The Intersection of Energy and Agriculture: Implications of Rising Demand for Biofuels and the Search for the Next Generation

Steven Sexton, Deepak Rajagopal, David Zilberman, and David Roland-Holst

As production of the current generation of biofuels expands, it will impose pressure on food production and environmental preservation, have considerable distributional effects, and cause a restructuring of agriculture. A continued evolution of biofuel technology, driven by the university-industrial complex, promises to mitigate these effects.

World energy demand is expected to increase 70 percent in the next quarter-century amid economic growth in Asia that has led millions in India and China to begin dreaming of owning automobiles. China alone will be responsible for one-fifth of energy demand growth, as its per capita energy consumption moves closer to that of the United States. The growth in energy demand presents a considerable challenge to the world community, which must confront mounting evidence of global warming and the prospect of depleted oil reserves within 70 years. These developments have fueled a scramble for new energy sources from which biofuels have emerged as a promising alternative. Liquid biofuels require only minor adjustments to existing engine technology and fuelling infrastructure, making them relatively more attractive than other technologies like the hydrogen fuel cell and electric vehicles.

Two centuries ago, as much as 20 percent of agricultural land was devoted to producing fuel for transportation. Fossil fuels have since allowed movement away from agriculture as a source of transportation energy, but a return seems imminent. If agriculture is to be relied upon to fuel a growing world population (and a growing driving population), then a serious consideration of the consequences of widespread biofuel adoption is warranted; the technology is not without costs. Rising energy demand is likely to put pressure on food production and the environment, have significant distributional effects, and induce reorganization in agriculture.

The current generation of biofuels, produced primarily from sugar, corn, and soy, addresses many concerns associated with the new energy paradigm. Most countries can grow energy crops, lessening their demands for energy imports. Biofuels support rural development by increasing farm income. They offer hope of economic growth, especially for developing countries near the equator, where energy crop production is expected to be particularly cost-effective. They also offer modest greenhouse gas emissions reductions. These benefits are known and understood. The costs have received much less attention.

While the ability of biofuels to reduce oil imports and increase farm income are significant benefits, the *raison d'etre* of biofuels is their capacity to provide a transportation fuel cleaner than oil. The consensus measure of the efficiency of biofuels is their net energy content and their net life cycle greenhouse gas emissions. These measures account for the energy used in production of energy crop and in processing of crop to fuel, as well as the fact that energy crops sequester carbon that is later emitted when biofuel is combusted. It is thus generally assumed biofuels are carbon-neutral, though the latest environmental analyses suggest differently.

Some analyses have shown biofuels require more energy in production than they yield. Estimates of the carbon-emissions savings have also varied, with the latest study concluding that biofuels are modestly cleaner than gasoline. The latest such accounting for corn-based ethanol in the United States yields an average net greenhouse gas emissions reduction of 18 percent per unit of fuel energy produced and a net energy ratio of 1.2, which implies a gain of 20 percent. It corrects errors in previous studies, particularly adding an energy credit for the animal feed co-product of ethanol that would otherwise be produced from an energy-intensive process. This latest study is the closest to a consensus view that exists today.

Life cycle analyses are not straightforward and have proven controversial. For instance, the animal feed co-product of ethanol saves energy that would be used to produce such products and those savings should rightly accrue as credit to ethanol production. However, as ethanol production expands, it may well yield more co-product than is demanded. The co-product produced beyond market demand should not accrue as a credit and eliminating the credit would substantially worsen the net energy gain from corn ethanol.

Biofuel technology is land intensive. Theoretical estimates for global ethanol production from six potential crops, namely, sugarcane, corn (maize), wheat, sorghum, sugarbeet, and cassava, based on global average yields, is shown in Table 1. These six crops account for over 30 percent of global cropland of 1.4 billion hectares. Utilization of the entire supply of these six crops would account for at most 50 percent of the global gasoline use today. A more realistic scenario of 25 percent utilization of such crops and residues for ethanol implies a mere 12 percent offset in gasoline use.

Current crops and conversion technologies, therefore, are ill-equipped for large-scale displacement of gasoline. Similar calculations based on cropping patterns, crop yields, and conversion technologies suggest that the United States, Canada, and EU-15 would require between 30 percent and 70 percent of their respective current crop areas if they are to replace even 10 percent of their transport fuel consumption by biofuels.

Table 1. Global Biofuel Production by Feedstock

Crop	Avg. Yield	Global Acreage (mil. hec)	Global Production (mil. tons)	Conversion Efficiency liters/ton	Land Intensity (liters/hec)	Max. fuel (billion litres)	Gasoline equivalent (bil. liters)	% Annual Global Gasoline
Sugarcane	65.0	20	1300	70	4550	91	61	4%
Corn	4.9	145	711	402	1971	286	191	12%
Wheat	2.8	215	602	340	952	205	137	9%
Sorghum	1.3	45	59	60	78	4	2	0%
Sugarbeet	46.0	5.4	248	110	5060	27	18	1%
Cassava	11.5	19	219	180	2070	39	26	2%
Wasted Crops	–	–	74	664	–	49	33	2%
Crop residues	–	–	1500	295	–	442	296	19%
Total		**449**				**1143**	**766**	**50%**

Source: FAOStat, Kim and Dale, RIS

Rising Food Prices and Their Geopolitical Consequences

Because the stock of land is fixed, as demand for biofuel rises, there will be pressure on the other primary uses of land: food production and environmental preservation. As land devoted to biofuel production increases, it will necessarily mean a reduction of land for food production or the environment or both. Food prices will rise. While higher commodity prices may benefit some farmers, that effect will not be universal. Some sectors will suffer from rising prices for corn and other commodities that are inputs in production. Specifically, the price of animal feed is increasing in the United States, putting pressure on livestock producers. Any benefits that do accrue to farmers from higher food prices will likely be captured by landowners in the form of higher rents.

Higher food prices will also hurt consumers. Globally, corn prices have doubled since the start of last year and reached a 10-year high early this year. Wheat prices reached a 10-year high, and soybeans touched a two-and-a-half-year high around the same time. Global corn and wheat stockpiles have fallen to 25-year lows. The stockpile system creates a stealth effect for prices, and we have yet to see the full price implications of these depletions. Commodity stockpiles are generally designed to dampen transitory market volatility. Existing agricultural capacity can compensate for cyclical stock depletion, but rising to meet a sustained demand shift is another matter. Historically, this kind of scarcity can only be overcome by recruiting more resources to agriculture, usually in response to higher prices.

While higher food prices may be absorbed in developed countries, they will likely impose hunger in poor regions of the world. Growing ethanol demand is blamed for the doubling of tortilla prices in Mexico toward the end of 2006. Rising food prices in China have prompted the government to close some biofuel plants to reduce demand for energy crops and thereby lessen pressure on food prices. Land economics implies that as we grow more crops for cars in the developed world, we grow fewer crops for food, which will particularly hurt the developing world. These distributional effects of biofuel adoption may have significant geopolitical ramifications.

If the consensus policy of the North and the South that promotes cheap food were to unravel because of rising demand for agricultural products, it could have implications as dramatic as other great multilateral realignments in modern history, including the Cold War. More ominously, overt conflicts may occur within and between countries that experience dramatic changes in food purchasing power. Although we have been spared this experience for many years, it is not difficult to envision the dynamics of a world with sustained increases in food prices. This would be a world where economic convergence—a welcome historic trend of poorer countries growing faster than developed countries—would be reversed.

Given dramatic initial differences in per capita income, a multinational food auction would doubtless be won by higher-income bidders, with dire consequences for food security in low-income countries. History has definitive lessons for leaders whose populations enter food crises. Political consensus evaporates, leaving an ultimatum between regime change and martial law. The development of technologies that can improve agricultural productivity and that permit the harvest of grain for food and the conversion of other plant parts to biofuel is of paramount importance to mitigate this risk.

Losing Natural Habitat and Biodiversity

The impact of biofuels on the environment will be much the same as for food—demand for land for energy production will impose pressure on land for environmental purposes. The result is that biofuels, which are embraced for their ability to help the environment, will harm the environment. The net environmental effect of biofuel is

Table 2: Potential Biofuel Production from Cellulosic Crops

Crop	Avg. Yield	Global Acreage (mil. hec)	Global Production (mil. tons)	Conversion Efficiency liters/ton	Land Intensity (liter/hec)	Max. fuel (billion liters)	Gasoline equivalent (bil. liters)	% Annual Global Gasoline
Switchgrass	10	100	1000	380	5200	520	348	23%
Miscanthus	22	100	2200	380	11440	1144	766	50%
Total		**719**				**1644**	**1115**	**73%**

Source: FAOStat, Kim and Dale, RIS, Madhu, Voigt and Long

uncertain. The agricultural land base is expected to grow with rising biofuel demand. Agricultural production is already considered a major cause of non-climatic global change, and it is expected to double in the next 50 years (not accounting for biofuel production) as the world population becomes wealthier and grows to nine billion. The agricultural land base is expected to grow 18 percent by 2050 just to meet the demand for food, let alone demand for biofuels. This will necessarily mean a worldwide loss of natural habitat larger than the United States. It likely will result in the loss of one-third of remaining tropical and temperate forests.

As more land is brought into production it will be taken away from fallowed land, grazing land, and natural habitat. In the U.S., this pressure will be felt by the Conservation Reserve Program, which offers payments to farmers in ecologically sensitive areas for voluntarily fallowing their lands. As the gains from farming their lands increase, farmers will opt out of the program or demand greater payments. Lands that were idled will be brought back into production.

The loss of natural lands will reduce biodiversity, exacerbating a problem that is already considered costly to the world community. The costs of biodiversity loss are poorly understood, but it is estimated they presently outweigh the costs of climate change. Considering the ecological services biodiversity provides—from cleaning water, restoring nutrients to soil, sequestering carbon, etc.—and the role of biodiversity in medical breakthroughs, it seems clear the loss of biodiversity warrants attention. Biodiversity loss is also irreversible; there is yet no way to bring an extinct species back to life.

The expansion of biofuel production will also produce greater demand for agricultural inputs like fertilizers, pesticides, and water. Increased use of some inputs, especially pesticides and fertilizers, will have negative impacts on the environment. Because biofuels are water-intensive relative to fossil fuels, substitution toward biofuels will induce greater water demand that will divert water from its de facto environmental uses. Water extraction and conveyance will also become more costly amid rising energy prices, which will impact most greatly those who rely on water conveyance for their livelihoods.

Biofuels can also be expected to produce a restructuring of some agricultural sectors. In particular, rising energy costs will make the transportation of commodities to market increasingly costly and may cause agricultural production to relocate nearer demand. Transportation of ethanol is especially costly because it cannot be sent through pipelines like fossil fuels. Ethanol must instead be shipped on train or truck. Therefore, as demand grows beyond that which is regulation-induced, producers may locate along the coasts, rather than in the Midwest where they are clustered now. Moving corn to refineries will also become increasingly expensive, as will moving biofuel residuals to livestock producers. Therefore, feedstock production, fuel production, and livestock production may co-locate in the future near large markets. The effect of this restructuring will be to raise the price of land near cities and reduce the price of land that is far from markets.

Further, the increasing dependency of energy on agriculture may lead to the integration of energy and agriculture. Energy companies traditionally viewed as oil companies may become major players in agriculture as they move into biofuel production. They may vertically integrate into feedstock and livestock production because of the growing interdependence of these sectors.

The Next Generation

The costs of widespread biofuel adoption are significant. They auger for a commitment to improving the efficiency of biofuels and the productivity of agriculture. As demand for the current generation of biofuels grows, the next generation of biofuels is being developed by scientists to provide a more efficient and cleaner form of transportation fuel that reduces the costs of the biofuels considered here.

Cellulosic ethanol is the most promising biofuel on the horizon, but it is expected to be five to 10 years away from commercialization, at best. Cellulosic ethanol is more efficient, making use of more parts of feedstock plants than corn and sugar ethanol. The next generation will be able to convert non-crop plants like trees and grasses to ethanol and will even be able to convert agricultural residues, like corn husks or wheat stocks, into fuel. In addition to making more efficient use of feedstocks, cellulosic feedstocks are also less costly to produce, can be grown on marginal lands, and are less factor-intensive than traditional crops. This expands the stock of land for energy crop production, improves the net energy content of ethanol, and reduces the need for fertilizer and pesticide inputs. Cellulosic ethanol, however, renders marginal lands, that were previously unproductive, available for biofuel production, potentially worsening pressure on environmental lands.

In Table 2, a hypothetical scenario of cellulosic ethanol production is depicted. If current trends in agricultural productivity persist, it will be possible to meet food demand on at least 100 million fewer hectares of cropland. If the freed 100 million hectares of cropland were allocated to growth of Switchgrass and Miscanthus to generate lingo-cellulosic biomass for ethanol production, under the assumptions shown, we could produce 1,115 billion liters of gasoline equivalent ethanol. At today's consumption levels, this level of production could offset 73 percent of the global demand for gasoline without displacing food crops. This scenario hinges on the successful development and commercialization of cellulosic conversion technologies, which seems probable but not certain.

The search for more efficient biofuels should not ignore the role of agricultural biotechnology to improve efficiency, reduce demand for costly inputs, and improve the net carbon emissions of fuels. In particular, agricultural biotechnology has produced crops commonly used in the United States, Argentina, China, and India that reduce the need for pesticides because of pest-resistant genes. These and other technologies have improved the productivity of corn production, in particular, and grains more generally. Future generations of genetically modified crops promise to reduce demand for other inputs, including water. Improvements in the productivity of other biofuel feedstocks (beyond corn) can make all forms of biofuel more viable. Furthermore, continued advances in agricultural productivity generally will reduce the pressure on land and can mitigate the upward pressure on food prices.

The Role of the University-Industry Complex

Within the past few months, several oil companies have announced partnerships with major research universities to develop alternative fuels. They include Chevron and UC Davis, Conoco Phillips and Iowa State University, and a $500 million agreement between BP and UC Berkeley. The Berkeley project in particular will focus on developing cellulosic ethanol. These partnerships are the latest manifestations of the university-industrial complex that was constructed in the 1990s in the biotechnology sector. Since their inception, the agreements have been controversial. Critics worry that corporate money will corrupt research and that research not fueling corporate profits will languish. They also cite an apparent contradiction between public university missions to produce research to the benefit of the public and the licensing of innovations to firms with profit motives.

Supporters of the university-industry complex point out the dearth of research dollars starting in the 1990s and argue that partnerships are efficient in that they permit the university and the firm to perform the tasks at which they have comparative advantages. Universities have the genius and creativity to generate basic research, whereas the private sector is better able to develop basic research and market it. It is argued, therefore, that licensing agreements speed the adoption of new technology relative to university-performed product development.

The performance of the university-industry complex in other sectors indicates the success that may come from its latest iteration. For instance, one in three California biotechnology companies was founded by UC scientists, including faculty, postdocs, and alumni. They include Amgen, Genentech, and Chiron. One in five California high-tech firms was founded by UC scientists and engineers, including Sun Microsystems, Qualcomm, and Broadcom. Research spurred by the corporate-funded biofuel research may produce additional offspring that can power the California economy and produce the next generation of biofuels that may be a true substitute to fossil fuel.

A Role for Policy

The pressures on agriculture will be great in the next half-century as it is relied upon to produce fuel and food for growing populations and growing economies. Agriculture can meet this challenge, but then it will need policies to offer the right incentives to market participants. Intervention may be needed along a number of dimensions. First, policy may be needed to secure a stable food supply. Whereas higher prices for agricultural commodities would auger for a reduction in agricultural policy, reductions in food stockpiles and land devoted to food production may induce greater price variability and impose pressure on low-income consumers. Second, policy may be necessary to protect non-market values of natural resources. Greater demand for land is expected to put pressure on native lands. Third, farmers can be expected to serve a biofuel feedstock market, but incentives may be needed to encourage investment in biofuel processing capacity given up-front costs and uncertainty.

The distributional effects of biofuel may also be significant. It is now recognized that, while biofuel may aid rural development, farm incomes will not universally benefit from higher commodity prices. Land near urban centers may increase in value as firms seek to reduce the costs of transporting production to market. This will hurt some landowners. Higher food prices may endanger poor populations. These and other distributional effects can be mitigated with transfers. Economics must inform and guide these policies.

Steven Sexton is a Ph.D. student in Agricultural and Resource Economics (ARE) at UC Berkeley. He can be reached at ssexton@berkeley.edu. David Zilberman is a professor and David Roland-Holst is an adjunct professor in the UC Berkeley ARE department. Deepak Rajagopal is a Ph.D. candidate in the Energy and Resources Group at UC Berkeley.