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Biofuels: Promises and Constraints*

Concerns about energy supply, national security, climate change, and economic development crowd the public policy agendas of most countries around the world and dominate international dialogues. Political instability in many oil exporting countries threatens the steady supply of fossil fuel to importing countries, while diminishing oil reserves cause more environmentally damaging techniques to be employed in order to extract oil from less accessible sources. Both these factors, along with the rising demand for energy from the developed world, combine to raise oil prices, thus creating a significant drain on foreign exchange in developed and developing countries alike. Concurrently, the expanding use of energy increases greenhouse gas emissions, adding to the destructive effects of climate change.

Into the fray of these diverse and cross-cutting issues steps biofuels. In this ordinary product, different countries and constituencies find potential answers for their utmost concerns. In the United States, national security advocates think biofuels will facilitate energy independence from unstable, unreliable sources. Signers of the Kyoto Protocol, such as the European Union and Japan, view biofuels as a tool towards meeting their emission reduction goals; environmentalists also are supportive for this reason. For farmers, biofuels represent a new market and a way to diversify risk. Developing countries hope these products will be new export commodities, and both developing and developed countries see them as an opportunity to keep expenditures on energy within the domestic economy.

Of course, an energy source that could single-handedly address energy supply constraints, climate change, national security, and economic development issues would be too good to be true, and indeed, the beneficial aspects of biofuels' ability to address these diverse demands are countered by their own issues related to food security and economic and environmental sustainability. The promises of biofuels must be weighed against their costs. This paper seeks to put forward the potential benefits of biofuels as well as their plausible drawbacks to present a thorough overview of policy issues related to biofuels.

Biofuels: A Primer

Biofuels are liquid or gaseous fuels derived from biomass, which can be identified generally as organic matter; for the purposes of fuel, organic matter is plant material or animal waste. While biofuels include compounds and elements such as methanol, methane, and hydrogen, the two fuels primarily in commercial production are ethanol and biodiesel. Ethanol is a liquid fuel generated from converting the carbohydrate portion of biomass into sugar and then fermenting the sugar, while biodiesel is produced through the transesterfication of organically-derived oils or fats.[1] Ethanol can be used as a fuel oxygenate and, in compatible engines, as a substitute for gasoline. Biodiesel can replace petroleum diesel, but it is typically mixed for commercial use in 2/98, 5/95, or 20/80 biodiesel/petroleum diesel blends.

Brazil and the United States are the leading producers of ethanol. Brazil uses sugarcane as its feedstock, while corn is the crop of choice in the United States. By converting rapeseed oil into fuel, Germany produced over half of the world's biodiesel in 2005.[2] Production in the US is rising, where soybeans are the primary feedstock. Malaysia and Indonesia, with an eye to export to Europe, are increasing their production of biodiesel from palm oil.

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Biofuel production from traditionally agricultural crops uses "first generation" technology. Alternatively, "second generation" biofuels utilize crops specifically grown for fuel. This difference is particularly relevant for ethanol, which, as technology advances, may be processed economically from cellulose. Cellulose, also a carbohydrate, is found in plant cell walls. In first generation technology, the sugar from sugarcane is fermented, or the starch from corn is converted into sugar and then this resulting sugar is fermented. Like sugar and corn, cellulose contains glucose. However, unlike first generation energy crops, the sugar is difficult to isolate. To extract it, enzymes are introduced, which break the cellulose down into different chemical compounds, thereby making the sugar available for fermentation.

To date, the enzymatic process remains too expensive to compete with first generation technology. However, should cellulosic technology become cost-competitive with sugar- and corn-based ethanol, shifts in crop and ethanol production are anticipated. Because of their relatively greater energy-conversion efficiency, sugarcane and palm oil may still be used as fuel feedstock. Corn may revert to use for strictly food consumption, while new non-food crops, specifically planted for energy conversion, would be introduced. The frontrunners for these "energy crops" include switchgrass, miscanthus, fast-growing trees, jatropha, and castor oil.[3] Crop residue also may be a feedstock for cellulosic ethanol.

When looking at the promises and drawbacks of biofuels, both first and second generation technologies must be considered, as they have differing implications for policy decisions. The following sections will examine the pros and cons of today's biofuels as well as those of cellulosic ethanol as they relate to economic development, investment and trade, food security, and sustainability.

Economic Development

Even though the policy mechanisms implemented will not be identical for developed and developing countries, biofuels may provide growth opportunities for both types of economies.

Developed Countries: Rural Areas

Agricultural areas in developed countries are typically in a state of economic decline. The consolidation of farms, and the accompanying loss of rural population, has depleted many rural communities of financial and human capital. With their appeal to multiple rural constituencies, biofuels present the possibility of enticing both these resources to return.

For farmers, biofuels' potential benefits are several-fold. First, they are an opportunity for risk diversification. If the fuel market price for a crop differs from the food market price, farmers can opt to sell to the more lucrative market. This choice alleviates some of the financial stress farmers experience as price-takers in the marketplace. Furthermore, the introduction of a competing market puts upward pressure on the price of food, thereby potentially increasing farmers' returns, regardless of the market they sell to.

Second, because the prices of ethanol and biodiesel are tied to the fuel market rather than the food market, fuel prices affect the value of biofuel feedstocks. High fuel prices push up the prices of commodities that can be converted into biofuels. In this respect, some farmers have benefited from the positive influence $65+/barrel oil has had on corn prices in the US and rapeseed prices in the European Union.

Third, farmers that send their crop to a local biorefinery lower their transportation costs. In the United States, for example, selling corn to a local ethanol plant rather than selling it for export via the Mississippi River significantly reduces the related transportation costs for which the farmer is responsible. As energy prices have risen over the past few years, such savings have become increasingly vital to turning a profit on the farm.

Fourth, ownership in biofuel plants offer farmers the opportunity to capture some of the profits from the value-added products processed from their crops. In the US Midwest, nearly half the ethanol plants are owned by farmer cooperatives. Farmers have a one-third stake in France's largest biodiesel company, Diester Industrie. These farmer-investors gain not only from the above three benefits of biofuels, but also from the plants' sales. Thus, members of farmer cooperatives avail themselves of another revenue stream.

Finally, some farmers see opportunities in the emergence of cost-competitive cellulosic ethanol. This market would present another diversification strategy to farmers, as they could add energy crops to their rotations. It also would increase the numbers of farmers able to take advantage of the biofuels market, as temperate climate farmers could plant a wider variety of fuel feedstock crops. Additionally, farmers could possibly expand their cropped acreage by planting perennial energy crops on less fertile land, thereby raising the volume of their harvests. Farmers would be able to harvest crop residue for energy as well, capitalizing on the energy market after the harvest of their food crop. Therefore, cellulosic ethanol could increase farmers' profits.

For agricultural communities in developed countries, land and agribusiness consolidations have meant a steady loss of jobs in rural places. While the advent of biofuel processing plants cannot undo this loss, new jobs at these refineries represent the most dynamic opportunities that many communities reliant upon agriculture have had in at least a generation. And, unlike most manufacturing jobs in rural areas, some jobs at these plants require skilled labor and cannot be relocated to sites with lower overhead and labor costs, as they are tied to the productivity of the land. Thus, they offer the promise of sustained opportunities, which few industries in rural areas provide today.

New jobs from biofuel plants have the wherewithal to increase the financial capital circulating in and the tax revenue accruing to these rural communities, thus benefiting farmers and non-farmers alike. Such economic promise naturally generates enthusiasm for biofuels. However, these assumptions come with caveats.

First, not all rural communities can support biorefineries. Rural areas may lack a readily available supply of feedstock, or the land may simply not support appropriate crops for conversion to energy. Proximity to other refineries may limit the economic viability of a new plant. Sufficient and affordable supplies of water and energy resources to operate the plant also may be lacking. Refineries may have problems attracting and retaining appropriately skilled labor. Because of such limitations, biofuels will not save every rural town.

Second, estimates of the number of jobs created by the biofuels industry vary widely and are heavily disputed. Different studies have put the job multiplier effect of processing plants between six and fifty-one! Some scholars call into question claims that biofuels are responsible for tens of thousands of new jobs in the rural United States. One US study finds the cumulative impact of jobs created directly, indirectly, or induced per ethanol plant to total only 207.[4]

Third, enthusiasm about farmers' opportunities to be investors in biorefineries may be overdone. In the past few years, the number of biorefineries in the United States owned by agribusinesses has surpassed the number owned by farmer cooperatives. In the EU, farmer cooperatives that partner with agribusinesses usually have a minority share in the operation. With deeper pockets and a more streamlined decision-making process, companies like ADM and Cargill are able to take more risks, such as expanding the processing capacity of their plants. They also have the ability to buy out farmer-investors, thereby consolidating ownership of biorefineries. On the one hand, this aggregation may decrease the potential return to farmers and their power in the biofuels market. On the other hand, farmers may be happy to let agribusiness take on the risk of a new technology. Hence, the argument that biorefineries are good investment opportunities for farmers can be seen in two lights.

Shifts from selling crops to export markets to selling them to local biofuel processing plants may also stress rural infrastructure. Instead of transporting grain along main thoroughfares, transit of grain to biorefineries may significantly increase traffic on rural roads. Bottlenecks and the overburdening of local resources may result.

These issues raise questions about the potential for biofuels to be a rural development tool in small communities. What is the true potential for biofuels to spur economic development in rural areas? How many jobs will really result because of biofuel plants? Will rural communities be able to attract and retain the skilled labor needed for these operations? Will the biofuels industry have a meaningful multiplier effect in the economies of shrinking rural towns? Will local investment in biofuel plants generate profits? Faced with competition from agribusiness interests in biofuels, will local ownership of plants continue to be viable? Will agribusiness-owned biorefineries create growth or extract wealth from rural communities? Which will be greater, the wealth accruing to rural communities due to the new biofuel market or the costs to their infrastructures due to accelerated wear-and-tear?

Additionally, just as farmers may significantly profit from biofuels, overinvestment in this strategy may also put them in financial jeopardy. What if the price of oil drops precipitously? What if farmers are faced with a decrease in government support? What will happen if cellulosic ethanol becomes a viable reality? Will farmers be able to adjust and take advantage of this new technology or will they be tied down by their investments in fuel derived from food crops? Will they even be interested in cellulosic crops, if the government support they receive is connected to the production of food crops? Overall, will diversification into biofuels stabilize, or even increase, farmer incomes or contribute to uncertainty in the marketplace?

Developed Countries: Urban and Peri-Urban Areas

Not all developed countries, or even all regions in developed countries, will be able to produce or utilize affordable feedstock for biofuels. Countries such as Japan, the Netherlands, and Belgium have little arable land to spare for the production of biofuel feedstocks. Transporting ethanol from the Midwest to the coasts of the United States can be prohibitively expensive.

However, urban and peri-urban areas may still be able to prosper from biofuel production, thanks to international trade. Biorefineries in countries with limited space for agriculture will not only utilize their own feedstock, but will also import feedstock from developing countries. Thus, port cities in these countries can support biorefineries. For example, a biodiesel plant with 400,000-ton capacity is under construction in Rotterdam. Similarly, because of transportation costs and low labor costs, it is more cost-effective to import ethanol from Brazil to the East Coast of the United States than from the Midwest.[5] Biorefineries in the densely populated, coastal areas of developed countries could therefore create jobs, provide a market for biomass from developing countries, and diversify energy spending away from petroleum.

Developing Countries: Rural Development

As alluded to above, biofuels hold economic development potential for rural residents in developing countries as well. Rural areas in developing countries are hampered by their insufficient infrastructure, and therefore, their inaccessibility to markets. Communication and transportation to these areas are extremely expensive, or sometimes, non-existent. However, advancements in technologies frequently leapfrog such obstacles. In the case of communication, cellular telephones and satellites are eliminating the need to install telecommunication wires in sparsely populated areas; thus, rural residents are transitioning from limited communication abilities with the rest of the world to international connectivity without the time and expense of building the physical infrastructure. While financial and technical constraints remain, rural people's access to information and ideas has dramatically improved with innovation in communication technology. This access, in turn, increases their ability to participate in the marketplace.

Biofuels, and renewable energy in general, hold similar promise for advancing rural areas. In many cases, it is prohibitively expensive to build electricity lines or transport fuel to remote areas. By producing their own fuel, rural residents will not have to dispose hard-earned income on oil products in order to get their crops to market. While home-produced fuel would not address the depressing state (or complete lack) of roads in developing countries, it would save rural residents the cost of purchasing fuel while also reducing the need for investment in the necessary infrastructure to transport oil to remote areas. Thus, because it would provide them with transportation fuel, producing biofuels could make taking goods to the marketplace for sale more affordable for rural residents.

In addition to lowering their expenditures on fuel, growing feedstock crops for biofuels could also help increase the incomes of farmers in developing economies, as they could be new cash crop opportunities. Since developed countries consume much more energy than developing ones, a biofuels export market is ripe for exploiting, and developing countries have the climates and growing seasons to take advantage of this opportunity. Several developing countries have climates suited to growing sugarcane or oil palm trees, currently the most efficient feedstocks for conversion to ethanol and biodiesel, respectively. Conversely, the United States is the largest energy consumer in the world by far, has a shorter growing season than the Tropics, and uses less energy-efficient corn for the production of ethanol. Farmers in some developing countries may be able to profit from these imbalances by growing biofuel feedstock for the developed world's voracious energy appetite.

Cellulosic ethanol could create an even more advantageous situation for developing country farmers. The longer growing season and better climate conditions should enable farmers to be more prolific producers of biomass than colder climate countries. With more biomass but lower domestic energy demands, farmers could export excess biomass to markets in developed countries. Planting new crops, introduced specifically for energy conversion, would also diversify farmers' investments and thereby lower their risks. Furthermore, these new energy crops may allow for greater planting flexibility than do many cash crops commonly produced. Growing trees for biomass conversion would be similar to cash crops such as coffee and cocoa, which require significant time investment before yielding any returns and therefore lock farmers into limited planting strategies that cannot be adjusted each season to match changing market and weather conditions. But fields seeded to perennial grasses appropriate to the climate could be rotated much more readily should another crop become more profitable. Therefore, in addition to creating a market for biomass in which developing countries have the comparative advantage, cellulosic ethanol may provide poor farmers with more diversity and flexibility in their cash crop strategies than is currently possible.

In both developed countries and developing countries, the harvesting of biomass for energy production introduces concerns about environmental sustainability. Additionally, while exporting cash crops have long been touted as the solution to alleviating developing country farmers' poverty, the strategy has achieved only middling success toward this end. In food insecure places, the wisdom of devoting land to fuel feedstock is also questionable. Because of the underlying assumptions about trade and the uncertainty related to food security, these and other qualms exist about the efficacy of biofuels as a rural development strategy.

Developing Countries: Economic Development

New cash crops, especially ones in demand in the energy-hungry developed world, could represent economic boons that reach beyond the agricultural sectors of developing economies. Some countries are already taking advantage of this new market, exporting biomass to developed countries. However, if these countries were able to process their domestic feedstock into biofuels, the new industry would not only represent a larger revenue source for farmers, but new jobs as well. If processing facilities were located in rural areas, these jobs would diversify rural employment opportunities; alternatively, processing plants in cities could draw people from farms to these new jobs. Either way, the transfer of labor from agriculture to a new industry would theoretically increase incomes for rural people by improving the efficiency of those continuing in agricultural production and providing alternate livelihoods for those who choose to leave the sector.

In addition to improving their citizens' economic prospects, developing countries would capture more foreign exchange by processing feedstocks into biofuels because they would be exporting value-added products rather than raw materials. Furthermore, domestic biofuels production would decrease their expenditures on foreign energy sources, thereby saving much needed currency for other investments.

Investment and Trade

Many of the above arguments are predicated on international trade in biomass and biofuels. In order for many of the promising aspects of biofuels to be realized in developed or developing countries, investment capital and trade must exist.

Investment in Developed Countries

Governments of developed economies have the necessary resources to spur economic growth in this new technology by encouraging investments in biofuel production and deployment. Domestic support, often in the form of mandates, tax incentives, and subsidies, encourages producers and consumers to enter the market by defraying many of the risks involved and providing market stability. Governments establish such policies not only to invigorate rural areas, as discussed above, but also to enhance their energy security. While they may be wealthier, the high-energy consumption habits of developed countries mean that, like developing countries, they spend a significant percentage of their budget on oil. As most oil reserves are found in politically unstable regions of the world, this reliance has raised concerns about national security.

For many developed countries, biofuels are a popular solution to the energy security dilemma because they can be sourced domestically. While agriculture has declined over the past century as a percentage of GDP, most developed countries still have agricultural sectors, often kept aloft by government support programs. Proponents of biofuels from the national security point of view frequently advocate the continuation of these subsidies, as long as they encourage the domestic production of energy.

Biofuels are also favored because they are a readily available alternative to oil. Unlike hydrogen fuel cells, which are not yet cost-effective and would require a new transportation system, biofuels are already in the marketplace and fit into the existing infrastructure. While some engines have to be converted in order to be compatible and ethanol or biodiesel pumps need to be more widely available at fueling stations, the technology is relatively copasetic with the components of the transportation system in place. This harmony, combined with their domestic production, serves the priorities of national security advocates.

However, the argument that support to biofuels is justified because it reduces spending on oil and provides energy security needs to be examined thoroughly. First of all, the issue of subsidization must be addressed. Should governments implement policies that encourage biofuels? Is this a cost-effective use of taxpayer money?

If biofuels should receive support, what entities should these subsidies target? Is it better to aim policies at the farmer or the processor? Perhaps the money would be best directed to research and development. What is the best mechanism to encourage the participation of car manufacturers and fuel consumers? What policy or combination of policies should be enacted? How long should subsidization to the industry last? Given the quick but unpredictable pace of technological advancement, should subsidies promote first or second generation fuels?

Second, questions about the compatibility with existing infrastructure and the ability to meet energy demands must also be asked. While biofuels do fit better than most other alternative energy sources with current transportation technology, they are not without their incongruities. For example, transporting ethanol via pipelines is prohibitively expensive and inefficient if there is not a consistent and adequate volume of ethanol to transport. Unlike oil, ethanol mixes with water and impurities found in gasoline pipelines. While this contamination can be avoided if the pipelines are first cleaned and then continually used for ethanol, the small amount of ethanol produced in developed countries today does not warrant pipelines devoted solely to ethanol. Therefore, because it is not cost-effective to alternate the use of pipelines to transport ethanol and oil, E85 is typically "splash blended" with gasoline at storage terminals and then transported by truck to retail stations.[6] This multistep system increases transportation costs.

Using the United States as an example, even if the present pipelines were serviceable, the infrastructure is constructed to transport fuel from the Gulf Coast to the East and West Coasts. To utilize this system, corn or ethanol would have to be transported down the Mississippi River to the refinery stations, blended, and then transported out to the coasts. This creates extra transportation costs. Alternatively, studies looking at the construction of pipelines that would ship ethanol from the Midwest to the US Coasts find such a project to be unjustifiably expensive because of the volume, distance, and related construction and operation costs.[7] Importing ethanol from Brazil to serve the US East Coast market would be more cost-effective.

Third, do biofuels have the ability to displace enough oil in the marketplace to warrant investment in them? In 2005, the world consumed 83.94 million barrels of oil a day.[8] The United States was the largest consumer by far, using 20.6 million barrels a day (b/d). Almost half of US consumption (9.1 million b/d) was used for transportation fuel.[9] In contrast, total world production of ethanol was 12.15 billion gallons for the year 2005.[10] In other words, global annual production was equivalent to less 300 million barrels of oil.[11] Moreover, ethanol is only 67 percent as energy efficient as gasoline. Therefore, the entire world's production of ethanol in 2005 would have supplied the US with transportation fuel for just three weeks! Biodiesel production levels are no better: the European Union and the United States combined produced less of this alternative fuel than the equivalent of 25 million barrels of oil in 2005.[12]

Moreover, energy consumption in the developing world is rising at record pace. India used 100,000 more b/d in 2005 than in 2004; for China, the increase in this time period was over 400,000 barrels.[13] If current levels of biofuel production only meet the demands of one country for a few weeks, how can it meet the demands of an increasingly energy-hungry world?

Fourth and finally, is it correct to assume that biofuels will be sourced domestically? Japan, for example, is the world's third largest consumer of oil, but has very little arable land to devote to energy farming. Furthermore, if developing countries have more favorable climates and growing seasons, will it even be economical for developed countries with arable land to grow their own fuel? As mentioned, it is currently cheaper for the US East Coast to import ethanol from Brazil than to source the fuel from the Midwest. If domestic production is not economical, how will sourcing their energy from countries different from those that currently supply oil affect the energy security of developed countries?

Investment in Developing Countries

As discussed earlier, biofuel production is a prospective tool for rural and economic development. Like in developed countries, significant investment is needed for the feedstock or fuel to come to market. However, most developing country governments do not have the economic resources to provide tax incentives and other encouraging measures to this industry. In fact, these countries may lose revenue by switching to biofuels and thus decreasing fossil fuel consumption, as tax on fuel is one of the easiest ways for governments in developing countries to collect revenue. If it is not within the government's capacity or in its interest to encourage biofuels, will such an industry emerge in developing countries?

Energy-hungry developed countries are already interested in the biomass potential of developing countries. Therefore, if domestic investment capital is insufficient, it is possible that foreign direct investment (FDI) will develop the industry. What will be the consequences of this? What will be the outcomes regarding the amount and quality of employment in the new industry, market opportunities for crops, property, and resource rights? What happens if it is in the interests of the country to meet its own energy needs, but in the interests of the foreign-owned company to export?

Trade

The export of biomass or biofuel, and any theoretical economic gains that come from this transaction, obviously assumes international trade in these products. In order for biofuels to be a feasible development strategy for developing countries, they must be internationally tradable commodities. Currently, low levels of productions, trade barriers such as tariffs and subsidies, and a lack of international standards limit the international trade of biofuels. As was discussed above, less than thirteen billion gallons of ethanol were produced in 2005. Brazil, essentially the only exporter of fuel ethanol, currently only exports 790 million gallons a year.[14] The largest potential ethanol market, the United States, places a 54-cent tariff on ethanol imports to protect its domestic industry.

Such limited capacity and trade barriers curtail international trade in biofuels today, but the situation could quickly change. Looking to meet their Kyoto Protocol commitments, Japan and several countries in the EU are instituting mandates to increase their use of biofuels. Anticipating this surge, Brazil is looking to expand its production capacity. It is also providing technical assistance to other developing countries to help them develop their biofuel production capabilities and thus expand the number of biofuel providers to the nascent international market.

Assuming at least some developing countries are able to participate in the international trade of biofuel products, what will be the impact of this trade on their economic development prospects? The answer to this question will depend on 1) the level of investment and 2) the trade regulations in place. Investment capital must fund the construction of biorefineries in these countries in order for this new product to be a significant source of new jobs. Additionally, exporting a finished product will provide greater economic returns than the export of raw biomass material.

However, will trade regulations encourage or discourage the development of this industry in developing countries? It is possible that tariff escalations will be instituted, persuading developing countries to export biomass rather than value-added products like fuel. If tariffs, such as the one implemented by the US, and other barriers to trade exist, what will be the economic viability of biofuels as a development strategy for poor countries? With developed countries heavily supporting domestic biofuels programs, can such industries in developing countries compete, even with investment capital?

What about the role of standards in the international trade of biofuels? Some countries and non-profit organizations are currently pushing for the development of international standards. Will such regulations help or hinder the ability of biofuels to be an economic development tool for poorer countries? The issue of standards will be addressed later.

Finally, returning to the developing country farmers discussed in the first section, will any extra profit generated from the biofuels industry reach them? Perhaps tariffs and subsidies in developed countries will undercut the comparative advantages developing country producers have in climate and growing season. Or maybe the disincentive to export value-added products will make the returns to farmers negligible. Or it is possible that, because of poor roads, the rates charged by middlemen to transport biomass from the farm to the port will undermine any income increase a farmer might hope to see. What will be the end result for rural areas in developing countries?

Food, Feed, or Fuel

Obviously, sourcing fuel from food crops introduces a conflict between calorie demands and transportation needs. Even using arable land to grow non-edible crops for transportation fuel presents this problem as it prioritizes land use differently. How will these competing interests play out?

Developed Countries

As discussed earlier, biofuels have the potential to bring new economic activity to rural areas by increasing the crop prices received by farmers and by creating new jobs. However, there are many more players in the rural economy than just farmers and job seekers. Even among farmers, great diversity exists. And since everyone consumes food, biofuels' effect on the food sector will be felt far beyond rural areas. Therefore, how will different constituencies and interests be affected by biofuels?

Given the numerous ways biofuel production and industry could develop, exact impacts are difficult to predict. However, it is reasonable to assume that, since the price of biofuel is linked to the price of oil, rising fuel prices will put upward pressure on the price of fuel feedstocks. Moreover, since feedstocks commonly used for biofuel production also happen to be key ingredients for processed foods, products containing refined sugar, high fructose corn syrup, partially hydrogenated soybean oil, or canola oil, just to name a few, will become more expensive for food manufacturers to produce. Ultimately, these market changes will manifest themselves in higher food prices for consumers.

Higher feedstock prices may affect livestock producers in the form of higher feed prices. However, a byproduct of ethanol production is dried distilled grains, which can be used as feed for some types of livestock. A glut of this product could actually make the feed for some types of livestock cheaper. What, then, will be the impact on the livestock sector? Will dried distilled grains be a workable alternative to grain feed, i.e., will it contain the necessary nutrients, be produced in high enough quantity, and be affordable and available to livestock producers? Will it be appropriate for all the kinds of livestock that currently are fed with grain or will livestock production shifts occur? What about the economic returns of meat production? If feed prices rise, how large will the effect on the price of meat be? Will consumer demand for meat change if the price goes up? Will such a change significantly impact the livelihoods of livestock producers?

This competition among different markets and the interrelated effects on price beg various questions. If the prices of feedstocks that can be used for food, feed, or fuel do go up, what will be the response of growers? Will yields increase, or acreage, or both? What will be the interaction between food processing companies and fuel processing companies? Will they be in competition, or will traditional food and feed companies simply diversify into fuel production as well? How will food companies whose products depend upon processed inputs, such as high fructose corn syrup or partially hydrogenated soybean oil, be affected?

Finally, what about the consumer? If the biofuels market causes commodity prices to increase, the price of groceries will also rise. Will customers tolerate this increase when food prices are already projected to rise because of soaring energy costs? While this increase might be bearable for most consumers in developed countries, it will be of concern to those with little or no disposable income. How will the interaction between food prices and biofuel production affect the poor?

Developing Countries

This same question applies to developing countries with even greater repercussions. As is often cited, over one billion people live on less than $1 a day. Will biofuels help to alleviate or exacerbate this poverty and its related hunger?

If biofuel feedstock prices follow the upward trend of oil prices, farmers in developing countries could see increased returns for their energy crops. As nearly one-half of the labor force in developing countries is employed in agriculture, this boost to incomes could have a significant effect on the purchasing power of rural people. Even those farmers not selling feedstock directly to the biofuels market would benefit from the lift to commodity prices. In this scenario, biofuels could address some of the poverty in developing countries.

This increase in income assumes that farmers do see beneficial returns from a biofuels market, which, as discussed above, is not guaranteed. And, even if incomes do increase, what if they come at the expense of sufficient food supplies? If farmers switch to biofuels, will the developing world become more food insecure? Will climbing fuel prices cause food prices in developing countries to rise as well? If so, what if the increase to incomes is eroded by the rise in food prices, as ingredients also become more expensive? Would not such a price effect simply drop more people into destitution rather than helping to alleviate poverty?

Furthermore, by 2050, the world population is expected to swell to nine billion, with most of this growth occurring in the developing world. Can the arable land on Earth feasibly sustain the fuel and food needs of that many people?

Mitigating Factors

If world population increases by 50 percent in the next few decades, food crops are used for fuel, and incomes remain the same, some Malthusian tragedy may befall most of the world. However, technological changes have disproved Malthus' Principle of Population so far and may do so again.

Most immediately, yield increases through traditional breeding programs or from genetic modification are expected to continue. In addition to increasing the yields of food crops, work is also being done to boost the fuel yields from crops. Such scientific advancements may reduce the conflict between food and fuel.

If cellulosic ethanol becomes a cost-competitive technology, some of the pressure on food security would be alleviated. First, crops for the fuel market and those for the food market might not compete intensively for land, as cellulosic energy crops could be grown on marginal soils inappropriate for food crops. Already, crops such as jatropha and castor bean could follow this model today using first generation technology, as they are not edible and can grow on marginal land. Therefore, the land devoted to the food supply need not decrease substantially.

Second, since food crops would not be diverted to fuel production, they would not be directly linked to fuel prices. This segregation of markets would reduce upward pressure on the price of food, helping to keep food affordable for those with little disposable income. However, this scenario also depends on the balanced planting schemes of farmers. If farmers decide to plant predominantly cellulosic crops, food insecurity will increase regardless of the technological innovation.

Another possibility is that a rush on biomass in developing countries does not occur. Infrastructural development and investment may be limited, in which case an export market for biofuels from developing countries would be small. This situation would, of course, not create rising incomes for farmers through a new market, but it also would alleviate tension between food and fuel production, as domestic demands for biofuel would have a much lower impact on the food supply than would demand from the international marketplace.

Incomes are also projected to rise over the next few decades, which should make food security a reality for more people. Additionally, higher incomes will lead to an increase in meat consumption. This development is particularly good news for livestock producers in developed countries fearing competition for grain with biofuels because, as meat consumption increases, so will the price of meat. Therefore, purchasers of feed may be able to compete with purchasers of grain for fuel, as they will be selling to more consumers and collecting more from these consumers for their livestock.

Thus, while the emergence of biofuels does pit food against fuel, the variety of factors weighing into this conflict and the different scenarios that could emerge make the outcome of this competition difficult to predict.

Sustainability

Woven into most aspects of the debate on biofuels is the issue of sustainability. Is there enough land to produce food and fuel? Will cultivation choices be made in ways that foster the continued fertility of the land? Is investing in a biofuels industry the best use of resources to sustain rural livelihoods or create new jobs? Questions such as these, regarding the sustainable production of biofuels, have so far only been alluded to. But these issues are critical to assessing the true viability of biofuels.

Climate Effects and Energy Expenditure

At the turn of the century, carbon dioxide emissions from transportation fossil fuels accounted for 20 percent of CO_2 emissions worldwide.[15] Carbon dioxide emissions from transportation in the United States, the largest CO_2 emitter, already totaled two billion metric tons in 2004 and are forecasted to increase 40 percent by the year 2030.[16] Faced with the warming consequences on the environment of greenhouse gas emissions, policymakers around the world are searching for counteractive solutions.

To some, biofuels play a part in the mitigation of climate change. Fossil fuels contribute to global warming by releasing CO_2 previously sequestered underground in the organic matter from which the fuel is made. Alternatively, the CO_2 released when biofuels are burned was not stored billions of years ago, but only recently was captured by the feedstock plants. Furthermore, with the adoption of biofuels, more plants will be needed, which will, in turn, capture the CO_2 released by the burning of fuel. Proponents of biofuels therefore argue that first generation biofuels have a net reduction effect on greenhouse gas emissions.

Research indicates that biofuels do positively affect greenhouse gas emissions. Biodiesel derived from rapeseed has carbon dioxide emission levels 53 percent lower than petroleum diesel; for soybeans, the reduction is 41 percent.[17] Compared with gasoline, CO_2 emissions from corn ethanol are 12 percent less.[18] A study in Brazil in the 1990s found that sugarcane ethanol reduced that country's CO_2 emissions by almost thirteen million tons.[19]

However, opponents challenge that the impact on greenhouse gas emissions is insignificant. Compared to the US's emissions of two billion tons a year, Brazil's reduction of thirteen million tons is a drop in the bucket. A 12 percent decrease in emissions from corn ethanol also seems relatively inconsequential against the air pollution created in the United States by transportation vehicles.

Furthermore, the connection between biofuels and climate change goes beyond end-use emissions. Whereas the combustion of biofuels may emit less greenhouse gas than fossil fuel, the manufacturing of biofuels requires fossil-based energy. This is particularly true in developed countries, where industrialized agriculture relies upon fossil fuels for its productivity. Fossil fuel, most commonly natural gas, is fundamental to the production of chemical fertilizers, while oil is a key ingredient to synthetic pesticides.[20] As most grain crops have been bred to thrive with these inputs, the consumption of fossil energy in the cultivation of crops used for biofuel feedstock is considerable. Corn grown in the United States illustrates the connection: in 2000, US corn growers applied over seven million tons of commercial fertilizer to their fields, more than twice as much as wheat growers, the next largest users.[21] As corn is the primary feedstock for ethanol production in the US, will the emissions saved by burning biofuels outweigh the emissions from producing the fertilizers and pesticides needed to grow corn or any other biofuel feedstock reliant upon chemical inputs?

Additionally, critics charge that the vehicles used in the biofuels industry expend large amounts of fossil fuels. They power farm equipment. Since ethanol is not conveyed by pipeline in developed countries, trucks and trains, operating on fossil fuels, transport the fuel from farm to pump. And if the international trade of biofuels becomes commonplace, what type of fuel will power cargo ships? Therefore, how do the emission reductions from biofuels balance with the emissions of the vehicles transporting them to the market?

Lastly, ethanol processing plants themselves frequently operate on non-renewable fuels. In Brazil, bagasse, the remaining fibrous material from the sugarcane after the cane juice is extracted, is burned to provide energy for the processing plant. This system is energy self-sufficient. However, in the United States, natural gas, often a co-product of oil extraction, has typically been used to power the plants' machinery. Moreover, in a trend that concerns environmentalists, the increase in the price of natural gas is causing plant construction projects to turn to coal as a fuel source. Replacing one fossil fuel with a less-clean burning one will not assist the argument that biofuels contribute to the fight against global warming.

While these concerns about the fuel use of the equipment and the processing facilities remain, those who believe biofuels can offer environmental benefits argue that other crops may yield better or require fewer inputs. To produce biofuels using first generation technology, scientists and investors are developing more energy efficient crops. For example, Monsanto is developing a variety of corn that yields more ethanol per bushel. Interested parties are also looking beyond the traditional grain and oilseed feedstocks. Jatropha, a non-food crop whose oil is typically used for soaps and candles, is already being used for biodiesel in some places; researchers are studying the economics of this crop to determine whether it can be scaled up for large-scale production. Oil from the castor bean plant is also being used to make biodiesel. With its high starch content, cassava holds promise as a feedstock for ethanol. From an economic development standpoint, these plants could be desirable feedstocks because they are already grown in developing countries and can be cultivated with comparatively lower inputs.

Some studies also contend that second generation technology, that is cellulosic ethanol, could reduce the need for fossil fuel-laden inputs.[22] If produced from low-input crops, second generation energy crops could significantly reduce the amount of fossil fuel consumed in the production of biofuels, thereby making a positive difference to the global warming predicament. The projected reduction in greenhouse gases from burning cellulosic ethanol is also much more favorable than corn ethanol.

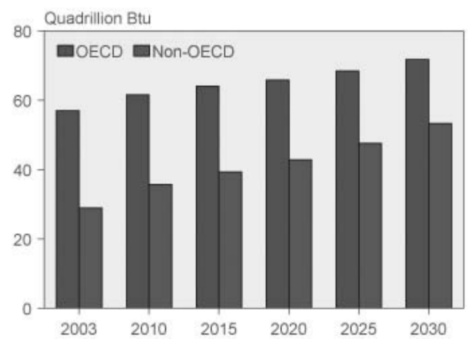
However, such an outcome depends greatly upon climate, soil types, and farmers' planting decisions as well as technological advancements. Will low-input energy crops be viable in all types of climates and soils, whether in developed or developing countries? Will the advancements in second generation technology develop energy crops that are low-input and emit low levels of greenhouse gas when used as fuel? Will the investment that has already taken place in today's feedstocks discourage the production and processing of more environmentally friendly energy crops?

Land Use

If energy crops that require lower levels of chemical fertilizer and pesticides come on-line, this scenario still does not guarantee that biofuels production will be environmentally sustainable. As discussed previously, the United States consumes 9.1 million barrels of oil a day in transportation fuel. The high level of consumption is not abating; at the same time, demand in developing countries is also rising (see Figures 1 and 2). Presently, the Energy Information Administration's projections to 2030 do not anticipate that renewable energy will displace much of the future demand for oil (Figure 3).[23]

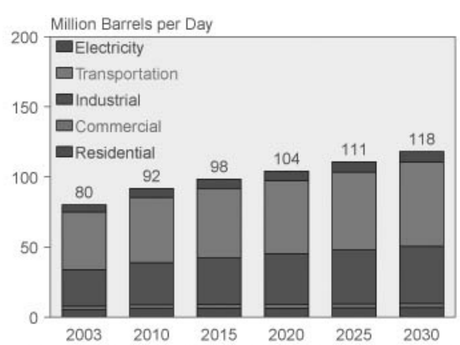
In terms of the environment, what would happen if biofuel producers tried to meet this energy demand using first generation energy crops? Would it lead farmers to apply larger amount of inputs to the land, in the hopes of extracting as much feedstock as possible? How would such enthusiasm affect soil fertility and water use? Would cultivation spread into marginal or protected land?

Figure 1. OECD and Non-OECD Transportation Sector Delivered Energy Consumption, 2003-2030



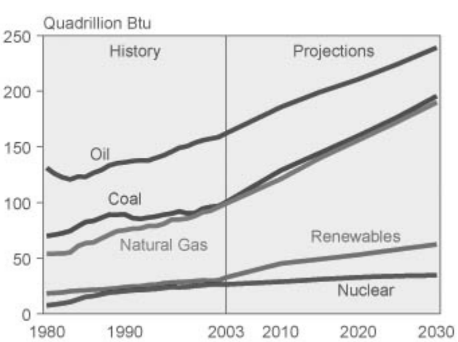
Sources: **2003:** Derived from Energy Information Administration (EIA), *International Energy Annual 2003* (May-July 2005), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2006).

Figure 2. World Oil Consumption by Sector, 2003-2030



Sources: **2003:** Derived from Energy Information Administration (EIA), *International Energy Annual 2003* (May-July 2005), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2006).

Figure 3. World Marketed Energy Use by Fuel, 1980-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2003* (May-July 2005), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2006).

The environmental repercussions of the sustained high demand for oil must be examined under a second generation technology scenario as well. What might happen if cellulosic ethanol becomes economically viable? This technology solves some issues while raising others. On the one hand, cellulosic ethanol could create greater flexibility in land use and expand farmers' incomes. Agricultural residues, such as corn stover and wheat stubble, could be harvested and processed into ethanol; they would essentially be a second crop for farmers. Also, perennial energy crops, such as switchgrass, miscanthus, and fast-growing trees, would require less tillage, thereby reducing soil erosion. Because less disruption of the soil would be required, they could be planted on more marginal land, expanding the acreage under production. With this technology, agriculture could increase the amount of land devoted to energy production.

On the other hand, such practices could easily be unsustainable. Stripping the land of crop residues would reduce nutrient recycling into the soil; the loss of carbon would be particularly problematic. The outcome would be increased vulnerability to soil erosion and decreased soil fertility, resulting in the need for larger applications of chemical fertilizers. Also, even with minimal tillage, expanding into marginal land might have negative environmental consequences. Energy crop production could further stress areas already prone to drought and increased use of farm equipment on marginal land could exacerbate erosion, even if these crops are perennial. Therefore, without a balanced approach, second generation crops could be environmentally damaging.

Furthermore, cellulosic ethanol could lead to the exploitation of existing vegetation. If wood can be converted into transportation fuel, how would the environmental and aesthetic value of forests compare to the trees' value as fuel feedstock? Would laws to protect certain areas, such as national forests, be enforceable given the world's appetite for fuel?

Cellulosic ethanol also has implications for biodiversity. Planting perennial grasses may positively impact animal wildlife by providing them with suitable habitats; this would particularly be relevant to developed countries that have large monoculture fields. Energy crops may even allow farmers to diversify their fields more by adding another crop to their rotation or by diversifying the types of crops planted in a single year. However, energy crops could become monocultures in and of themselves, thereby creating pest and disease problems commonplace in industrial agriculture today.

Certification

To ensure sustainable production, some organizations and governments are pushing for certification standards for biofuels. As part of the standards, these entities want sustainability to be a requirement for certification. But this raises one of the most complex questions of all: what is encompassed by the definition of sustainability?

One criterion, as outlined above, could be land use and cultivation practices. Are biofuel feedstocks grown on arable land, or does production take place on highly erodable, ill-suited locations? Is cultivation conducted in a sustainable manner, or do producers use techniques that damage soil fertility, such as exhaustive cultivation and excessive use of chemical inputs, or practices that bring marginal or protected land into cultivation, like swidden-fallow production? What is the impact on the carbon content of the soil? Relatedly, should biofuel production's impact on biodiversity be evaluated as a part of sustainability as well?

Another possibility is for sustainable certification to be judged by food supplies. Should the production of crops for biofuels only be considered sustainable if it does not cut into the supply of food of the producing country? What if food supply is not affected, but food prices are? Are biofuels sustainable if food becomes less affordable, particularly for those already spending most of their disposable income on food?

Perhaps biofuels should be judged by their impact on fossil fuel use and climate change. Do the climatic benefits of burning biofuels offset the emissions of the fossil fuels used to make the ethanol or biodiesel?

What about the feedstock used? Sugarcane is by far the most efficient feedstock used today for ethanol; one hectare of sugarcane produces six times more ethanol than one hectare of barley, for example.[24] Similarly, the conversion of palm oil to biodiesel is vastly more efficient than conversion from soybean oil. Should biofuels made from less efficient crops not be certified as sustainable? What if they are less efficient, but non-food sources? For example, should jatropha be eliminated as a feedstock because its conversion rate is not as efficient as palm oil's, even though jatropha does not have a competing food use and can be grown on marginal land?

Another issue to consider is what determines the sustainability of a crop. Is it its water use? Its need for chemical inputs? Its efficiency for converting into energy? The climate or soil type it is grown in? The amount of employment it provides? The quality of employment provided? Given the variability of production styles and locations and crop choices, do sustainable criteria need to be developed for crops individually? Would these criteria need to be cross-referenced with soil types, farming practices, or climates?

Furthermore, should sustainability also relate to people's livelihoods? This criterion would be particularly important to biofuels from the developing world. Should certification depend upon the working conditions of farm hands or processing plant employees? Should it encompass property rights and whether or not the land used to grow biofuels was coerced from poorer holders? What if the use of land for biofuel feedstock results in farm consolidation and the loss of livelihoods for small-scale farmers? Will agricultural changes cause migration from rural to urban areas? What if there are no sustainable livelihoods in the cities? Should the approval of biofuels for sale be predicated on sufficient stakeholder participation? If so, who qualifies as a stakeholder and how is 'sufficient participation' quantified?

Biotechnology could also be a certification issue. Are biofuels certifiable if they are derived from genetically modified plants? Is this a point of contention, even if the end use is not human or animal consumption? Does it matter if these plants cannot be used as food? In other words, would genetically modified switchgrass be subject to the same restrictions as genetically modified corn?

Sustainability certification could be judged on one or any combination of the above issues. Which should be included? Who should determine which criteria are included? Should this be done at the national or the international level? Would an international body similar to Codex Alimentarius or the International Plant Protection Convention be needed for countries to reach consensus on sustainability criteria? Would they be able to reach consensus?

These questions simply beg even more quandaries related to trade. If countries devise their own certification, will their primary goal be ensuring sustainable production of biofuels or protecting their domestic biofuels industry? Will certification criteria simply become a convenient cloak for non-tariff trade barriers? This could even be the case under international trade law, particularly if more developed economies with more advanced biofuel industries used their power in the international sphere to shape certification requirements.

If an international certification scheme were agreed upon, who would enforce it? Would countries even give any international body enforcement authority over the sustainable production of biofuels?

Obviously, certifying biofuels as sustainably produced could be tremendously complicated. And it begs one last pivotal question: should the cultivation and production of biofuels be held to standards that current fossil energy and agricultural products are not?

Conclusion

Biofuels certainly occupy enough gray area in the realm of public policy to engage stakeholders in years of debate. However, biofuels are rapidly increasing and their implication on food security, the environmental, and livelihoods cannot wait for slow decisions from bureaucrats. Technology is moving forward quickly, and sound, informed decisions need to be made sooner rather than later.

If the above questions can be settled, policymakers may still find that the job is not done. What will happen to the environment if it turns out that biofuels serve to perpetuate the use of fossil fuels? What will happen to the biofuels market if there is a crop failure? Will biofuels always need government support? With the volatility that is common in both the oil market and the agricultural commodities market, can a stable biofuels market ever be achieved?

Finally, implied in the biofuels debate are the repercussions that unrestrained energy consumption, rising food demand, and an increasing world population will have on the habitability of the world. Debating this alternative energy source is therefore timely and necessary, but with so many unknowns and with implications for so many policy areas, creating a policy that appropriately maximizes the promises of biofuels while minimizing the constraints will challenge decision makers from the varied fields of agriculture, energy, and the environment for some time to come.

ENDNOTES

1 Transesterfication is a chemical process in which an alcohol reacts with the triglycerides contained in vegetable oils and animals fats to produce biodiesel and glycerin. For this and other biofuel-related definitions, see the US Department of Energy's Biomass Program Glossary at http://www1.eere.energy.gov/biomass/student_glossary.html. For scientifically technical definitions, see http://www1.eere.energy.gov/biomass/feedstock_glossary.html.

2 Worldwatch Institute. *Biofuels for Transportation: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century – Summary*. June 2006.

3 Switchgrass and miscanthus are perennial grasses which could be harvested much like alfalfa is today in industrialized countries. Fast-growing tree varieties commonly proposed for use in the United States include poplar and willow trees for cooler climates and sycamore and sweetgum for warmer climates.

4 Swenson, Dave. "Input-Outrageous: The Economic Impacts of Modern Biofuels Production." Iowa State University, Department of Economics, ECON Staff Report. June 1, 2006. Available at: http://www.econ.iastate.edu/research/webpapers/paper_12644.pdf (last viewed November 3, 2006). On the one hand, it should be noted that, as rural communities in the United States are classified as places with fewer than 2,500 residents, even this low estimate would represent at least an 8 percent increase in population if new residents filled all these jobs. On the other hand, it unrealistic to assume that all these jobs would be filled by in-migrants to rural communities.

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6 E-85 is a mixture of 85 percent ethanol and 15 percent gasoline based on volume.

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10 Renewable Fuels Association. http://www.ethanolrfa.org/industry/statistics/ (last viewed November 3, 2006).

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