-2%	-4%
Petroleum		-10%	-17%	-12%	-21%	-22%	-34%
NOx		-9%	-17%	-11%	-19%	-16%	-26%
CO2		-4%	-7%	-4%	-7%	-6%	-9%

Corn production, however, accounts for a relatively small share of the total energy use in ethanol production. After all the direct and indirect costs have been accounted for, corn only comprises 19% of the total energy consumption of a gallon of ethanol. Thus yield growth from novel biotech traits generated modest energy savings when the full production process of ethanol was considered—between 2% and 4% across all scenarios.

The assumed yield growth from the corn biotech pipeline offered more meaningful benefits to the petroleum balance of ethanol. Crop production accounts for a large share of the petroleum used in the production of ethanol. Accordingly, under the conservative yield growth scenario, petroleum use in ethanol declined by 14% in 2017 and 24% in 2025. Under the more aggressive yield scenario, petroleum use was reduced by 18% and 31%, respectively. Reductions in NOx emissions were equally significant.

Analysis of the potential impacts of biotech traits targeting an improved ethanol conversion process is similarly instructive. We assume that corn varieties with altered composition (e.g. high starch, high amylase) decrease the direct energy requirement of ethanol processing 0.54% per year in the conservative case and 1% in the aggressive case. These rates would equate to approximately a 5% direct energy reduction in 2017 and 10% in 2025 in the conservative scenario and double that in the more aggressive scenario. The 5% reduction in direct energy inputs is realized as a 2% reduction in the total energy and a 4% reduction in CO_2 needed to produce a gallon of ethanol. At a 20% reduction in direct energy (i.e. the aggressive case in 2025), total energy use falls by 7% while CO_2 falls by 14%.

The effects of increasing corn yields and improvements in the efficiency of the conversion process are additive and could be examined together. Under the scenario of moderate annual yield growth in corn production of 1.8% and 1% annual reduction in direct conversion energy the result is a 5% decrease in energy use in 2017 and 9% in 2025 (Table 3). Petroleum use decreased by 13% and 22% in the respective time periods. With the more aggressive yield increases, energy use decreased by 6% in 2017 and 10% in 2025 while petroleum use decreased by 23% and 36% respectively.

Table 3. GREET energy use changes from baseline with corn yield increases and decreased energy requirements for ethanol conversion

Year	2017	2025	2017	2025		
Corn Yield Path	1.8	1.8	4	4	Herbaceous Biomass	Corn Stover
Conversion Energy Path	-1%	-1%	-1%	-1%		
Total energy	-5%	-9%	-6%	-10%	-14%	-23%
Petroleum	-13%	-22%	-23%	-36%	-23%	-19%
NOx	-14%	-25%	-19%	-32%	19%	16%

To put these impacts into perspective it is instructive to compare this improved corn ethanol system to that of cellulosic ethanol. Stock assumptions in GREET (Wang, 2008) were used employing a yield of 90 gal. of cellulosic ethanol per ton of biomass, which is believed to be appropriate for the time period considered here (e.g. Tiffany, 2007). These cellulosic scenarios were then compared to a baseline of 2007/08 production of corn ethanol, in similar fashion to the preceding scenarios. The conversion of herbaceous biomass decreased energy use by 14%, petroleum by 23% and led to increases in fuel related NOx emissions. Corn stover offered more robust energy savings with a decrease of 23% and petroleum use by 19%. In either case it would appear that the cellulosic system could outpace corn biotechnology in reducing the energy demands of ethanol. However, corn ethanol might excel at reducing petroleum consumption and certain fuel related GHG emissions.

Economic Analysis

The energy, environmental and economic impacts of the biotech pipeline in corn ethanol production may not always move in parallel. One reason for this is that the corn feedstock represents a much higher share of ethanol's cost than its energy use. To this point, in the LCA baseline examined above, corn production is associated with approximately 35% of the direct energy used to produce ethanol and 19% of the total energy. In comparison, between 2005 and 2008 corn represented between 41% and 76% of the total costs in ethanol production at representative dry mills (Hofstrand, 2008).

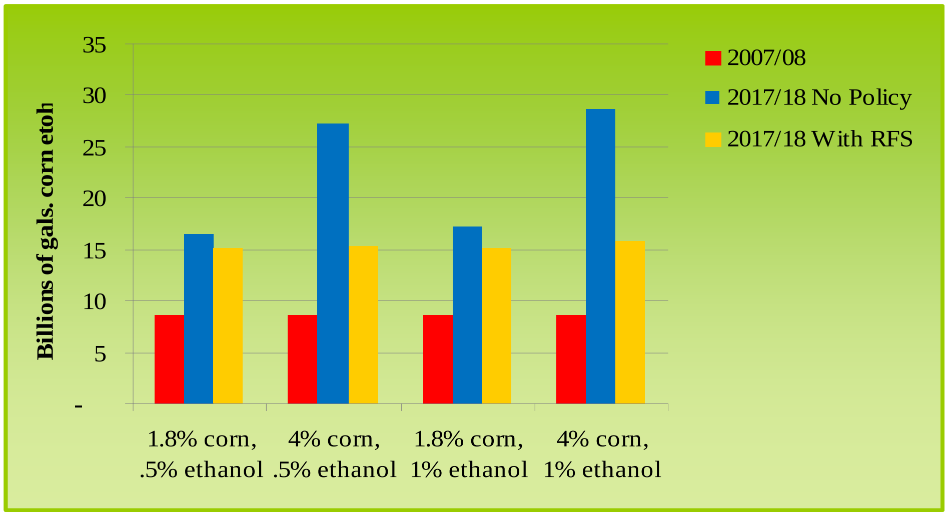
We explore these issues in some detail by evaluating the economic implications of the same innovation scenarios examined above within the context of a partial equilibrium model. The scenarios used for the economic analysis are similar to those used in the LCA with corn yields increasing by either 1.8% or 4%. However, instead of reducing processing energy, as in the LCA, we increased the amount of ethanol that could be derived from a bushel of corn by either .54% or 1% (Figure 2).

Using these yield paths, we first analyze the potential impacts of increased corn productivity on the supply of ethanol in the US. To emphasize the conditioning effects of market structure and government policies, we first calculate such supply response under some unrealistic but instructive assumptions. Namely, we assume that corn area is constant, the amount of corn directed to feed and exports is constant, and the amount of ethanol imports does not change. Under these assumptions, we can determine how much ethanol supply could grow with increasing yields by calculating the residual of the corn market that is available to ethanol production.

In 2007/08, the U.S. was scheduled to produce 8.6 billion gallons of fuel ethanol (Figure 3 "2007/2008"). Under the more conservative yield scenario, approximately 17 billion gallons could be produced in 2017/18 (Figure 3 "2017/18 No Policy"). Under the more aggressive yield scenario, the productive capacity of the U.S. would grow to 27 billion gallons. Further doubling the growth rate in the ethanol conversion yield from 0.54% to 1% per year increases the capacity by another billion gallons.

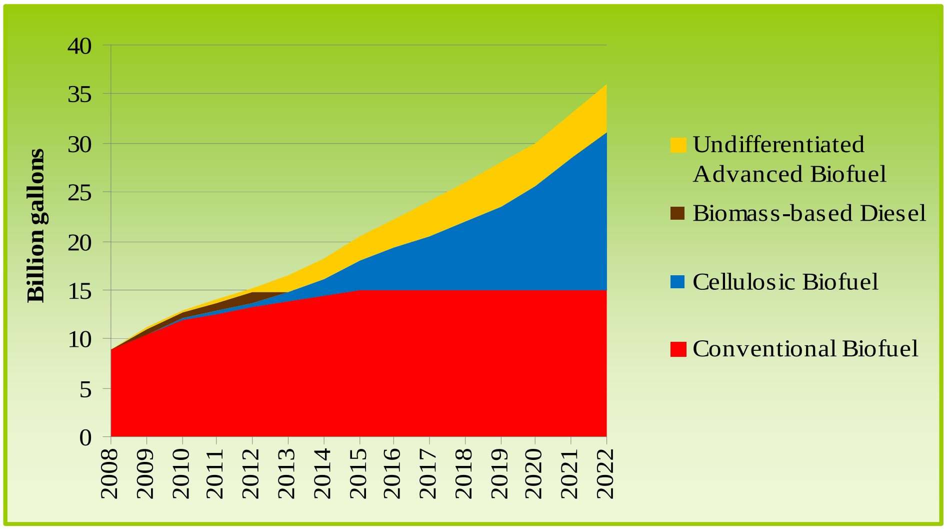
Although these large increases in corn ethanol production provide a sense of the potential impact of the biotechnology pipeline, they do not reflect reality as market dynamics and government policies are not regarded. A number of policies have been implemented to support ethanol production complicating market response to the technological improvements. Perhaps most notable of these policies is the RFS which sets supply and demand mandates.

Figure 3. Market impacts of corn and ethanol yield increases



The RFS encourages corn ethanol growth from 8.6 billion gallons in 2008 to 15 billion gallons in 2015 where the mandate then remains fixed (Figure 4). During this period separate cellulosic and "other advanced" biofuel mandates are put in place and increased, extending total biofuel production to over 25 billion gallons in 2018. This means that 9 of the 25 billion gallons of biofuel mandated in 2018 will need to come from cellulosic and "other advanced" feedstocks, regardless of the cost to make these fuels. Only if increased corn supply could lower corn price (and thus ethanol price) to a point where consumers were willing to consume more than 25 billion gallons of biofuel could the market for corn ethanol expand. However, other corn uses (e.g. export, feed) also expand with declining corn prices making it unlikely that corn price would fall to that level. As expected, when the RFS is explicitly considered and corn market is allowed to adjust to price changes, corn ethanol production is effectively capped at around 15 billion gallons (Figure 3 "2017/18 With RFS").

Figure 4. The Energy Independence & Security Act of 2007



In order to evaluate the influence of market complexities and government policies on the potential impacts of the biotech pipeline in ethanol production, we use the US FAPRI model—a detailed economic model of major US agricultural commodity and biofuel markets (Thompson et al., 2008). In addition to carrying market trends out to 2018 the model incorporates the foreseeable policy environment, where all relevant policies are held constant or at announced levels, including the RFS. We report key results from this analysis in Table 4.

Our empirical results suggest that between 2008 and 2018 under the most aggressive corn and ethanol yield scenario corn acreage decreases by 3% while production increases by 13%. Corn prices fall by 21% resulting in a 33% expansion in exports and a 14% increase in domestic feed use. Production and price of other grains decrease under pressure from the expanding corn supply and declining corn price.

Table 4. Market Effects of Corn Biotechnology Scenarios Under the RFS

Annual Corn Yield Increase: **Annual Conversion Yield Increase:**		**1.8%** **0.5%**	**4.0%** **0.5%**	**1.8%** **1.0%**	**4.0%** **1.0%**
Corn	Planted Area	0%	-3%	-1%	-3%
	Production	2%	13%	2%	13%
	Domestic Use	1%	8%	0%	7%
	Exports	5%	33%	7%	33%
	Price ($/bu.)	-3%	-21%	-4%	-21%
Soybean	Planted Area	0%	2%	1%	3%
	Soybeans ($/bu.)	0%	-2%	0%	-2%
Sorghum	Planted Area	-2%	-9%	-2%	-9%
	Sorghum ($/bu.)	-2%	-13%	-2%	-13%
Ethanol	Production	0%	1%	0%	3%
	Corn Dry Milled	0%	2%	-2%	1%
	Corn Cost of Ethanol	-3%	-21%	-7%	-23%
	Ethanol ($/gallon)	-2%	-12%	-4%	-13%
	Distillers Grains ($/ton)	-3%	-20%	-2%	-19%
	Net Operating Return	1%	-8%	-3%	-5%
	Net Imports (Ethyl Alcohol)	-4%	-13%	-8%	-13%

During this period the amount of corn ethanol produced increases only mildly, and cellulosic biofuels decline. Perhaps most interesting to this paper is the negative effect of yield enhancements on the economics of the ethanol facility. Although the cost of corn in ethanol production decreases by 23%, this decrease is conditioned by a 13% decrease in ethanol price and a 19% decrease in distiller dried grain price.

Next consider a world without an RFS. The technology scenarios have a starkly different impact on the market (Table 5). As might be expected ethanol production is up 15%, a level much higher than in the world with the RFS. The ethanol industry also accounts for a larger share of the increased corn production and the export market relatively less, although it too is up 28% from the baseline. The stronger ethanol demand and the absence of the competing biofuel mandates lead to less downward pressure on ethanol prices. With ethanol price only declining

4% from the baseline, the more efficient ethanol plants see large revenue increases—47% in the case of the aggressive scenario. These results illustrate the significant role that government policies can play on the impacts of the biotech pipeline in corn ethanol production.

Table 5. Market Effects of Corn Biotechnology Scenarios in a World with No RFS

Annual Corn Yield Increase: **Annual Conversion Yield Increase:**		**1.8%** **0.5%**	**4.0%** **0.5%**	**1.8%** **1.0%**	**4.0%** **1.0%**
Corn	Planted Area	0%	-1%	0%	-1%
	Production	2%	15%	2%	15%
	Domestic Use	2%	11%	2%	11%
	Exports	4%	27%	4%	28%
	Price ($/bu.)	-3%	-19%	-3%	-19%
Soybean	Planted Area	0%	1%	0%	2%
	Soybeans ($/bu.)	0%	2%	0%	2%
Sorghum	Planted Area	-2%	-8%	-2%	-8%
	Sorghum ($/bu.)	-2%	-11%	-2%	-12%
Ethanol	Production	2%	13%	5%	15%
	Corn Dry Milled	2%	14%	2%	14%
	Corn Cost of Ethanol	-3%	-18%	-6%	-21%
	Ethanol ($/gallon)	0%	-3%	-1%	-4%
	Distillers Grains ($/ton)	-4%	-23%	-7%	-25%
	Net Operating Return	6%	41%	11%	47%
	Net Imports (Ethyl Alcohol)	2%	10%	4%	11%

4. Concluding Comments

Our analysis suggests that significant benefits may be possible from corn yield increases and reductions in input use derived from biotech traits. These include large reductions in the amount of petroleum used for crop production; meaningful reductions in gross energy use and certain greenhouse gas emissions; as well as decreased costs and increased revenue of ethanol production that stem from a more efficient feedstock and processing system. Favorable plant economics coupled with the increased corn production have the potential to significantly increase ethanol production in the US.

We also find that the magnitudes of these benefits are influenced by government policies and market structure. The RFS, for example, would limit the utilization of corn for ethanol in favor of other fuels despite the efficiency improvements from the biotech pipeline. This may be justified as cellulosic fuels appear to offer reductions in energy consumption and greenhouse gas emissions. However, the cost competitiveness of cellulosic biofuels is currently unclear and so is the industry's ability to develop a system that can effectively produce and handle the vast amounts of feedstock necessary to fulfill the RFS. Given the early stages of development we expect that government policies will continue to evolve along with technological innovation.

References

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. "Land Clearing and the Biofuel Carbon Debt." *Science* 319(5867):1235-38.

Farrell, A.E., R.J. Plevin, B.T. Turner, A.D. Jones, M. O'Hare, and D.M. Kammen. 2006. "Ethanol can Contribute to Energy and Environmental Goals." *Science* 310:506-8.

Fernandez-Cornejo, J., and M. Caswell. 2006. *The First Decade of Genetically Engineered Crops in the United States*. Economic Information Bulletin 11, April. Washington DC: U.S Department of Agriculture, Economic Research Service.

Heaton, E., T. Voigt, and S.P. Long. 2004. "A Quantitative Review Comparing the Yields of Two Candidate C4 Perennial Biomass Crops in Relation to Nitrogen, Temperature and Water." *Biomass and Bioenergy* 27:21-30.

Hertel, T., W. Tyner, and D. Birur. 2008. *Biofuels for All? Understanding the Global Impacts of Multinational Mandates*. GTAP Working Paper No. 51. West Lafayette, IN: Purdue University.

Haefele, D., F. Owens, K. O'Bryan, and D. Sevenich. 2004. "Selection and Optimization of Corn Hybrids for Fuel Ethanol Production. In *Proceedings of the 59th Annual Corn and Sorghum Research Conference*. Alexandria, VA: American Seed Trade Association.

Hofstrand, D., and A. Johanns. 2008. *Tracking Ethanol Profitability*. Ag Decision Maker, D1-10 Ethanol Profitability. Ames, IA: Iowa State University. Available on the World Wide Web: http://www.extension.iastate.edu/AGDM/energy/html/d1-10.html.

Kalaitzandonakes, N. 2003. *Economic and Environmental Impacts of Agbiotech: A Global Perspective*. New York: Kluwer-Plenum Academic Publishers.

McCarl, B.A., D. Gillig, L.H. Chi, M. El-Halwagi, X.Y. Qin, and G.C. Cornforth. 2005. "Potential for Biofuel-Based Greenhouse Gas Emission Mitigation: Rationale and Potential." In J.L. Outlaw, K.J. Collins, and J.A. Duffield, eds., *Agriculture as a Producer and Consumer of Energy*. Cambridge, MA: CABI Publishers.

McLaren, J.S. 2008. "The Economic Realities, Sustainable Opportunities, and Technical Promises of Biofuels." *AgBioForum* 11(1):8-20.

Monsanto website. n.d. Available at http://www.monsanto.com/responsibility/our_pledge/healthier_environment/raising_yield_peracre.asp (accessed 27 August 2008).

Patzek, T.W. 2004. "Thermodynamics of the Corn-Ethanol Biofuel Cycle." *Critical Reviews in Plant Sciences* 23(6):519-67.

Pimentel, D., and T.W. Patzek. 2005. "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower." *Natural Resource Research* 14(1):65-76.

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change." *Science* 319(5867):1238-40.

Shapouri, H., J.A. Duffield, and M. Wang. 2002. *The Energy Balance of Corn Ethanol: An Update*. Agricultural Economic Report No. 814. Washington DC: U.S. Department of Agriculture, Office of the Chief Economist.

Thompson, W., S. Meyer, and P. Westhoff. 2008, July. *Model of the US Ethanol Market*. FAPRI-MU Report #07-08. Columbia, MO: University of Missouri, Food and Agricultural Policy Research Institute (FAPRI). Available at www.fapri.missouri.edu/outreach/publications/2008/FAPRI_MU_Report_07_08.pdf.

Tiffany, D.G., B. Jordan, E. Dietrich, and B. Vargo-Daggett. 2006. *Energy and Chemicals from Native Grasses: Production, Transportation and Processing Technologies Considered in the Northern Great Plains*. Staff Paper P06-11. St. Paul, MN: University of Minnesota, Department of Applied Economics.

Tokgoz, S., A. Elobeid, J.F. Fabiosa, D.J. Hayes, B.A. Babcock, T-H. Yu. 2007. *Emerging Biofuels: Outlook of Effects on U.S. Grain, Oilseed, and Livestock Markets*. Staff Report 07-SR 101. Ames, IA: Iowa State University, Center for Agricultural and Rural Development (CARD).

Urbanchuk, J. M. 2007. "Economic Impact Analysis of Event 3272 Corn on Dry Mill Ethanol Production." Wayne, PA: LECG, LLC.

U.S. Department of Agriculture, National Agricultural Statistics Service (NASS). 2008. *Quickstats*. Washington, DC: Author.

U.S. Department of Agriculture, Economic Research Service (ERS). 2007 *U.S. Fertilizer Use and Price.* Washington, DC.

U.S. Department of Agriculture, Economic Research Service (ERS), National Agricultural Statistics Service (NASS). 2006 *Agricultural Resource Management Survey (ARMS)* Washington, DC.

U.S. Department of Energy, Energy Efficiency and Renewable Energy. "Theoretical Yield Calculator." Accessed 27 August, 2008. Available at http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html.

Wang, M. 2001. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model (Version 1.6) [Computer software]. Argonne, IL: Transportation Technology R&D Center, Argonne National Laboratory.

——. 2008. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model (Version 1.8b) [Computer software]. Argonne, IL: Transportation Technology R&D Center, Argonne National Laboratory.

Wu, M. 2008, March 27. *Analysis of the Efficiency of the U.S. Ethanol Industry 2007*. Argonne, IL: Center for Transportation Research, Argonne National Laboratory.

Weaning Off Corn: Crop Residues and the Transition to Cellulosic Ethanol

Scott A. Malcolm[1]

Abstract: Recent legislation has set ambitious targets for cellulosic ethanol to be realized in the not-too-distant future. While corn-based ethanol will continue to be the most important supply, its share—but not the quantity—will diminish over time. How agriculture responds to market and environmental challenges will be in large part governed by the evolution and adoption of cellulosic ethanol production technology. One possible scenario is that development of cellulosic production technology occurs more rapidly than expected, before the establishment of alternative cellulosic feedstocks, enabling crop residues to be used in lieu of corn during the transition to dedicated energy crops. This article examines the market and environmental consequences of shifting biofuel production from corn to cellulosic production technology fed by crop residues. Results show that reducing corn required for ethanol by increasing production of crop residue-based cellulosic ethanol shifts crop production and changes tillage and rotation choice. These changes demonstrate mixed effects on key environmental indicators, with benefits and adverse consequences varying regionally.

Recent and recurring episodes in energy markets, environmental concerns, and growing concerns about dependency on oil imports have fueled great interest in biofuels. Demand for biofuels has expanded the market for agricultural products, putting pressure on the land base and squeezing competitive demands for corn. Emerging biofuel production technologies will in fact create new agricultural products, which will compete for land and resources with traditional crops. These new products, while promising for the long-term, are not yet planted in commercial quantities, and are unlikely to be major components of the first wave of cellulosic ethanol production. Concurrently, high prices for food and feed have led to calls for reduced reliance on traditional crops for the production of biofuels.

Recent legislation has set ambitious targets for cellulosic ethanol to be realized in the not-too-distant future. Throughout the duration of the legislation, corn-based ethanol will continue to be the most important supply, but its share—not its quantity—will diminish over time. How agriculture responds to market and environmental challenges will be in large part governed by the evolution of cellulosic ethanol. One possible scenario is that development of cellulosic production technology occurs more rapidly than expected, before the establishment of alternative cellulosic feedstocks, enabling crop residues to be used in lieu of corn during the transition to dedicated energy crops. This article examines the market and environmental consequences of shifting biofuel production from corn to nascent cellulosic production technology fed by crop

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residues. Results show that taking pressure off corn by encouraging crop residue-based cellulosic ethanol provides some environmental gains.

Over the history of domestic biofuel production the predominant feedstock has been corn. During most of that time, ethanol has been a small market for corn growers. Recently, however, the share of total domestic corn production supplying the ethanol market has grown, rising from 7.5% (705 million bushels) in 2001 to 22.6% (2950 million bushels) in 2007 (USDA-ERS, 2008). This share is expected to climb even further, to around 35%, when corn ethanol production reaches 15 billion gallons. This diversion of a significant portion of the corn crop for energy uses has sparked a wide debate on its effects on food and feed prices, both domestically and internationally. Also, because of the relatively intensive nature of corn production, the effects on the environment of greater corn production at the expense of other, less intensive crops are of concern.

Technological advances in production of ethanol from cellulosic feedstocks promise to be commercially realized in the near future. Recent policy initiatives, such as the Energy Independence and Security Act of 2007 (EISA), are founded on the premise that such technology will come online soon and grow at a rate that will make cellulosic-based ethanol a majority of production by 2022. While there is a provision in the legislation for waivers of mandated levels for cellulosic-based biofuels, predictions about when and how much cellulosic capacity will actually be available range from very pessimistic to very optimistic.

As new technologies emerge, corn will remain the predominant feedstock for ethanol production, but different cellulosic feedstocks will compete to supply the new refineries. Crop residues, such as corn stover and wheat straw, are already widely available, although significant markets for residues do not currently exist. Crop residues do, however, play an important role in nutrient, erosion, and carbon levels in the soil, and the amount of residue that can be harvested while maintaining soil productivity is affected by tillage regime and other factors (USDA-NRCS, 2006). Switchgrass and other perennial grasses present high-yielding alternatives to crop residues. While they show promise in field trials, these grasses are not yet grown on a commercial scale, and issues of farmer adoption, logistics, and market institutions will need to be resolved before large-scale production of these crops takes place. Since the management practices that will prevail are unknown, the consequences to the environment of large-scale production of perennial grasses are difficult to assess. Short-rotation woody crops, such as willow and poplar, are another feedstock option. These are fast growing trees that produce sufficient biomass for harvest in a few years, rather than the decades common in traditional forestry. These crops are also not currently grown on a wide scale. While it is impossible to forecast the supply of each feedstock with certainty, it is reasonable to assume that crop residues will factor prominently in the early phases of cellulosic production.

EISA is the latest step on a policy pathway to stimulate greater production and use of biofuels. The legislation sets separate targets for two major categories: “conventional” ethanol, principally from corn; and “advanced” biofuels, which includes ethanol from cellulosic sources. Since the end product—ethanol—is the same for both processes and the production costs are likely to be different, there is no reason to believe that the pre-ordained quantity levels specified by legislation will be the most economically efficient. Production of ethanol from corn is a mature technology but there are likely to be many competing cellulosic conversion systems, some of which may not prove to be commercially sustainable in the long-run. Predicting capacity levels for cellulosic ethanol production is difficult, though it is possible to analyze the consequences of various production levels of crop residue-based systems.

Using a regional partial-equilibrium model of agricultural supply and demand in the United States, we assess the implications of cellulosic ethanol being allowed to substitute on a gallon-for-gallon basis for corn-based ethanol, thus reducing the amount of corn necessary for ethanol production. The results show that there are both market and environmental benefits to accelerating the development of crop residue-based cellulosic biofuel production, primarily due to the reduced need for corn and taking advantage of existing residue supply. The increasing economic value of residue drives movement into no-till systems, reducing soil erosion and improving nutrient deposition. This indicates a need to spur research into crop residue management and cellulosic ethanol technologies to use them.

2. Modeling Framework and Data

The Regional Environment and Agriculture Programming Model (REAP) is a mathematical optimization model that quantifies agricultural production and its associated environmental outcomes for 50 regions in the United States (Johansson, et al., 2007). The regions are defined by the intersection of the USDA's Farm Production Regions (10 groups of states with similar agro-economic characteristics) and the Natural Resource Conservation Service's Land Resource Regions (defined by predominant soil type and geography). Production levels are also determined for livestock and processed products, which are integrated with the crop production system. Regional differences in crop rotations, tillage practices, and input use such as fertilizer and pesticides are explicitly accounted for. Input use and national product prices are determined endogenously. Data on crop yields, input requirements, costs and returns, and environmental indicators are derived from the USDA Agricultural Resource and Management Survey (ARMS) and the Environmental Productivity and Integrated Climate (EPIC) model. The model is calibrated to prices and quantities established by the 2008 USDA Baseline (USDA, 2008). REAP has been widely applied to address agro-environmental issues such as water quality and environmental policy design (Johansson and Kaplan, 2004), environmental credit trading (Ribaudo et al., 2005), climate change mitigation policy (Faeth and Greenhalgh, 2002), and regional effects of trade agreements (Cooper et al., 2005)

REAP is implemented as a non-linear mathematical program using the General Algebraic Modeling System (GAMS) programming environment. The goal of the model is to find the competitive equilibrium (welfare-maximizing) outcome of production levels subject to land constraints and processing and production balance requirements. The model is calibrated to production levels for 2016 given by the 2008 USDA baseline. It should be noted that REAP holds constant many factors that influence planting decisions and the markets for agricultural commodities. Weather and pest conditions are assumed to be average for the growing season.

Total ethanol production for 2016 is taken to be 19.25 billion gallons (15 billion from corn, 4.25 billion from cellulosic in the base scenario) as specified in EISA. Both corn-based and cellulosic ethanol demand are modeled as perfectly inelastic; there are no explicit factors in the model to generate the market-based allocation of the two quantities. To measure the effects of a different proportion of corn to cellulosic ethanol, crop residue-based ethanol production is ranged from 2.0 billion gallons to 8.5 billion gallons with corn-based ethanol making up the difference. So that corn-based ethanol production is capped at 15 billion gallons, crop residue ethanol production less than 4.25 billion gallons is complemented by switchgrass production. For the purpose of this analysis, switchgrass is modeled as a continuous hay rotation with similar production, cost, and environmental parameters.

Crops that provide residue for cellulosic ethanol production are corn, wheat, soybeans, barley, and oats. The quantity of residue produced per bushel of crop is taken from Graham et al. (2007) (Table 1). The amount of residue that can be recovered from a field is determined by harvest technology, soil nutrients, water availability, and erosion potential, among other factors. While there has been much research examining the relationship (Wilhelm et al., 2004), much is yet unknown about the effects of removing residue on soil productivity. In this analysis, we assume that 50% can be harvested from fields using no-till systems, 30% from fields using reduced tillage systems, and 10% from systems using conventional systems. These figures are meant as a starting point, and are meant to represent one possible residue collection scenario. Future research will refine these values. Residue harvest costs vary by crop, amount collected, the value of nutrients, and soil and future yield lost. Nutrient loss depends on the crop and amount harvested. Typical nutrient contents are about 17 pounds of nitrogen and 4 pounds of phosphate per ton of corn residue, and 11 pounds of nitrogen and 3 pounds of phosphate per ton of wheat residue. Wortmann et al. (2008) places the value of nutrients lost per ton of corn residue at $17.93. Graham et al. (2007) provide a set of curves that estimate the cost of collection as a function of stover collected per acre and collection method, including the cost of nutrient replacement (given as $6.50 per ton). For this analysis we simplify by imposing a constant $40/ton cost across regions and crop residue. This value represents the midpoint of the curves in Graham et al. adjusted by the higher replacement cost of the Wortmann et al. analysis. There is much ongoing research into how much residue can be harvested to maintain soil productivity, and the removal rates used in this analysis may be higher than optimal given soil organic carbon requirements (Wilhelm et al., 2007). Because of erosion considerations, no residue is allowed to be harvested from land classified as highly erodible.

Table 1. Residue to grain ratio (pounds of residue per pound of grain, dry mass)

	Residue-to-grain ratio
Corn	1.0
Soybeans	1.5
Wheat	1.3
Oats	1.4
Barley	1.5
Sorghum	1.0

To eliminate harvest of residues where transportation costs are likely to be too high and where there is insufficient economically retrievable material to support a commercially-sized biofuel plant, collection of crop residues is further limited to regions where at least 769,000 tons can be harvested—sufficient to produce 50 million gallons at 65 gallons per ton of residue. This is implemented as an endogenous constraint, so conceivably some regions could produce more crops than they otherwise would if the value of residue made it feasible to do so.

3. Results

Of the 42 REAP regions that grow the residue-producing crops, 13 produce quantities sufficient to meet the 50 million gallon minimum. The total production of cellulosic ethanol from crop residues in each region estimated to be produced under alternative scenarios for cellulosic ethanol demand is shown in Table 2. (Note that the results are reported by Farm Production Region, which are aggregates of REAP model regions). Below 4.5 billion gallons of cellulosic ethanol production, supply of crop residue exceeds the demand by ethanol producers in most regions. There are some regions where all available crop residues are used, after accounting for rate of removal by tillage, thereby inducing a marginal value for the residue. Above 4.5 billion gallons of cellulosic demand, all available residue is consumed in each region where the 50 million gallon requirement is met, effectively creating a national market value for residue. The shadow price for residue reaches $38.83 per ton at a demand of 8.5 billion gallons.

Table 2. Cellulosic ethanol production from crop residues, by region

	Cellulosic production (million gallons)				
Farm Production Region	2082	4250	5525	7012.5	8500
Northeast	100.0	100.0	106.7	133.0	157.6
Lake States	352.4	502.6	635.4	802.5	966.1
Corn Belt	503.3	2471.8	3156.8	3915.0	4749.6
Northern Plains	965.1	1010.1	1403.9	1864.7	2254.6
Appalachian	161.6	165.5	222.2	297.3	372.1

Crop prices relative to the 4.25 billion gallon cellulosic demand are shown in Figure 1. Prices for all major crops vary considerably over the range of cellulosic production. Corn shows the largest decline in price, dropping 6.5% as cellulosic production increases from 4.25 to 8.5 billion gallons. The price decline for corn is steady over the whole range. Less corn for ethanol and lower prices lead to more corn for food and feed. Wheat prices decline slightly over the whole range. Over the range of analysis, the fraction of the corn crop used for ethanol declines from 36.3% to 27.3% while the amount of corn available for food, feed, and exports increases from 9.4 billion bushels to 10.2 billion bushels.

Figure 1. Prices for crops, relative to 4.25 billion gallon cellulosic demand

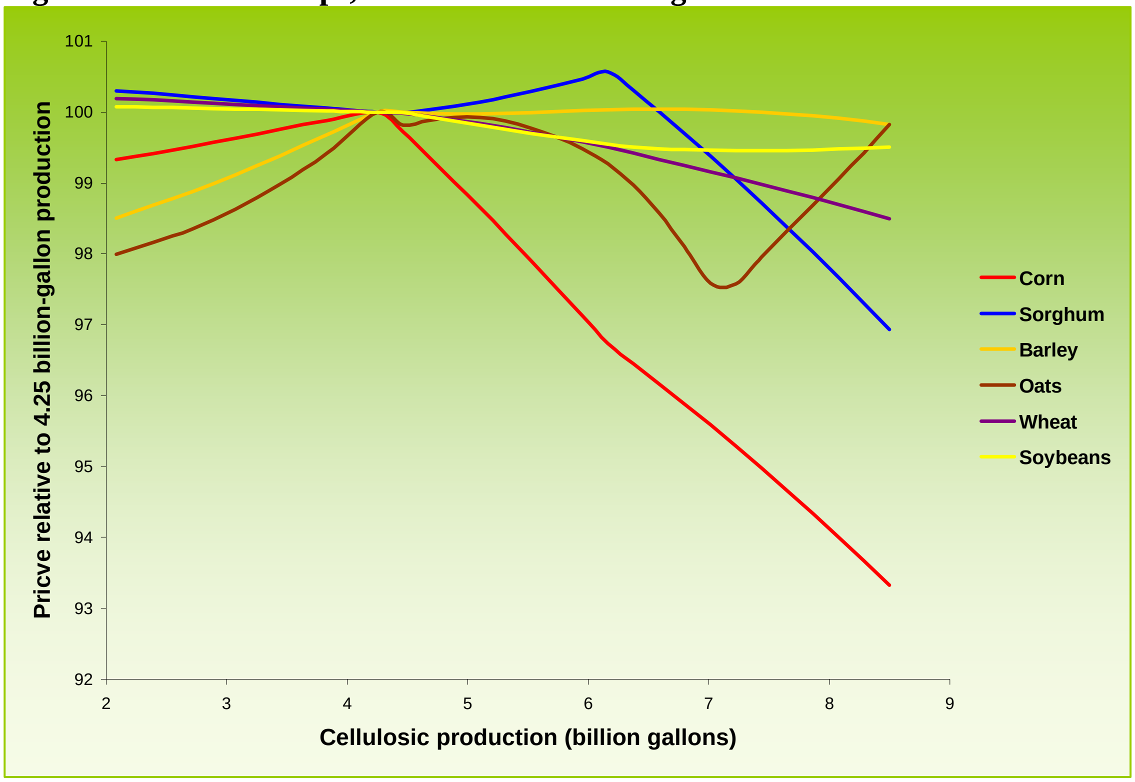
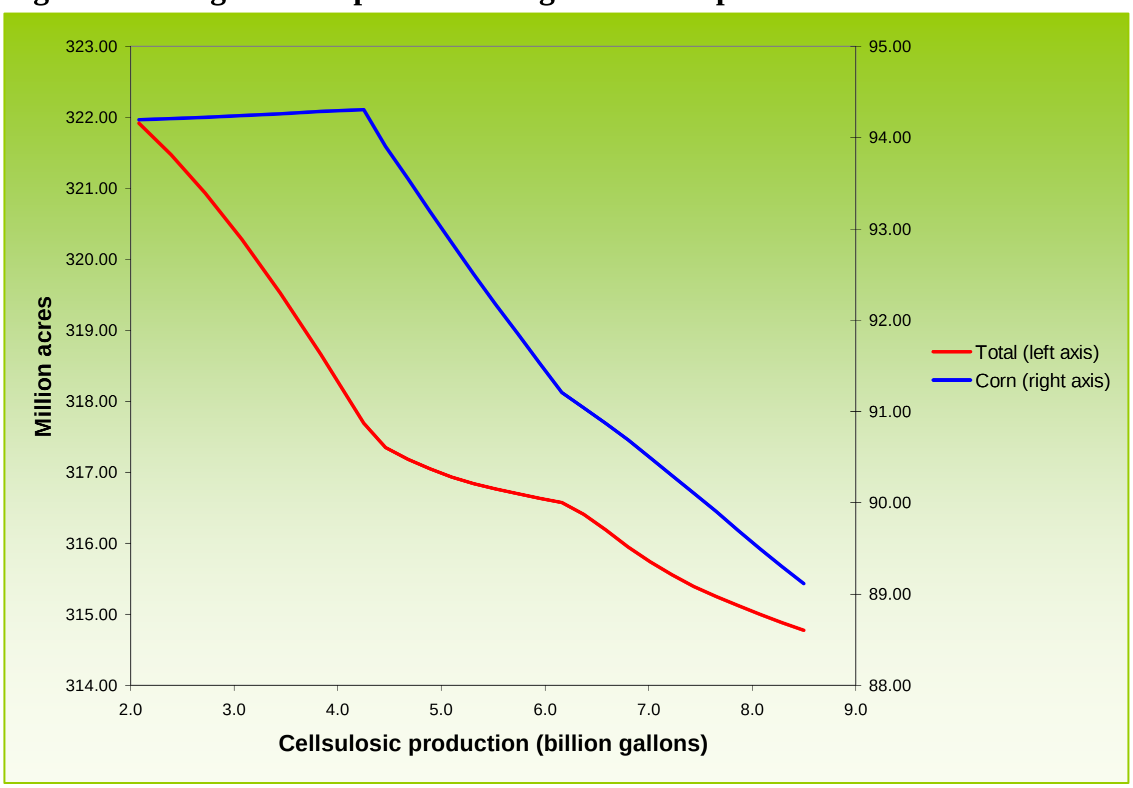
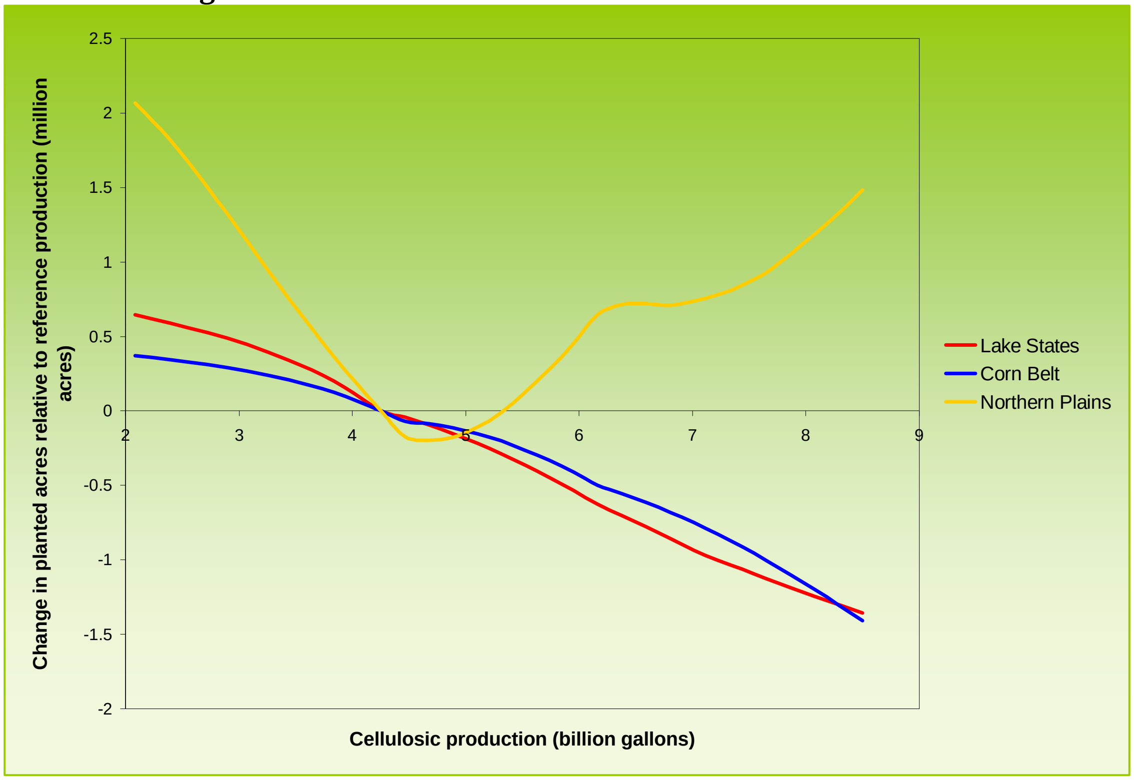


Figure 2. Change in total planted acreage and acres planted to corn



At the target level of 15 billion gallons of ethanol from corn and 4.25 billion gallons of cellulosic ethanol, total land planted to major crops is 317.7 million acres. As cellulosic demand increases, less total land is planted to traditional crops. The rate of decline in acreage as cellulosic demand increases is about 700,000 acres per billion gallon demand increase (Figure 2). The Corn Belt and Lake States show declines in total acreage as cellulosic demand is increased but the Northern Plains shows an increase, as illustrated in Figure 3. As crop residues gain economic value, the Northern Plains adds wheat acres, contributing to an increase in acreage in the region. Land for corn in the major corn producing regions of the Corn Belt, Lake States, and Northern Plains are the principal components of the decline in acreage. Over the 4.25 to 8.5 billion gallon range, corn acres decline from 94.3 to 89.1 million acres (Figure 2).

Figure 3. Change in total planted acreage for major crop producing regions, relative to 4.25 billion gallon cellulosic ethanol demand



Even though total acreage is reduced at higher levels of cellulosic ethanol demand, aggregate environmental effects are not reduced. In general, this is due to the fertilizer that needs to be applied to replace the nutrients removed with the harvested residue. We examine the levels of four critical environmental measures – nitrogen deposited to groundwater, nitrogen deposited to estuaries, nitrogen deposited to surface water, and soil erosion. Figure 4 shows how these measures change across the range of cellulosic ethanol demand relative to the baseline target. To remove the direct effect of the contribution of fewer acres, the values have been adjusted by dividing by the change in total acres for the given demand level. Net levels of the environmental measures generally increase despite the reduction in total land. Nitrogen deposited to groundwater holds fairly steady up to about 6 billion gallons of cellulosic demand, and increases as demand increases. However, not all regions exhibit an increase in this measure, as shown in figure 5 (also adjusted for changes in total acreage). The increase in the national level of nitrogen lost by surface runoff at lower cellulosic demands is mainly caused by high levels of runoff in the corn producing regions. The Delta and Southeast regions show a decrease in nitrogen deposition to groundwater, demonstrating that environmental consequences do not appear uniformly among regions. Shifting ethanol demand from corn to residue based systems increases nitrogen fertilizer requirements, although the effect of potentially applying less fertilizer and settling for lower yields has not been examined. Changes in management practices contribute to lower levels of soil erosion. The major management changes that happen over this range are a reduction in acres planted to continuous corn, particularly in the Corn Belt, and a national movement into no till systems (figure 6). No till systems grow from 11% to 21% and conventional systems decline from 72% to 53%. This is driven by the economic value for crop residues, more of which can be harvested from no till systems.

Figure 4. Change in selected national environmental measures, relative to 4.25 billion gallon cellulosic ethanol demand

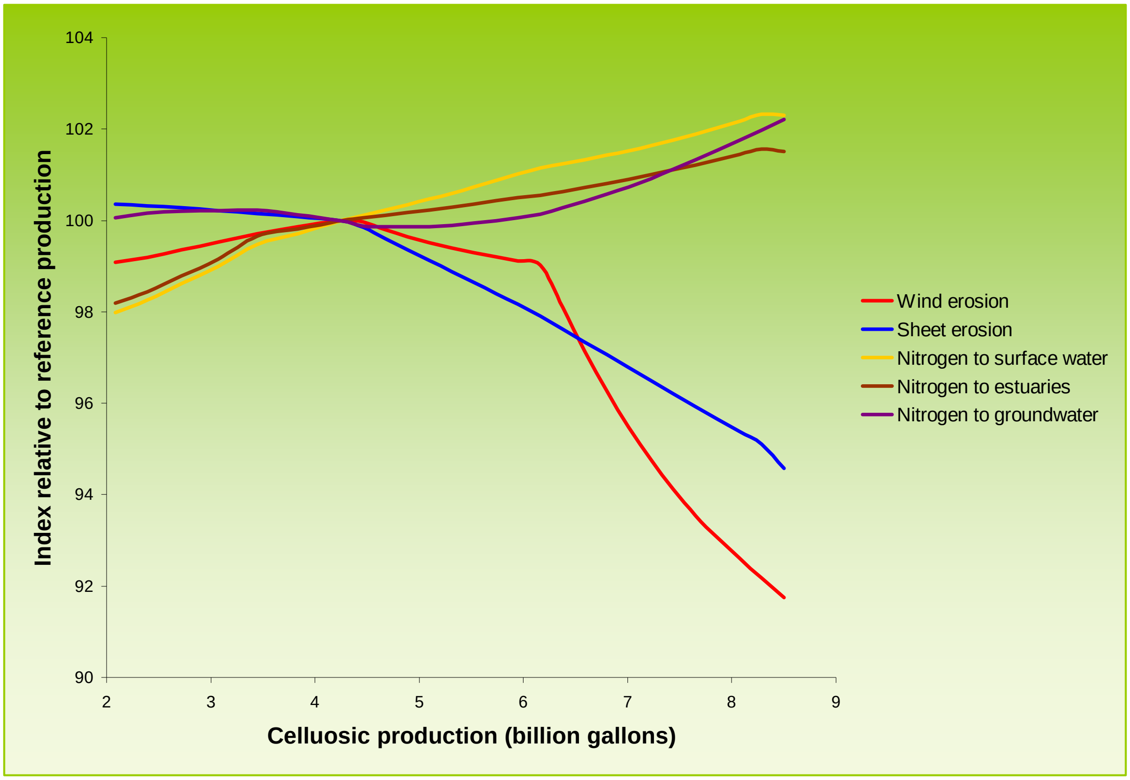


Figure 5. **Index of nitrogen deposition to groundwater, by region, relative to 4.25 billion gallon cellulosic ethanol demand**

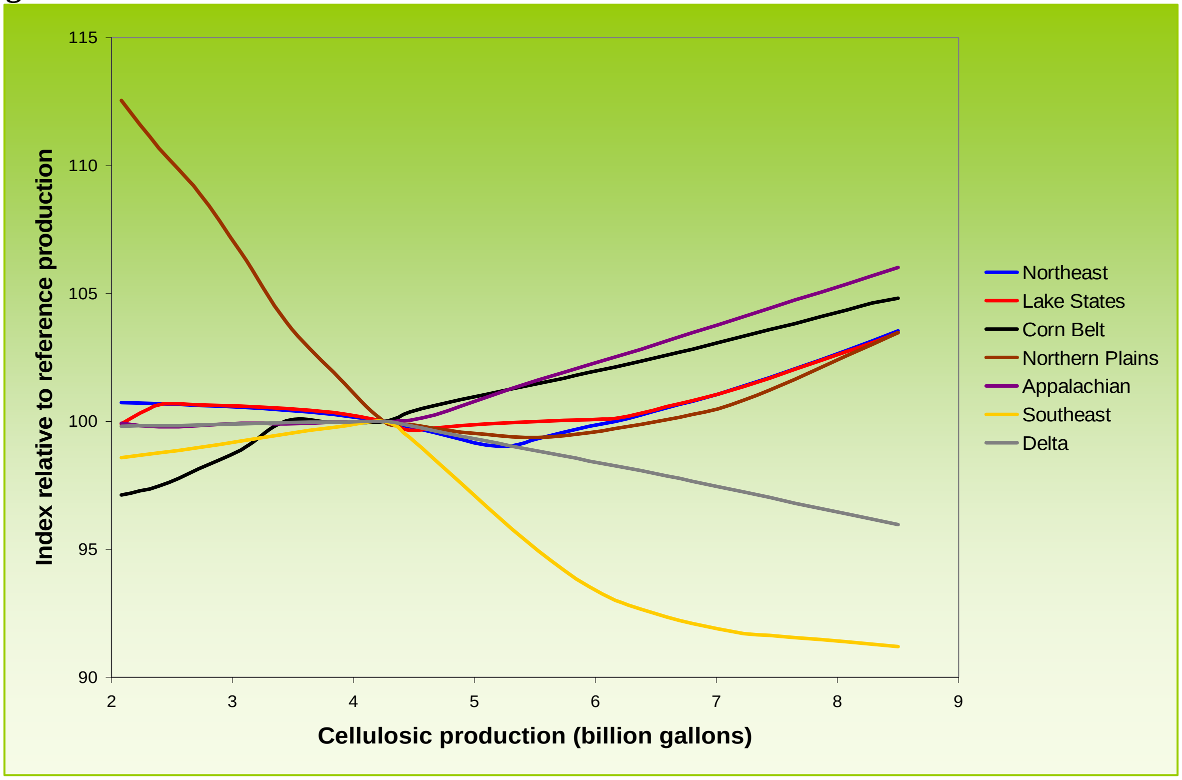


Figure 6. **National planted acreage by tillage system (million acres)**

5. Discussion

Unless and until alternative cellulosic crops like switchgrass and short-rotation woody crops are planted on a large scale, it is likely that the first wave of cellulosic production capacity will be attracted to those regions already planting residue-producing crops—namely the Corn Belt, Lake States, and Northern Plains. A sufficient supply of economically recoverable crop-residues will be available in 2016 to meet feedstock requirements at the EISA target of 4.25 billion gallons. If corn ethanol production is able to shift to crop residue-based cellulosic production, it will mean a greater need for crop residues, but the crop production system would not be significantly stressed by that need. Greater demand for crop residue would further concentrate cellulosic capacity in the major crop producing regions, rather than increase residue producing plantings in other regions.

Shifting away from corn and using more crop residues in place of corn provides mixed results on the environment. On the one hand, the reduced need for corn coupled with an ample supply of residues means less land is needed to meet agricultural market needs. Much of the reduction in corn acres is manifest in a move away from intensive continuous corn rotations. More use of nitrogen fertilizer leads to greater nutrient loadings. Change on a broad scale away from conventional tillage and into conservation tillage improves soil erosion. Since crops, practices, and growing conditions are widely distributed, the environmental outcomes vary by region.

One consequence of pricing crop residues is that with accelerated and localized use, producers in regions where the source of residue is too far from ethanol plants to be commercially viable will suffer lower returns relative to their colleagues nearer to ethanol plants. This is due to the lower price for the crop and the inability to sell the residue. This especially holds true for corn, which shows the largest drop in price as cellulosic demand is ramped up and demand for corn ethanol is reduced. Overall, returns to crop production increase as cellulosic demand increases beyond 4.25 billion gallons since returns from crop residues make up for the losses in crop production that result from lower crop prices. Regionally, returns to residues are not proportional to returns to crops; the major crop producing regions garner a relatively greater fraction.

Critical to the economic development of crop residues for biofuels is a thorough understanding of the implications of removal of residues on the land that produces them. Removal of residue affects soil nutrient content, erosion, and water retention. The REAP model accounts for these factors through tillage and rotation choice in each region. However, the possibility exists that in an environment where residues have real economic value there will be an incentive to remove residues in excess of the amount optimal to maintain soil productivity. Sensitivity analysis around the removal rates (which are likely to be different for each crop) and the implications for excess removal are topics for further research.

One of the challenging aspects of analyzing the costs and benefits of biofuels is to assess their life cycle carbon footprint. While beyond the scope of this study, this framework can be extended to account for sector-wide changes in carbon sequestration and greenhouse gas emissions. Changes in management practice that lead to changes in carbon sequestration and

GHG factors can be quantified under a set of policies, such as carbon prices, emissions trading programs, and incentives (green payments, cost sharing).

This analysis has focused on the near-term use of crop residues as the transitional feedstock. Alternative cellulosic crops will make an appearance once demand for such products is in place and issues have been resolved surrounding best management practices, market institutions, and protection from risk. Any analysis that looks further into the future must consider these alternative crops even though there is much uncertainty regarding how and where they will, or most economically, be grown and marketed.

References

Cooper, J., R. Johansson, and M. Peters. 2005. "Some Domestic Environmental Effects of U.S. Agricultural Adjustments under Liberalized Trade: A Preliminary Analysis." In J. Cooper, ed. *Global Agricultural Policy Reform and Trade: Environmental Gains and Losses.* London England: Edward Elgar, 39-62.

Faeth, P. and S. Greenhalgh. 2002. “Policy Synergies between Nutrient Over-enrichment and Climate Change.” *Estuaries* 25(4b): 869-877.

Graham, R.L., R. Nelson, J. Sheehan, R.D. Perlack, and L.L. Wright. 2007. “Current and Potential U.S. Corn Stover Supplies.” *Agronomy Journal* 99:1-11.

Johansson, R.C. and J.D. Kaplan. 2004. “A Carrot and Stick Approach to Environmental Improvement: Marrying Agri-Environmental Payments and Water Quality Regulations,” *Agriculture and Resource Economics Review* 31(1): 91-104.

Johannson, R.C., M. Peters and R. House. 2007. “Regional Environment and Agriculture Programming Model (REAP).” USDA-ERS Technical Bulletin TB-1916, March 2007.

Ribaudo, M., R. Heimlich, and M. Peters. 2005. "Nitrogen Sources and Gulf Hypoxia: Potential for Environmental Credit Trading." *Ecological Economics,* 52(2): 159-168.

USDA. 2008. “USDA Agricultural Projections to 2017.” OCE-2008-1

USDA-ERS. 2008 “Feed Grains Database.” http://www.ers.usda.gov/data/feedgrains/, accessed July 31, 2008.

USDA-NRCS. 2006. “Crop Residue Removal for Biomass Energy Production: Effects on Soils and Recommendations.” Technical Note No. 19, August 2006.

Wilhelm, W.W., J. M. F. Johnson, J. L. Hatfield, W. B. Voorhees, and D. R. Linden. 2004. “Crop and Soil Productivity Response to Corn Residue Removal: A Literature Review.” *Agronomy Journal* 96(1): 1 - 17.

Wilhelm, W.W., J.M.F. Johnson, D.L. Karlen and D.T. Lightle. 2007. "Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply." *Agronomy Journal* 99(6): 1665-1667.

Wortmann, C.S., R.N. Klein, W.W. Wilhelm and C. Shapiro. 2008. "Harvesting Crop Residues." University of Nebraska Extension Report, G1846, May.

Expected Changes in Farm Landscape with the Introduction of a Biomass Market

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Abstract: This study examines how the introduction of dedicated energy crops—switchgrass and forage sorghum—may affect Arkansas' crop allocation decisions. The study captures crop production practices at the county or crop reporting district level. Results are in a static equilibrium framework and limited to a one-year ahead forecast. The model's predictive success was evaluated by comparing 2007 model results with no energy crop production to actual acreages harvested. Switchgrass entered land use at approximately $25 and $35/dry ton in 2007 and 2008, respectively. Higher 2008 commodity prices for traditional crops caused lower switchgrass acreage peaks compared to 2007. Further, at higher biomass price levels—$45 to $55/dry ton depending on year and whether or not land charges were applied—the annual energy crop, forage sorghum, surpassed switchgrass acreage primarily as a result of its higher yield. Since acreage supply response is quite elastic, biorefineries will be exposed to significant price risk, especially at higher biomass prices, when the annual energy crop exceeds perennial switchgrass in acreage. Finally, the study examined impacts of biomass production on resource use. Regardless of ownership scenario, in 2007 and 2008, a 13 and 10 percent reduction, respectively, in irrigation water per acre occurred when the price of switchgrass increases from $25 to $65. Labor and fuel use showed no such trends. This is a significant finding, given diminishing water resources for a large portion of the Arkansas crop producing region.

As second generation biofuel production becomes an increasing reality, it is anticipated that a percentage of traditional farmland will shift to the production of biomass in the form of dedicated energy crops. This study examines potential changes to Arkansas' farm crop allocation decisions by simulating to what extent crop, hay, and pasture land are affected by the introduction of two potential biomass crops—switchgrass and forage sorghum. Historical minimum and maximum harvested acres and yields, cooperative extension information on cost of production, and expected production cost information for biomass crops are used in a constrained optimization problem. Significant changes in fuel (and thereby irrigation cost), commodity, and fertilizer prices demonstrate how changes in production cost and revenue experienced from 2007 to 2008 may affect resource allocation decisions.

Modeling efforts of a similar type have been conducted at the national level (Walsh et al., 2003; English et al., 2006) to determine the potential supply and location of biomass crops. These efforts utilize regional cost of production information at the Agricultural Statistical District (ASD) level. A weakness of these national models is that county-level details regarding, for example, double cropping practices or technology-driven changes in production costs are overlooked. In contrast, this modeling effort uses expert opinion to determine costs of production on a county or crop reporting district level for the state of Arkansas. While most national models make broad assumptions and disaggregate down, this model incorporates county level detail and aggregates up. By surveying county level crop extension agents a more precise representation of

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the production nuances of each county can be captured. This modeling effort also differs from previous studies by including forage sorghum as a bioenergy crop and—for switchgrass—estimating the opportunity cost of missed crop production for the first year of switchgrass establishment. Switchgrass and forage sorghum were chosen as the alternative crops since i) they represent a continuum of low to high input in terms of irrigation water and fertilizer use; ii) they differ in yield potential and seasonal yield availability (a perennial cut late season with a significant stand establishment period required vs. an annual with as many as two cuttings); and iii) different modes of storage due to likely moisture content differences at time of harvest. These crops thus represent the expected spectrum of choices for producers interested in participating in either the short or long term production of biofuels.

One weakness of this modeling effort is the static equilibrium framework where results are limited to a one-year ahead forecast without detail on the dynamics of changes in land use. Switchgrass, for example, enters the solution at its prorated cost of production and yield as estimated for the eight to ten year useful life of the stand.

The objective of the paper is therefore to develop i) a 2007 land allocation baseline with and without land charges as a means to validate the model against actual acreage allocations as reported in 2007; ii) a 2008 land use baseline using fall 2007 costs of production and commodity futures prices; iii) estimation of biomass supply functions under varying output price scenarios; and iv) impacts of biomass production on resource use (labor, fuel, and irrigation water).

2. Data and Methods

Cost of production information, as reported by the cooperative extension service of the University of Arkansas, was entered into an EXCEL spreadsheet for all traditional crops of cotton, corn, rice, sorghum, soybeans, and wheat. These data are summarized in Table 1 and indicate average and range of costs for irrigated, non-irrigated and double cropped production across technology and soil type parameters (University of Arkansas Cooperative Extension Service, 2008). Fuel, labor, fertilizer, and irrigation water use were recorded both in terms of quantity and cost to allow for sensitivity analyses. Table 2 summarizes similar information for the expected cost of production of dedicated bioenergy crops using expert opinion.

Crop specific extension experts were also consulted on various production technology methods implemented within the nine crop reporting districts (CRD) as defined by the Arkansas Agricultural Statistics Service. That is, cotton extension experts were asked to assign percentages to each of the 28 possible cotton production methods in Arkansas within each CRD. This effort resulted in CRD-specific cost of production estimates. County level average 2004-2007 yields (USDA NASS, 2008) helped determine returns above total specified expenses for the 75 counties in Arkansas. This spatial differentiation on the basis of cost and yield was not possible for the dedicated energy crops – forage sorghum and switchgrass—as production methods are still somewhat new and county-specific yield data were not available.

Table 1. Summary of average and range of per acre estimated total specified expenses for traditional crops of corn, cotton, grain sorghum, rice, soybean and wheat across reported production practices using input costs as of November, 2007, Arkansas

		Corn	Cotton		Grain Sorghum		Rice	Soybean			Wheat
Description	Units	Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Irr.	Dbl. Crop	Non-Irr.	Winter
Fertilizer (N-P-K-S-B)											
Urea (46-0-0)	lb	215	218	174	293	239	329	--	--	--	290
Liq. Nitrogen (32-0-0)	lb	405	--	--	--	--	--	--	--	--	--
Amm. Nitrate (34-0-0)	lb	--	--	--	--	--	--	--	--	--	--
D. Phos. (18-46-0)	lb	--	--	--	--	--	--	--	--	--	150
Phosphate (0-45-0)	lb	163	130	130	130	109	98	80	70	80	--
Potash (0-0-60)	lb	125	200	200	117	100	113	120	75	120	--
Sulfur (0-0-0-90)	lb	--	11	11	--	--	--	--	--	--	--
Boron (0-0-0-0-15)	lb	--	7	7	--	--	--	--	--	--	--
Irrigation	inch	12	10	0	6	0	32	12	10	0	0
Labor											
Operator	hrs	0.72	1.11	1.58	0.59	0.55	0.92	0.54	0.49	0.39	0.40
Hired	hrs	0.39	0.68	0.66	0.19	0.10	0.58	0.31	0.26	0.11	0.09
Fuel (incl. custom hire)	gal	22.08	28.30	18.96	15.46	7.06	43.55	21.94	19.09	6.30	5.67
Cost of Production											
Seed (incl.fees)	$	60.72	99.71	72.67	14.82	10.26	48.96	22.95	32.16	22.95	29.70
Chemicals[1]	$	16.19	96.54	80.84	24.68	24.68	71.92	41.59	38.77	41.59	7.23
Custom hire (no fuel)	$	10.52	55.56	51.01	16.67	16.67	45.08	24.91	26.09	24.91	24.41
Repair & Maint.	$	14.23	25.71	23.22	11.20	7.14	17.48	11.78	11.25	6.25	6.09
Ownership Charges[2]	$	71.48	133.1	104.6	72.40	31.35	80.04	70.15	70.91	26.79	25.61
Operating Interest[3]	$	11.46	19.17	13.60	7.61	5.84	14.10	6.98	6.90	5.23	6.27
Total Specified Exp.[4]											
Average	$	410.5	623.2	506.8	297.6	204.1	496.9	276.7	275.1	181.3	211.0
Range (Max – Min)	$	80.35	135.3	9.33	62.99	--	200.5	68.33	93.20	12.62	24.14
# of Prod. Methods		7	28	3	3	1	8	8	10	2	4
Land Charge[5]	$	69.23	92.31	64.17	80.77	64.17	115.38	92.31	40.83	52.50	40.83

Notes:

1 Chemicals include herbicide, insecticide, fungicides, surfactants, adjuvants, harvest aides and growth regulators.

2 Ownership charges include depreciation and capital costs but not housing, insurance and taxes.

3 Operating interest (7%) is based on half of total specified expenses less ownership charges.

4 A number of different crop production methods exist for each crop. Expert opinion was used to determine which of the reported methods was most relevant for each of the crop reporting districts.

5 Land charges were based on reported charges for irrigated and non-irrigated acres as per Arkansas Agricultural Statistic Service (USDA NASS, 2008). These charges were further differentiated by crop using information from a focus group study conducted in 2001 (Hill, Popp and Manning, 2003).

Table 2. Summary of per acre estimated total specified expenses for alternative crops of switchgrass and forage sorghum across expected production practices using input costs as of November, 2007, Arkansas

		Switchgrass			Forage Sorghum	
Description	Units	Crop[1]	Hayland[2]	Pasture[2]	Irr.	Non-Irr.
Fertilizer (N - P - K - S)						
Urea (46-0-0)	lb	--	--	--	300	220
Ammonium Nitrate (34-0-0)	lb	198[3]	193[3]	193[3]	--	--
Phosphate (0-45-0)	lb	44[4]	44[4]	44[4]	110	110
Potash (0-0-60)	lb	77[5]	76[5]	76[5]	235	235
Lime	ton	0.10[6]	0.13[6]	0.13[6]	--	--
Irrigation	inch	0	0	0	6	0
Labor						
Operator	hrs	0.92	0.84	0.77	0.55	0.45
Hired	hrs	0.02	0.02	0.02	0.25	0.10
Fuel (incl. custom hire)	gal	5.08	4.68	4.33	12.81	5.80
Cost of Production						
Seed (incl. seed treatment & tech. fees)	$	8.40	10.50	10.50	22.53	15.17
Chemicals[7]	$	4.29	3.80	3.80	25.71	25.71
Custom hire (excl. fuel)	$	3.97	8.06	8.01	17.89	17.89
Bale Wrap	$	10.68	9.89	8.93	--	--
Repair & Maintenance	$	6.83	6.44	5.91	7.24	4.67
Ownership Charges[8]	$	18.49	17.40	15.89	51.49	21.77
Operating Interest[9]	$	3.22	3.45	3.35	8.33	6.41
Total Specified Expenses[10]	$	104.80	109.94	105.73	297.69	211.28
Land Charge[11]	$	56.00	35.00	25.00	80.77	64.17

Notes:

1,2 All costs and quantities are prorated over the useful life of 10 and 8 years, respectively, for establishing switchgrass on crop vs. hay or pasture land. For both establishment practices, 8 lb of pure live seed are applied per acre and cost of harvest is yield dependent. Note that chemical costs for establishment on hay or pasture land are based on the use of Atrazine, which is currently not licensed. Using alternatives would add an additional $3.99 prorated cost per acre.

3 Assumes 0 pounds per acre in the establishment year and 220 pounds per acre thereafter. The amounts differ between crop and hay land due to the difference in useful life.

4 Assumes approximately 20 lbs of phosphate fertilizer per acre per year. This amount is an estimate as current recommendations are to apply 40 lbs of fertilizer if soil P tests are medium +. Since P yield responses have been demonstrated to be insignificant (Parrish et al, 2003), we assume that the above fertilizer rate is adequate given Arkansas soils. Removal is also significantly affected by time of harvest.

5 Assumes approximately 45 lbs of potash fertilizer per acre per year. Again estimate is based on current recommendation to apply 80 lbs of potash fertilizer per acre per year based on soil tests. Same caveats as for P.

6 Assumes 1 ton per acre in the establishment year only.

7 Chemicals include herbicide, insecticide, fungicides, surfactants, adjuvants, harvest aides and growth regulators. Chemicals are only applied in year one for switchgrass and thus numbers represent prorated amounts.

8 Ownership charges include depreciation and capital costs but not housing, insurance and taxes.

9 Operating interest (7%) is based on half of total specified expenses less ownership charges.

10 Opportunity costs per acre for the establishment year are not included in total specified expenses and amount to $25 and $35 per acre for pasture and hay land prorated over 8 years and $52.21 per acre and $98.71 per acre for 2007 and 2008, respectively, on crop land prorated over 10 years.

11 State-wide average non-irrigated land charges are a conservative estimate for switchgrass on cropland. Forage sorghums are charged the same rate as grain sorghums due to similarities in production. Land charges for switchgrass on hay and pasture land reflect profitability of hay land and pasture land, respectively.

Historical harvested crop land information (including all crops, fruits, vegetables, hay land, and hay yield), pasture and irrigated acres were collected from agricultural census data for 1987, 1992, 1997 and 2002 (USDA Census of Agriculture). Conservation Reserve Program (CRP) acreage, as well as average county specific payments for 2007, were obtained from the USDA's Farm Service Agency (FSA, 2008). Annual harvested acres for the traditional crops were also available electronically by county from the Arkansas Agricultural Statistics Service from 1975 to 2007 (USDA NASS, 2008). Variation in pasture and hay land nutrient management systems (e.g. poultry litter or use of nitrogen fixing companion crops), number of harvests, grazing methods and operator rental arrangements proved too cumbersome to model. Hence pasture rental rates and hay land returns were set to reflect surrounding states' cash rental returns to pasture at \$25/acre (USDA, 2008 Pasture Cash Rent) and hay land returns were set higher at \$35/acre to reflect more productive land that could be harvested with conventional haying equipment. Since land rental arrangements vary significantly across Arkansas, cash rental rates by crop were used to differentiate between ownership (no land charges and thereby land allocation on the basis of relative profitability only) and cash rent only, where land allocation includes a proxy for ownership costs via cash rent. While neither extreme applies to Arkansas conditions, the two scenarios are expected to provide a reasonable range of estimates.

The net return (*NR*) of Arkansas crop, hay, and pasture land could then be maximized by choosing crop acres (*x*) on the basis of expected commodity prices (*p*), county relevant yield (*y*) and cost of production information (*c*) as follows:

$$\text{Maximize } NR = \sum_{i=1}^{75}\sum_{j=1}^{18}\left(p_j \cdot y_{ij} - c_{ij}\right)\cdot x_{ij} \qquad (1)$$

Subject to:

$xmin_{ij} \leq x_{ij} \leq xmax_{ij}$

$irrmin_i \leq \sum irr_{ij} \leq irrmax_i$

$iacresmin_i \leq \sum x_{ij} \leq iacresmax_i$ for irrigated crops only

$acresmin_i \leq \sum x_{ij} \leq acresmax_i$ for all crops except pasture and CRP

where *i* denotes each of the 75 counties of production and *j* denotes the 18 land management choices. *Xmin* and *xmax* are historically reported county acreage minima and maxima over the harvest years 2000 through 2007 for each crop (USDA NASS, 2008). The model was also run using historical minima and maxima reaching back to 1975 when cotton acreage was very small in Arkansas. The model predicted large acreage shifts from cotton to biomass. This was considered unrealistic given Arkansas' investment in cotton gins and specialized harvesting equipment. Energy crops had zero minima. Switchgrass on crop land was limited to a maximum of 10% of total harvested land to reflect an expected farmer adoption lag for a new crop. Switchgrass on hay and pasture land was limited to a maximum of 10% of the sum of hay and pasture land so as not to encroach on current livestock production. Cattle and calf numbers for the census years corresponding to hay and pasture land numbers were used to determine average acreage per head of livestock. The January 1, 2008, inventory numbers were subsequently multiplied by the average acreage per head to determine how much hay and pasture land were required to maintain the current herd of cattle. In the most restricted county, Faulkner, the minimum was 90% of the maximum and hence the 10% of maximum constraint. Because forage sorghum is similar in production technology to grain sorghum, it was not curtailed, except to historically reported maximum irrigated county crop acres (*iacresmax*) and harvested county crop land (*acresmax*) for irrigated and non-irrigated production, respectively. *Irrmin* and *irrmax* restricted the amount of water *(irr)* that can be used across crops and county. Restrictions were based on initial base model runs primarily for purposes of analyzing a hypothetical restriction of water use to sustainable levels (not reported here). *Iacresmin* and *iacresmax* are the 1987 to 2007 census-based reported irrigated acres that reflect technological, socioeconomic, and capital barriers to irrigation, again at the county level. *Acresmin* and *acresmax* are total harvested acres at the county level, as collected by the Census, and were amended by adding 10% of county CRP enrollments to the maximum harvested acre totals to reflect the potential for added acres from land coming out of CRP and the typical ten year enrollment horizon of CRP acreage. Note that winter wheat was considered as part of harvested acres even though this crop is usually entertained in double crop rotations with soybean, corn, or sorghum crops.

Crop price information (p_j) was based on the July futures prices as of December of the previous year and no commodity price program support with the exception of wheat where May futures prices as of September of the previous year were used to reflect different planting times (Great Pacific Trading Company, 2008). Basis expectations, defined as the local cash price less the nearby futures contract to account for time, location, and quality differences, were set to zero for all crops and prices were adjusted for hauling, drying and commodity board check off charges as appropriate (Table 3).

Switchgrass and forage sorghum prices were then modified over a range of \$25 to \$65 per dry ton (dt) to estimate the supply response functions under various input cost scenarios (2007 vs 2008). With the recent rise in fertilizer prices, local startup companies interested in collecting rice and wheat straw were bidding \$40 to \$50 to encourage farmer participation at the time of this writing. The range of prices chosen reflects the authors' best guess as to prices biorefineries may be willing to entertain to obtain adequate biomass supply. A discount of \$5 per dt relative to baled switchgrass stored at the side of the field was applied to forage sorghum as it was assumed to be sold standing in the field for forage chopping and direct hauling to the processing facility where it would be artificially dried. This discount is an estimate given a lack of accurate available cost information on relative harvest, storage, packaging, drying, transport and processing costs for switchgrass and forage sorghum. Per acre yields (y_{ij}) are county averages for most crops. Because double cropped soybean yields are only reported at the CRD level for Arkansas and not separated by irrigation management, this crop was assumed to be exclusively irrigated within minimum and maximum county acreage restrictions prorated on the basis of irrigated full season soybean county acreage information. For Arkansas grain sorghum, NASS does not separate yields by irrigated management, so county extension agents were asked to provide a breakdown of irrigated vs. non-irrigated production by CRD. A yield increase (decrease) of 17.5 bushels from the overall average was then applied to irrigated (non-irrigated) grain sorghum based on 2000-2007 NASS data for the state of Kansas where yield differences are tracked (NASS, 2007). Per acre cost of production estimates (c_{ij}) were developed as reported above, and depending on the model run, estimates either included or excluded cash rent.

Table 3. Summary of 2007 and 2008 commodity price, yield, and input cost information

Commodity Prices and Yields

Commodity	Unit	Futures Prices[1] 2007	Futures Prices[1] 2008	Custom Hauling[2] / Drying[3] and Checkoff / Other[4]	2007 baseline average yield[5] (2004-2007)	Production Method / Region
Corn	bu	$4.00	$4.25	$0.35	151.5	Irrigated
Wheat	bu	$4.60	$7.00	$0.16	51.9	Irrigated
Beans	bu	$7.10	$11.00	$0.186 (2007) $0.205 (2008)	40.6 26.8 32.7	Irrigated Non-irrigated Double cropped
Rice	lb	$0.11	$0.14	$0.01	6,896.3	Irrigated
Cotton	lb	$0.58	$0.67	-$0.04	1,099.7 888.8	Irrigated Non-irrigated
Grain Sorghum	bu	$3.80	$4.04	$0.16	105.2 70.0	Irrigated Non-irrigated
CRP	acre	$52.00				State average
Forage Sorghum	dt				9.75 6.50	Irrigated Non-irrigated
Switchgrass	dt				5.20 4.56 4.13	Cropland Hay Pasture

Input Prices

	Units	2007	2008
Fertilizer (N - P - K - S)			
Urea (46-0-0)	lb	0.18	0.20
Liquid Nitrogen (32-0-0)	lb	0.12	0.15
Ammonium Nitrate (34-0-0)	lb	0.12	0.15
Diammonium Phosphate (18-46-0)	lb	0.14	0.24
Phosphate (0-45-0)	lb	0.14	0.22
Potash (0-0-60)	lb	0.13	0.14
Sulfur (0-0-0-90)	lb	0.23	0.20
Boron (0-0-0-0-15)	lb	0.53	0.40
Lime	ton	33.00	33.00
Labor			
Operator	hrs	9.45	9.45
Hired	hrs	8.19	8.19
Fuel	gal	2.20	2.33
Operating Interest	%	7.75	7.00

Notes:

1 Futures prices were for the July contract month as of December of the previous year except for wheat where May futures prices as of September were used to reflect a different planting period (GPTC, 2008).

2 Custom hauling charges amounted to $0.15 per bushel for all commodities except cotton.

3 Drying charges were $0.19 per bushel on corn and $0.30 per bushel on rice.

4 Commodity check off was ½% of price on soybean, $0.01 per bushel on grain sorghum, corn, cotton and wheat and $0.0135 per bushel on rice. Cotton ginning returns of $0.05 per lb were added for cotton.

5 Average yields are for the 2007 baseline scenario without alternative energy crops using per acre county average yields reported by NASS for 2004 through 2007. Forage sorghum yields did not vary by county due to lack of information. Switchgrass yields are prorated and a result of 0, 4 and 6 dt/acre in years 1, 2 and 3 through 10 on crop land, 0, 3.5 and 5.5 dt/acre in years 1, 2 and 3 through 8 on hay land, and 0, 3 and 5 dt/acre in years 1, 2 and 3 through 8 on pasture land.

All model runs were estimated in a linear programming context using the Premium Solver Plus software add-in to EXCEL (Frontline, 2008) as the model required in excess of 3,000 adjustable variables to maximize NR subject to an even larger number of constraints, as described in Equation 1. The 2007 baseline was executed using zero prices for alternative energy crops to see how accurately the model would predict observed total harvested land allocations in 2007 on the basis of 2006 input cost and 2007 commodity price expectations. The baseline results were also used to provide an estimate of per acre opportunity costs that would be incurred in the year of establishment for switchgrass, a crop that does not yield to its full potential until year three with zero saleable product in year one. This opportunity cost (o_i) was added to the prorated net returns above total specified expenses for switchgrass (*nr*) as follows:

$$nr_{i,switchgrass} = \left(\sum_{n=1}^{k^t} [((p \cdot y_n^t) - c_n^t)/(1+r)^n] \right) - o_i / k^t \qquad (2)$$

where n is the production year in the useful life (k^t) of switchgrass with useful life varying by land type (t – crop, hay, or pasture land), p is the price per dt of switchgrass, y_n^t and c_n^t are the production year-dependent yield and cost of production by land type, r is the capital recovery rate (6%) and o_i are the average county net return estimates to pasture, hay, or conventional crops observed in the base run with switchgrass and forage sorghum prices set to zero.

To conduct the sensitivity analyses surrounding commodity and input costs, the 2007 baseline was updated to 2008 by using fall of 2007 commodity price expectations and input costs as shown in Table 3.

3. Results

Comparing the 2007 baseline prediction (2007 Base—no rent and 2007 Base—with rent) to actual acreage of harvested crop land suggested that the model was slightly conservative in crop production (-2.4% and -7.1%) for the entire state (Table 4). The largest prediction errors amongst land use choices varied depending on whether or not land charges were included. Perhaps the profitability of hay land was set too low and/or zero basis assumptions were optimistic for rice and wheat. Nonetheless, the range of baseline expectations with and without land charges was deemed sufficiently representative to allow for the estimation of biomass supply functions and sensitivity analyses on crop and input prices.

The bottom four rows of Table 4 show acreage allocation changes due to changes in commodity and input prices between 2007 and 2008. A brief review and comparison of the futures prices of 2007 and 2008 (Table 3) explains the baseline acreage increases primarily in soybeans and wheat as their prices relative to other commodities experienced greater increases (Table 4).

Adding switchgrass production at $5 increments in switchgrass price to the above model runs resulted in significant changes in acreage allocations. In the no-rent scenarios for 2007 and 2008, switchgrass entered the crop mix at relatively low switchgrass prices (P_s) of $25 and $35, respectively. In 2007 switchgrass acreage peaked at or near $40 (no rent—483 thousand acres) and $45 (with rent—674 thousand acres). Given higher commodity prices in 2008, biomass acreage decreased with switchgrass acreage peaking at or near $45 (no rent—368 thousand acres) and $50 (with rent—374 thousand acres).

Table 4. 2007 and 2008 baseline crop acreage allocation in thousands of acres—predicted vs. actual and year to year changes

Description	Corn	Cotton	Soybean	Rice	Wheat	Grain Sorghum	Hay-land	Pasture	Total (Excl. Pasture
2007 Actual Harvested Acres	590.0	850.0	2,790.0	1,325.0	700.0	215.0	1,580.0	1,977.1	8,031.0
2007 Base – no rent	543.7	868.9	2,532.5	1,464.4	801.3	216.5	1,409.8	2,036.8	7,837.0
% deviation from actual	-7.8%	2.2%	-9.2%	10.5%	14.5%	0.7%	-10.8%	3.0%	-2.4%
2007 Base – with rent	543.2	732.7	2,480.3	1,459.2	607.9	204.3	1,434.8	2,036.8	7,462.4
% deviation from actual	-7.9%	-13.8%	-11.1%	10.1%	-13.2%	5.0%	9.2%	3.0%	-7.1%
2008 Base – no rent	321.7	805.7	2,778.1	1,550.9	1,009.8	70.4	1,340.9	2,036.8	7,877.4
% change from 2007	-40.8%	-7.3%	9.7%	5.9%	26.0%	-67.5%	-4.9%	0.0%	0.5%
2008 Base – with rent	329.2	756.6	2,686.9	1,547.1	1,029.4	108.1	1,383.1	2,036.8	7,840.4
% change from 2007	-39.4%	3.3%	8.3%	6.0%	69.3%	-47.1%	-3.6%	0.0%	5.1%

Table 5. Profit per acre of switchgrass and forage sorghum under different pricing levels and production methods with and without land charges

		Switchgrass Price[1]								
Year	Land Use	$25	$30	$35	$40	$45	$50	$55	$60	$65
		----------------------------- Profit Per Acre[2] -----------------------------								
2007	Switchgrass on Crop Land	-$13	$7	$26	$46	$65	$85	$104	$124	$143
	with rent	-$66	-$46	-$27	-$7	$12	$32	$51	$70	$90
	Switchgrass on Hay Land	-$24	-$6	$12	$30	$48	$66	$84	$102	$120
	Switchgrass on Pasture	-$28	-$11	$5	$21	$38	$54	$70	$86	$103
	Non-irrigated Forage Sorghum	-$63	-$31	$2	$34	$67	$99	$132	$164	$197
	with rent	-$127	-$95	-$62	-$30	$3	$35	$68	$100	$133
	Irrigated Forage Sorghum	-$82	-$33	$16	$64	$113	$162	$211	$259	$308
	with rent	-$163	-$114	-$65	-$17	$32	$81	$130	$178	$227
2008	Switchgrass on Crop Land	-$26	-$6	$13	$32	$52	$71	$91	$110	$130
	with rent	-$84	-$64	-$45	-$25	-$6	$14	$33	$53	$72
	Switchgrass on Hay Land	-$33	-$15	$3	$21	$39	$57	$75	$93	$111
	Switchgrass on Pasture	-$36	-$20	-$4	$12	$29	$45	$61	$77	$94
	Non-irrigated Forage Sorghum	-$81	-$49	-$16	$16	$49	$81	$114	$146	$179
	with rent	-$151	-$119	-$86	-$54	-$21	$11	$44	$76	$109
	Irrigated Forage Sorghum	-$103	-$54	-$5	$44	$92	$141	$190	$239	$287
	with rent	-$187	-$138	-$90	-$41	$8	$57	$105	$154	$203

Notes:

1 Note that forage sorghum was priced at a constant 5 per dry ton less than switchgrass for all switchgrass price levels and that average yields for switchgrass on crop, hay and pasture land, non-irrigated and irrigated forage sorghum were 5.2, 4.56, 4.125, 6.5 and 9.75 dry tons per acre, respectively.

2 Profit per acre figures include opportunity cost for the year of establishment for switchgrass and amounted to 3.13, 4.38, 5.22 and 9.88 per acre on hay, pasture, 2007crop and 2008 crop land, respectively. Forage sorghum is not expected to be grown on pasture land. Non-irrigated forage sorghum as well as other non-irrigated crops of grain sorghum, soybean, wheat and cotton can be established on hayland with the cost of preparing a seedbed allocated to the haying enterprise.

In 2007, forage sorghum surpassed switchgrass acreage at P_s near \$50 (with rent) and \$45 (no rent) with that price threshold increasing to \$55 for 2008 (with rent) and remaining at \$45 (no rent). This is likely a function of forage sorghum's profitability, relative to switchgrass (Table 5). Given forage sorghum's yield advantage over switchgrass, its profitability increased by approximately \$30 and \$50 per \$5 increase in P_s in 2007 and 2008, respectively (Table 5). Hence, forage sorghum reaches acreage in excess of 2.2 million at the high end of P_s in 2007 (regardless of land charges).

At relatively low biomass prices, marginal soybean, wheat, grain sorghum and hay land are replaced to provide the initial increases in biomass acreage (namely, switchgrass acreage). At higher biomass prices, however, the profitability of annually grown forage sorghum drives large increases in production, allowing forage sorghum to surpass even rice in acreage totals and rise to the number two crop behind soybeans in 2007 and 2008 albeit at the high end of biomass prices.

The top panel in Figure 1 shows the above mentioned biomass acreage response for 2007 and 2008 with and without land charges. As expected, higher commodity prices for traditional crops in 2008, compared to 2007, shift the supply function of biomass to the left. Similarly, the inclusion of land charges raises the threshold price level for significant production of biomass, given the increased opportunity cost of growing switchgrass. Given the modeling framework presented here, biorefineries interested in a given level of production (drawing a vertical line through the graph at some desired output level) to fill the needs of their plant will likely experience relatively large changes in the price they need to pay for biomass either from year to year or whether land charges are included. The vertical gap between supply functions shown for 2007 and 2008 in the bottom panel of Figure 1 is approximately \$10 per ton when comparing supply responses with or without rent. Also, for production levels between ¼ and 2 million acres, the supply response to \$1 changes in P_s is approaching 120,000 and 80,000 acres in 2007 and 2008, respectively. This suggests that biorefineries are exposed to a significant amount of price risk especially at higher biomass prices when producers are expected to and can readily switch in and out of annual forage sorghum production.

With the introduction of any new alternative cropping decision, tracking the change in input use is imperative. A major finding in this study is that estimated irrigation water use per acre declines as alternative biofuel crops take on a larger role. Regardless of land charges, both in 2007 and 2008, a 13% and 10% reduction in water usage per acre occurred as P_s increased from \$25 to \$65, respectively (Table 6). Average irrigation water savings of 0.73 ac-inch per acre or 3.83% per \$10 increase in P_s (between \$35 and \$65) can be expected across 2007 and 2008 commodity and input price conditions. Given diminishing water resources in the Arkansas Delta, these findings are significant for maintaining profitable crop production with anticipated irrigation restrictions.

Figure 1. Estimated Combined Switchgrass and Forage Sorghum Acreage (A) and Production (B) with Changes in Input and Output Prices as well as Land Charges.

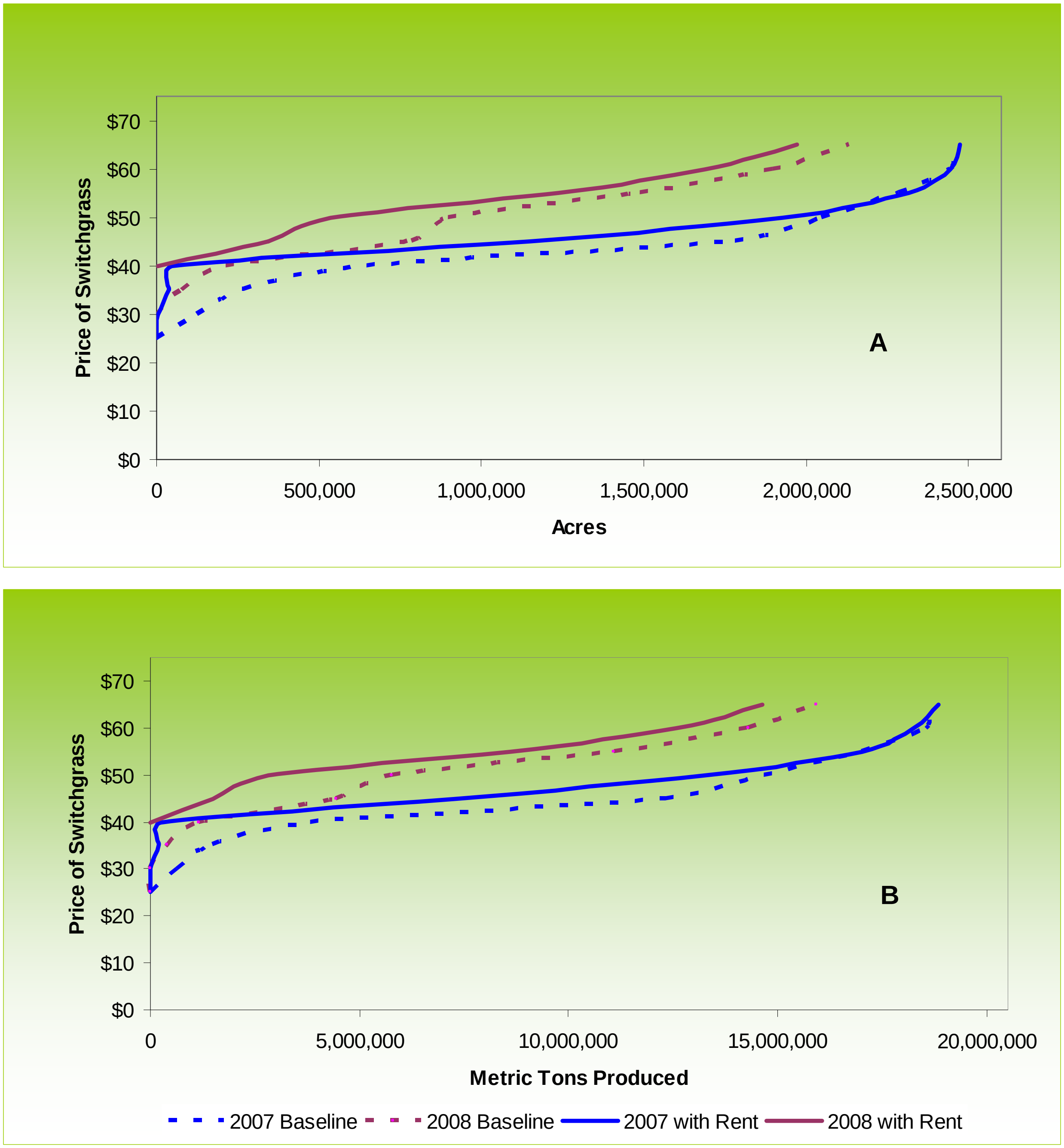

Table 6. Resource use with biomass crop activity, 2007 and 2008, Arkansas

Year	Land Charge		Price of Switchgrass[1]				
			$25	$35	$45	$55	$65
2007	Yes	Fuel Use[2] (000s gal)	148,015	147,994	151,791	148,913	147,863
		Fuel Use/ac	19.83	19.83	18.98	18.62	18.48
		Irrigation (000s ac-inch)	83,950	83,950	83,957	79,052	78,101
		Irrigation (ac-inch/ac)	18.74	18.74	17.82	16.51	16.31
		Labor Use[2] (000s hrs)	6,703	6,719	7,302	7,354	7,257
		Labor/ac	0.90	0.90	0.91	0.92	0.91
	No	Fuel Use[2] (000s gal)	151,981	152,721	155,850	151,178	148,089
		Fuel Use/ac	19.39	19.09	19.48	18.90	18.51
		Irrigation (000s ac-inch)	84,420	84,436	84,302	80,777	78,284
		Irrigation (ac-inch/ac)	18.74	18.72	17.76	16.87	16.35
		Labor Use[2] (000s hrs)	7,077	7,232	7,608	7,359	7,268
		Labor/ac	0.90	0.90	0.95	0.92	0.91
2008	Yes	Fuel Use[2] (000s gal)	149,750	149,747	151,295	153,330	153,709
		Fuel Use/ac	19.10	19.10	19.29	19.17	19.22
		Irrigation (000s ac-inch)	84,229	84,229	84,245	84,220	83,890
		Irrigation (ac-inch/ac)	19.50	19.50	19.48	18.41	17.52
		Labor Use[2] (000s hrs)	6,795	6,796	7,074	7,295	7,374
		Labor/ac	0.87	0.87	0.90	0.91	0.92
	No	Fuel Use[2] (000s gal)	151,075	151,463	154,849	153,731	154,692
		Fuel Use/ac	19.18	19.04	19.36	19.22	19.34
		Irrigation (000s ac-inch)	84,489	84,489	84,473	84,209	84,147
		Irrigation (ac-inch/ac)	19.58	19.58	19.59	18.01	17.58
		Labor Use[2] (000s hrs)	6,903	6,975	7,418	7,300	7,392
		Labor/ac	0.88	0.88	0.93	0.91	0.92

Notes:
1 Note that forage sorghum was priced at a constant $5 per dry ton less than switchgrass for all switchgrass price levels.
2 Fuel and labor use exclude hay, pasture and CRP land due to lack of data. Forage sorghum harvest is also not included.

Per acre fuel and labor use fluctuated up and down as P_s increased. 2007 results demonstrated a moderate reduction (2%) in per acre fuel usage as P_s increased from $25 to $65, but with higher commodity prices in 2008, fuel usage per acre remained nearly constant. Labor use in both 2007 and 2008 was also relatively stable per acre (+/- 4% deviation from average across price scenarios) with some increases in total hours observed primarily at the mid price range of P_s. A caveat for these findings is that fuel and labor use on hay, pasture and CRP land could not be tracked and forage sorghum harvest is not modeled as the crop is sold standing in the field.

4. Summary and Conclusions

A model for Arkansas crop, hay, and pasture land allocation was developed to estimate potential acreage allocation decisions with varying assumptions on land charges as biomass crops such as forage sorghum and switchgrass are anticipated to provide a portion of the feedstock for second generation biofuels. Given acreage restrictions based on historical minimum and maximum acres of traditional crops for each county in Arkansas, the model results suggest that significant acreage of both switchgrass, at low biomass prices, and forage sorghum, at higher biomass prices, enter land use allocations, even with high commodity prices for traditional crops. Predictions of exact acreage and location will remain a challenge, however, as supply response is deemed quite elastic at switchgrass prices above $35 per dry ton. Of significant importance to Arkansas producers, facing declines in aquifer water supply, is the decline in per acre irrigation water use with the adoption of biomass crops.

Shortcomings of the model are its static nature, as well as the need for a best guess on price differentials among biomass crops given uncertainty in desired end product characteristics, harvest, storage, preprocessing, and transportation costs. Inclusion of crop residue from conventional crops would also add to providing a clearer picture of spatial biomass supply. Finally, because of the lack of spatial yield histories on forage sorghum and switchgrass, the above results are subject to considerable error on yield potential. Additional errors are possible as differences in harvest and storage technology could lead to significant differences in yield losses between time of harvest and biorefinery processing.

References

English, B., D. De La Torre Ugarte, M. Walsh, C. Hellwinkel, and J. Menard. 2006. “Economic Competitiveness of Bioenery Production and Effects on Agriculture of the Southern Region.” *Journal of Agricultural and Applied Economics.* 38(2):389-402.

Farm Service Agency (FSA), Arkansas, 2008. “2008 County CRP Data” http://www.fsa.usda.gov/FSA/ldppcpStateInfo, accessed June 1, 2008.

Frontline Solver, Premium Solver Platform. Version 8.0. 2008. Nevada: Frontline Systems Inc.

Great Pacific Trading Company (GPTC), 2008. “Charts and Quotes”. http://www.gptc.com/quotes.html, accessed June 5, 2008.

Hill, J., M. Popp, and P. Manning. 2003. “Focus Group Survey Results: Typical Arkansas Crop Producer Production and Marketing Practices”. University of Arkansas Research Report 971, January.

Parrish, D.J., D.D. Wolf, J.H. Fike, and W.L. Daniels. 2003. *Switchgrass as a Biofuels Crop for the Upper Southeast: Variety Trials and Cultural Improvements*. Final report for 1997 to 2001, ORNL/SUB-03-19XSY163/01.

University of Arkansas Cooperative Extension Service. 2008. “Crop Production Budgets for Farm Planning”, http://www.aragriculture.org/, accessed June 5, 2008.

United States Department of Agriculture (USDA), National Agricultural Statistics Service (NASS), Arkansas Field Office. 2008. “Arkansas County Data-Crops”, http://www.nass.usda.gov/QuickStats/Create_County_Indv.jsp, accessed June 7, 2008.

__. Arkansas Field Office, 2008. “Arkansas Land Values and Cash Rents”, http://www.nass.usda.gov/Statistics_by_State/Arkansas/Publications/ Statistical_Bulletin/ econvalu.pdf, accessed December 2, 2008.

__. Kansas Field Office, 2007. “Kansas County Data-Crops”, http://www.nass.usda.gov/QuickStats/PullData_US_CNTY.jsp, accessed June 7, 2008.

__. Charts and Maps, 2008. “2008 Pasture Cash Rent by State.” http://www.nass.usda.gov/Charts_and_Maps/Land_Values_and_Cash_Rents/past_rent_map.asp, accessed December 19, 2008

__. Census of Agriculture, 2004. “2002 Census of Agriculture- Arkansas State and County Data.” Volume 1, Geographic Area Series Part 4. Washington, DC, June.

__. Census of Agriculture, 1999. “1997 Census of Agriculture- Arkansas State and County Data. Volume 1, Geographic Area Series Part 4. Washington DC., March.

__. Census of Agriculture, 1994. “1992 Census of Agriculture- Arkansas State and County Data. Volume 1, Geographic Area Series Part 4. Washington DC, September.

Walsh, M., D. De La Torre Ugarte, H. Shapouri, and S. Slinsky. 2003. “Bioenergy Crop Production in the United States.” *Environmental and Resource Economics*. 24(4):313-333.

Optimal Biorefinery Locations and Transportation Network for the Future Biofuels Industry in Illinois

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Abstract: This article addresses development of the Illinois ethanol industry through the period 2007-2022, responding to the ethanol production mandates of the Renewable Fuel Standard by the U.S. Environmental Protection Agency. The planning for corn-based and cellulosic ethanol production requires integrated decisions on transportation, plant location, and capacity. The objective is to minimize the total system costs for transportation and processing of biomass, transportation of ethanol from refineries to the blending terminals and demand destinations, capital investment in refineries, and by-product credits. A multi-year transshipment and facility location model is presented to determine the optimal size and time to build each plant in the system, the amount of raw material processed by individual plants, and the distribution of bioenergy crops and ethanol.

Currently corn ethanol is the major type of renewable fuel that is extensively used as an additive in the United States. Ethanol is now sold across the country and is blended in 50% of the nation's gasoline at varying percentages between 10% and 85%, and its usage continues to increase. Ethanol blends at higher volumes, such as 85% (E85), are available especially in Midwestern states for use in flex-fuel vehicles. Given such demand, the ethanol production facilities and capacity expansion projects are booming. U.S. ethanol production increased from about 1.6 billion gallons in 2000 to 6.5 billion gallons in 2007. In January 2007 the number of ethanol plants was 110; by November 21, 2008 there were 180 operating biorefineries, with a total production capacity of 11 billion gallons per year. Twenty-one additional refineries are currently under construction, which will further expand the total capacity by 1.6 billion gallons each year (RFA 2008). In the long-run the existence and competitiveness of the ethanol industry depend on economic and strategic plans for facility location, transportation infrastructure, and logistics.

In order to achieve a sustainable supply of transportation fuels through renewable energy sources, particularly from ethanol, the Renewable Fuel Standard (RFS) established by the U.S. Environmental Protection Agency mandates production targets for both corn-based and cellulosic ethanol. The RFS requires increasing the use of renewable fuels every year through 2022. By 2012, at least 7.5 billion gallons of renewable fuel must be blended into motor-vehicle fuel (EPA, 2008). The program targets producing 36 billion gallons of biofuels by 2022, including 15 billion gallons of corn ethanol and 21 billion gallons of advance biofuels derived

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from renewable sources other than corn (which comprises 16 billion gallons of cellulosic ethanol derived from corn, stover, perennial grasses, and woody biomass, and 5 billion gallons of biofuels from undifferentiated sources). This raises complex issues regarding the production and processing of raw materials, logistics and facility location, and the distribution of a substantial amount of biofuel in the entire U.S.

In preparation for an extensive and comprehensive analysis, this article describes the basic methodology and presents some preliminary results of an ongoing research effort. A mathematical programming framework is developed to determine the optimal transportation and processing of raw materials, delivery of the end product, selection of the biorefinery types, and capacity and location decisions to meet the mandated ethanol targets throughout the 2007-2022 planning horizon.

In this exploratory study, our analysis on transportation logistics and refinery location focuses on the State of Illinois as a test bed. This is because of three reasons. First, Illinois is a major corn producing state, producing nearly 20% of the corn grain used for ethanol production. Second, Illinois is also a major ethanol consumption region, including some of the largest metropolitan areas such as Chicago. Finally, Illinois is one of the major hubs for various modes of freight transportation such as rail and highway, and the transportation of raw materials and end products constitutes a crucial component of cost in the bioenergy industry.

2. The Corn and Biomass Transportation and Biorefinery Location Problem

Transportation of corn and cellulosic biomass feedstocks to biorefineries is an important cost factor in the integrated regional biofuel assessment. Field harvested corn and cellulosic biomass has a low energy density in comparison with solid fossil fuel sources such as coal, requiring large amounts of feedstock to be transported. To address the problem, Sokhansanj et al. (2006) developed a logistics model for an integrated supply analysis that simulates the collection, storage, and transportation of corn and cellulosic biomass supply to a biorefinery. Using time dependent discrete event simulation and queuing analysis that represent the entire network of material flow from the field to a biorefinery, they predicted the number and size of equipment needed to meet the biorefinery demand for feedstock. Mapemba (2006) and Mapemba et al. (2007) estimated the cost to deliver feedstock to a biorefinery as a function of the biorefinery size, the number of harvest days, and the harvest frequency. The results showed that increasing the biorefinery capacity would require larger transportation distances, thus increasing the expected delivery cost.

Kumar et al. (2006) provided a ranking of biomass collection systems based on the cost of delivered biomass, quality of biomass supplied, emissions during collection, energy input, and maturity of supply system technologies. For a given capacity, rail transport of biomass was shown to be the best option, followed by truck transport and pipeline transport, the latter of which is not appropriate for ethanol transport due to water contamination. Rail transshipment may also be preferable in cases where road congestion precludes truck delivery. Mahmudi and Flynn (2006) suggested that a combined truck-and-train transport system would be more economical than truck delivery only. There is a minimum shipping distance for rail transport above which lower costs per mile offset incremental fixed costs.

Location models of ethanol plants and biorefineries incorporate and integrate factors such as land use, transportation and optimal plant size. The problem is to locate the processing facilities so as to minimize the total transportation cost adjusted by the returns from by-product sales, such as corn distillers dried grains with solubles (DDGS). This type of facility-location problem has typically been solved using integer-programming (Daskin, 1995, Drezner, 1995) which searches for an optimal network configuration (Fuller et al., 1976; Hilger et al., 1977), selecting biorefinery locations from a set of candidates, according to some specified criteria such as water availability or distance to the transportation network (Peluso et al., 1998). Kaylen et al. (2000) built a mathematical programming model to analyze the economic feasibility of producing ethanol from lignocellulosic feedstocks at minimal cost, distinguishing between capital cost, operating cost, feedstock cost, and transportation cost. As plant size increases marginal operating cost declines with plant capacity due to economies of scale but transportation cost increases because feedstock will have to be shipped from greater distances. Under these conditions, improved feedstock logistics is essential (Hess et al., 2007).

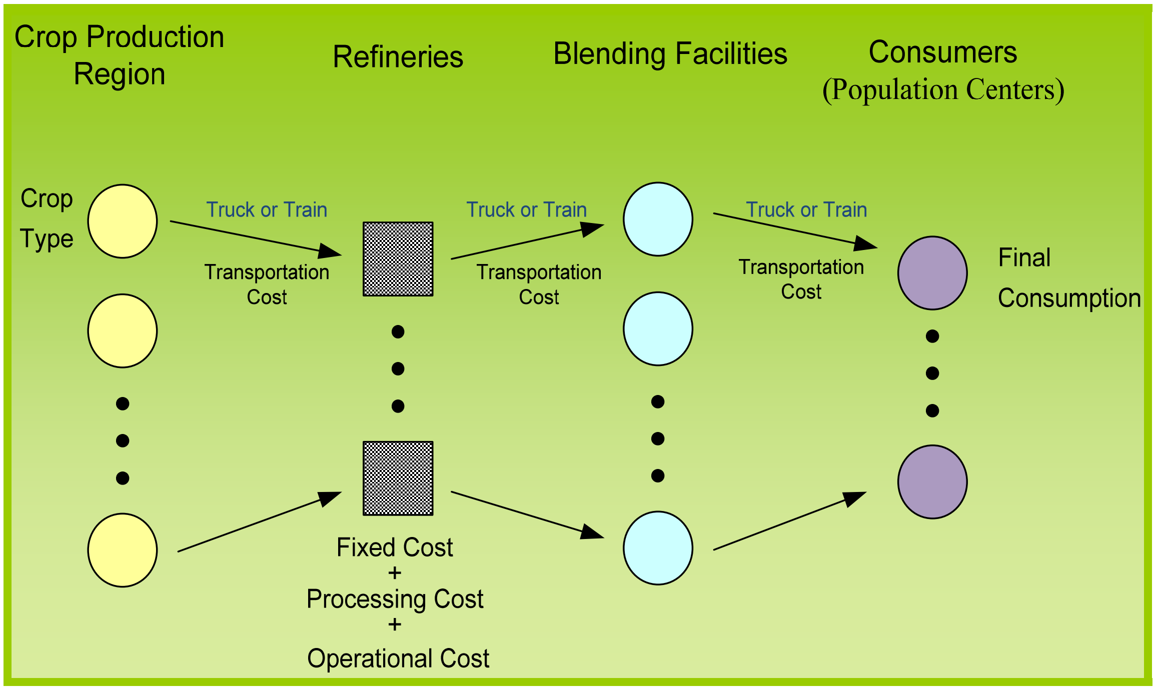
Ethanol becomes more competitive if DDGS and higher valued chemicals are produced as co-products. Several competing conversion technologies that enable the use of lignocellulosic biomass as biorefinery feedstock are under development, including gasification, pyrolysis, liquefaction, hydrolysis, fermentation, and anaerobic digestion. Finding the best mix can lead to significant cost reductions for the future biorefinery (Wright and Brown, 2007).

The challenge is to develop integrated models that incorporate the selection of the feedstock, farm, biorefinery site, size, and technology under market conditions as an instrument of decision-making. For instance, Eathington and Swenson (2007) have developed a GIS-based decision tool for the selection of optimal site, size, and technology of ethanol plants to assess different policy and economic scenarios, including biofuels-related job impacts, local demand, and growth of the industry. Building on our research on biofuels and land use in Illinois (Khanna et al., 2008a; Scheffran and Bendor, 2008) we are expanding this analysis by including modeling of optimal feedstock transportation and biorefinery location.

3. An Overview of the Model

The development of the future ethanol industry, including both production and distribution, involves several integrated decision layers that must be addressed simultaneously. These include: i) the type of processing facilities, their capacities, years in which they are built, and locations; ii) amount of raw materials (corn, stover, and perennial grasses) transported from production regions to biorefineries; and iii) amount of ethanol deliveries to blending facilities and then to final demand destinations. This is a typical transshipment problem with network flows including yes/no type facility location selection decisions (Dantzig and Thapa, 2003). We formulated the problem as a linear mixed-integer programming model where the transportation decisions are defined as non-negative variables while the decision to build a biorefinery in a given year and at a given location is defined as a binary variable. The capacity of each biorefinery is also defined as a nonnegative variable. A schematic representation of the problem is shown in Figure 1.

Figure 1. A schematic representation of ethanol production and distribution



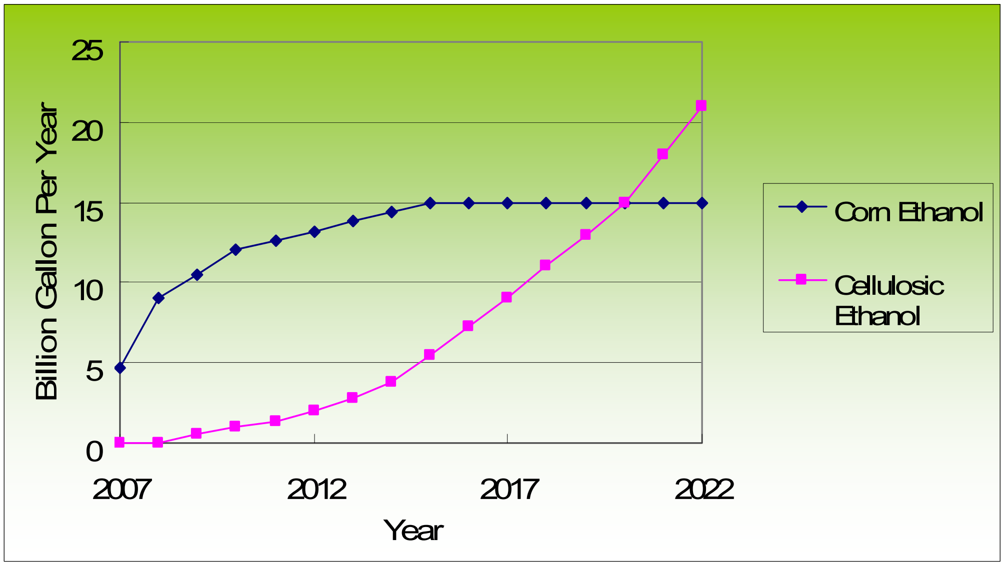
The objective of the model is to minimize the total cost of all operations, including the transportation costs of raw materials and the end product (ethanol), costs of processing, and fixed investment costs associated with building refineries, minus byproduct credits (namely the values of DDGS produced as a byproduct of corn ethanol processing and electricity generated by burning wastes of cellulosic biomass).

A supply constraint in the model, defined for each production region and each year, ensures that the amount of corn and biomass shipped from any given region to all biorefineries in the system cannot exceed the available supply in that region. An in/out constraint, defined for each processing facility and each year, restricts the amount of ethanol produced and shipped out by any biorefinery to the corresponding amount of raw inputs coming into that facility. The amount of ethanol produced by any facility is also restricted by the processing capacity of that plant specified at the time of construction, which is also determined by the model as a decision variable. The model allows expanding the capacity of a previously built biorefinery over time, but this may occur at additional investment costs. We assume that once a biorefinery is built at a given location and in a given year, then it remains operational in the following years throughout the planning horizon (i.e. closing and reopening the plant in a later year is not allowed). The capacity of any plant at construction time cannot fall below a minimum and cannot exceed a maximum capacity, both of which are specified a priori (based on the sizes of existing processing plants and capacities of the plants currently being built). We also restrict the capacity utilization in any processing facility to a specified minimum percentage of the construction capacity (if that facility is included in the system). The ethanol produced by all refineries (both corn-based and cellulosic) is delivered first to blending facilities (terminals) and then to final demand destinations after blending with gasoline. An in/out constraint balances the incoming and outgoing amount of ethanol to each blending facility. Finally, a demand constraint ensures that the ethanol demand of each demand location (specified a priori) is met.

The facility location component of the model identifies the optimal locations of both corn-based and cellulosic ethanol plants based on the transportation costs, fixed and variable costs associated with building and operating biorefineries. If a location is selected for a particular type of processing facility, then processing (up to the construction capacity) can occur at that location, otherwise no input/output can be delivered to/from that location. This is reflected in the model by a technical constraint relating the processing capacity variables to the location selection variables for individual plants.

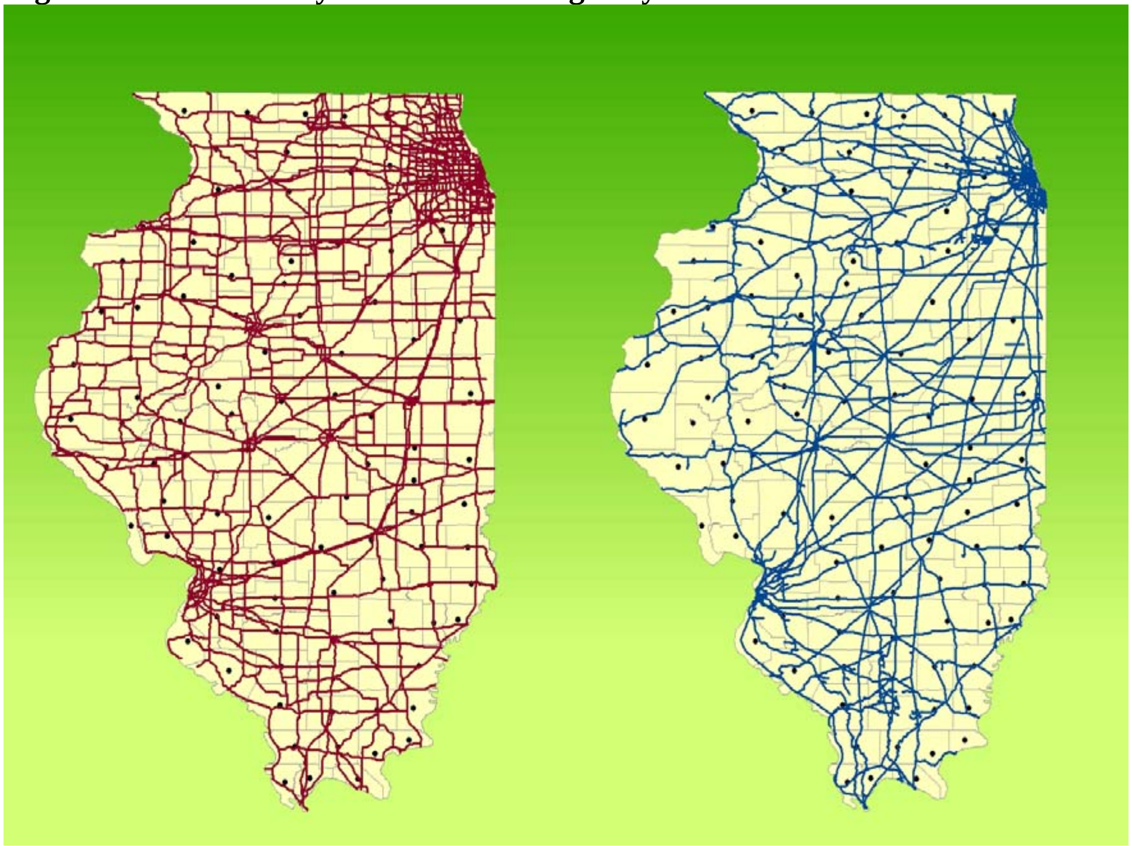
The model described above requires several sets of input data. The amounts of energy crops supplied by each production region are specified exogenously for each year of the planning horizon. These are pre-determined by use of the supply response model by Khanna et al. (2008b). Since the fermentation processes of cellulose and glucose vary significantly from each other, we consider corn-based and cellulosic ethanol plants separately with varying fixed costs, processing costs and other operational costs. We assume that the ethanol produced by all biorefineries is delivered to the existing terminals in Illinois where it is blended to gasoline. We used the centroids of the counties where existing terminals are located as ethanol transshipment points. Finally, based on the population shares of Illinois counties and the aggregate ethanol consumption target for the State, the ethanol demand of each county is specified for each year of the planning horizon. Therefore, in parallel to the growth of national ethanol production targets (Figure 2), the annual ethanol demands of individual counties also exhibit an increasing pattern throughout the planning horizon.

Figure 2. Ethanol production mandates of the Renewable Fuel Standard



The transportation costs between production regions and potential refinery locations, between refineries and blenders, and between blending facilities and final demand destinations (county centroids) are determined based on the minimum costs of delivery via available transportation modes (highway or railway, see Figure 3) through the multimodal transportation network, including any costs incurred from transshipment, loading/unloading and handling operations. The transportation costs are generated by shortest-path algorithms with shipping cost functions.

Figure 3. Illinois county centroids with highway and railroad network



Highway Railroad

The cost components at the biorefinery level include annualized fixed investment costs, processing costs, and other operational costs. The procedures and assumptions used for obtaining these cost figures will be discussed in the following section. The by-product credits are based on the current market price of DDGS and the value of electricity generated by burning processed biomass. Fixed conversion factors determine the amount of ethanol produced by each facility processing and converting corn and/or biomass into ethanol.

4. Model Implementation and Data

The model described above is applied to the State of Illinois for the period of 2007-2022, which is consistent with the time frame considered in the RFS program. Each of the 102 counties in Illinois is considered as a producer region that can supply one or more of the bioenergy crops. Each county centroid is assumed to be a candidate plant location where a corn-based biorefinery, or a cellulosic biorefinery, or both, can be built in any given year. Seventeen existing blending terminals in Illinois are considered, assuming that all ethanol produced in Illinois will be processed by those facilities. We also assume that 19% of the nation's ethanol targets, for both corn-based and cellulosic ethanol, would be produced and consumed in the State (based on the current share of Illinois in the total corn-based ethanol supply).

Several data sets are needed as model input, including the supplies of bioenergy crops, costs of transportation from production regions to plant locations and then to blending facilities and demand locations, and the costs for different types of ethanol plants. The procedures used to generate these data are explained below.

Supply of Bioenergy Inputs

A key data set needed in the facility location model involves the spatial and temporal distribution of bioenergy input supplies, i.e., the amounts of corn and cellulosic biomass supplied by each county in each year of the planning horizon. We generated these by using the supply response component of the *Agricultural Policy Analysis Model (APAM*), a spatial and temporal resource allocation model for U.S. agriculture developed in the Department of Agricultural and Consumer Economics at the University of Illinois. In the present study we modified the model according to the particular purposes of this research and restricted its coverage to Illinois only. For the methodological and algebraic details of this model see Khanna et al. (2008).

The Multimodal Transportation Network and Cost Matrix

The main criteria for qualifying candidate locations of biorefineries include accessibility to the transportation mode and sufficient water resources (necessary for ethanol processing). Most counties in Illinois have access to railroad and highways within county boundaries, and water is also widely available from major surface waters and aquifers. Hence, all counties are assumed to be a candidate site for future biorefineries. As an approximation we treat the centroid of each county both as an origin and destination of all types of freight.

Transportation costs for corn, biomass and ethanol are calculated based on the highway and railroad network provided by the Bureau of Transportation Statistics National Transportation Atlas Database. Using centroid connectors linking the centroids to their nearest node of the highway and railroad networks, the Dijkstra's shortest path algorithm (Dijkstra, 1959) is used to determine the minimum network distance for each pair of centroids.

Railroad transportation has significantly lower per-mile variable cost, but transshipment through railroad usually incurs a higher fixed cost (Mahmudi et al., 2006) because of extra handling of the load (e.g., hauling, storage and unloading within the railroad terminal, for transshipment between truck and railcars). Initial fixed cost for railroad transportation is assumed such that the breakeven point of highway and railroad transportation is 200 km. The per-bushel-mile delivery costs of corn and cellulosic biomass are calculated for both truck and rail transportation, based on Sokhansanj et al. (2006). Similarly, we calculated the ethanol transportation costs per gallon-mile as suggested by Morrow et al. (2006).

Cost Data of Biorefineries

Corn-based and cellulosic ethanol plants are associated with different cost structures. Refinery costs for each type of plant are divided into three main components: i) annualized fixed cost, which includes the cost of land allocated to the refinery physical structure (based on farmland prices and the size of required land), and the costs of construction and machinery investment; ii) processing cost, which is proportional to the capacity utilized (i.e. the amount of corn or cellulosic feedstock processed); and iii) other costs related to operational expenses, such as labor and administrative expenses, which are linked not to the utilization level, but to the capacity of the refinery. The cost parameters for corn based refineries are generated by the 'Dry Mill Simulator' component of Farm Analysis and Solution Tools (FAST) developed by Ellinger (2008) at the University of Illinois. These costs are based on the simulated performance of a 100 million gallon capacity corn ethanol plant. As the costs of cellulosic biorefineries we use the estimates by Wallace et al. (2005) for a 25 million gallon capacity plant.

Ethanol Demand
The planning horizon of our analysis is 2007-2022. The mandated target for corn ethanol increases monotonically in the first half of this period and then remains constant, whereas the cellulosic ethanol demand constantly increases throughout the planning horizon. As mentioned earlier, we assumed that the State will produce and blend 19% of the national ethanol target. For simplicity, we assume that this share is the same for both corn-based and cellulosic ethanol and the biofuels from undifferentiated sources in the RFS mandates (5 billion gallons) will also come from cellulosic sources.

5. Model Results
Illinois is investigated in our case study as a pilot project because of the readily available input data and the State's important role in renewable energy production. The results presented below are of preliminary nature and should not be taken literally. This is the first step of a comprehensive modeling effort, which aims to address similar policy issues and prospects for the entire U.S. ethanol industry. Although being rather narrow in scope, the present application may have significant practical implications not only for Illinois but also for other major ethanol producer states.

Figure 4 shows the projected regional production of corn, corn stover, and miscanthus in the year 2022, which is used as exogenous input data by the transshipment-site selection model. A similar regional production data set is generated a priori by the supply response model (described in Section 4) for each year of the planning horizon. The model results presented below as well as the results obtained for the remaining years are driven mainly by these data. For space reasons here we present the results for 2022 only.

The optimum refinery locations that are consistent with the given input supplies are shown in Figures 5a and 5b for corn-based and cellulosic ethanol plants, respectively, along with the locations of the existing blending facilities and the top 10 major demand areas. Figure 5a reveals quite an expected result, namely corn-based biorefineries are located in those counties that are close to the major demand locations and also corn for ethanol is available at greater amounts. The situation for cellulosic biorefineries is similar. Although most of the large scale cellulosic refineries were located in southern Illinois, where much of the cellulosic biomass is produced, several biorefineries were built in the northcentral region, surrounding the greater Chicago area, supplying relatively large amount of corn stover. Besides the regional input availabilities, exact locations and sizes of the biorefineries are driven by the trade-off between costs of transportation of corn and cellulosic biomass from production regions to processing plants and transportation of ethanol from refineries to the major demand centers.

According to the model solutions, within the first three years of the planning horizon the number of corn-based biorefineries would grow from 11 in 2007 to 14 in 2009. (The number of refineries is actually the number of counties having at least one refinery. Some counties have multiple refineries, such as Peoria and Tazewell. The refinery capacity for those counties is the total capacity of all refineries located in the county.) After 2009, only one additional corn-based refinery is built (in 2015, see Figure 6). Six of the existing refineries increase their capacities (shown by the concentric circles in Figure 5a), which are in general small refineries. The three largest refineries (located in Central Illinois, namely in Macon, Peoria, and Tazewell counties) maintain their processing capacity. In order to satisfy the rising demand in the northern and northeastern counties, several new refineries have to be built in that region (Ford, Iroquois, Kane, and La Salle counties, all near the greater Chicago metropolitan area) while one large corn-based refinery is built in the southwest (Macopin county, near St. Louis). Two of those new northern refineries have the maximum capacity that we specified exogenously, namely 300 million gallons per year (this limit is based on the actual sizes of the existing plants; the largest corn ethanol plant in 2007 has the annual capacity of 274 million gallons, the ADM plant in Macon county). The average corn-based refinery capacity thus rises from 121.1 million gallons in 2007 to 200.0 million gallons in 2022.

In contrast, the number of cellulosic biorefineries increases steadily from zero (no plant exists in 2007) to a total of 18 plants in 2022 (Figures 5b and 6). This is also an expected result because of the increasing trend in the RFS targets for cellulosic ethanol production (Figure 2). The smallest cellulosic plant has an annual production capacity of 111.9 million gallons while the average plant size is 233.3 million gallons, higher than the average corn-based ethanol plant size. Five of those plants, all located in southern counties (Bond, Jefferson, Perry, Richland, and Washington), hit the maximum capacity limit (300 million gallons per year), while in the north two large scale cellulosic plants are built at near maximum capacity (in La Salle and Livingston counties, with 292.3 and 262.9 million gallons, respectively).

Table 1 displays some summary statistics for the minimum, average, and maximum sizes of the corn-based and cellulosic biorefineries in 2022. According to the model results there is no observable difference between the average distances corn and biomass are transported from production regions to processing plants. The procurement areas of individual corn-based and cellulosic biorefineries are shown in Figures 7a and 7b, respectively. There is no apparent relationship between the size of the procurement area and the plant size. This relationship depends on the amount of corn and biomass input availability in the areas surrounding a given plant. For instance, some large corn ethanol plants in central counties have relatively smaller procurement areas compared to the plants located in southern counties because the relatively abundant availability of corn for ethanol in those areas.

Figure 4: Spatial distribution of projected (2022) biofuel feedstocks production in Illinois

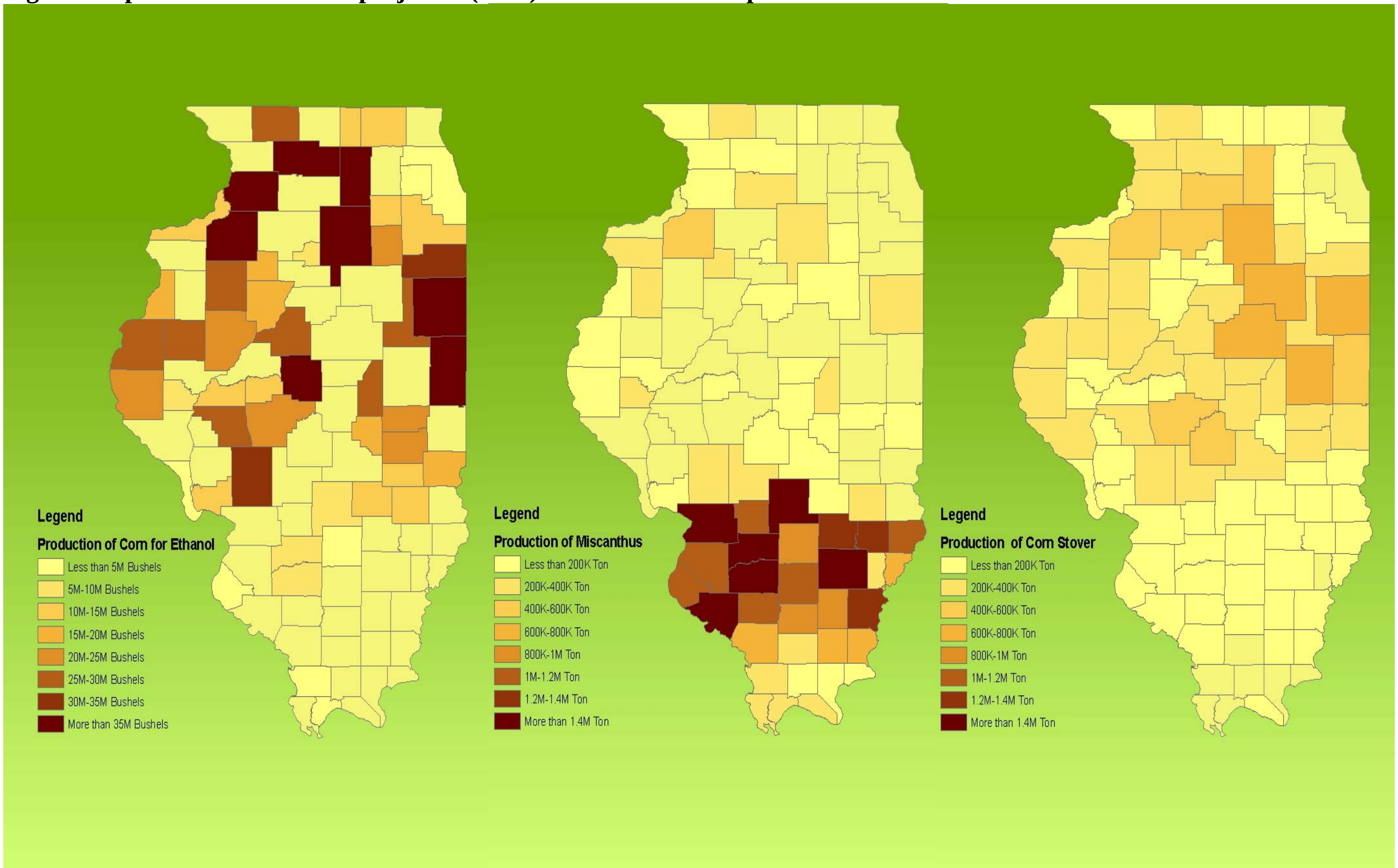


Figure 5a. Optimal location of corn-based ethanol refineries in 2022

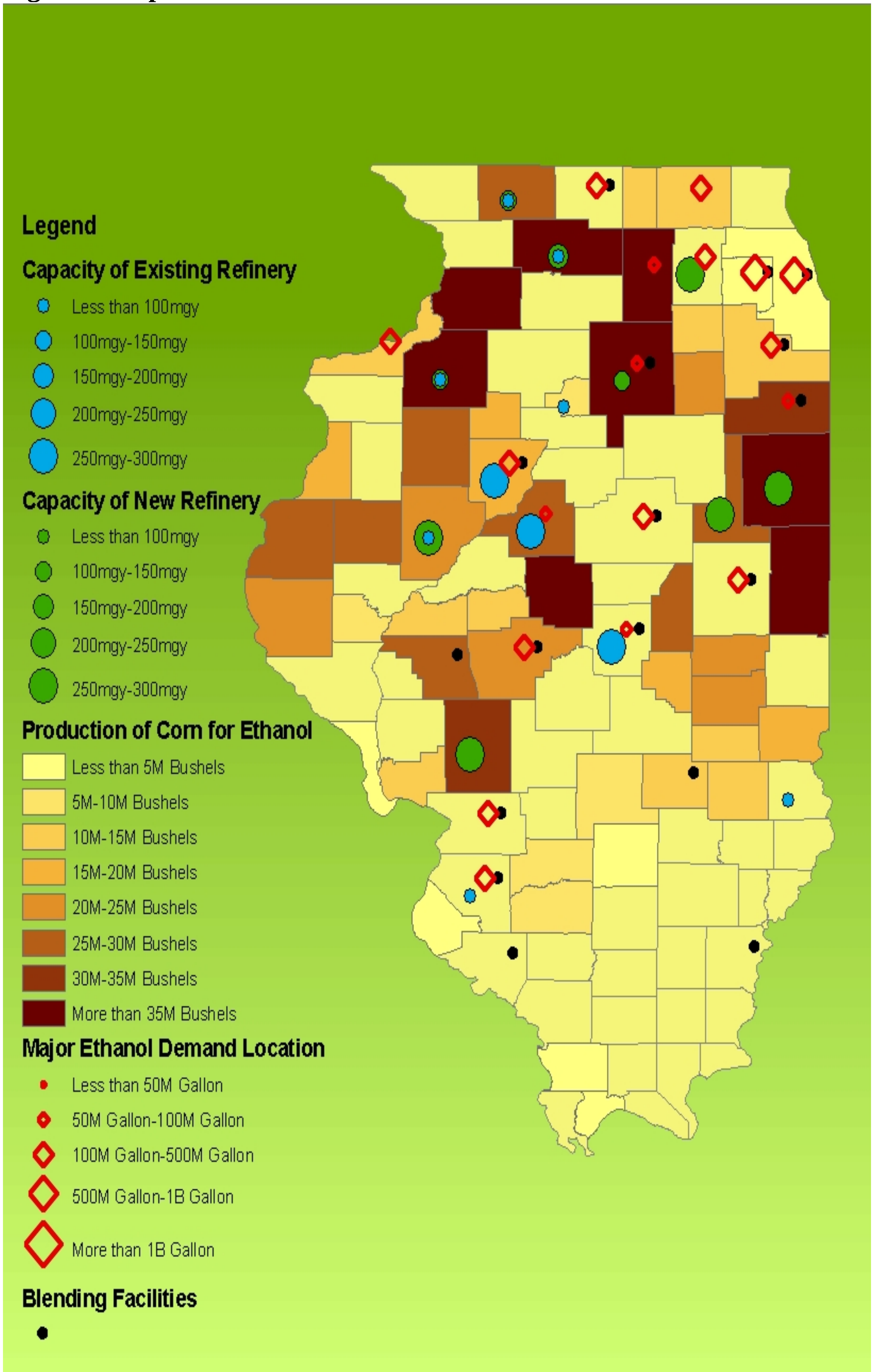


Figure 5b. Optimal location of cellulosic ethanol refineries in 2022

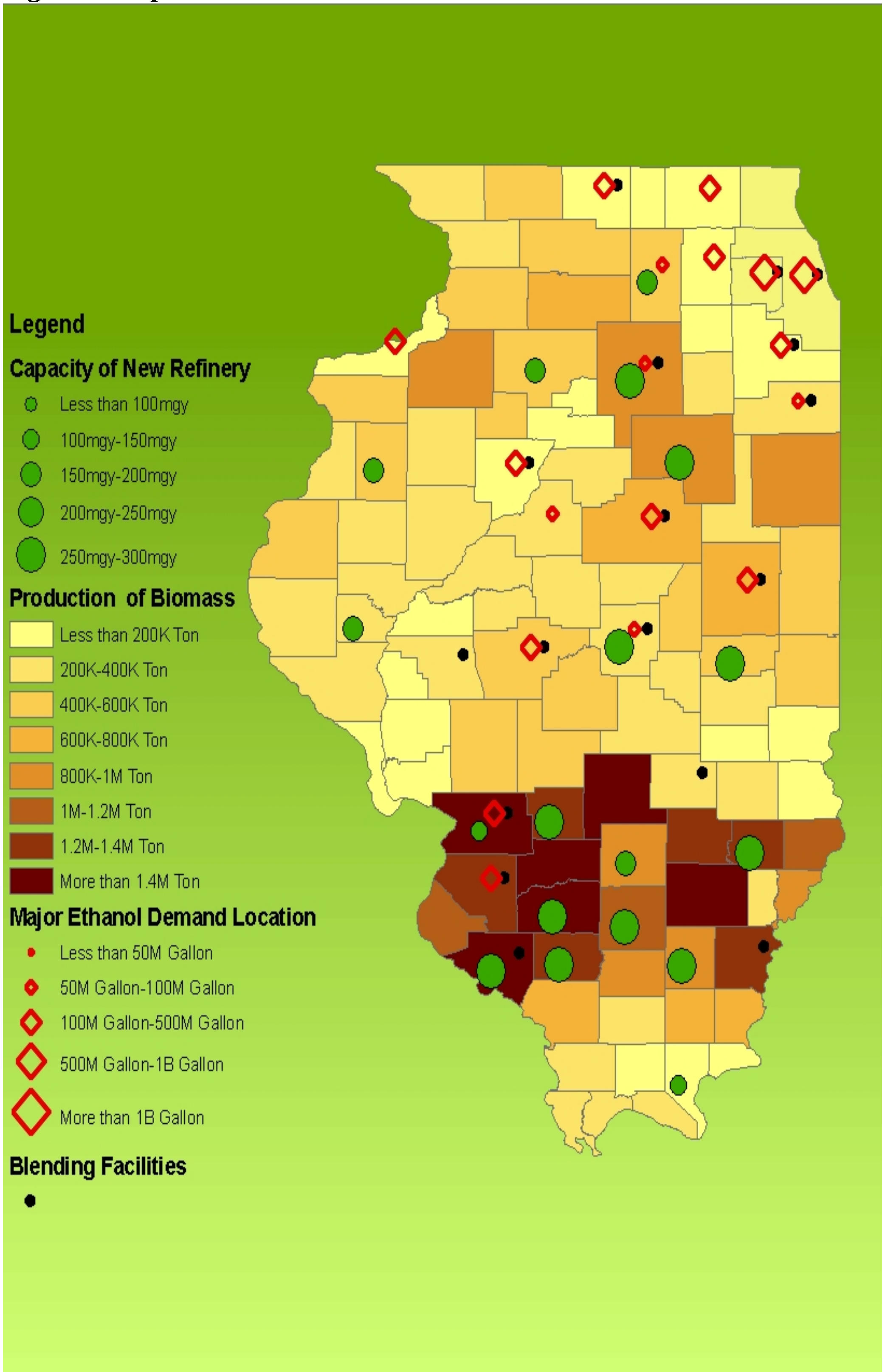


Figure 6. Projected growth of Illinois ethanol industry during 2007-2022.

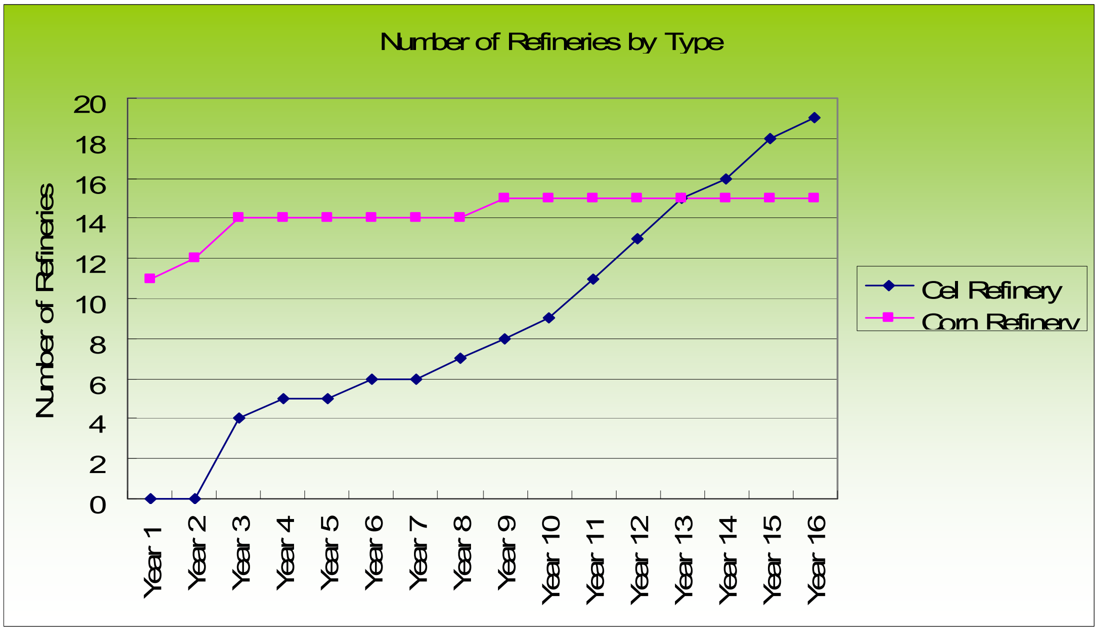


Table 1. Summary statistics for biorefinery capacities and delivery distances

	Min	Average	Max
Capacity of Corn Refinery (mgy)	78	200	300
Capacity of Cel. Refinery (mgy)	112	233	300
Transportation Distance of Corn (km)	9.6	61.2	200.1
Transportation Distance of Biomass (km)	12.3	57.3	193.4

Figure 7a. Procurement areas for corn-based biorefineries (2022)

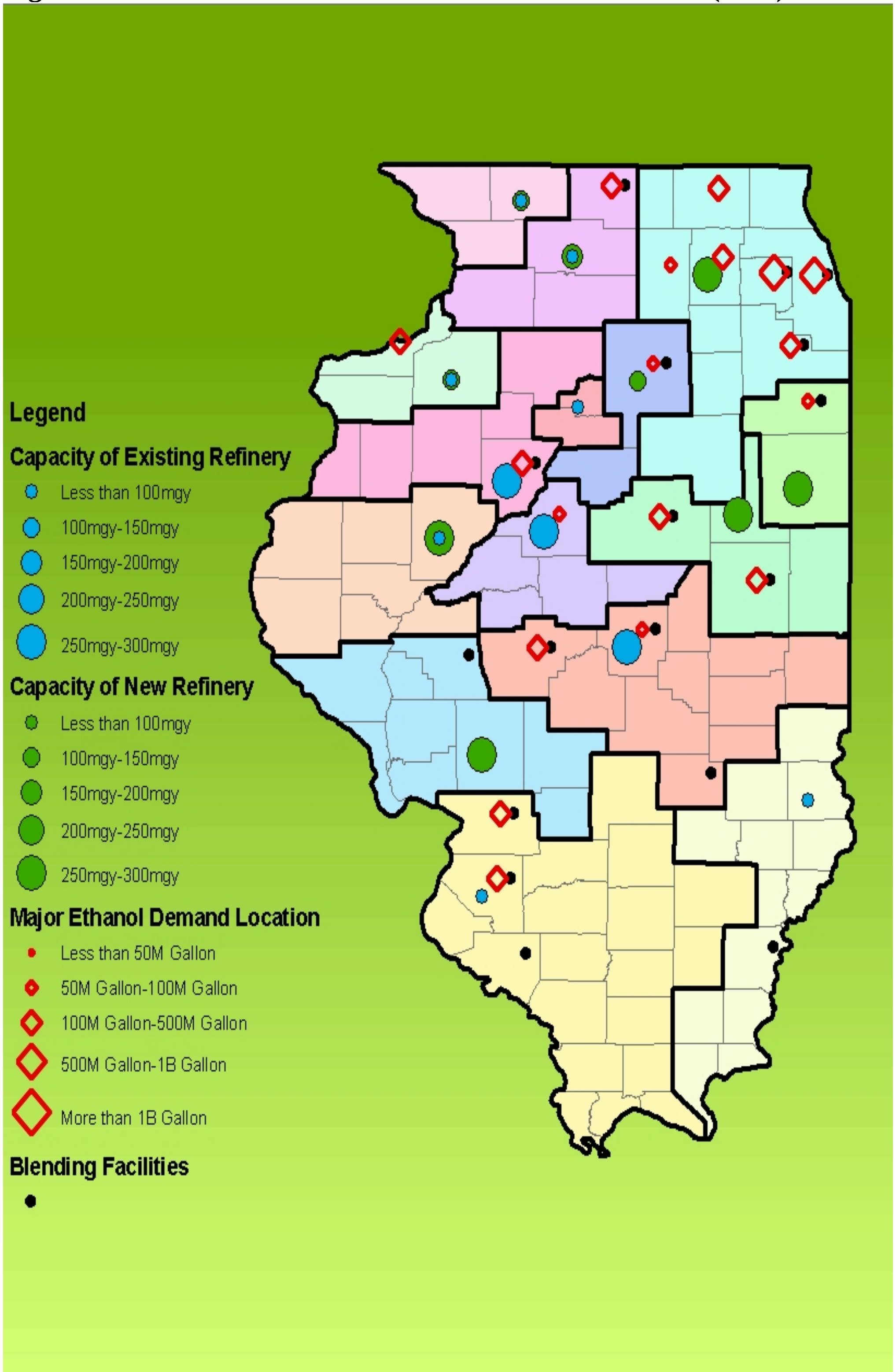
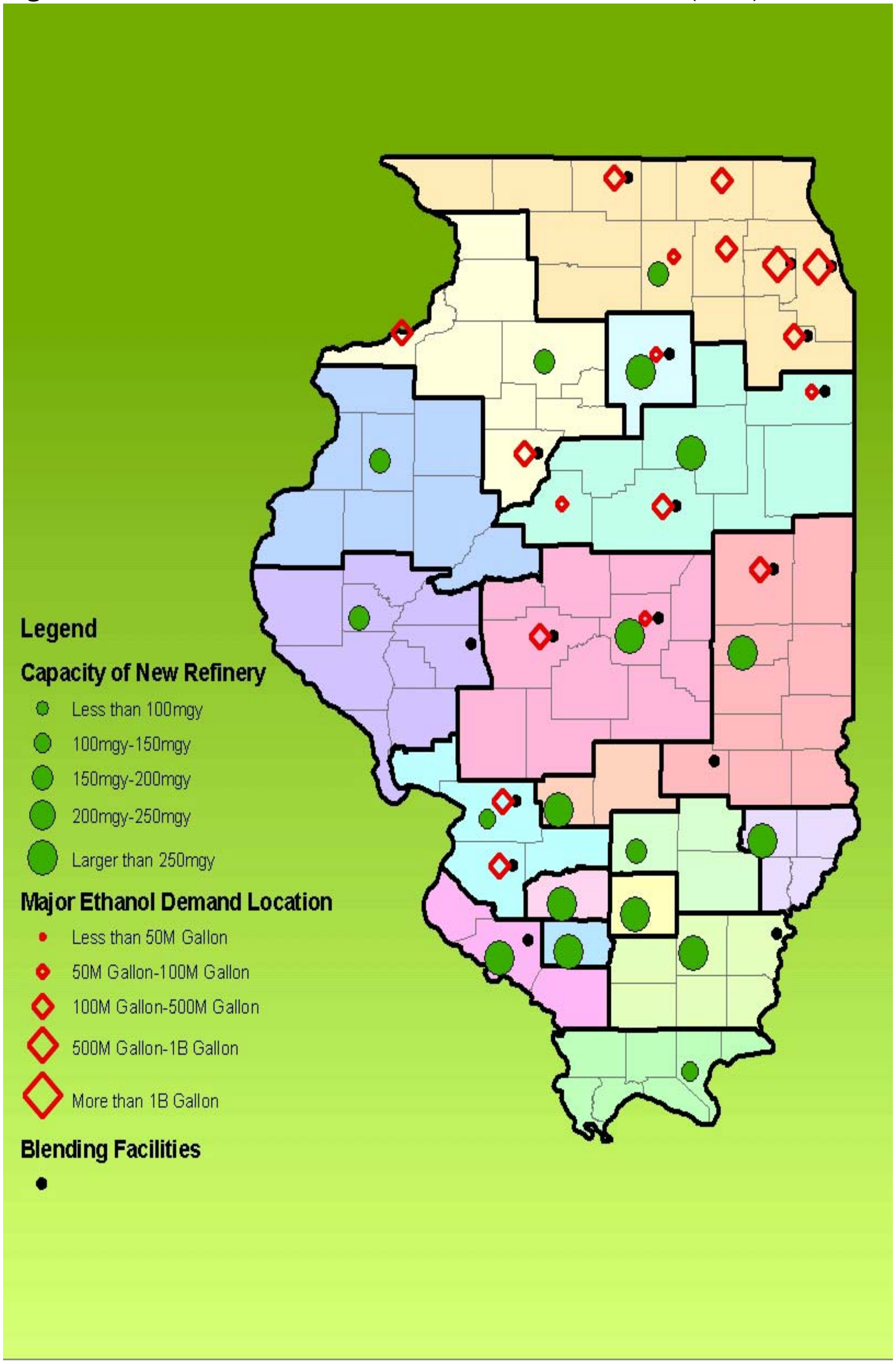


Figure 7b. Procurement areas for cellulosic biorefineries (2022)



6. Summary and Conclusions

In this article we presented the preliminary results of a mathematical programming model which aims to determine optimal locations of biorefineries in Illinois, delivery of bioenergy crops to biorefineries, and processing and distribution of ethanol produced in those facilities.

Our results show that four new and large scale corn ethanol refineries would be built in Illinois by the year 2022 and some of the existing plants would be expanded, increasing the average plant size nearly 50%. Most of the new and expanded plants are in the northern and northeastern counties, where the major demand centers are located and the increase in ethanol demand is relatively large. In contrast, 18 cellulosic ethanol refineries would be built by 2022. These refineries have generally larger capacities, with an average size of 233 million gallons per year, and they are located throughout the southern and northeastern counties where cellulosic biomass (miscanthus and corn stover) is supplied at larger amounts.

The model and application presented in this article is the first step of a comprehensive study that will address similar issues for the entire U.S. renewable biofuel industry. In the next step of our analysis the current coverage will be expanded to the Midwest region and later to a total of 28 states that are likely to supply corn and cellulosic biomass to the U.S. ethanol industry.

It would be ideal to solve the regional supply of bioenergy crops and optimal location of processing facilities simultaneously. However, the supply response model that provides input to the transhipment and facility location model used in the present study is already a very large-scale mathematical programming model. The model used in this study is also a very large-scale mixed integer programming model (including over 19,000 equations and 150,000 variables, 3,000 of which are binary variables). Solving mixed integer programs of this size is in general difficult (in this particular application solving the model took nearly six hours of processing time). Thus solving the two problems simultaneously would require a much larger-scale mixed-integer program which may be computationally intractable. This may be considered as a drawback of the present analysis. A remedy to this deficiency is to incorporate the optimal locations of biorefineries (obtained in the second stage) in the supply response model and solve it again with known refinery locations. This may lead to a near-optimal solution, if not exact optimal. We are in the process of employing this approach. Alternatively, instead of solving the model for each and every year of the planning horizon, the model can be solved only for a few benchmark years. This approach may result in an approximately optimal solution and may provide an equally valuable insight to policy makers as well as the future investors in the bioenergy industry.

Acknowledgements

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this report reflect the view of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of BP. This report does not constitute a standard, specification, or regulation.

References

Dantzig, G.B., and M.N. Thapa. 2003. *Linear Programming: Theory and Extensions*. New York: Springer.

Daskin, M.S. 1995. *Network and Discrete Location: Models, Algorithms, and Applications*. New York: John Wiley and Sons.

Dijkstra, E.W. 1959. "A Note on Two Problems in Connexion with Graphs." *Numerische Mathematik* 1: 269–271.

Drezner, Z. 1995. *Facility Location*. New York: Springer.

Eathington, L., and D.A. Swenson. 2007. "Dude, Where's My Corn? Constraints on the Location of Ethanol Production in the Corn Belt." Department of Economics, Iowa State University.

Ellinger, P. 2008. Ethanol Plant Simulator. Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, Urbana, IL.

Fuller, S.W., P. Randolph, and D. Klingman. 1976. "Optimizing Subindustry Marketing Organizations: A Network Analysis Approach." *American Journal of Agricultural Economics* 58(3): 425-436.

Hess, J.R., C.T. Wright , and K.L.K. Kenney. 2007. "Cellulosic biomass feedstocks and logistics for ethanol production." *Biofuels, Bioproducts and Biorefining* 1(3): 181-190.

Hilger, D.A., B.A. McCarl, and J.W. Uhrig. 1977. "Facilities Location: The Case of Grain Subterminals." *American Journal of Agricultural Economics* 59(4): 674-682.

Kaylen, M., D. L. Van Dyne, Y.S. Choi and M. Blasé. 2000. "Economic feasibility of producing ethanol from lignocellulosic feedstocks." *Bioresource Technology* 72: 19-32.

Khanna, M., B. Dhungana, and J. Clifton-Brown. 2008. "Costs of producing miscanthus and switchgrass for bioenergy in Illinois." *Biomass and Bioenergy* 32(6): 482-493.

Khanna, M., H. Önal, X. Chen, and H. Huang. This Volume. "Meeting Biofuels Targets: Implications for Land Use, Greenhouse Gas Emissions and Nitrogen Use in Illinois." In Khanna, ed. *Transition to a Bioeceonomy: Environmental and Rural Development Impacts*, Proceedings of Farm Foundation/USDA Conference, St. Louis, Missouri, October 15-16, 2008. Farm Foundation, Oak Brook..

Kumar, A., S. Sokhansanj, and P.C. Flynn. 2006. "Development of a Multicriteria Assessment Model for Ranking Biomass Feedstock Collection and Transportation Systems." Proceedings of 27th Symposium on Biotechnology for Fuels and Chemicals, 71-87.

Mahmudi, H., and P. Flynn. 2006. "Rail vs Truck Transport of Biomass." *Applied Biochemistry and Biotechnology* 129(1): 88-103.

Mapemba, L.D. 2005. "Cost to Deliver Lignocellulosic Biomass to a Biorefinery." Ph.D Dissertation, Oklahoma State University.

Mapemba, L.D., M. Epplin, C. M. Taliaferro, and R. L. Huhnke. 2007. "Biorefinery Feedstock Production on Conservation Reserve Program Land." *Review of Agricultural Economics* 29(2): 227-246.

Morrow, W.R., W.M. Griffin, and H.S. Matthews. 2006. "Modeling Switchgrass Derived Cellulosic Ethanol Distribution in the United States." *Environ. Sci. Technol.* 40(9): 2877-2886.

Peluso, T., L. Baker, and P.J. Thomassin. 1998. "The Siting of Ethanol Plants in Quebec." *Canadian Journal of Regional Science* 21(1): 73-86.

RFA. 2008 "Industry Statistics", Renewable Fuel Association, accessed 28 November 2008, http://www.ethanolrfa.org/industry/locations.

Scheffran, J., and T. Bendor. 2008 "Bioenergy and Land Use – A Spatial-Agent Dynamic Model of Energy Crop Production in Illinois." *Internat. J. of Environment and Pollution*: in press.

Sokhansanj, S., and J. Fenton. 2006. "Cost benefit of Biomass Supply and Pre-processing Enterprises in Canada." BIOCAP Canada.

Sokhansanj, S., A. Kumar, and A.F. Turhollow. 2006. "Development and implementation of integrated biomass supply analysis and logistics model (IBSAL)." *Biomass and Bioenergy* 30(10): 838-847.

U.S.EPA. 2007. "Renewable Fuel Standard Implementation." Available at: http://www.epa.gov/OTAQ/renewablefuels/index.htm

Wallace, R., K. Ibsen, A. McAloon, and W. Yee. 2005. "Feasibility Study for Co-Locating and Integrating Ethanol Production Plants from Corn Starch and Lignocellulogic Feedstocks." NREL/TP-510-37092 Revised January Edition: USDA/USDOE/NREL.

Wright, M., and R.C. Brown. 2007. "Establishing the optimal sizes of different kinds of biorefineries." *Biofuels, Bioproducts and Biorefining* 1(3): 191-200.

Local and Regional Economic Impacts of Biofuel Development

Larry Leistritz and Nancy Hodur[1]

Abstract: Expanded processing of agricultural products in rural areas has been widely pursued as a strategy for rural economic development. By adding value to farm products before they leave the area, new processing plants can create new employment opportunities and generate economic spinoffs in rural areas that have experienced economic stagnation or decline as a result of long term trends of farm consolidation. In addition, farmer owned processing facilities provide a way for producers to integrate forward and capture potential profits from processing and marketing their products. Consequently, the expansion of agricultural processing in rural areas usually receives broad-based support from commodity groups, rural development interests, and state political leaders. In recent years, the most prevalent type of new agricultural processing ventures in the Midwest and Great Plains states has been corn ethanol plants. Like other types of agricultural processing, these biofuel ventures have generally received widespread support, and numerous studies have addressed their contributions to local or regional economies. However, while the methods employed have seemingly been quite similar, the findings have varied widely with the impacts attributed to ethanol development differing as much as ten-fold. The purpose of this paper is to (1) examine reasons why estimates of local or regional economic impacts of biofuel development may vary and (2) compare the economic impacts of corn-based ethanol production with those expected to be associated with cellulosic ethanol production.

Expanded processing of agricultural products in rural areas has been widely pursued as a strategy for rural economic development. By adding value to farm products before they leave the area, new processing plants can create new employment opportunities and generate economic spinoffs in rural areas that have experienced economic stagnation or decline as a result of long term trends of farm consolidation. In addition, farmer-owned processing facilities provide a way for producers to integrate forward and capture potential profits from processing and marketing their products. Consequently, the expansion of agricultural processing in rural areas usually receives broad-based support from commodity groups, rural development interests, and state political leaders.

In recent years, the most prevalent type of new agricultural processing ventures in the Midwest and Great Plains states has been corn ethanol plants. Like other types of agricultural processing, these biofuel ventures have generally received widespread support, and numerous studies have addressed their contributions to local or regional economies. However, while the methods employed have seemingly been quite similar, the findings have varied widely with the impacts attributed to ethanol development differing as much as ten-fold (Schlosser et al., 2008). The purpose of this paper is to (1) examine reasons why estimates of local or regional economic

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impacts of biofuel development may vary and (2) compare the economic impacts of corn-based ethanol production with those expected to be associated with cellulosic ethanol production.

2. Economic Impact Assessment for Agricultural Processing Projects

The rationale and methods for estimating the economic impact of a corn-based ethanol plant are similar to those for assessing impacts of other agricultural processing initiatives. Processing a commodity like corn contributes to the local or regional economy to the extent that local inputs are used. Payments for these inputs, such as wages and salaries for plant employees, payments for locally purchased supplies, materials, and utilities, and possibly payments to local financial institutions, represent an addition or contribution to the local economy. These initial local expenditures (direct impacts) then set in motion rounds of spending and respending that result in secondary impacts (indirect and induced effects). These effects are most often estimated using input-output models, and the IMPLAN and RIMS models appear to be the most widely used (Leistritz, 2003).

Review of recent analyses of corn-based ethanol plants suggests that there may be a number of reasons for the wide variance in estimates. These fall into five categories: (1) misuse of impact models, (2) differences in unit of analysis (county vs. state), (3) nature of ownership (local vs. corporate), (4) specific model/analysis assumptions, which in turn may result from differences among projects, and (5) differences in study areas.

Misuse of Models

When analyzing the economic impact of an agricultural processing project, the usual assumption is that the processed commodity is already being produced and, in the absence of the project, would be sold to an alternative market. Thus, the direct impacts of the processing operation include payments for locally produced inputs like labor and utilities but do not include commodity purchases. Some ethanol impact analyses have produced impact estimates that seem inflated when compared to those for other types of agricultural processing. When these are examined more closely, it appears that corn purchases generally were included as part of the direct impacts. For instance, Swenson (2006) cites a national study that indicated 114,844 jobs were indirectly supported by the ethanol industry. This would represent a very substantial employment multiplier, as the direct employment of the U.S. ethanol industry at the time was at most 4,000. Closer examination of the study revealed that 85,311 of the jobs were associated with the production of corn. If those jobs were subtracted, the secondary employment impact would be 29,533 and the employment multiplier 8.4 – seemingly more plausible estimates.

When estimating the impacts of a corn ethanol plant, the purchases of corn **should not** be included as part of the direct impacts as doing so implies that corn production in the impact area is increased by the amount of the plant’s purchases. This is almost never the case; the corn is simply being diverted from other markets. Even in cases where corn production does increase, it will generally be at the expense of other crops, as the total land in crop production has been relatively stable. (However, this may be changing somewhat as high commodity prices are encouraging some producers to take land out of the Conservation Reserve Program.) Development of an ethanol plant generally means that local corn producers receive a somewhat better price because transportation costs are reduced, that is, the local basis (difference between local and futures price) declines. Some analyses include this price premium as part of the direct impact, but research indicates the premium is relatively small (e.g., $0.05/bu.) (Swenson 2006). Finally, some studies have assumed that the advent of an ethanol plant will lead local farmers to shift acres from other crops (e.g., soybeans) to corn. As corn is more input-intensive than most alternative crops, the shift can add to local impacts through increased input purchases (e.g., fertilizer) (for example, see Low and Isserman, 2008).

Unit of Analysis

Another reason why impact analysis results may differ is differences in the definition of the study area. Some studies estimate impacts for a site county (Peters, 2007; Low and Isserman, 2008) or for a small multi-county site area (Swenson and Eathington, 2006) while others estimate the impact for the state economy (Flanders et al., 2007; Hodur et al., 2006). None of these approaches is more or less appropriate than another, and the definition of the study area often depends on who constitutes the primary audience for the study (i.e., local leaders or state decision makers). However, other things equal, the impacts measured at the state level will always be greater than those for a single county or multi-county area within the state.

Local vs. Corporate Ownership

Another factor that can give rise to substantial differences in impact estimates is the degree of local ownership. That is, if a plant is largely or wholly owned by farmers or other local investors, the profits will be redistributed to these local owners, and a substantial portion may be spent locally. If the facility is owned by a corporation headquartered elsewhere, the profits leave the local area. In addition, some suggest that some other local expenditures are likely to be greater for a locally owned facility; accounting, administrative, and marketing functions are more likely to be performed locally for a locally owned plant whereas much of this activity might be centralized off site for a corporately owned facility. (There may be some question about the marketing aspect, as many locally owned plants are believed to have marketing agreements with ethanol construction /management firms [Dunn et al., 2005].) Finally, financing for locally owned firms is more likely to involve local banks (Urbanchuk, 2007).

The extent of local ownership can have a substantial influence on impact estimates. Swenson and Eathington (2006) present estimates for a 50 million gallon per year (MGY) plant employing 35 workers. With no local ownership, the project supports 172 secondary jobs for a total of 207 jobs and an employment multiplier of 5.9. When local ownership was increased to 25 percent, the employment multiplier increased to 6.8. At 50 percent local ownership, the multiplier was 7.6, and at 75 percent it was 8.4.

Model/Analysis Assumptions

Some differences in impact estimates can result from differences in assumptions incorporated in the impact model and analysis procedure. For example, as noted previously, some analyses incorporate a small premium for locally supplied corn whereas others do not. Sometimes the attributes of the project influence the specific assumptions used. For example, Hodur et al. (2006) chose not to include a corn price premium as very little of the corn that would supply the study plant came from the local area; most of the corn would be shipped in by unit train.

Other project attributes can substantially affect impact estimates. For example, Hodur et al. (2006) estimated impacts of a North Dakota plant, with a resulting employment multiplier of 13.4. This estimate might appear inflated at first glance even for a state level analysis, but closer examination reveals that the plant would be fueled by North Dakota lignite coal and that the coal purchases would represent a net increase in coal production for the state. Coal purchases represent 49 percent of the plant's direct impacts. In this context, the resulting estimates appear more reasonable.

Sometimes seemingly simple assumptions can affect the reporting of results and their apparent reasonableness. For example, in analyzing impacts of a cellulosic ethanol plant, Leistritz et al. (2007) assumed that persons involved in harvesting the feedstock and transporting it to the plant would be contract workers rather than plant employees. Thus, they were not included in the project's direct employment but rather were shown as part of the indirect employment. The resulting multiplier (31) would ordinarily seem excessive, but if transportation workers were assumed to be plant employees, the project's direct employment would likely be doubled and the multiplier reduced by more than half. To summarize, it is important to review study findings in light of the assumptions incorporated in the analysis.

Differences in Study Areas

A final factor affecting impact estimates is the nature of the study area. A site area that incorporates a substantial trade center and has a somewhat diversified, self-sufficient economy will have larger secondary impacts, other things equal, than a sparsely populated rural site. Low and Isserman (2008) analyze the impact of 100 MGY ethanol plants at two locations in Illinois. One site county has a population of 109,000 and is described as mixed rural while the other has a population of less than 9,000 and is described as rural. Secondary employment in the more urbanized county was estimated to be 211, compared to 114 in the more rural county.

3. Comparing Economic Impacts of Corn-based and Cellulosic Ethanol Production

While the rapid growth of the corn-based ethanol industry shows the potential for biofuels and numerous studies have estimated the related economic impacts, a broader resource base is clearly needed in order to make a substantial contribution to the U.S. energy supply. As a result, federal resources for R&D efforts to improve and commercialize biomass conversion processes have been increased substantially in recent years, and several studies have examined potential biomass feedstock supplies. However, one aspect of biomass-based industry that has received very little attention is its potential as an economic development stimulus for rural areas with high biomass production potential. This section addresses the rural economic development potential of biofuels development.

Local Economic Impact of Lignocellulosic Ethanol Production

As previously discussed, recent studies have shown that the local impacts of corn-based facilities are moderate, as the corn they utilize would otherwise be sold to other markets and local effects arise primarily from worker payrolls and other local expenditures for supplies and utilities. Biomass-based plants will have substantially greater impacts as the feedstocks will typically be from sources that do not presently have a market (e.g., agricultural residues, wood wastes) or from biofuel crops grown on lands with limited alternative use (e.g., Conservation Reserve Program [CRP] land). Studies recently completed in North Dakota allow a comparison of the economic impacts of the two types of facilities. Hodur et al. (2006) examined a recently developed corn ethanol plant; the plant had a production capacity of 50 MGY, employed 40 workers, and made annual expenditures (direct impacts) of about $16.8 million to North Dakota entities (Table 1). Purchases of corn were not included in this total, as the corn would otherwise have been sold to markets outside the state. On the other hand, the plant was fueled with North Dakota coal, so the plant's fuel costs ($8.25 million annually) were included as part of the direct impacts.

As part of an analysis of the economic feasibility of a biorefinery using wheat straw feedstock, Leistritz et al. (2007) estimated the economic impact of a 50 MGY facility. The base case facility was analyzed using an update of an economic-engineering model originally developed by the National Renewable Energy Laboratory (NREL). Plant construction cost was estimated to be $176.5 million; during plant operation, $53 million of the plant's $74.6 million annual operating expenditures were estimated to be made to North Dakota entities. By far the largest expenditure item was feedstock purchases ($36 million). The feedstock purchases represent income for local farmers, custom baling operators, and persons involved in transporting the feedstock to the plant. The plant would directly employ 77 workers with an estimated payroll of $2.7 million (Table 1). Input-output analysis indicated that the $53 million of direct expenditures would result in secondary impacts totaling $130 million for a total contribution to the state economy of $183 million annually. The economic activity generated by the plant would support more than 2,400 jobs in various sectors of the state economy, including persons involved in baling and transporting feedstock.

Table 1 allows for direct comparison of the economic impacts of corn-based and cellulosic ethanol production. The cellulosic plant has direct economic impacts (i.e., expenditures to in-state entities) that are more than three times those of the corn-based plant, as well as nearly twice as many direct employees.

Given the relatively undeveloped state of technology for lignocellulosic biomass conversion, these findings should be considered as somewhat tentative. Further, the results are obviously somewhat sensitive to the assumptions incorporated in the analysis. For example, increased fuel costs could lead to some increases in the cost of feedstock harvest and transportation, while increases in conversion efficiency could reduce feedstock requirements and costs. Also, some plant inputs may be available locally in some areas but not others, changing the proportion of plant operating expenditures that represent payments to local or in-state entities. The fact that feedstock costs make up a high percentage of total operating costs for cellulosic biorefineries, however, supports the premise that their economic development effects will be substantial.

Table 1. Direct economic impacts of corn-based cellulosic ethanol production, North Dakota

Sector	Corn-based Ethanol [a]	Cellulosic Ethanol [b]
	$ million	
Agriculture, crops	--	11.07
Construction	0.62	--
Communications and utilities	1.53	--
Transportation	1.00	8.82
Manufacturing	--	9.94
Retail trade	1.10	1.84
Finance, insurance, and real estate	0.48	2.16
Business and personal services	0.28	0.36
Professional and social services	--	0.36
Households	3.59	18.45
Coal mining	8.25	--
Total	16.84	53.01
Direct employment (FTE)[c]	40	77

Source: Hodur et al. (2006)
[b]Source: Leistritz et al. (2007)
[c]Does not include persons involved in harvesting and transporting feedstock

Rural Economic Development Implications of Meeting EISA Mandates

The recently enacted Energy Independence and Security Act (EISA) of 2007 established a Renewable Fuel Standard (RFS) of 36 billion gallons by 2022, of which 21 billion gallons must be advanced biofuels with a minimum of 16 billion gallons of cellulosic biofuels. If the 16 billion gallon cellulosic mandate is to be met exclusively from domestic production, a substantial number of new biorefineries will need to be developed. If these facilities are assumed to have an annual production capacity of 50 MGY, 320 new plants would be needed. While many questions remain about the conversion technologies and feedstock sources that will find the greatest success, one aspect of the industry's development seems virtually assured—the conversion facilities will be located as close as possible to reliable feedstock sources.

The potential development of the cellulosic-based industry can be illustrated by assuming that conversion facilities are located in proportion to potential supplies of major feedstocks. A recent NREL study analyzed feedstock availability and determined that agricultural and forest sources accounted for 97 percent of total biomass resources (Milbrandt 2005). Agricultural feedstocks (crop residues and energy crops from CRP land) were estimated to total 241 million tonnes nationwide while forest resources totaled 92 million tonnes, if only the unused portion of primary mill wastes are included. The states of the North Central region account for 60 percent of total available biomass (75 percent of agricultural biomass and 20 percent of wood)(Table 2). If 60 percent of the 16 billion gallons of production capacity were located in the North Central region, 9.6 billion gallons of capacity would be built. If capacity were proportional to feedstock by state, Iowa would be the leading state with 1.7 billion gallons of capacity, followed by Illinois (1.3) and Minnesota (1.2).

Development of a cellulosic-based industry on this scale could have major rural economic development implications. A 9.6 billion GPY industry would be equivalent to 192 plants with 50 MGY capacity. Assuming that the values reported by Leistritz et al. (2007) are representative of likely investment costs and operating expenditures, the initial investment in 192, 50 MGY plants would be nearly $34 billion and their annual direct expenditures to local and regional economies would total nearly $10 billion. The processing facilities would directly employ nearly 15,000 workers, as well as supporting many thousand additional jobs in feedstock harvest and transportation. Feedstock payments could also represent a substantial income supplement for agricultural producers; nearly half of a plant's annual operating expenditures are estimated to be for feedstock. To put the magnitude of the potential development in perspective, if development were to occur proportionally to potential feedstock supplies, North Dakota could be the home of 16 plants with production capacity of 826 MGY. If development were to occur on this scale, the cellulosic ethanol industry's annual contribution to the state economy would exceed that of the state's substantial coal mining and conversion industry.

4. Implications

The potential economic development contributions of an emerging biofuels industry are particularly significant because many of the areas where such an industry could concentrate have in the not distant past faced adverse economic and demographic trends. The rural, agricultural counties of the western Corn Belt and northern Great Plains have experienced long term trends of farm consolidation, leading to fewer and larger farms. In the absence of major nonfarm employers, many counties have experienced substantial out-migration and population losses (Rathge and Highman, 1998l; Rowley, 1998; McGranahan, 1998). Farm households have also become more dependent on off-farm employment. In North Dakota, during the period 1993-2007, off-farm wages and salaries of farm households more than doubled, growing from $6,847 in 2003 to over $16,000 in 2007 (ND Farm Management, 2007). An emerging biofuels industry could offer the new jobs and economic stimulus that many agriculturally dependent areas have been seeking and could also substantively change the economic and demographic makeup of some Midwest and Great Plains counties.

Table 2. Biomass resource availability, North Central states and U.S., 2005

State	Crop Residue	Switchgrass from CRP	Wood Wastes[a]	Total	% of U.S.
Iowa	23.6	10.2	0.7	34.5	10.4
Illinois	19.6	5.3	2.1	27.0	8.3
Minnesota	14.2	7.9	2.9	25.0	7.5
Missouri	6.0	8.5	2.7	17.2	5.3
North Dakota	6.6	10.5	0.1	17.2	5.2
Nebraska	10.9	3.3	0.3	14.5	4.4
Kansas	7.6	6.3	0.5	14.4	4.3
Indiana	9.0	1.6	1.7	12.3	3.7
Wisconsin	4.4	3.1	2.7	10.2	3.1
South Dakota	5.1	4.8	0.2	10.1	3.0
Ohio	5.0	1.6	2.2	8.8	2.6
Michigan	3.6	1.5	2.6	7.7	2.3
North Central Region	115.6	64.6	18.6	198.8	59.8
U.S.	157.2	83.6	91.7	332.5	100.0
North Central Region as percent of U.S.	73.5	77.3	20.2	59.8	

[a] Includes only the unused portion of primary mill residues. Source: Milbrandt (2005)

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References

Crooks, Tony and John Dunn. 2006. *The Role of Information Technology in the Fuel Ethanol Industry*. Washington, DC: U.S. Department of Agriculture, RBS Research Report. 209.

Flanders, Archie, Audrey Luke-Morgan, George Shumaker, and John McKissick. 2007. "Economic Impacts of Ethanol Production in Georgia." Center for Agribusiness and Economic Development Bull. No. FR-07-02 University of Georgia.

Hodur, Nancy M., F. Larry Leistritz, and Tarrand Hertsgaard. 2006. "Contribution of the North Dakota Agricultural Products Utilization Commission Programs to the State Economy." Dept. of Agribusiness & Applied Economics AAE 06006, North Dakota State University.

Leistritz, F. Larry, Nancy M. Hodur, Donald M. Senechal, Mark D. Stowers, Darold McCalla, and Chris M. Saffron. 2007. "Biorefineries Using Agricultural Residue Feedstock in the Great Plains." Dept. of Agribusiness & Applied Economics AAE 07001, North Dakota State University.

Leistritz, F. Larry. 2003. "Measuring the Economic Impact of Producer Cooperatives."In C. Merrett and N. Walzer, eds.*Cooperatives and Local Development: Theory and Applications for the 21st Century*. Armonk, NY: M. E. Sharp. pp 247-261.

Low, Sarah A. & Isserman, Andrew M., 2008. "Ethanol: Implications for Rural Communities," Paper presented at American Agricultural Economics Association, Orlando, FL, 27-29 July. (New Name 2008: Agricultural and Applied Economics Association).

McGranahan, D. A. 1998. "Can Manufacturing Reverse Great Plains Depopulation?" *Rural Development Perspectives* 13 (1): 35-45.

Milbrandt, A. 2005. *A Geographic Perspective on the Current Biomass Resource Availability in the United States.* Golden, CO: National Renewable Energy Laboratory, Technical Report TP-560-39181.

ND Farm and Ranch Business Management Association. 2007. ND Farm and Ranch Business Management State Averages, Annual Report. Accessed November, 2008. Retrieved from www.ndfarmmanagement.com.

Peters, David J. 2007. "The Economic Impact of Ethanol Production in Hall County." Department of Agricultural Economics, RD-2007-1. University of Nebraska.

Rathge, R., and P. Highman. 1998. “Population Change in the Great Plains: A history of prolonged decline.” *Rural Development Perspectives* 13(1):19-26.

Rowley, T. D. 1998. “Sustaining the Great Plains.” *Rural Development Perspectives* 13(1):2-6.

Schlosser, Janet A., John C. Leatherman, and Jeffrey M. Peterson. 2008. “Are Biofuels Revitalizing Rural Economies? Projected versus Actual Labor Market Impacts in the Great Plains.” Paper presented at AAEA annual meeting, Orlando, FL, 27-29 July.

Swenson, Dave. 2006. “Input Outrageous: The Economic Impacts of Modern Biofuels Production.” Paper presented at the Mid-continent Regional Science Association and the Biennial Implan National Users Conference, Indianapolis, IN, 8-10. Accessed December, 2008. Retrieved from www.nercrd.psu.edu/Biofuels/Swenson.pdf.

Swenson, David, and Liesl Eathington. 2006. “Determining the Regional Economic Values of Ethanol Production in Iowa Considering Different Levels of Local Investment. Part A: Developing a Modeling and Measurement Structure.” Dept. of Economics, Iowa State University. Accessed December, 2008. Retrieved from http://www.valuechains.org/bewg/Documents/eth_full0706.pdf.

Urbanchuk, John M. 2007. *Economic Impacts on the Farm Community of Cooperative Ownership of Ethanol Production*. Washington, D.C.: U. S. Department of Agriculture, Agricultural, Agricultural Outlook Forum. 8083.

Financing Growth of Cellulosic Ethanol

Dr. Cole R. Gustafson[1]

Abstract: The corn grain ethanol industry experienced rapid growth from 2005- 07. U.S. financial markets obliged and supplied credit at reasonable cost and terms which facilitated this expansion. Now, the biofuel industry is being challenged to nearly triple production under recently passed federal legislation, 2007 Energy Independence and Security Act, in the midst of a collapse of worldwide financial markets. However, the status of U.S. financial markets is in question. Both existing first generation and prospective next generation biofuel plants are demanding a large influx of capital to support adoption of new technological innovations. First generation plants require the innovations to remain low cost producers in highly competitive commodity markets. Second generation plants seek innovations to commercialize the production of cellulosic and advanced biofuels. In either case, the ability of financial markets to supply needed credit is unclear due to impediments that have reduced the borrowing capacity of biofuel firms; uncertainty surrounding future industry performance benchmarks, tax provisions, and implementation of current biofuel legislation; and the need for new risk management strategies which protect firm margins in volatile economic times.

The U.S. biofuel industry is striving to produce ethanol from cellulosic feedstock sources in an effort to augment its existing corn grain-based ethanol production infrastructure. Technology to commercially produce cellulosic ethanol is rapidly advancing due in large part to the availability of substancial federal research and development funding. The most recent round of grant funding awarded 10 grants totaling more than $10 million to accelerate fundamental research in the development of cellulosic biofuels (USDA, 2008). At the moment, several firms have pilot scale cellulosic ethanol production facilities under construction and testing.

The transition from pilot scale to full commercialization of cellulosic ethanol will be difficult, due in large part to financial constraints being imposed both internally and externally on the biofuels industry. This paper provides an overview of the biofuel industry's current financial setting and describes future challenges it faces in attempting to expand. These challenges are rooted in lack of industry capital, limited availability of performance benchmarks, concerns regarding future prospects of the industry, and general uncertainty in U.S. financial markets. If the U.S. biofuels industry is unable to capitalize and develop this next phase of growth, foreign competitors, primarily Brazil and Mexico, appear well positioned to fill U.S. consumer's demand for advanced biofuels.

2. Background

In 2005, the U.S. established ambitious goals for production of ethanol and other biofuels with passage of the Renewable Fuel Standard (RFS) as part of the Energy Policy Act of 2005 (H.R.2)[2]. This legislation set a national goal of increasing the volume of renewable fuel

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[2] For brevity, the rest of this paper will focus on ethanol. Comments made generally apply to other biofuels as well.

required to be blended into gasoline of 7.5 billion gallons by 2012. To achieve this goal, a number of tax credits including $0.51 per gallon of ethanol blended, a $0.54 tariff on imported ethanol and other incentives stimulating both ethanol supply and demand were provided. Many states also provided incentives and mandates to complement the new federal legislation.

Following passage of this legislation, investment in new corn grain ethanol facilities skyrocketed. Production capacity in 2005 totaled 3.9 bil. gal. (Renewable Fuel Association). In 2008, production is expected to exceed 9 bil. gal, surpassing the original RFS goal nearly four years early.

In addition to favorable federal legislation, several positive economic factors contributed to rapid growth of the corn grain ethanol industry. First, national corn prices averaged $2.00/bu. (USDA/NASS, 2008), relatively low compared to both historical and current levels. Moreover, oil prices were continuing to increase due to rising domestic and foreign demand coupled with stagnating increases in supply (Hamilton, 2008). Consequently, ethanol plant profit margins were very positive enabling many plants to repay their debt financing ahead of schedule and profit from larger than expected returns to equity investors. The strong financial performance of the industry caught the attention of Wall Street investors. In Oct. 2007, the Wall Street Journal reported that over $3 billion has flowed from Wall Street investors to rural America. This inflow of funds created new economic activity in rural areas of the economy that were previously quite stressed.

The final important economic factor leading to rapid expansion of the industry was ready access to current technology as well as the availability of production standards. When investors were evaluating potential construction of a new corn grain ethanol production facility, they could be assured that the plant would produce at the name plate capacity. In additional, the supply chain and risk management support provided as part of the comprehensive investment package yielded attractive, but more importantly, stable returns. Consequently, replication of ethanol plant facilities rapidly advanced across the country, further heightening investor expectations.

In addition to investors, rural communities benefited from both the economic activity associated with construction as well as on-going revenue enhancement from operations. Urbanchuk (2008) estimated a direct increase of $1.3 billion in state and local tax revenues attributable to the biofuel industry. These additional revenues have been invaluable to cash-strapped rural communities who face both population declines as well increasing federal and state mandates.

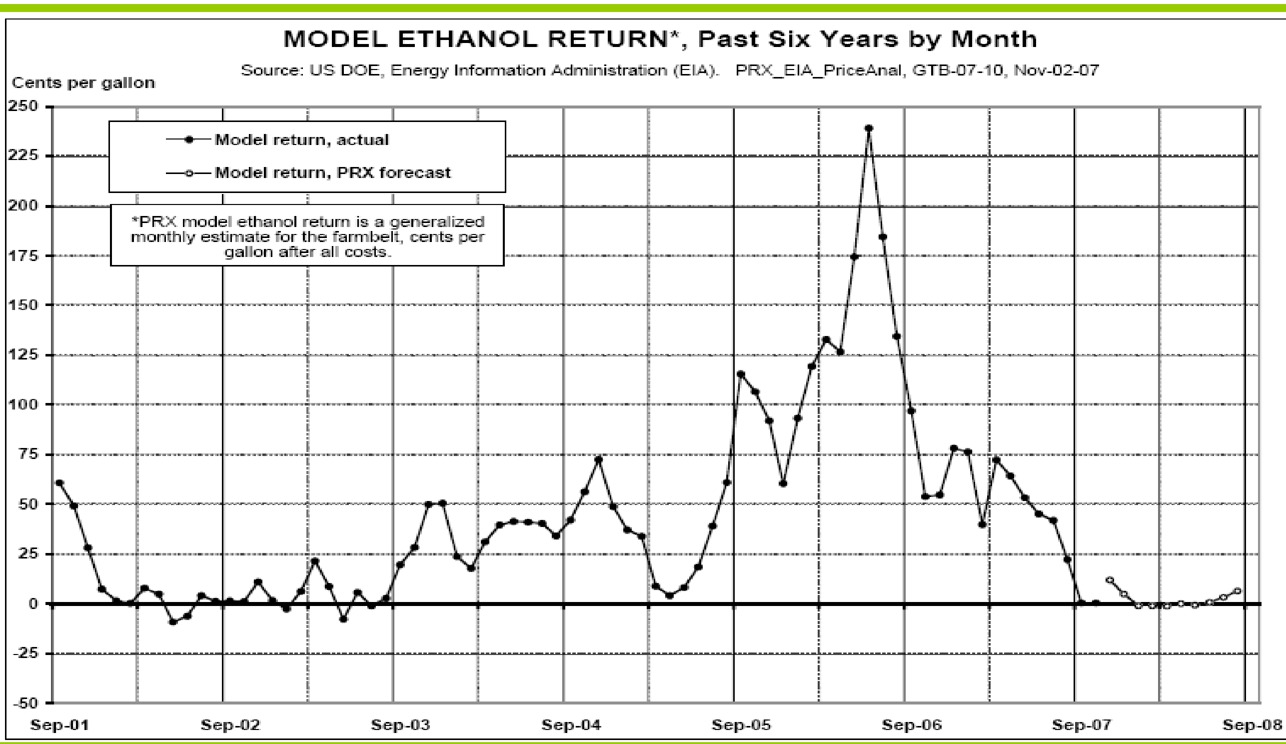
While many original ethanol producing facilities were organized and financed by local investors and cooperatives, the growth of external finance has changed the local economic impact of these firms. Swenson and Eathington (2008) find that for each one percent reduction in ethanol plant ownership, one less job is created in a local community. Rather than patronize local firms and hire people from the surrounding region, externally owned plants purchase items from national suppliers and bring in people with experience working on previous projects.

3. Current Financial Situation

Figure 1 shows historical ethanol plant margins compiled by ProExporter. Ethanol plant margin is defined as residual returns after all costs are subtracted from available revenues. The data illustrate the growth of investment returns from 2002 to mid-2006. At peak profitability investment returns spiked to over $2.25 per gallon. At the time, plant investment costs hovered around $1.00 per gallon. Consequently, investors at that time could rapidly recover their original investment and earn substantial returns.

Since mid-2006 though, ethanol plant margins have steadily deteriorated. Ethanol prices have declined as the increasing number of plants entering the industry have expanded supply. Larger supplies of ethanol have pressured ethanol prices because demand has not risen commensurately. Likewise, the greater number of plants have bid up corn feedstock costs which in turn has raised costs of production and lowered profitability. The effects of both changes have resulted in ethanol plant margins being driven to near zero. When plant margins approach zero in any industry, the point is reached where existing firms continue to operate at breakeven levels, but new firms are not encouraged to enter. Consequently, external financial capital now has limited interest in the industry.

Figure 1. Ethanol plant margins



Share prices of publically traded ethanol firms have declined in tandem with falling margins. Figure 2 illustrates the negative trend in Verasun Energy Corporation's stock price. Verasun's current stock price is approximately one-tenth of its peak value. This decline in firm value makes attraction of additional capital and expansion difficult. However, declining share prices have minimal impact on firm operations—more important are operating margins.

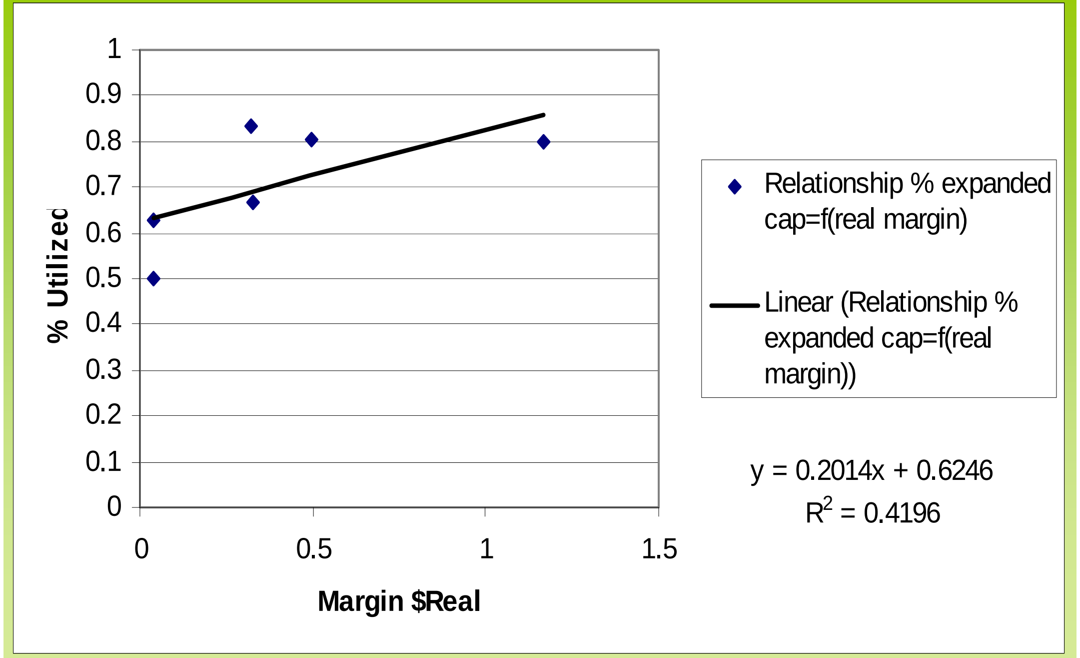
One must remember that existing firms in the industry have differing financial characteristics and profitability as they were constructed at different times, face varying input and product price opportunities, and have made diverse strategic and risk management decisions.

Therefore, at any one time some firms are likely to be quite profitable, even in less than favorable economic climates, while others will struggle in the best of times. Figure 2 shows that some firms will be idle even at high profit margins (Wilson, 2008). At presently low margins, capacity utilization declines to only 62 percent. Again, new firms have minimal incentive to enter the industry.

In addition to margin pressures, several other industry forces are discouraging further investment in new corn grain ethanol facilities. First, construction costs for erecting a new plant have doubled since passage of the original RFS. Current construction costs exceed $2 per gallon of capacity (DeVos, 2007). Second, tax credits underpinning growth of the industry are not certain. Most were scheduled to expire at the end of 2010. However, the recently passed Emergency Economic Stabilization Act (EESA) extends these tax provisions 1-2 years. Although helpful, this extension is of minimal value to prospective investors because they desire great certainty and assurances that tax benefits will continue over the lifespan of their project. Third, the general public has raised new concerns regarding environmental impacts and resource demands, especially water, associated with ethanol plant operations, and competition with available food supplies. Fourth, DeVos (2007) carefully describes limitations of existing credit programs designed to facilitate industry expansion. As individual ethanol plants increase in physical size and capacity, size restrictions placed in legislative provisions constrain their usefulness to plant operators and investors. Finally, one of the most important factors is the rapid availability of new ethanol plant technology following large federal investments in research and development. Essentially, new construction of corn grain ethanol plants has stalled as investors wait for the availability of next generation cellulosic ethanol plants.

In a commodity market, which both ethanol and corn are, firms must be low cost producers in order to compete. Consequently, they most quickly adopt innovations which either increase revenues or lower costs. In addition to potential adoption of new cellulosic feedstock technology, the industry is striving to adopt new fractionation and gasification technology. Fractionation is a process whereby incoming feedstock is separated into component parts prior to entering fermenation. As a result, the enriched input provides a higher conversion rate which expands plant capacity (e.g. less waste material needs to be handled). In addition, Gustafson and Goel (2008) find that fractionation can also quicken fermentation which improves throughput, again increasing capacity. Gustafson and Goel also find that the value of co-products increases with fractionation. Since not all starch is fermented, the higher quality input results in higher quality co-products. Finally, the other fraction, which is typically a higher protein or oil-based product provides a new additional revenue stream. Gasification enables an ethanol plant to either gasify a waste product or lower cost feedstock for plant heat.

Figure 2. Ethanol plant margin vs. capacity utilization



While investor interest in new projects is at a temporary lull, the overall health of the industry remains positive. AgCountry, a regional Farm Credit System lender, has financed 44 ethanol plants or one-fourth of the country's industry through direct loans, participations, and securitization. As of Sept. 2008, only 3 plants were under "watch" due to poor financial health, and only one plant was "a concern" (DeVos, 2008). However, the last plant's situation is not dire, and AgCountry does not expect to lose any portion of credit that they have extended to the firm.

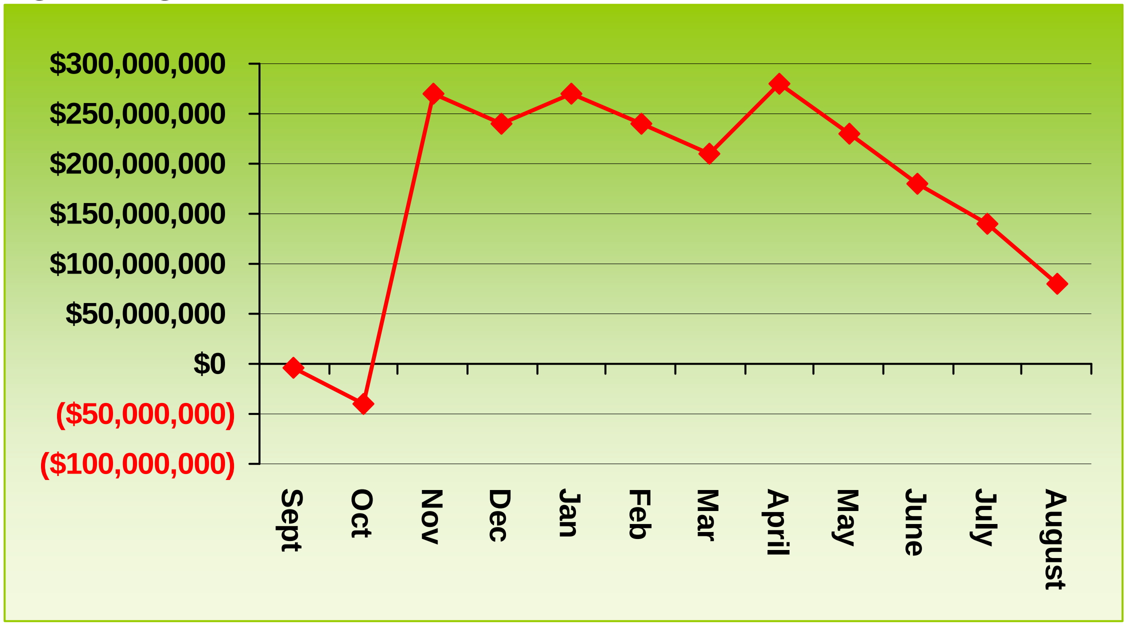
4. Collapse of International Credit Markets

The most recent development impacting financial health of the ethanol industry is the collapse of international credit markets. Given slim industry margins and other factors prevailing in the corn grain ethanol industry's notably cool investment climate, financing for either new ethanol plants or major expansion projects was virtually nonexistant prior to the collapse. Therefore, the actual collapse of international financial markets has had a minimal effect on industry expansion.

Likewise, existing biofuel plants have only been "bruised" by the collapse given the large impact seasonality has on the industry. Due to the seasonality of feedstock supply most agribusinesses negotiate their credit arrangements prior to the harvest season when input supply purchases begin. They start by forecasting peak operating credit need for the coming year (Figure 3).

In this example, the firm's fiscal year begins Sept. 1st. With some produce left to sell from the previous fiscal year, they start with a small surplus. However, when feedstock purchases begin in mid- October, their seasonal credit needs escalate to a point in April when a maximum of $280 million is required. To finance this need, the firm obtains either a letter of credit or revolving loan from a lender. Given the magnitude of the credit request, the lender will partner with other creditors and develop either a participation or securitization instrument[3]. Larger agribusinesses typically pay a fee to obtain this line of credit, but usually do not expect to draw upon available funds. In essence, annual letters of credit serve as a safety net and signify creditworthiness that permits large agribusiness to borrow less expensive credit in commercial paper markets. Credit obtained through commercial paper is lower cost, otherwise firms would simply draw on existing letters of credit. When national credit and commercial paper markets dried up in fall 2008, large ethanol plants had backup sources of credit (their existing formal letters of credit), albeit at higher cost. Therefore, when commercial paper financing was unavailable, plant operations could continue and firms drew upon letters of credit, lowering firm profitability. Smaller firms, precluded from commercial paper markets due to size, were already drawing upon existing lines of credit. Firms most impacted by the collapse were those that delayed negotiating letters of credit. They did so in an attempt to lock in lower rates in an environment of declining interest rates due to favorable monetary policy and lower credit demand. However, they found their situation problematic as lenders had difficulty forging participation and securitization agreements.

Figure 3. Agribusiness seasonal credit need



The EESA provides the biofuel industry with a number of beneficial tax provisions. Many existing biofuel tax provisions are extended for another 1-2 years, as mentioned above. An important new addition is that cellulosic biofuel plants are now eligible for a 50 percent tax credit. The cellulosic biofuel industry is on the verge of becoming commercially viable in the next couple of years. Rising construction costs are an important constraint to commercialization.

[3] In a participation, the lead lender has primary contact with creditor who services the loan. Under securitization, all lenders have direct contact and service responsibility, although shares and involvment may not be equal.

Due to their complexity and additional equipment requirements, cellulosic biofuel plants are nearly twice as expensive as corn ethanol plants ($4 compared with $2 per gallon of capacity), Devos (2007). The new cellulosic tax provision reduces construction costs of a new cellulosic plant, placing it nearly on par with existing corn grain ethanol plants. Several pilot scale facilities are operational, and construction of commercial scale plants are expected in the near future if test runs are positive.

The 2008 EESA also provides an important glimpse into growth of the U.S. carbon market. U.S. citizens are becoming more concerned about global warming, climate change, greenhouse gas emissions, and carbon. Therefore, it is central to the development of recent biofuels legislation. In addition, California, Florida and Massachusetts have passed state legislation lowering the carbon intensity of their liquid transportation fuels. It is quite likely that biofuels created with low carbon release processes will command a premium in the market place.

However, the economic value of carbon has been difficult to determine. The trading of carbon on the Chicago Climate Exchange has been somewhat thin. The federal government continues to discuss how national carbon values will be determined and controlled. One scheme being widely debated is “cap and trade.”

In the 2008 EESA, the legislation provides a $10 credit per ton for the first 75 million metric tons of carbon dioxide captured and transported from an industrial source for use in enhanced oil recovery and $20 credit per ton for carbon dioxide captured and transported from an industrial source for permanent storage in a geologic formation. Budget staff expects that more than $1.1 billion will be spent in the next decade. With publication of these values in the legislation, we now have a guidepost for establishing carbon values in the future. The biofuels industry will have an important benchmark for valuing carbon when new investment budgets are constructed. Inclusion of carbon credits in financial budgets will directly enhance both ethanol plant profitability and investment prospects.

5. Financing Next Generation Biofuel Plants

While financial growth of the corn grain biofuel industry has been relatively straightforward to document and track, defining financial prospects for the biofuels’ next stage of growth, primarily into cellulosic and other advanced biofuels outlined in EISA, is not as transparent. Several key uncertainties at the firm financial, industry, and capital market level cloud the investment horizon.

Issue 1: Lack of Capital

Only a handful of lenders across the country have actively provided credit to the biofuels industry. Most notable is First National Bank of Omaha. The portfolios of these lenders are saturated (DeVos, 2008). New suppliers of credit will be required to foster additional growth of the industry.

Likewise, existing ethanol firms have limited credit reserves. Most ethanol credit arrangements have covenants which dictate terms of credit advancement and other loan performance behavior. Most onerous of these is the imposition of “sweeps.” Sweeps were imposed during the industry's boom period. They are designed to accelerate repayment of principal and interest during periods of high profitability. In essence, both lenders and equity holders share in the prosperity and overall lending risks are reduced. However, imposition of sweeps constrains equity future growth as firms never get the chance to build equity reserves. Now when the industry is experiencing marginal profitability but requires significant capital to adopt new technology, firms have only modest equity to form a new borrowing base. This is especially problematic as new technology is four times as expensive as previous investment costs, although passage of EESA tax credits is helpful (DeVos, 2007).

Issue 2: Industry Uncertainty
Biofuel plants of the future will likely utilize a wide variety of feedstocks and conversion technologies, given the breadth of current research projects under study. As a result, there is likely to be wide variation in plant size and performance. Investors are going to have difficulty evaluating new proposals if industry performance benchmarks are unavailable. Recall growth of the industry to this point was fostered by widely available performance standards that enabled replication of corn ethanol plants across the countryside.

While federal tax credits have been extended for 1-2 years, uncertainty still surrounds their long term availability—especially in our country's present financial predicament. Passage of long-term provisions would alleviate investor concerns.

In addition, implementation of 2007 EISA, especially definition of the process for trading of RINs, is still under development (Meyer, 2008). Specification of the RIN trading process is required to establish and value low carbon fuels. Premiums commanded by these fuels will be a key determinant of future cellulosic plant profitability. As mentioned earlier, market values of carbon are not readily transparent and tradable. Consequently, investors are reluctant to advance equity funds until these values can be capitalized.

Finally, a gap exists between producer costs for biomass collection and a cellulosic plant's ability to pay for feedstock supplied—without any consideration of transportation cost (Bangsund and Leistritz, 2008; Epplin, 2008). While a $30-40 per ton cost is usually budgeted as a feedstock cost in a cellulosic ethanol feasibility study, producer supply costs are typically double that value.

Issue 3: Wall Street Turmoil
As this is being written, the extent of fallout from the collapse of Wall Street financial markets is unknown. Given what has already occurred, coupled with passage of the $700 billion package of assistance in EESA, our nation's economy and credit markets will be affected for some time. At the recent meeting of NC1014: Agricultural and Rural Finance Markets in Transition, Thomas Hoening, president, Federal Reserve Bank of Kansas City indicated that the economic performance of our country may be subdued for the next decade. When financial market crises have recently afflicted other countries, namely Japan and Sweden, it took nearly a decade to restore investor wealth to pre-existing levels. Throughout the recovery period, investors were hesitant and capital availability was constrained.

While the length of recovery can be debated, slower economic performance translates into lower demand for products. Now that the U.S. financial crisis has affected other countries spanning the globe, worldwide demand for oil is likely to decline. After closing NYMEX futures closed at $77.70/barrel on Friday, Oct. 10, 2008, prices for light sweet Texas crude oil are nearly one-half of their high last July. Consequently, prices of other liquid petroleum products have dropped as well, lowering future profitability of all biofuel plants.

Finally, given worldwide turmoil in financial markets, investors are driving up the exchange value of the U.S. dollar in a “flight to quality.” Given that the U.S. was the original source of the turmoil and real investor returns have been lowered following expansionary monetary policy, a decline in the dollar’s exchange rate would have been expected. However, given that financial market problems are of similar concern worldwide, investors have sought out U.S. securities and view them as most stable.

With a rising exchange value of the U.S. dollar, exports become less affordable overseas. Since a large proportion of agricultural commodities are exported, and are now in less demand, commodity prices have softened. Therefore, ethanol plants are striving to devise risk management plans in an environment when both input and output prices are rapidly declining. Increasing attention to margin protection will likely result. Nevertheless, investors will need assurance that newly devised margin risk management schemes will protect biofuel plant profitability and repayment capacity in whatever economic climate eventually unfolds.

If the investment pace in next generation biofuel plants slows, it appears that South American and Mexican firms are ready to fill the supply void in meeting 2007 EESA projections. Recently announced intentions include:

- ApexBrasil/Unica, $10 million promotion campaign
- Grupo Santos, $12 billion, 60 sugarcane plants
- BP, $60 million sugar to ethanol plant, Gaois, Brazil
- Bunge and Itochu ink Sugar-Ethanol JV in Brazil

Construction of these facilities would rapidly assist the U.S. in meeting its goal of producing 36 bgy of renewable energy.

6. Conclusion

The corn grain ethanol industry experienced rapid growth from 2005-07. U.S. financial markets obliged and supplied credit at reasonable cost and terms which facilitated this expansion. Now, the biofuel industry is being asked to nearly triple production under recently passed federal legislation, the 2007 EESA.

However, the status of U.S. financial markets is in question. Both existing first generation and prospective next generation biofuel plants are demanding a large influx of capital to support adoption of new technological innovations. First generation plants require the innovations to remain low cost producers in highly competitive commodity markets. Second generation plants seek innovations to commercialize the production of cellulosic and advanced biofuels. In either case, the ability of financial markets to supply needed credit is unclear due to impediments that have reduced the borrowing capacity of biofuel firms; uncertainty surrounding future industry performance benchmarks, tax provisions, and implementation of current biofuel legislation; and the need for new risk management strategies which protect firm margins in volatile economic times.

References

Bangsund, D. and L. Leistritz. 2008. "Supply Price for Switchgrass in Southcentral North Dakota." Presentation to Northern Plains BioMass Economy: What Makes Sense? Fargo, ND, Sept. 29. http://www.ndsu.nodak.edu/ndsu/bioopportunities/ConferencePresentations/BangsundNDSU092908.pdf

DeVos, Denny. 2007. Statement Before the Energy & Commerce Subcommittee on Energy & Air Quality, U.S. House of Representatives, April 24. http://energycommerce.house.gov/cmte_mtgs/110-eaq-hrg.042407.DeVos-testimony.pdf

DeVos, David. 2008. "Financing Bio-Fuel Projects." Presentation to Northern Plains BioMass Economy: What Makes Sense? North Dakota State University, Fargo, ND Sept. 29. http://www.ndsu.nodak.edu/ndsu/bioopportunities/ConferencePresentations/DevosNDSU092908.pdf

Epplin, F. 2008. "Cellulosic Biomass: Harvesting, Storage and Transportation." Presentation to Northern Plains BioMass Economy: What Makes Sense? North Dakota State University, Fargo, ND Sept. 29. http://www.ndsu.nodak.edu/ndsu/bioopportunities/ConferencePresentations/EpplinNDSU092908.pdf

Gustafson, C. and A. Goel. 2008. "Economic Feasibility of Supplementing Corn Ethanol Feedstock with Fractioned Dry Peas: A Risk Analysis." Transition to a Bioeconomy: Risk, Infrastructure & Industry Evolution, proceedings, Burton English, editor, forthcoming

Hamilton, J. 2008. "World Oil Markets: Implications for Consumers, Producers, and the World Economy." Presentation to American Agricultural Economics Association annual meeting, Orlando, FL, July 27-29.

Library of Congress, Emergency Economic Stabilization Act, H.R. 1424, Oct. 3, 2008, http://thomas.loc.gov/cgi-bin/bdquery/z?d110:H.R.1424:

Meyer, S. 2008. "Policy Risks: Potential Consequences for Biofuel's Industry." Transition to a Bioeconomy: Risk, Infrastructure & Industry Evolution, proceedings, Burton English, editor, forthcoming. http://www.farmfoundation.org/news/articlefiles/365-meyer.pdf

Renewable Fuel Association, Industry Statistics, viewed Oct. 8, 2008 http://www.ethanolrfa.org/industry/statistics/

Swenson, D. and L. Eathington. 2008. “Determining the Regional Economic Values of Ethanol Production in Iowa Considering Different Levels of Local Investment.” Unpublished paper, July, http://www.valuechains.org/bewg/Documents/eth_full0706.pdf

Urbanchuk, J. 2008. “Economic Impacts of Ethanol Production” Ethanol Across America, 12pgs., http://www.cleanfuelsdc.org/pubs/documents/EconomicIssueBrief2008.pdf

U.S. Department of Agriculture, National Agricultural Statistics Service, viewed Oct. 8, 2008, http://www.nass.usda.gov/QuickStats/index2.jsp

U.S. Dept. of Agriculture, *DOE and USDA Announce More than $10 Million in Bioenergy Plant Feedstock Research*, Newsroom, Washington, D.C. July 31, 2008. http://www.usda.gov/wps/portal/!ut/p/_s.7_0_A/7_0_1OB?contentidonly=true&contentid=2008/07/0202.xml

Wilson, W. 2008. “Energy Development Alternatives for Farmers and Ranchers as Economic Opportunities.” Presentation to National Association of Rural Rehabilitation Organizations, Fargo, ND, Sept. 28.