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Theme Overview: Economic and Policy Analysis of Advanced Biofuels

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JEL Classifications: Q2, Q4, Q13, Q42, Q48
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The existing federal biofuel policy—also known as the renewable fuels standard (RFS) as defined in the Energy Independence and Security Act of 2007—is leading to a very intense political debate, whose outcomes and decisions today affect the future development of advanced biofuels. In an effort to better understand the sources of the intense debate and the implications of existing policy decisions, the current theme attempts to explain various benefits and costs associated with the expansion of advanced biofuels and their co-products.

Zilberman and his colleagues begin the discussion, arguing that biofuel policy is an outcome of political economic processes whereby macro-level aggregate considerations, as well as micro-level considerations, lead to a fuel policy whose major impacts are improved balance of trade, increased farm-level income, and higher commodity prices.

Miranowski then discusses the merits of technology forcing and the commercialization of advanced biofuels. He examines the associated costs and benefits of forcing technological change, while reviewing supply of cellulosic and CO2 reduction costs at different levels of cellulosic ethanol production under the RFS as announced by the Environmental Protection Agency in 2013.

Miao and Madhu examine the risks associated with the production of two promising advanced biofuel crops: miscanthus and switchgrass. The authors compare the two crops with those of conventional row crops such as corn and soybeans, and quantify the relative riskiness of biomass production.

Tyner and Petter identify aviation as a potentially lucrative market for advanced biofuels. The authors present a comprehensive economic analysis of the conversion of corn stover to jet fuel using fast pyrolysis technology, and argue that risk is the primary factor currently inhibiting investment in aviation biofuels. The authors suggest policy options that might help attenuate the private sector risk and jump-start the industry.

Hochman ends this theme with an attempt to better understand the physical and economic hurdles that currently prevent commercialization of advanced biofuels. He concludes that energy production is but one of several profitable uses for biomass, and that the ultimate goal of any bioeconomy should be to make optimal use of its biomass feedstock.

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Political Economy of Biofuel

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Keywords: Balance of Trade, Biofuel, Biofuel Policy, Interest Groups, Oil

Production of ethanol and biodiesels has dramatically expanded since the beginning of the new millennium. The use of biofuels is central to many of the proposed policies to address climate change impacts. Most of the studies on the economics of climate change policies employ a *social welfare economic* perspective. The common conclusion of these studies is that the best policy to mitigate environmental externalities while maximizing social welfare is to introduce incentives that nudge producers of energy to pay the price of externalities associated with greenhouse gas (GHG) emissions, which will favor clean biofuel products. Furthermore, economists have found that current policies are inefficient and costly.

About Models Economists Use to Evaluate Biofuel Policies: Social Welfare Models and Political Economy Models

Social welfare models used by economists aim to maximize the sum of the welfare of consumers and producers minus the costs of environmental side effects of production and government expenditures (de Gorter and Just, 2010; de Gorter, Drabik, and Just, 2013; and Chen and Khanna, 2013). This type of analysis can be undertaken from the perspective of one country or the global economy. In contrast, models of political economy (Anderson, Rausser, and Swinnen, 2013) assume that political outcomes are the result of interactions among various power groups within a political system. For example, decisions are different under a dictatorship versus a democracy, and are affected by the voting system. Political economy models assume that political outcomes reflect the weighted net benefits accrued by interest groups from policies. Some political economy models assume that political outcomes also reflect macroeconomic considerations, such as economic growth, unemployment, and balance of trade.

Policies, however, are not created by economists, but by politicians. The analysis of policy choices by politicians is done using models of political economy. This article takes a political economic approach to identifying some of the key factors in the formulation of biofuel policies in the United States, the European Union (EU), and Brazil. Our analysis is conceptual, but illustrates recent evidence of this approach. We consider both macro-level indicators—economic growth, unemployment, and balance of trade—that are emphasized by the executive branch as well as the considerations of interest groups in determining policies.

Macro-Level Considerations

National policy makers—the President, congressmen and women, and senators—are judged by the performance of the macro-economy. During the 1992 presidential election campaign, James Carville coined the phrase "It's the economy, stupid" to identify the key factor affecting voting. In assessing biofuel policies, relevant macro measures include balance of trade, government expenditures, greenhouse gas emissions (GHG), and the security of energy supplies. One of President Obama's stated objectives was to reduce the balance of trade deficit, and substituting imported oil with domestic biofuel does just that. Furthermore, much of the gasoline replaced by biofuels has been exported. While in 2005 the United States consumed 141 billion gallons of gasoline, in 2011 consumption declined to 134 billion gallons. Simultaneously, ethanol consumption increased significantly while U.S. gasoline production still remains above its long-run trends (Hochman, Barrows, and Zilberman, 2013).

Increased use of biofuels also affects balance of trade by reducing the price of fuel due to increased supply. This effect might have been partially mitigated by a reduction of exports from the Organization of Petroleum Exporting Countries (OPEC) and shift of oil to domestic consumption (Hochman, Rajagopal, and Zilberman, 2011). Higher ethanol production did not reduce earnings from corn exports despite a decline in the exported volume from 49 million metric tons (MT) in 2000 to 42 million MT in 2011. Introduction of ethanol has contributed to increased corn prices as well as the value of corn exports, which have increased 180% from 2000 to 2011.

Balance of trade considerations have also been important in Brazil. The major reason Brazil introduced biofuel in 1975 was its dire balance-of-trade situation that did not allow it to import oil (Moraes and Zilberman, 2014). The discovery of large oil reserves in Brazil has reduced the importance of the biofuel program, which is capturing only a small share of the potential area for biofuel production in Brazil—8 million hectares out of a potential 60 million hectares (Youngs and Somerville, 2012). It seems that Brazil prefers to improve its balance of trade situation by investing in oil development rather than continuing to invest in biofuel (Khanna, Nunez, and Zilberman, 2014).

Another macro-objective is energy security—reduced probability of supply disruption because suppliers are politically unstable or unreliable. While balance of trade aims to reduce the trade deficit regardless of the source, energy security prioritizes some exporters over others, for example Canada and Brazil over the Middle East. Yet, balance-of-trade considerations still dominate, as suggested by the United States imposition of an import tariff on Brazilian ethanol, which ended on December 31, 2011.

Another macro-consideration is the contribution of biofuel to the budget deficit. The production of biofuel in its early stages and the development of second-generation biofuel require government outlays. But, the U.S. government has already committed to significant subsidies to farmers when agricultural commodity prices are low, thus a rise in commodity prices may reduce income support for farmers and replace it with biofuel support (Babcock, 2013), although the net effect of all subsidies requires further study. In Brazil and the EU, taxation of gasoline is an important source of government revenue and, when biofuel is taxed at a lower level, it is less appealing from a government revenue perspective. The transition of Brazil from an importer to an exporter of oil made biofuel more attractive, as domestic consumption of ethanol allows gasoline to be exported, which is also taxed and is a source of government revenue (Khanna, Nunez, and Zilberman, 2014).

The lower taxation of biofuels compared to gasoline also reflects concern about climate change. The introduction of the Renewable Fuels Standards (RFS) in the United States restricts the total life-cycle GHG emissions of biofuels to below 80% of those of gasoline. However, climate change is a less important policy consideration than balance of trade, since oil and coal replaced by biofuels and natural gas are exported to Europe. Concern about climate change in the EU is also limited, as we have seen expansion in the use of coal in Germany as a result of the containment of nuclear power.

Micro-Level Considerations

Traditionally, political economic research has investigated the attitudes of various interest groups towards policies and the impacts of these groups on policy formation. The key interest groups in the biofuel debate include consumers, the agricultural sector, environmentalists, the fossil fuel industry, alternative energy producers, the transportation industry, and others.

Food and Fuel Consumers

The impact of biofuel on domestic consumers in the United States is relatively small. The impact on retail food prices was estimated to be only 5.2% in 2008 when concern about the impact of biofuel on food prices reached its peak (Harrison, 2009). Additionally, there may be some benefit from reduction in fuel prices, estimated to be about 3% in 2007 due to biofuel (Rajagopal et al., 2007). The higher commodity prices associated with biofuels, especially during periods of low inventories of agricultural commodities (Wright, 2014), have higher relative impacts on consumers in developing countries who allocate a higher share of their incomes to food. Agricultural producers in developing countries may benefit if they are net sellers of commodities. The prices of agricultural commodities would have increased further without the adoption of genetically modified organisms (GMOs) after 1995 (Barrows, Sexton, and Zilberman, 2014). Consumers in developing countries benefit much less from reductions in fuel prices, primarily because many do not own cars.

The Agricultural Sector

U.S. farmers as a whole have benefitted from biofuels because they increase overall demand for agricultural commodities. The gains for the agricultural sector from biofuels are apparent from the rise in prices of agricultural land since 2007, despite the financial crisis. Similarly, sugarcane producers in Brazil benefitted from biofuels. Corn producers who face growing demand for corn syrup are indirect beneficiaries from the rise in the price of sugarcane. Farmers from developing countries, even with extreme levels of poverty, benefitted from the price effect of biofuel while the main losers in these regions were urban consumers and the landless (Huang et al., 2012).

Environmentalists

The perspective of environmentalists on biofuels has changed. When biofuels were introduced, they seemed to provide significant GHG emissions benefits and environmentalists supported them. The emergence of studies that doubted biofuel's contributions to GHG emissions reductions and the suggestion that biofuels may lead to deforestation have led environmentalists to hold negative attitudes towards first-generation biofuels while holding more positive ones about second-generation biofuels (Delshad et al., 2010). The environmental perspective on biofuels is evolving in that not all biofuels are treated alike. Palm oil biodiesel produced in Indonesia and biodiesel from soybean are viewed even less favorably than corn ethanol (Laborde and Valin, 2012).

Oil Companies and Producers

Basic economic analysis suggests that oil producers oppose biofuels because their production is likely to reduce the price of oil. The perspectives of individual oil companies vary. Some companies, such as BP and Shell, invest in biofuel technology. But the enthusiasm of oil companies for biofuel may be mitigated since they have to share a significant amount of the rent with farmers and, thus, biofuel is likely to be less profitable for these companies than oil. This perspective may explain why Petrobras, the leading oil company in Brazil, tends to emphasize investment in petroleum over biofuel (Moraes and Zilberman, 2014). Companies that obtain most of their revenue from oil or shale gas see biofuels as a competitor. Some companies may expect that, in the long run, GHG regulations may reduce the demand for fossil fuels even further. Thus, oil companies may oppose biofuels because they reduce companies' capacity to sell fossil or shale fuels in the short-term before strict regulations of biofuel and GHG emissions are introduced.

First-Generation Biofuel Producers

Much of the production of first-generation biofuels is controlled by corn or sugarcane producers who have invested in refineries. This group benefits from biofuels both because of the direct gains and because of its impact on commodity prices, whether in corn or sugarcane. There are also companies that have invested in refineries. While earnings have been unstable and there have been significant losses in the past, biofuel refiners have become more competitive over time and are now able to survive without subsidies (Babcock, 2013). In the United States, many of them would like to see the blend wall removed or the mandate increased. In Brazil, they hope that the upper limit on fuel prices will be removed so that producers there may prosper (Moraes and Zilberman, 2014).

Second-Generation Biofuel Producers

At the onset of the movement towards second-generation biofuel production, organizations that promoted second-generation biofuels tended to shed negative light on first-generation biofuels to justify large government expenditures as well as subsidies for their new products. Furthermore, with the existence of a blend wall, second-generation biofuels may find first-generation biofuels to be competitors in supplying a given market. But the relationship between first- and second-generation biofuels is complex. The economic viability of biofuels has been demonstrated by first-generation biofuels. The high price and seemingly slow progress of second-generation biofuels may lead opponents of the technology to advocate reducing support for both first- and second-generation biofuels.

Producers of Other Alternative Energy

Biofuels are among many sources of alternative energy, and these other sources, such as solar and wind, are also competing for government support. There is an implicit competition between solar and wind power, which may be used to fuel electric vehicles, and biofuels. Even new providers of natural gas through fracking and other means may see investment in biofuels as a competitor, despite natural gas being a nonrenewable, albeit cleaner fuel, than oil.

Automobile Companies

The automobile sector is diverse and different companies have different relative advantages. Companies such as Tesla that promote electric cars may see investment in biofuels as a distraction to the "real" backup technology. Some traditional automobile companies, especially ones with large capacity for production of flex fuel cars, will be supportive of the expansion of biofuel.

Companies may be hesitant to support raising the blend wall substantially because they may be worried about the performance of their cars when using blended fuels. If the United States wants to displace gasoline with ethanol, a major challenge of current policy is to increase use of ethanol beyond E10. One way to do this is to expand the availability of E85 (Babcock and Pouliot, 2013).

Automobile companies prefer clarity about the future of fuel in order to optimize the design of their cars. For example, car companies can tweak engines to be more efficient and take advantage of the higher octane content of ethanol if they are assured a large supply of ethanol will be available.

Other Groups

There are many other parties who have a stake in the biofuel debate that will affect their involvement in the policy arena. For example, airlines have realized that they will likely always be dependent on liquid fuels and, as Europe and other countries consider penalties for GHG emissions from transportation, there will be a premium for cleaner, alternative fuels. Thus, airlines will support investments in biofuel research. The military will continue to need fossil fuel, but may look at biofuels and other cleaner fuels as important investments for the future. Certain municipalities that see the relative advantage of production and refining of biofuels may support policies to enhance them. Universities and other organizations that support investments in research to increase knowledge about biofuels will back them as well.

Conclusions and Final Remarks

We have offered a framework to analyze the political economic forces that affect biofuel policies in the United States and globally. This framework assumes that policies are determined as a result of the weight given to macro-economic factors such as balance of trade, government budget deficit, and climate change, as well as the interests of specific groups, including consumers, farmers, and oil companies, among others. Much of the support for biofuel has been linked to its contribution to improved balance of trade and energy security, and less so to slowing climate change. We also argued that interests of oil companies in the United States and Brazil have curtailed the expansion of biofuels. Learning by doing that improved the economic viability of first-generation biofuels in the United States and Brazil helped to sustain it politically. While U.S. and Brazilian farmers are supportive of biofuels for the most part, it does not seem that U.S. consumers are very interested or concerned about biofuels either way, while consumers in developing countries are more likely to be concerned about biofuel because of food price inflation associated with it. Environmentalists are lukewarm towards biofuels at best, and oil producers may be ambivalent or even opposed.

It seems that the use of first-generation biofuels in the United States will continue in its limited form and production of sugarcane biofuel feedstock in Brazil will expand. Expansion of first-generation biofuels will depend on improvements in agricultural productivity and increases in energy prices. The large-scale expansion of biofuels will be dependent on improvements in the cost-effectiveness of second-generation biofuels both in terms of feedstocks and the refining process. It will also depend on the economics of substitute energy sources and concerns about climate change. Commercial interest and investment in second-generation biofuels will depend on government support for research and early introduction of the technology, which may include mandates and subsidies during a transitional period.

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Technology Forcing and Associated Costs and Benefits of Cellulosic Ethanol

John Miranowski

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Technology Forcing in Environmental Policy

Technology forcing regulations (policies) have long been used in environmental economics. To evaluate the technology forcing impacts of the RFS, it is important to address two questions: First, what is technology forcing and what is it designed to achieve? Second, why and how did it originally come about in the air quality arena, and what is the underlying economic rationale?

Technology forcing is a regulatory strategy that establishes currently unachievable and uneconomic performance standards to be met at some future point in time. The legislation or regulatory rules also set a defined time period for achieving these performance standards as well as intermediate or annual progress that must be demonstrated. In cases where the standards are not achieved in a timely fashion, fines are assessed or permits have to be purchased. Basically, technology forcing sets regulatory standards and provides incentives for achieving the standards or disincentives for not achieving them. In many respects it is analogous to a cap-and-trade system with phased-in or more restrictive emissions caps over time.

The origin of technology forcing in air quality control goes back to the 1960s. California and the U.S. government had been following what was referred to as "technology following" with respect to air quality regulations. California, the state with the worst air quality, required automobile pollution control devices be installed on new vehicles after two developers demonstrated their devices could meet specified emission levels at reasonable costs. This approach provided a disincentive for automakers to divulge development of their own control efforts until two others were certified (Miller and Solomon, 2009), and it led to collusive behavior both in limiting device development and overstating time needed to meet emission standards. The California experience led to adoption of technology forcing for auto emissions control.

Similarly, low private investment in air emissions control technology research, development, and demonstration led Congress to design the Clean Air Act Amendments (CAAA) of 1970 to: (1) stimulate private investment that would help meet new emission source performance standards, and (2) allow the states to require existing emission sources to meet technically or economically infeasible emission limitations as part of state implementation plans (*Yale Law Journal*, 1977). Further, the U.S. Supreme Court in *Union Electric C. v. EPA (1976)* found that Congress intended the 1970 amendments to induce rapid improvements in air pollution control technology, or technology forcing, and affirmed the states' authority to set such standards as well.

Technology forcing involves two policy challenges: First, who sets the performance standards and how do they forecast potential technology improvements in setting standards or targets? At the Federal level, this will be Congress and the Environmental Protection Agency (EPA) in the renewable fuel and air quality arena. Second, what is the enforcement mechanism and how stringent will the enforcement process be? Gerard and Lave (2005) discuss how these challenges were addressed in implementation of air quality policies and how they helped explain the success of technology forcing with respect to efficiency, industry costs of non-compliance, waivers, delays in implementation, and political deterioration (reduction) of performance standards. Further, Gerard and Love point out how these factors may create significant "policy risk," and disincentives for investors to develop new technologies when not designed or implemented appropriately. This is an important concern in the implementation of the RFS.

RFS Technology Forcing and Commercialization of Cellulosic Biofuel

Biofuel made from renewable resources offers an alternative fuel to petroleum. To encourage production and consumption of biofuel, Congress passed the initial Renewable Fuels Standard (RFS) as part of the Energy Policy Act of 2005. The RFS applied only to conventional ethanol biofuel and had a 2012 target of 7.5 billion gallons per year (bgy). As part of the 2007 Energy Independence and Security Act (EISA), Congress established the RFS mandate that required 36 bgy of biofuel by 2022. The EISA mandated conventional ethanol at 15 bgy, biodiesel production at 1.0 bgy, cellulosic ethanol at 16 bgy, and advanced biofuel at 4 bgy with annual targets over the intervening years. It is important to note that Congress, through the EISA, legislated the annual and 2022 mandates, and EPA is responsible for the rules implementing the mandated levels. EPA also established a separate Low Carbon Fuel Standard (LCFS) for each biofuel subcategory, ranging from a 20% reduction relative to gasoline for conventional ethanol to a 60% reduction of CO_2 emissions for cellulosic ethanol (U.S. EPA, 2010).

The annual mandates, unless waived or reduced by EPA, determine the number of gallons of biofuel from each category that need to be blended that year. Compliance with the mandate falls to oil refineries and is enforced through Renewable Identification Numbers (RINs). One RIN record is associated with each gallon of biofuel. If oil refineries do not have sufficient RINs relative to their liquid fuel sales, they need to purchase additional RINs in the market to make up the difference. The market clearing process determines the price of RINs. If the annual blending mandate (original or as adjusted by EPA) has been met, then the price of RINs should fall to zero. The RFS provides annual mandate quantities for each biofuel category. EPA does annual evaluations and is allowed revisions to prevent costly investment. When a portion of the biofuel mandate is waived, EPA is required to make waiver credits available to meet the revised mandated volumes in lieu of blending biofuel.

Technology forcing typically improves efficiency over government incentive programs that provide loans, technology grants, interest subsidies, output tax credits, loan guarantees, and other incentives. Why? Although the government may pick the biofuel categories, it does not pick the "winners" (e.g., companies, technologies, and feedstock) in terms of what technology platforms are researched and developed. These decisions are made by firms that compete in a market environment that can more efficiently supply the targeted product. For example, biofuel processors compete with each other to find the most efficient conversion technologies and feedstock producers compete to supply the least cost feedstock input. Unlike the government providing grants, subsidized loans, and other incentives to develop renewable energy and emissions control technologies, the government sets the targets and lets the market derive an efficient solution or get "the biggest bang for the buck" in biofuel supply. Ultimately, this approach should lead to renewables competing with petroleum products, especially with increasing oil prices over time. At the same time, this statement assumes: (1) that other government incentives (e.g., tax credits, subsidies) to oil companies are not distorting market prices, and (2) that biofuels are able to satisfy the mandated RFS targets on a competitive basis. Possibly because of regional equity (e.g., rural income and development) and environmental impacts, separate mandates for biofuel categories were specified in the EISA as discussed above. RFS program efficiency could be improved if biofuel categories (i.e., feedstock sources and conversion technologies) were competitively designed.

Historical Biofuel Policy

Duffield, Xiarchos, and Halbrook (2008) provides a historical review of modern biofuel policy. Biofuel policy really has its origin in the National Energy Policy Act (1978) that established a $0.40/gal excise tax credit for fuels containing at least a 10% ethanol blend. The Energy Security Act of 1980 offered insured loans to small ethanol plants and subsequent acts provided grants, loans or guarantees, and other incentives. In 1988, Congress passed the Alternative Motor Fuels Act that provided credits to automakers producing cars running on alternative fuels such as E85 in meeting Corporate Average Fuel Economy, or CAFÉ, standards. The CAAA of 1990 established the Oxygenated Fuels Program and the Reformulated Gasoline Program. Both programs required that oxygen be added to gasoline, and ethanol was an alternative for meeting the oxygen requirement. The 2002 Farm Security and Rural Investment Act created a number of incentives to promote production and consumption of bioenergy and bioproducts. These incentives increased conventional ethanol demand and helped the industry develop a technology base for rapid expansion. Yet, these incentives did not make ethanol competitive on a gasoline equivalent basis in the market. The industry produced only 1.6 bgy of ethanol in 2000 and 13.3 bgy by 2010. What really drove biofuel industry development in the 2000s beyond legislated ethanol demand and policy incentives were higher oil prices (Andrian and Miranowski, 2009; and Aukayangul and Miranowski, 2010).

Prior to the RFS, similar government incentives (loans, grants, feedstock incentives, and excise tax credits) were used to spur cellulosic technology development in the 1970s and in the 2000s (National Academy of Sciences, National Academy of Engineering, and the National Research Council (NAS-NAE-NRC), 2009). Except for short run, oil supply interruptions and high oil prices, research and development in cellulosic biofuel technologies were limited until the EISA was passed in 2007. As a result, substantial progress has been made in research, development, and commercialization.

Benefits Associated with the RFS Mandate?

The benefits discussed in the EISA 2007 of the RFS include energy security gained from having a domestic source of renewable liquid transportation fuel, an associated reduction in greenhouse gas (GHG) emissions, and enhanced rural incomes, employment, and economic development. Typically, the critique of the RFS centers on a few key issues: (1) the need of energy security in an era of gas and oil fracking and declining domestic liquid fuel consumption, (2) what biofuel costs relative to greenhouse gas (GHG) emissions reduction, and (3) unlike the CAAA, technology forcing biofuel policies will not bring growth and prosperity because biofuel will substitute for domestic fossil fuel activities. In the short run, biofuel expansion may compete with domestic fossil fuels in the market and even lead to contraction in some of the fossil fuel sectors. At the same time as a society, we live and participate in a global energy market where oil prices are largely determined by global oil supply and demand.

What are the economic benefits associated with the RFS mandate? This is truly one of those questions with an “it depends” answer. Benefits depend on which crude oil price (i.e., current or longer run) is used because gasoline, diesel, and biofuel are a function of oil prices. The benefits of the biofuel substitute increase and decrease with petroleum prices. If long run oil price is sustained at $150/bbl as forecast by the U.S. Energy Information Agency (EIA) (2014) for 2035, many cellulosic and advanced biofuels will become competitive with gasoline and diesel as long as blending constraints are not imposed (Miranowski and Rosburg, 2013; Rosburg and Miranowski, 2011; and National Resource Council (NRC), 2011). Alternatively, if current oil price is sustained in the long run, then biofuel becomes more costly to blend. Furthermore, the multi-objective nature of the legislation creates an important attribution problem in measuring and comparing “efficiency” versus “distribution” benefits.

The benefits of domestic energy security are difficult to measure. Energy security is a long run issue. Even if we have positive short run supply shocks (e.g., fracking gas and oil) and short run decreases in domestic consumption, global energy markets will drive energy prices and price volatility. The less dependent we are on global petroleum markets the better able the United States will be to deal with global oil shocks and potential supply interruptions.

The rural development impacts of biofuel have created significant employment and economic growth in rural regions with excess feedstock supplies, like the Midwest, as discussed in Miranowski et al. (2010) and Brown, Weber, and Wojan (2013). At the same time, these impacts may be more intermediate run and the livestock sector may have been disadvantaged by the competition for feedstock from biofuel expansion in the short run. Furthermore, the net economic benefits to the region in the longer run may be different than the private benefits of employment and income growth.

What are the potential carbon savings or how does the cellulosic ethanol footprint compare with that of gasoline? Although there is much conflict in the literature over the carbon savings associated with biofuels (NRC, 2011), the most frequently reported estimates are based on the GREET model. Rosburg and Miranowski (2011) used the GREET 1.8 version from the Center for Transportation Research, Argonne National Laboratory. These were derived by comparing total GHG emissions per mile for both conventional gasoline and cellulosic ethanol. They assumed biomass ethanol yield—70 gal/ton; ethanol fuel efficiency—23 MPG; and gasoline fuel efficiency—23 MPG in 2009 based on default options. The reductions in GHG emissions relative to gasoline-fueled vehicles ranged from 84% to115% over all cellulosic feedstock with corn stover at 89% and switchgrass at 84%. In terms of tons of GHG savings per ton of feedstock, these estimates ranged from 0.79 to 1.09 tons CO_2e reduction per ton feedstock with corn stover at 0.85 and switchgrass at 0.80. These numbers imply a substantial cellulosic ethanol reduction relative to gasoline.

Supply Costs of Cellulosic Ethanol Production Under the RFS Targets

I will consider two types of cellulosic biofuel costs. These data are similar, but derived under different assumptions. One approach is to consider the long run average supply cost for different cellulosic feedstock in different production regions. It is necessary to use comprehensive accounting of all feedstock supply costs including establishment, production, and land opportunity costs; harvest and storage costs; and transportation and delivery to the biofuel processing plant. Such estimates from NRC (2011) and Rosburg and Miranowski (2011) are used in this example for illustrative purposes, but similar estimates are reported in other studies using comprehensive cost estimates (Miranowski and Rosburg, 2013). Estimates for feedstock delivered to the biofuel plant range from about $75/ton for wheat straw and forest residues to about $89/ton for corn stover and farmed trees to about $98/ton for switchgrass in the lower cost production regions. Assuming a 70 gal/ton biofuel conversion rate, feedstock costs will be from $1-2/gal of biofuel depending on the feedstock used. Further, to supply the RFS mandated cellulosic biofuel levels will require a combination of feedstock. Assuming a long-run oil price of $100/bbl, the gap between what the biofuel producer can pay for feedstock and what the feedstock seller must have to breakeven is about $0.85-1.50/gal or $60-100/ton assuming a 70gal/ton biomass conversion rate.

There have been a number of estimates of the average costs of supplying cellulosic ethanol from different cellulosic feedstock but few supply or marginal cost curve estimates for supplying different quantities of cellulosic ethanol to the fuel market. Rosburg, Miranowski, and Jacobs (2013) estimated the supply cost of meeting the 2016 RFS.2 cellulosic ethanol requirement of 4.25 billion gallons using sustainably-harvested corn stover and switchgrass feedstock. If the industry is scaled-up commercially, they found that the 4.25 bgy could be produced at an ethanol price under $3.50/gal, or a wholesale gasoline-equivalent price $5.15/gal. Additionally, cellulosic ethanol would be cost competitive with gasoline at $150/bbl oil price. If the cellulosic ethanol industry were further scaled-up with assumed technology, it could produce about 12 bgy of cellulosic ethanol at a wholesale ethanol price of $4.00/gal. At the same time, technology should improve significantly over time and reduce cellulosic ethanol costs significantly. It is important to note that these estimated costs are calculated absent any cellulosic biofuel incentives, such as the producer tax credit of $1.01/gal and the Biomass Crop Assistance Program (BCAP) feedstock subsidy, which could substantially reduce these costs. Similar estimates have been developed in similar studies (e.g., Chen, Huang, and Khanna, 2012).

How do supply costs translate into implicit carbon cost per ton of CO_2e reduction? First, implicit carbon reduction cost estimates, like all biofuel benefit estimates, are a function of the price of oil. Second, as indicated above, the RFS.2 costs/benefits cannot be attributed exclusively to carbon reduction. That said, if we did attribute RFS.2 program costs exclusively to carbon reduction and considered crude oil prices of $100/bbl and $150/bbl, what would it cost per ton of carbon reduced? Using a different analysis and assumptions than those used above, Rosburg and Miranowski (2011) estimated an upper bound for implicit carbon costs (or prices) per ton of CO_2e reduction from $0-10/metric ton (MT) CO_2e at $150/bbl oil and $140-200/MT CO_2e at $100/bbl oil. Assuming all these costs are attributable to carbon reduction with a long run oil price of $150/bbl, the implicit carbon reduction costs are insignificant and well below carbon prices suggested in the climate change literature. If current oil prices prevail in the long run, then program costs are significantly higher, attributing all program costs to carbon reduction.

Technology Forcing: Rapid Technology Improvement vs. Uncertain Development

When the RFS was passed, conventional ethanol and biodiesel were established industries and well on their way to reaching the original 15 bgy and 1 bgy targets. The opposite was true of cellulosic ethanol and advanced biofuel. It is accurate to say that technology forcing induced rapid improvements in biofuel production technology given the industry's technology base when the EISA was passed in 2007. Although there were demonstration plants for cellulosic conversion operational at the end of 2013 and commercial plants under construction, the first viable commercial plants are expected to begin operation in 2014. Further, the capital investment and plant build-out required by 2022 were not achievable for the cellulosic ethanol industry. The National Academy of Sciences, National Academy of Engineering, and the National Research Council (NAS-NAE-NRC) study (2009) concluded that even assuming a robust commercial cellulosic conversion technology was available by 2015, the cellulosic plant capacity build rate would have to be double the build rate for conventional ethanol to produce 16 bgy by 2022. Further, the National Resource Council (NRC) study (2011) on economic and environmental impacts of the RFS mandates found that without major conversion and feedstock technology breakthroughs, high oil prices, or high carbon prices, it will likely not be possible to meet the 2022 cellulosic biofuel mandate and these conclusions are supported by more recent data (U.S. EPA, 2013).

A sustainable biomass feedstock and cellulosic biofuel market requires stable and predictable energy policy if investors are to assume the technology and capital risks involved. It is reasonable to assume that uncertainty over political sustainability and enforcement of the RFS, appropriate and viable, commercial technology, and feedstock supply chain development have all slowed cellulosic biofuel industry development. The current EPA proposed rule change on *2014 Standards for the Renewable Fuel Standards Program* (U.S. EPA, 2013) only increases the policy risk of investing in cellulosic feedstock, conversion technology, and scaled-up commercialization of the industry.

Modifying RFS to Improve Program Efficiency and Effectiveness

Congress prescribed RFS biofuel mandates for good reason—to achieve energy security, improve rural well-being, and reduce GHG emissions. The approach is consistent with the original "technology forcing" approach under CAAA of 1970. Given the state of the cellulosic feedstock supply chain (i.e., largely undeveloped) and conversion technology to commercially produce cellulosic ethanol (i.e., largely bench science without scaling-up to pilot and commercial plants) when the EISA was passed, it was nigh impossible to have a commercial industry operational in 10 years. The targets were unrealizable in the timeframe established by Congress.

If the mandate is implemented over a more achievable timeframe (e.g., 2030), insuring a reasonable period of commercialization, and mandate enforcement is strengthened, then political and technological risk is reduced. These changes will provide incentives to spur private investment in industry development and growth and continued improvement in both feedstock and conversion technology. As noted earlier, the corn ethanol industry achieved rapid growth and expansion when oil price and feedstock (corn) cost made it less costly to substitute ethanol for petroleum fuel.

Another modification that may improve policy and program efficiency is to remove the biofuel categories. Why pick the winning biofuel subcategory, especially when EPA has also imposed a Low Carbon Fuel Standard on each biofuel subcategory? If our objective is to minimize the total cost of achieving a targeted reduction in CO_2 emissions or increased share of renewable liquid fuels, then the biofuel subcategory classification does not insure a least-cost solution. As in any standard economic problem, loosening one or more constraints never leads to a reduction in program efficiency. If the only goal of the RFS were to reduce GHG emissions, then we should be seeking a least cost reduction of GHG emissions, but RFS goals are more complex.

Another argument against proceeding with implementation of the RFS is that current production of biofuel is already bumping against the "blend wall" in terms of the amount of biofuel that the liquid transportation fuel market can absorb. The "blend wall" is a short run constraint that exists, in part, because it is politically viable. As Babcock and Pouliot (2013 and 2014) demonstrate, E85 (and E15 as well) can provide a safety valve to get us over the "blend wall" hurdle, especially if the gasoline distribution system is willing to make the necessary infrastructure investment. In the long run, even with existing technology and blender pumps, blending larger biofuel quantities should not present a significant challenge.

Relaxing standards and especially enforcement of current RFS provisions will spell disaster for development of a commercial biofuel industry much like occurred in the 1980s. Throughout the RFS era, many have been skeptical of the RFS working, not because technology forcing will not work, but rather, because Congress and the EPA may not have the resolve to enforce the mandate in the long run, thus creating a high political risk factor for investors.

RFS and Nation's Biofuel Commitment

The nation has a choice. If it is not willing to "get market prices right" by internalizing external environmental costs (e.g., carbon taxes, carbon cap-and-trade) and eliminating price distorting tax subsidies (e.g., petroleum tax write-offs, tax credits), then the RFS provides an effective and relatively efficient approach to achieve the articulated energy policy goals.

The nation can follow the more aggressive commitment to the RFS policy to produce renewable fuels to improve energy security, reduce GHG emissions, and enhance rural incomes and development. If the nation is not committed to the EISA goals, it can follow the passive approach that was used historically with ethanol. Even though these programs established a relatively small-scale, corn ethanol industry, it took market forces like high oil prices and low corn prices to scaled-up commercialization of the corn ethanol industry and make it competitive.

During oil crises and shortly thereafter in the 1970s and 2000s, the government, private companies, and the oil industry put substantial research funding into biofuel and other alternative fuels. Yet without sustained support, such as offered by the EISA's RFS, the cellulosic industry will not reach scaled-up commercialization. Although we may be awash in gas and oil from fracking and domestic consumption of gasoline and diesel, are slowly decreasing, we live in a global oil market with growing incomes and population. This is bound to drive oil prices higher in the future and having renewable fuels competing in the marketplace may afford us welcomed energy security and price protection.

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Are Bioenergy Crops Riskier than Corn? Implications for Biomass Price

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Dedicated energy crops are considered promising sources of biomass for producing advanced biofuels because of their potential to provide high yields of biofuels per unit of land even if grown on land that has low productivity for producing conventional crops and with low chemical input application. These crops can also sequester more soil carbon per unit of land than conventional crops and lead to considerably large savings in life-cycle greenhouse emissions relative to oil while reducing soil erosion and nitrogen leaching (Hudiburg et al., forthcoming; and Dwivedi et al., 2014). Two energy crops, miscanthus (*Miscanthus × giganteus*) and switchgrass (*Panicum virgatum*), have been widely analyzed for their yields, carbon footprints, and costs of production. These crops are perennials and involve significant upfront investments in establishment, which can take one to three years, with returns to be earned over a 10- to 15-year life-span of the crop.

The production of these energy crops can expose farmers to various types of risks. Yield risk can differ across crops and for the same crop across regions depending on the tolerance of the crop to variability in temperature, precipitation, and soil fertility. Since they are perennials, yield risks could be significant if severe weather were to prevent re-emergence of the crops and require new investments in crop re-establishment. Moreover, energy crops used to produce biofuels are likely to receive a price that is linked to the price of oil and, hence, could be subject to considerable price volatility. Additionally, energy crop production involves an opportunity cost of land due to the foregone returns from conventional crop production or other alternative uses of that land. This opportunity cost of land can also fluctuate over time with variability in yields and prices of crops that would have otherwise been grown on this land, and thus contribute to additional variability in the net returns to energy crop production. Biomass is also costly to transport long distances and may face thin spot markets with few local buyers; thus their production makes farmers dependent on the capacity of local biorefineries and exposes them to risks of loss of demand due to refinery shut-downs. These risks described above are likely to create a demand for risk management strategies such as long-term contracts that provide an assurance of demand for farmers and guarantee feedstock supply for refineries. Fixed price contracts, which offer a guaranteed price for biomass production, are likely to emerge as one type of marketing contract to induce farmer participation in energy crop production.

In deciding whether to produce an energy crop, landowners can be expected to compare the net benefits (or utility) they obtain from energy crop production with that from the existing use of the land. We can use this comparison to determine the minimum fixed price of the energy crop that a landowner would need to receive in order to be willing to convert the land to energy crop production. Studies have determined these breakeven prices for producing energy crops assuming that the yield of these crops remains the same over their lifespan and that the opportunity cost of land is also fixed over time (Khanna et al., 2008; and Jain et al., 2010). These studies show that the breakeven price will be higher the larger the net returns that the landowner obtains from the existing use of the land and, thus, it will be higher for productive cropland and lower for low quality marginal land.

However, if landowners are risk-averse (that is, they are willing to accept a lower income with certainty than a higher but more variable income), then the decision to convert land from an existing use to an energy crop will depend not only on the average returns from the energy crop but also their riskiness relative to that of the current use of the land. We, therefore, expect that the breakeven price needed to induce a risk-averse landowner to convert the land to an energy crop will increase as the variability in returns with energy crop production increases relative to the variability in the returns from the existing use of the land.

In this article we focus on quantifying the yield risk associated with the production of miscanthus and switchgrass, and comparing it to the yield risk associated with corn or soybean production. In the absence of historically observed data for these crops, which are yet to be grown commercially on a large scale, we use county-specific simulated data on yields for the rainfed region in the United States. We analyze the temporal and spatial variability in energy crop yields and their implications on the relative yield risk for breakeven prices of biomass needed to induce landowners to convert land for energy crop production under various levels of risk aversion. We examine these breakeven prices for both cropland (that is assumed to be currently under a corn-soybean rotation in the Midwest and in continuous corn in the other regions) and marginal land (that might otherwise be enrolled in the Conservation Reserve Program (CRP)). We conclude by discussing the implications of this analysis for contract choices between landowners and biorefineries, and policy incentives needed to induce conversion of land to energy crop production.

Crop Yields and Variability

We model energy crop yields using the DayCent model, a biogeochemical model that can simulate plant growth based on information of precipitation, temperature, soil nutrient availability, and land-use practice (Del Grosso et al., 2011). Observed data from field experiments growing miscanthus and several switchgrass cultivars were used to calibrate the productivity parameters in the model (Hudiburg et al., forthcoming; and Dwivedi et al., 2014). The model was then used to simulate yield of miscanthus and switchgrass on both high-quality land under crop production (cropland) and low-quality land likely to be under pasture (marginal land) in the rainfed areas of the United States for a 30-year period using county-specific historical weather information. We construct yield data for two rotations of miscanthus with a 15-year life-span and three rotations of switchgrass with a 10-year lifespan. Corn and soybean yield data over the same period are obtained from the U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS).

Table 1 presents summary statistics of crop yields across different regions in the rain-fed United States. Miscanthus yield is about twice as large as switchgrass yield on both types of land. The average yield of miscanthus on cropland across the rainfed United States is about 9.7 dry (with 15% moisture) short tons (hereafter referred to as tons) per acre while that of switchgrass is about 5.1 tons per acre. On marginal land, however, the average yields of miscanthus and switchgrass are 9.5 tons per acre and 4.7 tons per acre, respectively. Energy crop yields on marginal land are found to be only slightly lower than those on cropland, indicating that energy grasses can be grown productively on low-quality land.

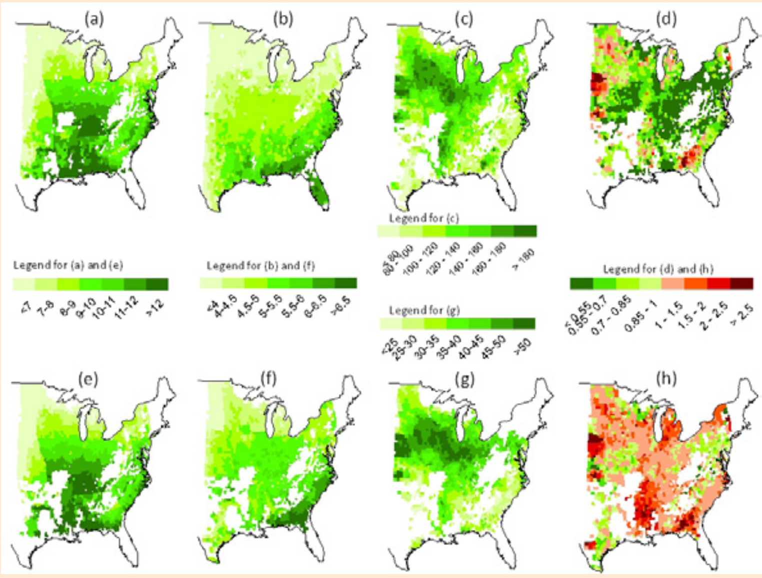
The average yields of both energy crops vary significantly across geographical regions (Figure 1). Both miscanthus and switchgrass yields are the highest in the Southeast region and low in the Great Plains and Northeast regions (Table 1). Unlike energy crops, corn and soybean yields are lowest in the Southeast. This indicates that the two energy crops require different growing conditions than conventional crops. This may explain why the yield correlation

Table 1: Yields and Breakeven Prices of Miscanthus and Switchgrass in Different Regions

		Great Plains	Midwest	Southeast	Northeast	Overall
Yield of energy crops planted on cropland (short ton/acre)	Average yield of miscanthus	7.2	9.4	11.3	8.5	9.7
	Risk of miscanthus yield	0.15	0.09	0.12	0.07	0.11
	Average yield of switchgrass	4.4	4.9	5.6	4.8	5.1
	Risk of switchgrass yield	0.2	0.16	0.23	0.15	0.2
Yield of energy crops planted on marginal land (short ton/acre)	Average yield of miscanthus	7.4	9	11.2	8.2	9.5
	Risk of miscanthus yield	0.16	0.09	0.12	0.08	0.12
	Average yield of switchgrass	4.3	4.2	5.3	4.1	4.7
	Risk of switchgrass yield	0.25	0.23	0.26	0.23	0.25
Yield of corn and soybeans (bu./acre)	Average yield of corn	116.9	148.2	115.6	119.2	128.5
	Risk of corn yield	0.19	0.14	0.2	0.15	0.17
	Average yield of soybeans	37.3	44.0	32.7	40.0	38.5
	Risk of soybeans yield	0.19	0.13	0.18	0.14	0.16
Yield correlation	Miscanthus and corn	-0.31	0.15	0.04	-0.09	-0.09
	Switchgrass and corn	-0.10	0.01	-0.14	-0.17	-0.14
	Miscanthus and switchgrass	0.66	0.65	0.46	0.38	0.61
Breakeven prices of energy crops planted on cropland ($/short ton)	Miscanthus, risk neutrality	105.5	86.3	69.9	98.7	84
	Miscanthus, risk aversion	117.7	96.9	69.2	107	90.3
	Switchgrass, risk neutrality	134.1	128.6	112.0	141.1	124.2
	Switchgrass, risk aversion	151.5	162.9	116.4	164.4	143.5
Breakeven prices of energy crops planted on marginal land ($/short ton)	Miscanthus, risk neutrality	46.0	45.3	37	50.4	42.4
	Miscanthus, risk aversion	46.6	45.7	37.2	50.7	42.8
	Switchgrass, risk neutrality	42.9	56.2	46.4	65.5	49.9
	Switchgrass, risk aversion	43.4	57.7	47	66.7	50.8

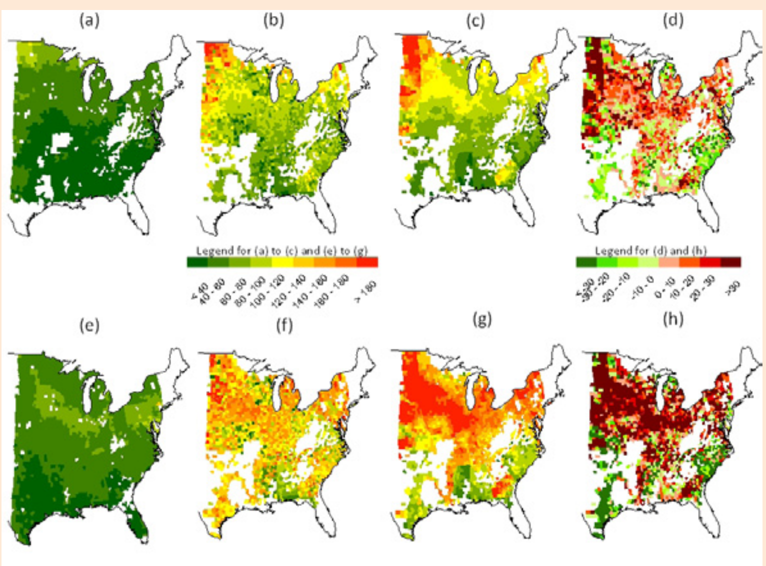
Note: In our analysis rainfed US include counties on the east of 100th Meridian. Great Plains area includes North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas; Midwest includes Minnesota, Wisconsin, Michigan, Iowa, Illinois, Indiana, Ohio, and Missouri; Southeast includes Arkansas, Louisiana, Kentucky, Tennessee, Mississippi, Alabama, West Virginia, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida; Northeast includes the remaining states in the rainfed US. Yield risk is measured by using coefficient of variation that is defined as the ratio of standard deviation of yield to average yield. We employ a constant absolute risk aversion (CARA) utility function to capture a landowner's risk-aversion and calibrate the risk aversion parameter for each county by assuming that the landowner is willing to pay 10% of the standard deviation of the revenue from row crops to eliminate income risk (Babcock et al. 1993; Hennessy et al. 1997).

Figure 1: County-level Average Yield and Yield Riskiness of Miscanthus, Switchgrass, Corn, and Soybeans



Note: Maps have difference scales. (a): Miscanthus yield on marginal land; (b): Switchgrass yield on marginal land; (c): Corn yield; (d): Ratio of risk of miscanthus yield to risk of corn yield; (e): Miscanthus yield on cropland; Map (f): Switchgrass yield on cropland; (g): Soybean yield; (h): Ratio of risk of switchgrass yield to risk of corn yield. Energy crop yield is in short tons/acre; corn and soybean yield is in bu./acre.

Figure 2: Breakeven Prices ($ per ton) of Miscanthus and Switchgrass on Marginal Land and Cropland



Note: (a): Breakeven prices of miscanthus grown on marginal land under risk neutrality scenario. (b): Breakeven prices of miscanthus grown on cropland under risk neutrality scenario. (c): Breakeven prices of miscanthus grown on cropland under risk aversion scenario. (d): Breakeven prices of miscanthus grown on cropland under risk aversion scenario minus those of under risk neutrality scenario. (e)- (h) are the counterparts of (a)-(d) for switchgrass.

between the energy crop yields and row crop yields is small and negative.

We estimate the variation of yields around the 30-year average for each crop and find that yield risk was lower for miscanthus than for switchgrass. The yield riskiness of growing miscanthus on cropland was similar to that on marginal land, but the yield riskiness of switchgrass was lower on cropland (Table 1). In large areas of the lower Midwest and the South, the riskiness of miscanthus yield is lower than that of corn. In contrast, the yield risk of switchgrass is typically larger than that of corn in much of the rainfed region except for some areas in the southern Great Plains and Northeast (Figure 1(d) and 1(h)).

Breakeven Prices of Energy Crops

We estimate the breakeven price of an energy crop under two alternative assumptions about the risk preferences of the landowner. First, we consider a risk neutral landowner who compares the discounted value of expected profits from energy crop production to that from corn/soybeans and does not consider variations in crop profits. Then we consider a risk-averse landowner who obtains a disutility from variations in crop profits. The breakeven price is the constant price across years that equates expected utility (or profits for a risk-neutral farmer) from the energy crop to that from the alternative use of that land (Jain et al., 2010). In the case of cropland, the alternative land-use is a corn-soybean rotation in the Midwest and continuous corn in other regions, while in the case of marginal land, the alternative use is assumed to be an activity that yields a return equivalent to the soil rental rate for enrolling in CRP.

We find that, in general, the average breakeven price of miscanthus and switchgrass is about twice as high on cropland than on marginal land, suggesting that it would be economically rational for landowners to prefer growing these crops on their available marginal land (Table 1). Moreover, the breakeven price of miscanthus is typically lower than that of switchgrass across all regions because its yield is about twice as high as that of switchgrass on average. An exception is the Great Plains region where the yield gap between the two crops on marginal land is relatively low and insufficient to compensate for the higher costs of establishing miscanthus than switchgrass, making it more expensive to produce miscanthus. In the absence of risk considerations, the breakeven price of miscanthus grown on cropland is $84 per ton on average while that of switchgrass is $124 per ton. The corresponding values for breakeven prices on marginal land for miscanthus and switchgrass are $42 per ton and $50 per ton, respectively.

The breakeven prices of energy crops vary significantly across regions and even within a region. For both miscanthus and switchgrass grown on cropland, the breakeven prices are the lowest in the Southeast because corn yields in this region are the lowest and the energy grass yields are the highest among the four regions (Table 1). Breakeven prices for energy crops grown on cropland or marginal land are highest in the northern Great Plains because energy crop yields are very low in this area (Figure 2).

Risk-averse landowners require higher prices for energy crop production than those discussed above. We define risk premium as breakeven price with risk aversion minus the breakeven price with risk neutrality. If the risk premium is greater than zero then it indicates that returns with energy crops are riskier than returns with row crops. We find that the risk premium is positive, on average, in the rainfed United States, even though miscanthus has a lower relative yield risk than corn in most counties in the lower Midwest and large tracts of the South. This is because the high fixed costs of producing miscanthus increase the relative variability of profits in response to variability in yields. The risk premium needed to induce conversion of cropland to switchgrass is even higher than for miscanthus due to the larger variability in switchgrass yields and the high opportunity costs of cropland.

Figures 2(d) and 2(h) show the spatial variability in the risk premium for miscanthus and switchgrass grown on cropland, respectively. The risk premium varies considerably across regions, and is lowest in the Southeast and highest in the Great Plains (Table 1). The risk premium ranges from -76% to 152% of the breakeven prices under risk neutrality for miscanthus and -93% to 215% for switchgrass. The risk discount (or negative risk premium) for both energy crops is largely in the Southeast and the Southern Great Plains, which is in part due to the relatively lower yield risk of energy crops in these areas compared to corn. On average, the risk premium required to induce landowners to convert cropland to switchgrass is expected to increase its breakeven price by 15.6% compared to that required under perfect certainty; the corresponding increase in the breakeven price of miscanthus is by 7.6%.

We find that not only the breakeven prices of energy crops grown on marginal land are lower than that of energy crops grown on cropland but the risk premium on marginal land is lower too. Energy crop yields have a slightly higher yield risk on marginal land than on cropland. Moreover, energy crop production exposes farmers to risk compared to the riskless rental payments from CRP assumed here. It should be noted, however, that a higher risk of yield does not necessarily imply higher variance of utility, since the latter will also depend on the costs of production and the price of the crop. The risk premium for an energy crop depends on the yield risk and price of corn, as well as on the production costs of both the energy crop and corn. The low risk premium on marginal land is due to the low opportunity costs of growing energy crops on marginal land which require relatively low breakeven prices of energy crops and lower variability in utility with energy crop production on marginal land than on cropland.

Discussion and Conclusions

Our analysis shows that opportunity costs of land can make a significant difference to the breakeven prices of biomass from energy crops under both risk neutrality and risk aversion. Additionally, the relatively higher yield risks associated with energy crop production as compared to corn/soybeans, particularly in the upper Midwest, can result in higher breakeven prices needed to induce risk-averse landowners to convert cropland to energy crops. However, in some regions, such as the Southeast, energy crops, particularly miscanthus, are less risky than corn/soybean production and the break-even price needed to induce a risk-averse landowner to produce them will be lower than that for a risk neutral landowner. The effects of yield risk on breakeven price are much smaller on land that may currently be under a crop/pasture rotation with a low and relatively constant opportunity cost of production. These findings suggest that landowners are more likely to first convert low-quality marginal land to energy crop production.

Based on data from 2007 Census of Agriculture (http://quickstats.nass.usda.gov/), the aggregate availability of land classified as cropland pasture or idle but not currently enrolled in CRP in the rainfed United States was estimated to be 21 million acres in 2007. However, its potential for conversion to energy crops will depend on its availability as contiguous acres that can be accessed by the equipment needed for planting and harvesting energy crops and transporting biomass. To the extent that production of biofuels will require plantation-style production of energy crops within a limited radius around a biorefinery, reliance solely on marginal land to meet the biomass needs of a refinery might involve trade-offs between costs of transporting biomass from low-cost land at further distances versus high-cost land nearby. Current use of this land for hunting, recreation, or as nature preserves, as well as the small size of individual holdings or ownership by absentee landlords could lead to high amenity values and transaction costs of converting this land for energy crop production. This could lead to much higher opportunity costs of converting marginal or idle land to energy crop production. Refineries may, therefore, have to rely on a mix of marginal land and cropland to meet their needs for biomass supply and the marginal-cost-based price of biomass is likely to be based on highest cost cropland that needs to be induced to produce energy crops in the proximity of the refinery.

The break-even prices estimated above can be interpreted as the terms of a fixed price contract that would need to be offered to landowners over the lifespan of the crop to induce them to convert land for energy crop production. While in some regions these prices are similar or even lower than those under risk neutrality, in other regions, such as Midwest, they can be 12% to 27% higher than under risk neutrality. A fixed price contract would put all the price risks associated with volatile oil prices on the refinery while leaving landowners to bear all the risks associated with the foregone returns from conventional crops.

Other types of contracts that result in alternative arrangements for sharing the yield and price risks between risk-averse landowners and a risk-neutral refinery might emerge to lower the cost of biomass for a refinery than indicated by the break-even prices estimated here. In regions where energy crop production is highly risky relative to conventional crops, a refinery that has a greater capacity to bear risk might prefer to lease land and bear all the yield and price risks rather than paying high risk premiums.

We assumed that all landowners have the same risk preferences. Heterogeneity in risk preferences across landowners would imply differences in the risk premium needed to induce production of energy crops under a fixed price contract across regions. Moreover, risk-loving landowners may even prefer price-indexed contracts that provide an opportunity for high returns. Yang et al. (2014) analyze the mix of contractual arrangements that can result in lower overall feedstock costs for a refinery by optimally sharing risks among landowners with heterogeneous risk preferences and with a risk-neutral refinery.

The breakeven prices estimated here, even under risk aversion, could be underestimated because they disregard the reliance by crop producers on subsidized yield, and revenue crop insurance and disaster relief payments for conventional crops like corn and soybeans. Such programs lower the down-side risk of producing these crops and will further increase the break-even price needed to induce farmers to switch to risky energy crop production without any safety-nets. We leave the analysis of the effects of crop price risks and the presence of instruments for mitigating risks associated with conventional crop production on the riskiness of producing energy crops to future research.

The Renewable Fuel Standard mandates the production of cellulosic biofuels and will create market incentives for obligated parties (oil refiners) to cover the costs of cellulosic biofuel production. Additional policy incentives for biomass production include the Biomass Crop Assistance Program (BCAP) and the Cellulosic Biofuel Production Tax Credit (CBPTC). BCAP provides cost-share payments to cover the costs of establishing energy crops and subsidies for collecting, harvesting, and transporting energy crops while the CBPTC subsidizes the blending of cellulosic biofuels with gasoline. However, none of these policies directly address the downside risks associated with the production of energy crops for landowners in a manner comparable to the safety net provided by subsidized crop insurance for corn and soybeans.

Our analysis has focused on the effects of risk on utility per acre of land. Further research is needed at the whole-farm level to examine the effects of risk preferences on the allocation of land operated by a farmer between energy crops and conventional crops. Moreover, to the extent that energy crop yields have a relatively low or negative correlation with corn/soybeans, their production can diversify the crop portfolio and potentially reduce overall riskiness of crop production. The risk premium needed in that case for growing energy crops will also depend on the share of annual farm income derived from energy crop production. A case study of a representative farm in Tennessee by Larson, English, and Lambert (2007) shows that contracts that shift the risk of switchgrass production to the processor can result in lower biomass prices than other contracts. The spatial variability in yield risks shown here coupled with whole farm analysis can be used to identify locations and the design of contracts for energy crop production that can result in higher net benefits for landowners and refineries.

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The Potential for Aviation Biofuels—Technical, Economic, and Policy Analysis

Wallace E. Tyner and Ryan Petter

JEL Classifications: Q42, Q48
Keywords: Aviation Biofuels, Biofuels Policy, Reverse Auction, Techno-economic Analysis

For a number of reasons, the aviation sector may be the most promising for expansion of the cellulosic biofuels industry (Tyner, 2012). The European Union is planning to implement a carbon tax on airplane takeoffs and landings in the EU (EU Business, 2013). Several U.S. aviation companies have expressed strong interest in renewable fuels (Midwest Aviation Sustainable Biofuels Initiative (MASBI), 2013). There are alternatives for the ground fleet that have emerged in recent years such as compressed or liquefied natural gas or electric vehicles. However, these options and ethanol are not viable in aviation. U.S. civilian aviation consumes over 21 billion gallons of jet fuel per year (U.S. Energy Information Agency - Department of Energy, 2014), so it is a sizeable market. For all these reasons, evaluating the technical and economic potential of aviation biofuels has merit. We do that here by summarizing the results of a techno-economic analysis done for the fast pyrolysis process to produce drop-in hydrocarbons, including jet fuel.

Fast pyrolysis is one of the thermochemical processes that goes directly to a mixture of hydrocarbons instead of ethanol. The projected fuel cost is in the same range as current fossil fuels, but the uncertainty in projected cost is very high. Given that uncertainty, it is useful to examine policy options that might help reduce private sector risk in biofuel investments.

Techno-economic Analysis

This section relies in part on a recent techno-economic analysis of corn stover biofuels (Petter & Tyner, 2014). The objective was to estimate the distribution of outcomes from investments in a fast pyrolysis conversion technology.

The technical assumptions were primarily from Brown, Thilakaratne, Brown, & Hu (2013). We replicated the breakeven cost in terms of $/gallon of gasoline equivalent (GGE) from Brown et al. before adapting the engineering analysis to an economic analysis. In so doing, we assumed a 2.5% inflation rate, adjusted some of the key parameters, and added uncertainty in feedstock costs, hydrogen prices, conversion yields, and fuel prices. Technical details are shown in Table 1.

Table 2 is the share in total cost net present value (NPV) of the capital, feedstock, and hydrogen components. The total NPV of all costs was a bit over $1 billion.

Table 1: Selected Technical Parameters

Item	Value
Production capacity	58 million gallons per year
Capital cost	$429,000,000
Debt-equity ratio	50%
Debt interest rate	7.50%
Real rate of return on equity	10%
Inflation rate	2.50%
Plant life	23 years

Table 2: Cost Shares for Key Pyrolysis Cost Components

Item	Cost share (%)
Capital cost incl. working capital	30.3
Feedstock	34.4
Hydrogen	21
Other operating cost	14.3
Total	100

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Uncertainty in future fossil fuel prices was handled in two ways. First, the expected gasoline price was fixed at $2.68/GGE, which is the economic breakeven price at a 10% real rate of return with no project financing. In other words, it is the price that drives NPV to zero with a 10% return. The breakeven financial price was $2.62/GGE (again at a 10% rate of return), but there was a 41% chance of a loss at that price. In the second case, the gasoline price was set to increase over the assumed plant life of 23 years at the rate contained in the U.S. Department of Energy's base price projection (U.S. Department of Energy, 2013) for crude oil with a random component added.

The mean feedstock and hydrogen prices were $83/MT and $2.06/gal, respectively. Jet fuel would be about 15% more costly to produce, so its breakeven could be around $3.01/gal. However, any thermochemical process like fast pyrolysis is likely to produce a mixture of products including diesel, gasoline, jet fuel, and naphtha. The analysis accounts for all products produced. It uses $/GGE to provide a single metric for the base economics and analysis of policy options. The diesel production was converted to a gasoline equivalent using the historical relationship between diesel and gasoline prices, and their respective energy contents.

Policy Options

If there were no policy incentives provided, private sector investments would not likely go forward as there is a 41% chance of loss for any private sector investor at current oil prices. This probability of loss emerges from all four uncertain variables, but future crude oil price is by far the most important factor in driving the investment uncertainty. Assuming the increasing price forecast of the second case, the probability of loss is reduced to 15%. Next, we consider two policy options.

Reverse Auction

Given that future oil price is an important determinant of riskiness of an investment, a reverse auction may be attractive to potential investors. In a reverse auction, military or civilian purchasers of jet fuel would offer to buy a fixed quantity of the fuel each year for some stipulated period of time, say 15 years. The qualified bidder with the lowest bid wins the contract (thus, reverse auction).

Another advantage of this option is that it is well known that a major barrier to biofuels investment is the lack of off-take contracts. An off-take contract is a long-term contract between a buyer and a seller with the price and quantity terms delineated in the contract. It is very difficult or impossible to obtain financing without a contract for the fuel being produced. A reverse auction also solves this problem.

In a reverse auction, potential biofuel suppliers bid for the right to supply a pre-specified quantity and type of biofuel for delivery each year for the term of the contract. Thus, with the reverse auction, for both the biofuel supplier and for the purchaser, the price of the biofuel under contract is known with certainty for the contract quantity and duration. In this scenario we forecasted the result of a forward contract at a fixed price for 45 million gallons per year. The facility always produces more than this amount, and we assumed the additional production volume is sold at the market price for that year.

The analysis of the reverse auction showed that the probability of a loss falls from 41% with constant crude oil prices on average to 13% with the reverse auction. The 13% is due to the remaining uncertainty in feedstock costs, conversion yields, and hydrogen prices, and the fact that all production beyond the 45 million gallon contract was assumed to be sold at the uncertain market price.

We also tested this scenario using the rising Department of Energy (DOE) crude oil price forecast. Using that forecast, the probability of loss went to zero. It is also important to consider the government cost of implementing such a reverse auction policy. The estimated net present value of the government's cost was $4.8 million for this version of the reverse auction.

Capital Subsidy

In another scenario, we used a capital subsidy of $5 million. This scenario has about the same expected cost as the reverse auction scenario. For the increasing price case, the reverse auction probability of loss was zero, yet the capital subsidy still had a 14% probability of a loss. Thus, when the reverse auction and capital subsidy have the same expected cost to the government, the reverse auction is far more effective at reducing risk for potential private sector investors. In essence, the government is absorbing the risk because its subsidy cost could be higher or lower, depending on what happens to crude oil prices in the future.

Key Points

There are several important conclusions that emerge from this analysis:

- First, uncertainty abounds in the process of converting corn stover or other cellulosic feedstocks to biofuel. This analysis has quantified many of the important sources of uncertainty, but not all.
- The sources of uncertainty that were quantified were feedstock costs, conversion yields (feedstock to biofuel), hydrogen prices, and fossil fuel prices. While all these factors are important, the future fossil fuel price is, by far, the most important source of uncertainty.

- To reduce private sector risk, a reverse auction resulting in a long-term off-take contract may be a viable option. In our analysis, the reverse auction resulted in a substantial reduction in private investor risk.
- We compared the reverse auction policy with a capital subsidy policy since governments seem to prefer capital subsidies in some form (such as a direct capital subsidy or a loan guarantee). We found that a capital subsidy having the same expected government cost as the reverse auction did not reduce private sector uncertainty nearly as much as the reverse auction. In other words, the reverse auction is a much more efficient and effective policy instrument than capital subsidies.

Big Picture

Stepping away from the details of the analysis, a big-picture conclusion also emerges. Thermochemical conversion technologies such as fast pyrolysis may be close to being economic, considering only expected cost; however, the variance due to that cost and future fossil fuel prices is large enough to deter private-sector investment especially in early plants. Once investment risk is taken into consideration, it is clear that private investments will not be forthcoming without off-take contracts. A reverse auction would result in such an off-take contract.

It will be difficult to get these contracts for the first few plants in the private sector because the likely contract price would be higher than the equivalent fossil fuel prices. Since these plants produce a mixture of products, there would need to be contracts or swapping mechanisms for all the plant outputs. Commercial airlines are only interested in jet or aviation fuel. The U.S. Navy may be interested in both jet fuel and diesel.

The bottom line is that the technologies with the assumptions used in this analysis may be getting very close to being competitive over the likely 20-year production horizon of any commercial plant. However, there are no financing mechanisms available at present to get the industry moving.

The Navy, DOE, and the U.S. Department of Agriculture (USDA) have created a partnership to get some early aviation biofuel plants built. The program hopes to enable the Navy to procure biofuels under provisions of the Defense Production Act (Else, 2009). Under this partnership, companies are being selected based on submission of techno-economic and greenhouse gas analyses. The selected companies will receive capital subsidies from DOE and feedstock subsidies from USDA that, hopefully, will get the product price down low enough to be competitive with fossil fuels.

Unfortunately, the length of contracts envisioned at present is one year with a possibility of 3-5 years available. The packages of incentives may or may not work to get plants built and producing aviation biofuels for the Navy. While this innovative partnership is to be commended for helping to get the industry moving, the analysis in this study suggests that a reverse auction would stimulate private investment at a lower total cost to the government while providing greater risk reduction for private sector investors.

We believe there is significant potential for aviation biofuels for both civilian and military applications. The techno-economic analysis suggests the fast pyrolysis process with hydrogenation of the bio-oil is getting close to being economic. Now we need a policy environment that is conducive to stimulating investment in advanced biofuel production facilities.

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Biofuels at a Crossroads

Gal Hochman

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Keywords: Biofuels, Biomass, Bioeconomy, Biofuel Policy, Value-added Products

Historically, fossil fuels have played a significant role in the supply of energy in the United States, and as of 2012, 79% of total primary energy produced in the United States originated from fossil fuels (down from 92% some 30 years ago). While energy is needed for economic growth, an economy that is largely reliant on a fossil fuel-based supply faces environmental, cost, and security concerns. First, this is true because fossil fuels are the Number 1 contributor to anthropogenic greenhouse gas emissions (Solomon et al., 2007) and, second, because, since 2000, the cost of fossil energy has been on the rise, creating an economic burden and heightened security issue for the economy.

The challenges of reducing energy costs, securing a supply, and addressing environmental concerns led the United States to introduce domestic policies that weakened the link between economic growth and energy consumption, and created incentives for the adoption of renewable technologies, as well as unconventional oil. While fuel efficiency policies, such as the Corporate Average Fuel Economy standards, ushered in the adoption of fuel-efficient technologies (Lee, Veloso, and Hounshell, 2011) that reduced the United States' appetite for gasoline (U.S. Energy Information Agency (EIA), 2012 and 2013), incentives were introduced that hastened the adoption of renewable technologies. For example, this includes the Renewable Fuel Standard enacted in 2005, which ensures that transport fuel sold in the United States contains a minimum volume of renewable fuel.

The Introduction of Biomass Feedstock

Although ethanol fuel made from biomass feedstock was first introduced into the United States fuel mix in the 1970s, its use did not become widespread until the beginning of the new millennium (Gardner and Tyner, 2007). This increase in ethanol usage did not come in response to energy scarcity; rather, it was a reaction to new information accumulated toward the end of the 1990s that suggested that methyl tert-butyl ether (MTBE), a chemical compound previously used as a fuel additive in gasoline, constitutes a serious health hazard that contaminates public water systems and private drinking water wells. In response to these findings, many states phased out the use of MTBE in the late 1990s and early 2000s, using ethanol as a substitute (EIA, 2000). A second factor that also contributed to the expansion of ethanol use in the United States was the ongoing increase in the price of oil since 2000; in December 2013, the West Texas Intermediate crude oil price was around $100 per barrel (EIA, 2014).

In 2012, biomass energy in the United States accounted for 26% of total non-fossil energy (Figure 1). While primary, non-fossil-based energy production was 16.90 quadrillion Btu and biomass-based energy was 4.42 quadrillion Btu, total U.S. energy consumption in 2012 was about 95 quadrillion Btu (EIA, 2014).

Although electricity generation using biomass feedstock increased by 21.6% from July 2001 to July 2013 (Figure 2), annual biofuel production increased from 1.65 billion

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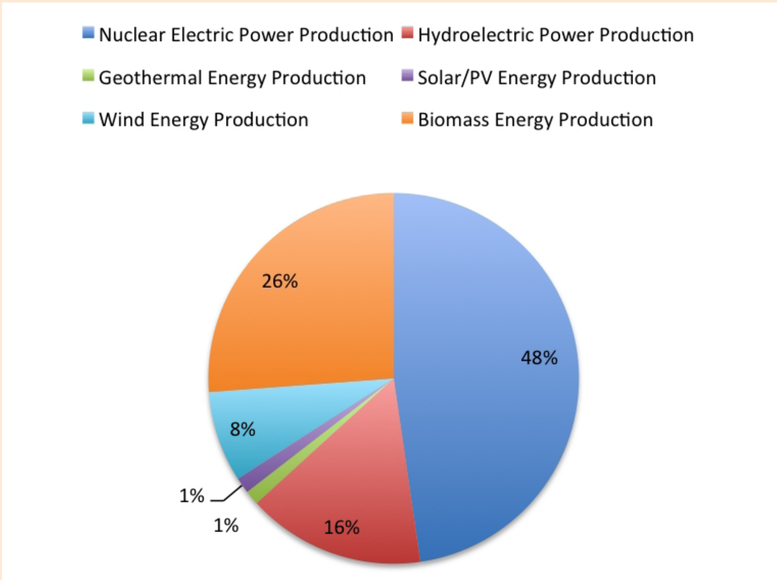
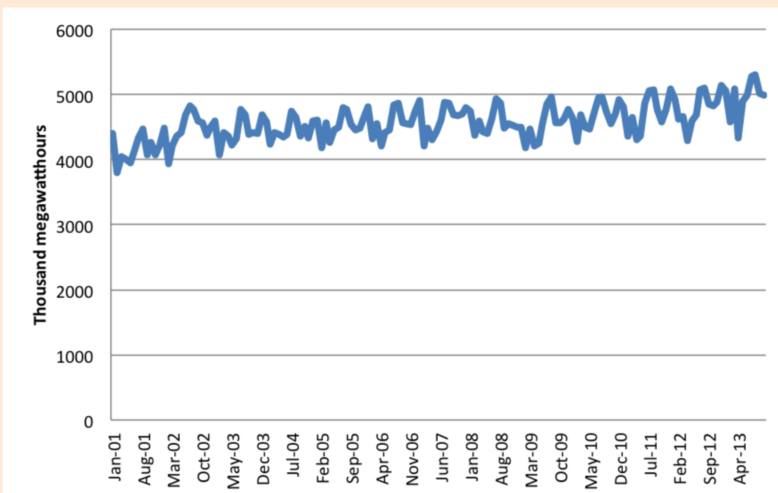
Figure 1: Renewable Energy Production



Source: U.S. Energy Information Administration, www.eia.gov

Figure 2: Net Electricity Generation from Biomass (Monthly)



Source: U.S. Energy Information Administration, www.eia.gov

gallons in 2000 to 10.76 billion gallons in 2009, and, in 2013, hit the E10 blend wall in the United States.

Implications of the Introduction of Biofuels

The introduction of biofuels did not, however, come without a price. The most analyzed indirect effect attributed to the introduction of biofuels is indirect land use change (ILUC), whereby the conversion of food croplands to biofuel agriculture drives food prices up. In response to higher food prices, other land is then converted from its previous use, such as rainforest, towards food crop production. A second major indirect effect associated with the introduction of biofuels stems from the food versus fuel debate. First-generation or conventional biofuels made from sugar, starch, or vegetable oil compete directly with food and the use of food crops to produce energy led to concerns for the food supply (Hochman, Rajagopal, and Zilberman, 2011), especially with respect to the poor (Chakravorty, Hubert, and Marchand, 2013).

First-generation ethanol failed to deliver in other key areas as well. Reduction in greenhouse gases benefits from corn ethanol but are limited at best, and are much lower than initially anticipated.

Production of energy and fuel using organic matter proved much more difficult and costly than expected. The complexity of converting biomass into fuel prevented commercialization of advanced biofuels, which are made from non-food crops and are expected to have much larger environmental benefits. An example of this is KiOR's drop-in fuel production facility at Columbus, Mississippi (KiOR is a joint venture between a Dutch biofuels startup named Bioecon and Khosla Ventures).

During the early years of the new millennium, international oil companies invested billions of dollars in advanced biofuel projects, most of which were abandoned. For example, in 2008, Shell invested in 10 advanced biofuel projects but has since terminated all these projects and not one of them was commercialized. Bringing biofuels to the market proved slower and more costly than initially expected. The introduction of biofuels and the U.S. Renewable Fuel Standard created an additional cost for the petroleum refining industry, and the delay in the commercialization of cellulosic, that is, advanced biofuels, increased costs even further for the petroleum refining industry. These deviations from the initial expectations from biofuels led to the U.S. Environmental Protection

Agency's proposal to reduce the 2013 target for cellulosic biofuels to just 53 million liters. On the other hand, electrification of transportation (plug-in hybrids and fully electric vehicles) will probably happen faster than most experts predicted just a few years ago. Biofuels will then compete in the vehicle-fuel market not only with gasoline and diesel, but also with electricity.

New developments have also reduced U.S. concerns over energy costs and energy security. Technological advancements made between 1998 and 2003 have led to hydraulic fracturing and to the discoveries of shale gas and tight oil. The spread of these technologies unlocked new oil and gas reserves and provided an alternative path to energy security for the United States.

Some of the indirect effects associated with biofuels may be beneficial as well: One indirect effect discussed extensively in the literature is the *indirect fuel effect* whereby the introduction of ethanol may lower the price of fuel (Rajagopal, Hochman, and Zilberman, 2011). A second, related indirect effect is the *indirect OPEC effect* whereby the upstream oil sector is dominated by a cartel of nations: The Organization for the Petroleum Exporting Countries (OPEC), which uses its monopolistic power to maximize benefit for its members, could respond to the introduction of biofuels by reducing exports while increasing domestic consumption (Hochman, Rajagopal, and Zilberman, 2011). A third, but equally important, indirect effect that, until recently, has been overlooked is the *balance of trade effect.* Reducing domestic demand for petroleum products due to the replacement of gasoline and diesel by biofuels encourages refineries to export the refined products they produce and thus improve the country's balance of trade (Hochman, Rajagopal, and Zilberman, 2011). Because of the increase in the price of corn in recent years and because corn-ethanol yields a co-product that is a substitute for raw grains in feed, namely, Dried Distillers Grains with Soluble (DDGS), and which China is a major consumer of, the effect of corn-ethanol on the U.S. balance of trade was significant (Zilberman et al., current issue).

Biofuels and the Future

The agriculture-energy-environment nexus cannot be broken, and, over time, these three forces will become even more intertwined. Thus, food security and energy security policies could be coordinated together with environmental policies, such as land use and water management. Biomass energy presents a possible viable alternative that addresses mounting concerns for the environment, population growth, and increasing prices of major inputs like fossil fuels. New discoveries may lead to the development of a bioeconomy whereby technologies are based on modern principles of chemistry and biology.

Aviation is another area in which biofuels may play a major role for years to come (Tyner and Petter, current issue), since it does not look like aviation will be going electric anytime soon. It would, however, be greatly beneficial if we could fly on carbon-neutral fuels that are not made from human food crops, but, rather, are made from items such as algae.

For the past 60 years, hydrocarbons have dominated the chemical production industry, due to low feedstock costs, such as oil and gas costs. Now biomass is emerging as an alternative feedstock that can supply similar intermediate inputs for cosmetics, pharmaceuticals, and biopolymers (Langeveld, Dixon, and Jaworski, 2010). Key, however, is reducing the cost of production and making this alternative process competitive with existing, traditional processes which use oil and gas.

By developing a bioeconomy industry—whereby biorefineries produce co-products alongside biofuels, power, and heat—additional value may be created. Some of the bio-based, value-added products, such as fine chemicals, lubricants, and solvents, may even combine large market volumes with medium- to high-price levels (Langeveld, Dixon, and Jaworski, 2010).

Facilitating the Transition to a Bioeconomy

To achieve the aforementioned goals, technology must overcome the physical and economic hurdles that currently prevent commercialization of advanced biofuels. Costs need to be reduced drastically through higher yields and more efficient conversion processes. Limiting factors of land and water, in terms of both quantity and quality, must also be addressed. Biomass should be used more efficiently, and energy recovery from waste and crop residues needs improvement. Such processes will not only limit use of land but may also have a substantial impact on greenhouse gas emissions (Centore, Hochman, and Zilberman, 2014). Research and development increase the efficiency of existing processes but are also likely to spill over to other areas of interest and lead to major breakthroughs in these related areas. Learning to grow algae in space, for instance, enhanced our knowledge and contributed to our understanding of algae production and harvesting on Earth.

The ultimate aim of any bioeconomy should be to make optimal use of its biomass feedstock. Energy production may not be the primary objective, but only one use of biomass. Feedstock selection, logistics, and processing techniques could be used to optimize economic and environmental values of available functionalities and biomass uses. Supply chains of various paths should be analyzed and the knowledge used to facilitate the realization of economic, environmental, and social opportunities. One possible path could be to first generate (low volume) high added-value products, followed by other, less valuable products. For example, established biomass refineries may be linked to the pharmaceutical industry so that biomass-based chemicals may be substituted for petrochemicals and green production supply chains of alternative drugs developed.

Biology is a science with a long history that began with the development of agriculture at the dawn of civilization. Research and development programs should be conducted to further our understanding of how best to use biomass to address mounting concerns for the environment and dependency on foreign oil, and to meet the increasing demand of a growing, affluent population.

Policy will undoubtedly play a key role in the adoption of these contentious technologies. It accounts for differences in patterns of adoption of anaerobic digesters in Europe and the United States, and played a central role in ramping up biofuel production and consumption in Brazil and in the United States. Policy could be used to lower entrance barriers and to foster more productive use of resources (Miranowski, current issue), as well as reduce the risk of growing bioenergy crops (Miao and Khanna, current issue). Such policies could be complemented with other policies that reduce demand for energy and uncouple energy consumption from economic growth (Trachtenberg and Hochman, 2014) by encouraging increased fuel efficiency of vehicles and fostering a modal shift in the way energy and economic growth are linked.

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