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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

EDITED BY
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Introduction

Bioenergy—that is, biofuels of biological and renewable origin, like bioethanol, biodiesel, and biomass for energy—is the subject of increasing attention around the world. Oil prices have climbed to unprecedented heights, and concerns about the environmental effects of fossil fuel use are on the rise. Bioenergy appears to offer hope for addressing these concerns while also providing new opportunities for poor people and farmers in developing countries. Can bioenergy fulfill the promise claimed by its proponents? Can it become an environmentally sustainable, economically viable, pro-poor source of energy? And what challenges will meeting these goals present?

This set of policy briefs examines the potential opportunities and risks bioenergy may pose for poor people and farmers in developing countries. The briefs consider economic, social, environmental, and science and technology issues. They look at how increased bioenergy production may affect the global food balance and examine the need for further research and development in the bioenergy field. Lessons from the experiences of Europe, as well as Brazil and other developing countries, are reviewed. Recommendations on how to move forward to develop bioenergy in ways that can serve the poor and the environment are presented.

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

Overview

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FOCUS 14 • BRIEF 1 OF 12 • DECEMBER 2006

In recent years bioenergy (see box for definitions) has drawn attention as a sustainable energy source that may help cope with rising energy prices, address environmental concerns about greenhouse gas emissions, and offer new income and employment to farmers and rural communities around the world. For many countries in the Organisation for Economic Cooperation and Development (OECD), the benefits to farmers are also perceived as a good way to reduce the costs and market distortions of their existing farm support policies, which now total about US$320 billion a year. Moreover, whereas oil and coal are unevenly distributed among countries, all countries could generate some bioenergy from domestically grown biomass of one type or another, thereby helping to reduce their dependence on imported fossil fuels.

Total global energy consumption is huge—about 400 EJ (exajoules) per year—and is expected to grow 50 percent by 2025. Most of the increase will occur in developing countries, especially China and India. Most of this demand is currently met by fossil fuels, particularly oil. Rapid growth in oil demand, finite oil supplies, and political instability in many of the major oil-exporting countries are pushing up oil prices and making them more volatile. This trend seems destined to continue. As a result, many importing countries are looking to expand and diversify their energy sources and are looking at bioenergy as a potentially attractive prospect within their broader energy portfolios. Already, bioenergy accounts for 10 percent of world energy supplies (see box), and the potential to better exploit many unused crop residues and to grow dedicated energy crops is enormous. Bioenergy's potential will also increase as second-generation technologies come on line, enabling more efficient conversion of cellulose-rich biomass to transport fuels and electricity. Technology advances will not only help make bioenergy more competitive with fossil fuels on price, but will also expand the range of feedstock that can be used, some of which (like fast-growing grasses and trees) can thrive in less fertile and more drought-prone regions that are less competitive with food and feed than current feedstock like sugarcane, maize, and rapeseed.

Many developing countries with tropical climates may have a comparative advantage in growing energy-rich biomass and could become major exporters. Even Africa has the biophysical potential to become an important producer and exporter of bioenergy.

In developing countries, biomass is also the main source of household energy in rural and urban areas. Urban households primarily use wood and charcoal for cooking and heating, and with continuing rapid growth in urban populations, finding sustainable ways of meeting this large and growing demand is also a challenge.

Adding to the interest in bioenergy is growing concern about global climate change and the need to reduce greenhouse gas emissions. As the Kyoto Protocol has shown, many countries now seem willing to take steps to cut their emissions, even if this has associated economic costs. Bioenergy is attractive because it is a renewable

Definitions and Background Information

Bioenergy is energy generated through biofuels. Traction energy provided through human or animal work, important in many countries, is excluded in this context. Biofuels are fuels of biological and renewable origin, such as fuelwood, charcoal, livestock manure, biogas, biohydrogen, bioalcohol, microbial biomass, agricultural waste and by-products, energy crops, and others (see http://www.fao.org/sd/EGdirect/EGre0055.htm). The main sources of bioenergy are (1) agricultural residues and wastes, (2) purpose-grown crops, and (3) wild vegetation. In their raw form, these sources are usually called biomass, though the term "energy feedstock" is also used, mostly for purpose-grown energy crops.

Unlike oil, biomass can be produced in just about every country. Bioenergy already accounts for nearly 10 percent of total world energy supplies. It accounts for 33 percent of energy use in developing countries but only 3–4 percent in industrial countries. There are also large differences between developing regions: biomass accounts for more than 60 percent of final energy use in Africa, 34 percent in Asia, and 25 percent in Latin America.

Most biomass in industrial countries is converted into electricity and heat in industrial-scale plants, whereas in developing countries it is mostly burnt by rural households as a source of energy for cooking and heating. Biomass is in fact the main source of household energy use for between 2 and 3 billion people in the developing world. Agriculture's own consumption of energy is relatively small—about 4–8 percent of total energy use in developing countries and 3–5 percent in OECD countries. This share has also declined over time as gains in efficiencies have reduced energy needs.

Liquid biofuels for transport (mostly bioethanol—usually abbreviated to ethanol—and biodiesel) are still relatively minor sources of energy use and are produced in just a few countries. Brazil and the United States are the largest producers of ethanol for transport, accounting for about 90 percent of world production. Both countries currently produce about 16 billion liters per year, and ethanol has displaced 40 percent of gasoline use in Brazil but only 3 percent in the United States. The primary feedstock for ethanol is sugarcane in Brazil and maize in the United States. The European Union, especially France and Germany, is the largest producer of biodiesel, accounting for 88 percent of world production, followed by the United States, which produces 8 percent. Globally, biodiesel production is only about one-tenth of total ethanol production. Rapeseed is the primary feedstock for biodiesel in the European Union. Other than Brazil, few developing countries have sizable biofuels programs at present. The main players are China, Colombia, India, and Thailand, but many others are interested in initiating (or have initiated) small pilot programs.

energy source that has the potential to significantly reduce or at least slow growth in carbon emissions without involving much change in the way energy is used (for instance, it can be used in internal combustion engines and combustion-fueled electric power plants). This is because plant biomass captures carbon from the air, and its subsequent release when generating energy (when burnt in a car engine or power station, for example) simply returns the carbon back to the air to complete the cycle.

Finally, with a chronic global oversupply of most agricultural commodities, diverting some agricultural resources to the production of bioenergy offers an attractive way of helping farmers, especially in rich countries. For example, the diversion of part of the maize crop to ethanol production in the United States helps maintain the maize price, reducing the need for price compensation and export subsidies.

All this seems very promising, but just how realistic are these hopes and expectations? And what are their implications for the poor and the environment? Bioenergy uses resources (land, water, and labor) that compete with food and feed production. This would lead to higher food prices in many poorer countries, but also around the globe if major food-exporting countries like the United States, the European Union, or Brazil were to significantly divert agricultural resources to bioenergy production. Higher food prices would hurt poor people, who are net buyers of food, while benefiting farmers. Yet the poor would gain from cheaper energy. In those countries that grow more biomass, the rural poor might also gain from greater employment and income in the bioenergy sector. For example, small farmers might grow feedstock for bioenergy, and rural workers might be employed in its transportation and processing, especially if the processing can be conducted at small scales and in rural areas. But how would all these pros and cons balance out, and what would be the net impact on the poor?

While international trade could in principle create opportunities for some countries to develop new exports and for importing countries to diversify their energy supplies, trade in biofuels still faces important barriers that are not on the current agenda of the trade negotiations sponsored by the World Trade Organization. Unless changed, these barriers will retard development of the bioenergy sector in countries with a comparative advantage (often developing countries with tropical climates) and encourage the development of protected and more costly bioenergy production in many rich countries. Removing these barriers now, during the early stages of bioenergy development, should be much easier than trying to remove them once powerful national interests have become entrenched.

Although bioenergy is in principle a carbon-neutral source of energy that could do much to reduce carbon emissions, it also requires fossil fuels for growing, transporting, and processing the feedstock and for refining and distributing of the biofuel. Depending on the type of feedstock, and on where and how it is grown and used, the net carbon balance can vary widely. Net carbon and energy savings are not at all assured. Some current first-generation feedstock and technologies have carbon balances not much better than oil, although some (like ethanol from sugarcane) are much better. Second-generation feedstocks and technologies promise to bring large improvements. For example, many fast-growing trees and grasses are perennials and require little cultivation once established, while sequestering much more carbon than alternative land uses. Part of this carbon will be retained in the soil on a long-term basis. Beyond issues related to carbon balances, bioenergy crops and plantations present their own local environmental challenges for soil, water, and biodiversity management.

In sum, despite the exciting prospects for bioenergy, many important questions remain unresolved about its implications for the poor, the environment, and international trade. Moreover, because most of the environmental and social benefits and costs of bioenergy are not priced in the market, leaving bioenergy development entirely to the private sector and the market will lead to bioenergy production and processes that fail to achieve the best environmental and social outcomes. To ensure better outcomes, the public sector has important roles to play. But what are these roles, and what policies, technologies, and investments are needed to ensure that bioenergy is developed in ways that are economically efficient as well as compatible with reducing poverty and global warming?

This set of briefs attempts to answer these questions, with a special focus on the issues for developing countries. The key issues are discussed in more detail, drawing on past experiences in the European Union, the United States, and Brazil and other developing countries to highlight policy options for the future. The briefs also analyze the potential trade-offs between bioenergy production and food in terms of food prices, explore some of the technology options and research priorities for the future, and discuss ways in which carbon payments schemes might be harnessed to promote bioenergy production. ■

For further reading see "The Energy and Agriculture Nexus," Environment and Natural Resources Working Paper No. 4 (Rome: Food and Agriculture Organization of the United Nations [FAO], 2000); M. Kojima and T. Johnson, *Potential for Biofuels for Transport in Developing Countries* (Washington, D.C.: World Bank, Energy Sector Management Assistance Program [ESMAP], 2005); and P. P. Bhojvaid, ed., *Biofuels: Towards a Greener and Secure Energy Future* (New Delhi: The Energy and Resources Institute [TERI], 2006).

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

Developing Bioenergy: Economic and Social Issues

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FOCUS 14 • BRIEF 2 OF 12 • DECEMBER 2006

BIOENERGY AND DEVELOPMENT

Modern biomass energy services have the potential to make a significant contribution to a new energy paradigm. The world currently consumes about 400 EJ (exajoules) of energy per year but generates the equivalent of about 100 EJ of largely unused crop residues. It could produce an additional 180 EJ from energy-dedicated grasses and trees. Despite this potential, bioenergy must be viewed not as the single replacement for oil, but as one element in a wider portfolio of renewable sources of energy.

The production of energy from biomass involves a range of technologies that include solid combustion, gasification, and fermentation. These technologies produce liquid and gas fuels from a diverse set of biological resources—traditional crops (sugarcane, maize, oilseeds), crop residues and waste (maize stover, wheat straw, rice hulls, cotton waste), energy-dedicated crops (grasses and trees), dung, and the organic component of urban waste. The results are bioenergy products that provide multiple energy services: cooking fuels, heat, electricity, and transportation fuels. It is this very diversity that holds the potential of a win-win-win development path for the environment, social and economic development, and energy security.

There is a clear link between access to energy services and poverty alleviation and development. The first set of critical energy needs are those that satisfy basic human needs: fuel for cooking, heating and lighting, energy for pumping water, and electricity for health and education services. The second set of critical energy needs are those that provide energy for income-generating activities that help break the cycle of poverty.

The poor rely heavily on biomass as a source of energy, but traditional bioenergy—derived mainly from the combustion of wood and agricultural residues—has severe negative impacts. First, when combusted in confined spaces, these substances produce significant indoor pollution to which women and children are primarily exposed. This exposure has severe health consequences, including respiratory illnesses and premature death. Second, this kind of biomass use puts immense pressure on local natural resources, especially as communities must satisfy increasing demands for energy services.

THE POTENTIAL DEMAND

The potential economic and social benefits of modern biomass energy arise from the fact that agriculture could face enormous demand for feedstock. This feedstock will need to be produced, harvested, transported, converted into biofuels, and distributed for final utilization. The size of the potential demand can be easily illustrated by looking at transportation fuels, where biofuels are still the only renewable alternative compatible with the current combustion-engine infrastructure.

Each day the world consumes about 21million barrels of gasoline and another 21 million barrels of diesel. These amounts translate into a potential demand of about 30 million barrels of ethanol and 23 million barrels of biodiesel a day. For illustration purposes only, if potential ethanol demand is translated into hectares of sugarcane or maize, the two major feedstocks for ethanol, then it would require the planting of 300 million hectares of sugarcane or 590 million hectares of maize—about 15 and 5 times, respectively, of the current world plantings of those crops. In the case of biodiesel, the potential demand would be equivalent to 225 million hectares of palm, or 20 times the current world plantings. The opportunities and challenges involved in meeting this demand in a sustainable and cost-competitive manner should be a central concern in the development discussion.

In the 20th century, agriculture was characterized by a long-term trend of declining real prices. Steady advances in technology led global supply to expand more rapidly than demand, resulting in lower returns per hectare and an increase in farm sizes to allow for acceptable levels of returns, and fueling an exodus from the rural to urban areas. Biofuels present agriculture and rural areas with a long-term opportunity in which demand could actually outpace the growth in supply and generate the resources to increase income and capital in rural areas.

The most advanced countries in biofuels owe their progress to economic incentives and domestic policies that have fostered the development of a bioenergy industry. These policies do not have to be protectionist in nature, but rather can spur market growth by setting national production targets or gasoline blending volumes. Many countries are now discovering the potential role that bioenergy could play in their economies and in the economies of countries that could be markets for bioenergy services, such as Japan, as well as opportunities that tradable environmental goods may have for their economies.

SYNERGISM BETWEEN ENERGY PRODUCTION AND RURAL DEVELOPMENT

Thus far, the preferred path for using bioenergy in the transportation sector has been to convert traditional crops, like sugarcane and maize, into ethanol to be either blended with gasoline or used directly in internal combustion engines. Palm, soybeans, jatropha, and other oilseed crops can also be converted to biodiesel fuel and used to extend or substitute for fossil-derived diesel fuel. This path offers many developing countries that produce these crops a well-tested opportunity to build their biofuel sector and reduce their need for costly imported fossil fuel.

The specificity of the feedstock, the logistics, the conversion, and local economic conditions make it difficult to define a single break-even point for the production of biofuels. If technology improves and oil prices continue their current upward trend, however, the production of biofuels would be economically competitive in more countries and for a wider variety of feedstocks. Ethanol production in Brazil is economically viable without any government support at oil prices above US$35 per barrel; this experience, based on the use of sugarcane, is transferable to other countries. In the United States, the other major ethanol producer, maize-based ethanol can be profitable at oil prices above US$45 to US$50 a barrel.

A key motivation in the development of biofuels is the possibility of diversifying energy resources and displacing large oil import bills with spending on locally produced biofuels. But the opportunities for rural development should also be a key priority. Rural development benefits from a dynamic bioenergy sector, beginning with feedstock production. Because agricultural production in many developing countries is characterized by labor-intensive activity, additional demand for agricultural products will increase employment and wages in the agricultural sector. Furthermore, the additional personal income generated has the potential to induce significant multiplier effects as it is spent by the rural population.

Given the weight and bulk of most biomass feedstocks, it is necessary to locate collection and conversion facilities in rural areas, close to where the feedstock is grown. Consequently, construction and operation of those facilities will generate additional economic activity in rural areas. This fact emphasizes the close link between the biofuels sector and rural development.

Local benefits, especially for the poor, can be enhanced by organizing small-scale producers to meet the throughput volume and reliability needs of conversion facilities. In Brazil and the United States, large corporations dominate the bioenergy industry, but farmer cooperatives play a useful role in linking these large firms to independent growers. Similar arrangements may be needed in other countries if the industry is not to develop in a vertically integrated way with only large-scale growing of biomass feedstocks.

Additionally, since certain energy crops like trees and grasses require few inputs, they sometimes can be grown on land too marginal for food crops. These energy crops have the potential to extend the land base available for agricultural activities and to create new markets for farmers. These positive impacts in the dynamics of the rural economy could have a substantial role in reducing the traditional exodus to urban areas and could create a more favorable economic environment for greater investment in rural infrastructure, health, and education.

THE INDIRECT CONTRIBUTION OF DEVELOPED COUNTRIES

Greater bioenergy production in developed countries would indirectly affect many developing countries by reducing exports of food and feed, leading to higher world prices for these goods. A study undertaken by the author has shown that between 15 and 30 million acres in the United States could shift toward energy-dedicated crops, leading to significant reductions in food and feed production and export surpluses. Given the weight of the United States in world markets, it is likely that world prices would also increase. Farmers in developing countries may benefit from the higher prices and expand their own production of food and feedcrops. Such a production increase would also raise the availability of crop residues in developing countries, and the bioenergy industry could gain additional strength based on this added energy feedstock. On the negative side, higher world prices would lead to higher food prices for the poor, but this impact might be offset in the longer term by the higher employment and incomes generated by agricultural-led growth.

Bioenergy could make multiple contributions to the fight to eradicate poverty and improve food security. In developed countries, shifting land use toward biomass for energy would reduce dumping in the commodity markets and give developing-country farmers access to higher prices. In developing countries, the production of energy in concert with sustainable food production and the sustainable use of local resources could also result in higher incomes for farmers and added energy services for the community, all of which would enhance the community's ability to develop economic activity designed to reduce poverty and enhance food security. ■

For further reading see S. T. Coelho, "Biofuels: Advantages and Trade Barriers," paper prepared for the session on biofuels at the United Nations Council on Trade and Development (UNCTAD) Expert Meeting on the Developing Countries' Participation in New and Dynamic Sectors of World Trade, Geneva, February 7-9, 2005; D. De La Torre Ugarte and C. Hellwinckel, "Commodity and Energy Policies under Globalization," paper presented at the conference "Agricultural Competitiveness and Change under Globalization," organized by the Center for Agricultural Policy and Trade Studies and the Freeman Center for International Economic Policy, Fargo, North Dakota, October 11-12, 2004; Intergovernmental Panel on Climate Change (IPCC), *Climate Change 1995: Impacts, Adaptations, and Mitigations of Climate Change: Scientific–Technical Analysis* (Cambridge: Cambridge University Press, 1996); S. Kartha and G. Leach, "Using Modern Bioenergy to Alleviate Rural Poverty," report for Modern Biomass Workshop, May 2001 (London: Shell Foundation Sustainable Energy Programme, 2001); and J. Woods and D. O. Hall, "Bioenergy for Development: Technical and Environmental Dimensions," FAO Environment and Energy Paper 13 (Rome: Food and Agriculture Organization of the United Nations [FAO], 1994).

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

Biofuels and the Global Food Balance

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Rising world fuel prices, the growing demand for energy, and concerns about global warming are the key factors driving the increasing interest in renewable energy sources, and in biofuels in particular. But some policymakers and analysts have voiced concern that aggressive growth in biofuel production could "crowd out" production of food crops in some developing countries, creating a tension between the need for energy and the need for food and feed.

This brief investigates the interaction between crop demand for biofuel feedstock and the demand and production of crops for both food and feed, in order to see how scenarios for projected growth in biofuel production could affect food availability, prices, and consumption at global and regional levels between now and 2020.

BIOFUEL SCENARIOS

The model used for this analysis is the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which the International Food Policy Research Institute (IFPRI) has used to project global food supply, food demand, and food security to the year 2020 and beyond. The model contains three categories of commodity demand: food, feed, and other use demand. This study manipulates the "other use" demand category in order to reflect the use of commodities as biofuel feedstocks, depending on the projected level of biofuel production. The commodities in question are maize, sugarcane, sugar beet, wheat, and cassava for bioethanol, and soybean and oilseed crops for biodiesel. Given that cellulosic feedstock sources such as crop residues and switchgrass are not represented, their effect is modeled by reducing the demand on the food commodities that are represented within IMPACT. A limitation of this approach is that it does not allow for substitution among different feedstocks in the production of biofuels, which when combined with the absence of trade in biofuel products, can cause the feedstock costs of biofuel production to vary enormously by country in the model solutions. Although this assumption about trade may be realistic in the short term, it would have to be relaxed for longer-term projections to allow for possible expansion in future biofuel trade.

Drawing on projections for biofuel demand for the relevant countries and regions, IMPACT models three scenarios in addition to the normal baseline, which contains no extra "other demand" usage for biofuel feedstock beyond that used in the base year 1997. These scenarios are as follows:

1. **Aggressive biofuel growth scenario with no productivity change.** This scenario assumes very rapid growth in demand for bioethanol across all regions and for biodiesel in Europe, together with continued high oil prices, and rapid breakthroughs in biofuel technology to support expansion of supply to meet the demand growth, but holds projected productivity increases for yields at baseline projection levels. The "aggressive biofuel growth" scenario replaces 10 percent of gasoline production with biofuels by 2010, 15 percent by 2015, and 20 percent by 2020 throughout most of the world, except for adjustments in line with other projections for Brazil, the European Union, and the United States. The biodiesel projections focus solely on the European Union 15 (EU-15) countries because they account for almost 90 percent of global production volume. Projections for all regions other than the European Union focus solely on bioethanol. For bioethanol production, maize, sugarcane, sugar beet, cassava, and wheat are considered feedstock crops. Table 1 shows the shares of biofuels in the context of total road transport fuel use, and these figures reflect the fact that although the scenario assumes displacement of either gasoline or diesel fuel in each country or region, many countries and regions use both types of fuel.
2. **Cellulosic biofuel scenario.** In this scenario, second-generation cellulosic conversion technologies come on line for large-scale production by 2015. In this case, the volume of biofuel feedstock demand is held constant starting in 2015, in order to represent the relaxation in the demand for food-based feedstock crops created by the rise of the new technologies that convert nonfood crop residues, grasses, and forest products. Crop productivity changes are still held to baseline levels.
3. **Aggressive biofuel growth scenario with productivity change and cellulosic conversion.** This scenario now considers, in addition to second-generation technologies, the effect of investments in crop technology that would lead to increased productivity over time, in order to better support the expansion of feedstock supply in response to growth in biofuel demand. These productivity improvements are parallel to those used in other IMPACT-based studies to show the benefits of sound agricultural investment policies in developing agricultural economies, and they emphasize strong agricultural productivity growth in Sub-Saharan Africa.

Table 1—Biofuel Production as Energy-Equivalent Shares of Total Gasoline and Diesel Demand for Transportation in the Aggressive Biofuel Growth Scenario (percent)

Year	China	India	Brazil	United States	European Union	Rest of world
2005	2	1	37	2	1	0
2010	4	5	47	3	4	2
2015	6	8	49	3	7	2
2020	8	11	58	4	10	2

Source: Authors' calculations based on 2005 actual production and energy demands from the Worldwatch Institute and the International Energy Agency (IEA). Brazil and U.S. projections based on IEA bioenergy and U.S. Department of Agriculture (USDA) sources, respectively.

Note: Higher shares in Brazil have significant exports of ethanol production embedded in them. The projection for the European Union is based on a potential path dominated by biodiesel, while other regions only represented displacement by bioethanol.

Table 2—Percentage Changes in World Prices of Feedstock Crops under Three Scenarios, Compared with Baseline

Feedstock crop	Scenario 1: Aggressive biofuel growth without technology improvements		Scenario 2: Cellulosic biofuel	Scenario 3: Aggressive biofuel growth with productivity change and cellulosic conversion
	2010	2020	2020	2020
Cassava	33	135	89	54
Maize	20	41	29	23
Oilseeds	26	76	45	43
Sugar beet	7	25	14	10
Sugarcane	26	66	49	43
Wheat	11	30	21	16

Source: IFPRI IMPACT projections.

RESULTS

The "aggressive biofuel growth" scenario shows dramatic increases in world prices for feedstock crops (Table 2). If cassava were to be used aggressively as a feedstock for bioethanol, cassava prices would rise tremendously, causing sizable welfare losses to the major consumers of this crop, who reside mostly in Sub-Saharan Africa. There would also be high economic costs. If cassava is not profitable as a biofuel feedstock at today's oil prices, it certainly would not be at more than double the cassava price. Thus, this scenario would entail subsidies for the biofuel sector, which already exist for many countries (such as within the European Union), and could take the form of tax concessions at the pump or producer credits. The high price increases for oils and cassava suggest that the relatively low-yielding oil and root crops will have to make up fairly high shares of total production in order to meet the oil-displacement trends embedded in the "aggressive biofuel growth" scenario.

In contrast, the second scenario, which includes the impact of cellulosic technologies, shows a considerable softening of these effects, especially for cassava and oil crops, and underlines the potential importance of such technical innovations at the industry level. Improvements in conversion efficiency for non-cellulosic processes are not introduced into the model, since these technologies have been in use for some time and show little room for improvement, based on studies cited in the literature.

The third scenario illustrates the importance of crop technology innovation at the farm production level and shows a further softening of price impacts, with cassava undergoing the largest decrease. This third scenario in particular shows how investments in the biofuel industry and the agricultural sector can be combined to produce a more favorable outcome, which can mitigate the consumer-level impacts. Moreover, this scenario seems the most plausible of the three, as neither national governments nor fuel producers would want to engage in a large-scale expansion of production without the necessary investments being in place to ensure a reliable supply of feedstock material at a reasonable cost, both for producers and for consumers of food and feed commodities.

Although the mechanisms by which feedstocks might be substituted in and out of biofuel production according to their competitiveness with long-term fossil-fuel prices and each other have not been modeled, an illustrative set of results (for a "fixed" menu of inputs) argues strongly for preparatory investments in both the agricultural sector and the fuel industry itself.

SUMMARY AND CONCLUSIONS

The results show a "food-versus-fuel" trade-off in cases where innovations and technology investments are largely absent and where trade and subsidy policies are failing. In view of past agricultural policy, such a scenario cannot be ruled out, unfortunately, but it could certainly be avoided. This bleak picture changes considerably when biofuel and crop production technology advancements are taken into account. Although there is some uncertainty about the timing of eventual large-scale use of cellulosic conversion technologies for biofuel production, the potential benefits are well recognized in the literature, making a strong case for further research in that area. The strong price increases for root crops like cassava in the first aggressive scenario suggest that without the necessary productivity improvements, aggressive growth in biofuels could have adverse effects on well-being in regions like Sub-Saharan Africa, where a large proportion of cassava consumption is for food. The third scenario, which gives an added boost to agricultural productivity growth in Africa, demonstrates this clearly.

The results suggest that the cost of biofuels could be considerably higher than the projected price of oil, so there would need to be compelling nonprice factors for its uptake at the aggressive levels assumed in first scenario in particular. Indeed, there may be factors favoring the decision to adopt biofuel production that cannot be captured within a strict quantitative comparison of biofuel versus fossil-fuel costs, such as national energy security or positive externalities to the environment. Nonetheless, if developing economies are to participate beneficially in the growth of renewable bioenergy production and still maintain adequate levels of food security, then a complementary set of investments would need to be made along the lines suggested. By making such investments, these countries are likely to produce benefits for consumers of both food and energy, while also contributing to the broader growth of their economies and the betterment of human well-being. ■

For further reading see L. Fulton, T. Howes, and J. Hardy, *Biofuels for Transport: An International Perspective* (Paris: International Energy Agency [IEA], 2004); International Energy Agency (IEA), *Bioenergy*, http://www.ieabioenergy.com; IEA, *World Energy Outlook*, http://www.worldenergyoutlook.org/; and Worldwatch Biofuels Project, http://www.worldwatch.org/taxonomy/term/62#1.

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Bioenergy and Agriculture: Promises and Challenges

Environmental Effects of Bioenergy

Sivan Kartha

2020 VISION
FOR FOOD, AGRICULTURE, AND THE ENVIRONMENT

Focus 14 • Brief 4 of 12 • December 2006

As concerns about climate change and energy security rise, bioenergy is often proposed as a renewable energy source that can be cost-effectively scaled up to a level that would allow it to contribute significantly to meeting global energy demand. Given that bioenergy can be generated in myriad ways, however, using various feedstocks and various energy technologies, few universal conclusions can be drawn about its environmental effects. One can easily imagine biomass production systems that are ideally suited to their environment, and even contribute to improving the environment by revegetating barren land, protecting watersheds, providing habitat for local species, and sequestering carbon, all while contributing to livelihoods of rural communities. Yet one can just as easily imagine biomass production systems that are fossil fuel intensive, exhaust the soil of nutrients, exacerbate erosion, deplete or degrade water resources, reduce biodiversity by displacing habitat, increase greenhouse gas emissions, and threaten the livelihoods of local communities. As with agricultural pursuits generally, the net impact of a bioenergy critically depends on how it is generated.

ENERGY AND CARBON BALANCES

Energy balances. Although biomass is invariably called a "renewable" source of energy, biomass production typically involves the consumption of fossil fuels. How much fossil fuel is used depends on the particular form of biomass and the production method. It includes fuels consumed by farm machinery in land preparation, planting, tending, irrigation, harvesting, storage, and transport; fossil feedstocks for chemical inputs such as herbicides, pesticides, and fertilizers; and energy required for processing the bioenergy crop into a usable biofuel.

Energy requirements are generally higher for annual than for perennial crops because they involve greater use of machinery and a higher level of chemical inputs. For many perennial energy crops, energy ratios (the quantity of useful bioenergy crop produced per unit of fossil fuel consumed) for feedstock production are high enough to make them attractive energy resources. For example, some crops (poplar, sorghum, and switchgrass) grown in temperate climates have energy ratios of 12 to 16. In tropical climates with good rainfall, however, these ratios could be considerably higher, owing both to higher yields and less energy-intensive (that is, more labor-intensive) agricultural practices. Energy ratios can be much lower for annual row crops that require high levels of inputs and a high level of mechanization and yield a relatively small proportion of usable bioenergy feedstock per unit of plant matter produced. Some oil crops in industrial countries, for example, have an energy ratio barely greater than 1.

Carbon emissions. Bioenergy can affect net carbon emissions in two main ways: (1) it provides energy that can displace fossil fuel energy, and (2) it can change the amount of carbon sequestered on land. The net carbon benefit depends on what would have happened otherwise—that is, both the amount and type of fossil fuel that would otherwise have been consumed and the land use that would otherwise have prevailed.

To assess the net impact of displacing fossil fuels, the relative carbon intensity must be assessed on the basis of the emissions associated with the biofuel crop production and the efficiency of the energy technology in which the biofuel is used. The table gives some approximate values for the carbon emissions of selected technologies.

This table assumes that the bioenergy crop is harvested in a carbon-neutral manner—that is, that there is no net change in carbon on the cropland and in the soil over the course of a full bioenergy crop cycle. In actuality, the carbon on the land could change significantly. The magnitude of the net change depends critically on how the biomass is produced and what would have happened otherwise.

Consider a case in which natural forest is cleared to provide fuel for a bioenergy facility, leaving a denuded site that cannot readily regenerate. In this case, the carbon emissions from the bioenergy cycle could well be greater than the carbon emissions from a fossil-fuel cycle providing an equivalent amount of energy. There is no justification for this fuel cycle from any environmental perspective. Nonetheless, this is a frequently used model for the production of non-energy biomass commodities and could be the most financially attractive strategy for a bioenergy project from the standpoint of near-term profits.

As a second case, consider a situation in which natural forest is cleared and replanted with an energy plantation harvested sustainably to supply a bioenergy facility with biomass continuously. The carbon sequestered in the natural forest will be released. The amount of carbon released depends on the type of forest, but a rough figure is 300 metric tons of carbon per hectare (tC/ha). As biomass feedstock is grown and harvested in cycles, carbon will be held on the land, partly compensating for the carbon released when the natural forest was cut down. Averaged over a growth cycle, a

Approximate Carbon Emissions from Sample Bioenergy and Fossil Energy Technologies for Electricity Generation

Fuel and technology	Generation efficiency	Grams of CO_2 per kWh
Diesel generator	20%	1,320
Coal steam cycle	33%	1,000
Natural gas combined cycle	45%	410
Biogas digester and diesel generator (with 15% diesel pilot fuel)	18%	220
Biomass steam cycle (biomass energy ratio[a] = 12)	22%	100
Biomass gasifier and gas turbine (biomass energy ratio[a] = 12)	35%	60

[a] The energy content of the biomass produced divided by the energy of the fossil fuel consumed to produce the biomass.

Source: S. Kartha and E. D. Larson, *Bioenergy Primer: Modernised Biomass Energy for Sustainable Development* (New York: United Nations Development Programme, 2000).

typical amount of carbon sequestered on the plantation land might be 30 tC/ha. The natural forest therefore holds 270 tC/ha more than the energy crop. If the bioenergy crop is used to displace fossil fuels, thereby reducing carbon emissions, it will compensate for this 270 tC/ha difference over a period of roughly 45 years. Thus, there might be a case based on carbon benefits for clearing natural forest to plant energy plantations. It is not, however, a very compelling case, and when environmental and social considerations, such as preserving habitat and protecting watersheds, are taken into account, these considerations might outweigh any carbon benefits.

In the third case, a bioenergy crop plantation is developed on unproductive land, such as degraded land that could benefit from revegetation. The degraded land most likely held considerably less carbon than the plantation, even in the soil and other below-ground biomass. In this case, the change in land use will offer not only benefits resulting from displacing fossil fuels, but also carbon benefits and other ecosystem benefits.

OTHER ENVIRONMENTAL IMPACTS

Biomass crops are no different from other farm crops when it comes to managing soil, water, agrochemicals, and biodiversity, and the consequences of not following good practice are generally the same as with other crops. But biomass production also presents some specific environmental challenges that need to be managed carefully.

Soil quality and fertility. Biomass crops pose a particular challenge for good soil management because the plant material is often completely harvested, leaving little organic matter or plant nutrients for recycling back into the soil. In many rural areas in the developing world where soil management depends on recycling crop wastes and manure rather than use of external inputs, biomass production could lead to dramatic declines in soil fertility and structure. To maintain soil organic matter, farmers must keep sufficient plant matter on the land, even though this practice may reduce the harvestable yields of bioenergy crop material.

In many cases, farmers can reduce the risk of nutrient depletion by allowing the most nutrient-rich parts of the plant—small branches, twigs, and leaves—to decompose on the field. Timing the harvest for the part of the growing cycle when the above-ground living biomass has relatively low nutrient content also helps.

In some bioenergy systems, the feedstock's nutrient content can be recovered from the conversion facility in the form of ash or sludge and then converted into a form that can be applied to the field rather than put in a landfill. The nutritive value of the ash or sludge may, however, be less than optimal. For example, ash will not contain nitrogen released during combustion, and certain other nutrients may not be in a bioavailable form.

Biodiversity. Bioenergy feedstock production significantly influences surrounding ecosystems, enhancing or suppressing biodiversity. To the extent that bioenergy crop production offers an environment that is more biodiverse and more similar to a natural habitat than other agricultural options, it can enhance biodiversity and fill gaps between remaining fragments of natural habitat. In Brazil, for example, environmental regulations now require 25 percent of the plantation area to be left in natural vegetation to help preserve biodiversity and provide other ecosystem services. Forestry companies have found that the natural areas support predators that help control pest populations in nearby plantation stands. Bioenergy crops can also serve as corridors between natural habitat areas for the benefit of migrating or wide-ranging wildlife.

Exotic industrial crops have proven capable of escaping the cultivated area and thriving uncontrollably at the expense of other indigenous species. For example, *Pinus patula* and *Acacia melanoxylon* in South Africa, *Pinus pinaster* in Uruguay, and eucalyptus in various regions have reproduced widely beyond plantations and become pests to the local vegetation. Similarly, monoculture must be avoided, since widespread planting of a single crop can function as an incubation medium for pests or disease, which can then spread into natural habitats. This situation has occurred in India, where a fungal disease spread from exotic pines on plantations to native pines.

Hydrological impacts. Bioenergy crops optimized for rapid growth generally consume more water than natural flora or many foodcrops. Some biomass crops like sugarcane compete directly with foodcrops for irrigation water. Others have been observed to lower the water table, reduce stream yields, and make wells less reliable; this is one reason local agricultural communities have often opposed the introduction of tree plantations. Certain practices, like harvesting residues, cultivating tree crops without undergrowth, and planting species that do not generate adequate amounts or types of litter, can reduce the ability of rainfall to infiltrate the soil and replenish groundwater supplies, exacerbating problems of water overconsumption.

CONCLUSION

Bioenergy crop systems can—if properly designed—yield significant benefits, both environmental and social. The right choice of biomass crops and production methods can lead to favorable carbon and energy balances and a net reduction in greenhouse gas emissions. But bioenergy production systems also need to be adapted to local conditions to avoid generating environmental problems. As a guiding principle, bioenergy crop systems can potentially provide benefits if implemented on land that is currently under annual row crops or is undergoing uncontrolled degradation. In either case, providing social benefits will require engaging local communities and understanding the current uses of the land, such as food production, livestock grazing, and fuelwood gathering. Bioenergy crop production can be a suitable alternative if designed in a participatory manner with those whose livelihoods will be affected. ■

For further reading, see J. Hill et al., "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels," *Proceedings of the National Academy of Sciences* 103, no. 30 (July 25, 2006): 11206–10; A. Moret, D. Rodrigues, and L. Ortiz, 2006, *Sustainability Criteria and Indicators for Bioenergy*, http://www.natbrasil.org.br/Docs/publicacoes/bioenergia_english_final.pdf; D. O'Connell, B. Keating, and M. Glover, *Sustainability Guide for Bioenergy: A Scoping Study*, RIRDC Publication No 05/190 (Barton, Australia: Rural Industries Research and Development Corporation, 2005); and the journals *Biomass and Bioenergy*, *Bioresource Technology*, and *Journal of Biobased Materials and Bioenergy*.

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

Potential of Carbon Payments for Bioenergy

ODIN KNUDSEN

2020 VISION FOR FOOD, AGRICULTURE, AND THE ENVIRONMENT

FOCUS 14 • BRIEF 5 OF 12 • DECEMBER 2006

Agriculture around the world is already mitigating climate change through the increased growing of crops and trees. But much more can be done to bring agriculture into the center of climate change mitigation and to encourage a greater role for sustainable bioenergy production. The result could be not only a better global environment, but increased revenues for farmers, more energy self-sufficiency for rural communities, and preservation of natural forests and biodiversity. Through the Kyoto Protocol, the world community moved toward realizing the potential of agriculture for mitigating climate change, but not enough to gain the full benefits.

If the world community can rally around the potential of agriculture and forest management in combating climate change and provide an international regulatory structure that permits this potential to be realized, the benefits to the world's climate and poverty reduction in developing countries could be enormous, perhaps even exceeding the benefits of trade in agricultural products and development aid. These steps would also enable carbon payments to be harnessed for the development of sustainable bioenergy production.

AGRICULTURE'S POTENTIAL CONTRIBUTION TO MITIGATING CLIMATE CHANGE

Agriculture is a potential instrument for reducing carbon and other greenhouse gases (GHGs) in the atmosphere. Crops naturally sequester carbon as part of the plant's growth cycle. This carbon can become an energy source for humans and animals or can be converted into bioenergy, which can substitute for fossil fuels. Residuals from agriculture left on the fields can reduce erosion and contribute to soil fertility, or much of this biomass can be collected and turned into energy. Manure can also be used as a fuel instead of being left to decay and release the potent greenhouse gas methane, with an atmospheric impact 21 times that of carbon dioxide (the other significant greenhouse gas from agriculture is nitrous dioxide, with an impact more than 300 times that of carbon dioxide).

Agricultural practices can also determine how agriculture contributes to climate change. For instance, leaving soil mostly undisturbed in cultivation means that carbon largely remains in the soil. If agriculture is combined with reforestation or afforestation, the growing of these trees becomes a long-term means of sequestration. Shorter-rotation forestry on degraded or deforested land can also be a means of sequestering carbon and may be more economical for landowners.

Agriculture can grow fuel crops such as sugarcane, maize, and switchgrass that can be converted into ethanol. The biomass from residuals such as rice husks can also be a source of fuel and a substitute for fossil fuels. Other crops can be converted into diesel fuels. The size of the greenhouse gas reduction depends on the net energy and carbon balance that the production of these crops yields.

These external benefits to the environment from agriculture are currently largely free to the world. Whereas projects to improve energy efficiency, capture landfill methane, or incinerate industrial gases earn emissions reduction credits under the Kyoto Protocol and generate payments to project developers, farmers in developing countries go largely unpaid for their contribution to mitigating climate change.

The near exclusion of developing-country agriculture from the Kyoto Protocol affects Africa most severely. Africa, which is heavily agricultural and has great potential in agroforestry, is largely missing out in the fast-growing trade of carbon assets under the Kyoto Protocol. In the agricultural areas that the protocol addresses, such as biomass production for bioenergy, the methodologies for accounting for emissions reductions are highly complex and closely related to energy use from the power grid. In rural areas, where access to specialized knowledge is limited and the power grid is sparse, farmers' prospects for capturing income from the Kyoto Protocol through bioenergy are highly limited. The only realistic prospect for African farmers is through carbon sequestration via agroforestry or reforestation, but again the accounting mechanisms for emissions reductions are some of the most complex of the protocol. In addition, the largest and most profitable market for emissions reductions from developing countries—the European Union's Emissions Trading System (ETS)—excludes reforestation and agroforestry activities in developing countries.

Yet Africa and most developing countries are highly vulnerable to climate change and are little able to adapt to such change. It is expected that climate change will destroy many farmers' livelihoods in developing countries through more frequent and intense droughts, floods, and other extreme climate events, and climate models forecast that African farmers are likely to be the primary victims of climate change.

Why were developing-country farmers excluded from compensation schemes? In the complex negotiations for the Kyoto Protocol and the ETS, the multiple goals of diverse constituents worked against spreading the benefits of climate change mitigation to agriculture in developing countries. Many parties viewed the protocol as a mechanism to improve energy efficiency in industrial countries and to reduce emissions of pollutants like sulfur dioxide. They did not want these objectives to be diluted by land-use and agricultural approaches that could reduce the focus on energy efficiency.

THE KYOTO PROTOCOL AND THE CLEAN DEVELOPMENT MECHANISM

Under the Kyoto Protocol, three mechanisms were established for trading carbon emission reductions: (1) International Emissions Trading among countries with compliance obligations, (2) Joint Implementation (JI) allowing trading from economies in transition, and (3) the Clean Development Mechanism (CDM) for developing countries. It is the CDM where the potential benefits for developing countries and agriculture primarily reside.

The CDM seeks to create support for sustainable development and lower the costs of emissions reductions by allowing developing countries to sell credits for their emissions reductions to those countries with Kyoto targets (Canada, the European Union 15, and Japan) through a market mechanism. These credits—or certified emissions reductions (CERs)—are generated through projects that reduce emissions from a baseline scenario or from the level of emissions that would have occurred in the absence of the CDM project.

Although the Kyoto Protocol came into effect in February 2005, the CDM is still a nascent instrument that suffers from a number of weaknesses: (1) its initial operations were guaranteed until only 2012, which is too short a time given the long lead times required for project preparation and the long-term nature of capital stock turnover; (2) when established, few of the rules and methodologies for effective regulation of the system were in place, delaying early action; and (3) the oversight and functioning of the regulatory system were conducted largely by individuals inexperienced with market-based regulatory systems.

These issues are gradually being resolved, and the CDM is becoming an increasing force for meeting the compliance of industrial countries in a lower-cost manner. Current estimates suggest that US$10 billion to US$30 billion in emissions reduction payments will be made to the host developing countries by 2012. The bulk of these payments will be made for projects that reduce industrial GHGs and landfill methane. Other projects include energy efficiency, biomass energy, wind energy, and some small- or medium-scale hydropower.

Agricultural land-use change—the improved management of croplands and grazing land—is not eligible for the CDM. The mechanism does include afforestation and reforestation, but given the long gestation of these forestry activities and the short time frame of the protocol, these activities have not attracted much flow of CDM money. Improved forest management and forest preservation are not included. Thus no incentives were created to preserve forests rich in biodiversity and important for watersheds and erosion control, despite the fact that deforestation contributes to about a third of global GHG emissions. What remains for agriculture in developing countries is primarily the production of biomass to offset the use of fossil fuels. Even in this area, benefits are limited by the complex methodology and requirements to be met for a biomass energy project to gain credits under the CDM.

THE POST-2012 NEGOTIATIONS AND AGRICULTURE IN DEVELOPING COUNTRIES

It is unlikely that the poor of developing countries will benefit much from the current CDM and the Kyoto Protocol, and time has largely run out for making changes that could bear fruit by 2012, when the Kyoto Protocol expires. Reform of the CDM will be left to negotiations for the post-2012 period, when a new regime will, it is hoped, come into play.

Negotiations on post-Kyoto regulations will have to tackle many issues, including expanding the role of industrial countries and attracting other important signatories, like Australia and the United States. But no future climate agreement can be effective without the compliance of developing countries. Not only will developing countries need to reduce emissions from their own rapidly growing fossil-fuel industries, but they can also offer a more cost-effective means of achieving global goals. This next regime of climate change rules must be targeted toward reducing GHGs as cheaply and quickly as possible. Developing countries and their farmers are key to meeting this objective.

First, land-use changes and practices in developing countries must be included in mechanisms for reducing carbon emissions. The new regime must make carbon sinks, or the sequestering of carbon, a major focus. Carbon sinks based on land-use practices could offset a large share of carbon emissions from Europe and Japan at a lower cost than CO_2 emission mitigation in industrial countries.

Second, reforestation and afforestation must remain eligible categories, but forest preservation must also be part of the new regime. Forests are key not only to avoiding new emissions, but also to reducing the severity of climate change.

Third, methodologies for assessing bioenergy need to be simplified so that more projects can quickly be included. Biomass technologies should become eligible automatically without proof of additionality.

Fourth, small household- and community-level activities that reduce GHGs should be given more emphasis through more flexible interpretation of rules on bundling and displacement of unsustainable use of biomass.

Fifth, sectorwide and programmatic projects should receive eligibility under simplified procedures so that large volumes of emissions reductions and GHG sequestering can take place. A project-by-project approach is too costly in many situations and clogs the regulatory system.

These five reforms would go a long way toward making a future mechanism for carbon emissions trading more effective and more pro-development. They would allow farmers in developing countries to benefit substantially from the post-2012 system and would permit small communities and the poor to participate through simpler mechanisms. Finally, they would permit the world to achieve reduced GHGs in the atmosphere at a lower cost and with more benefits to sustainable development and an increasing reliance on sustainable bioenergy sources. ■

For further reading visit the website of the United Nations Framework Convention on Climate Change (UNFCCC) at http://unfccc.int, and the World Bank's Carbon Finance Unit website at http://carbonfinance.org/.

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

Science and Technology Options for Harnessing Bioenergy's Potential

JEREMY WOODS

2020 VISION FOR FOOD, AGRICULTURE, AND THE ENVIRONMENT

FOCUS 14 • BRIEF 6 OF 12 • DECEMBER 2006

Much of the technology development for bioenergy to date has been geared toward competing with cheap fossil fuels. Bioenergy technologies have focused on reducing the cost per unit of energy produced, often exclusively by exploiting very cheap feedstocks and processing them on a large scale. But as the era of cheap fossil fuels comes to an end and as societies become more willing to pay for sustainable energy sources that reduce greenhouse gas emissions, there will be new opportunities for developing and using bioenergy technologies that can contribute to a wider range of economic, social, and environmental objectives. This brief discusses current and future technologies and options appropriate to developing countries.

AVAILABLE AND EMERGING TECHNOLOGY OPTIONS

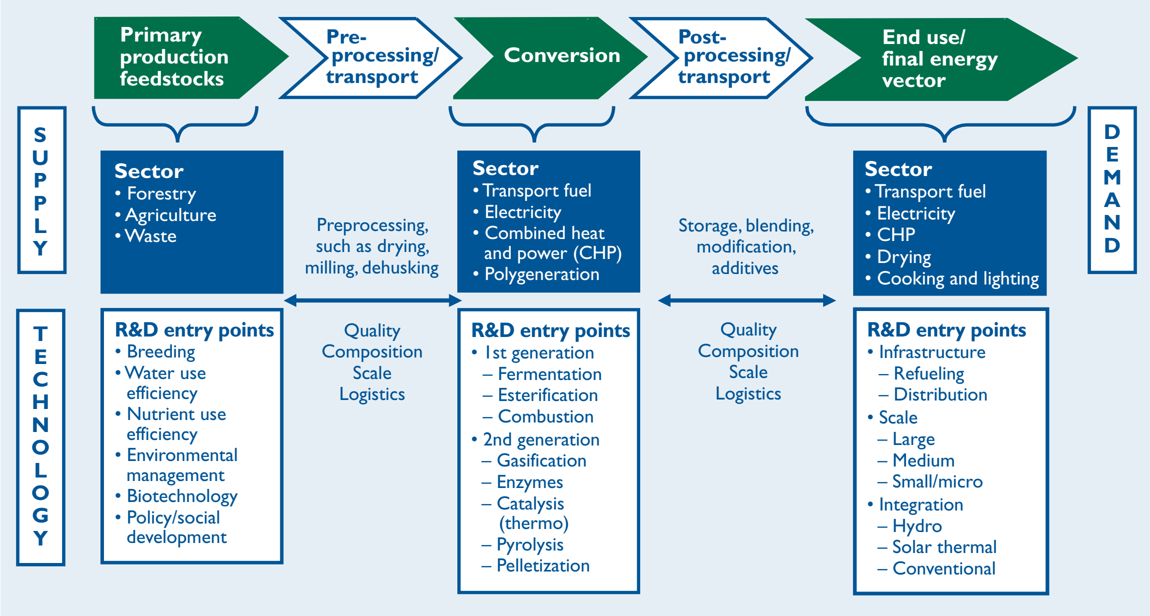
A large array of technologies and systems is currently available to provide biomass-based energy services, but many of them are still under development or in early-market stages of implementation (Figure 1). Existing bioenergy provision systems are often subsidiary to other more primary activities of large agribusinesses, such as production of crystalline sugar or bread. As such, the feedstocks and their characteristics, as well as the pre-processing methods used, are all selected with the primary products in mind. In addition, the bioenergy products of the conversion systems may well depend on the limitations and capabilities of the end-use technologies that are in place or likely to be in place—ranging from, for example, simple combustion for heat to hydrogen for fuel cells. For these reasons, the most efficient forms of bioenergy production that are possible are not always chosen.

In fact, much of the history of modern bioenergy development has been described as a "chicken-and-egg" conundrum in that the supply sector cannot be established before a demand for their products is in place, and the demand cannot be established before the supply infrastructure is in place. Liquid biofuels, for example, may be blended with gasoline or diesel in ratios compatible with the capabilities of the existing stock of automobile engines and supply infrastructures (up to 10 percent for ethanol). New biofuel types or high blends require changes in engine design (such as flexible-fuel engines for ethanol) and fuel distribution systems, entailing substantial up-front investment by industry and consumers. Brazil and parts of the United States have already moved in this direction, but changes in other countries are not likely to happen until biofuels are more abundant and more price competitive with oil.

First-generation technologies for ethanol rely on the fermentation of sugars. Processors can ferment high-sugar feedstocks like sugarcane or sugar beet directly, but for starchy feedstocks like maize and wheat, they must first convert the starch to sugar using enzymes. Biodiesel is made from plant oils by a process of esterification. The main feedstocks are soybeans, rapeseed, and palm oil. Biomass is also burned in power stations, sugar mills, and the like to generate electricity and in homes as a source of space-heating and for cooking. The main feedstocks for combustion are woody materials, animal manure, and plant waste. Some feedstocks provide multiple sources of bioenergy. Sugarcane, for example, provides sugar for direct fermentation to ethanol, while the residual bagasse can be burnt by the sugar mill to generate electricity to power the mill and to sell to the national grid.

First-generation technologies have been improved and refined over the years, leading to greater efficiencies and—as with improved cooking stoves for household use—to reduced air pollution and health problems. Despite this progress, the production of biofuels is often not competitive with oil unless subsidized or benefiting from tax credits that balance those already provided to the alternatives. Brazil is the least-cost producer of ethanol and can compete with oil at oil prices of about US$30–35 a barrel, but ethanol produced in the United States and European Union (EU) can compete with oil only at prices of about US$55 and US$80 a barrel, respectively. Improvements in the productivity and chemical content of feedstock have been important, and there is still potential for further gains (see Figure 1 and Brief 7 on agricultural research and development). But there may be inherent limitations to the attainable yields of sugars, starch, and oils, as well as to the efficiency with which these crops can be converted to energy sources.

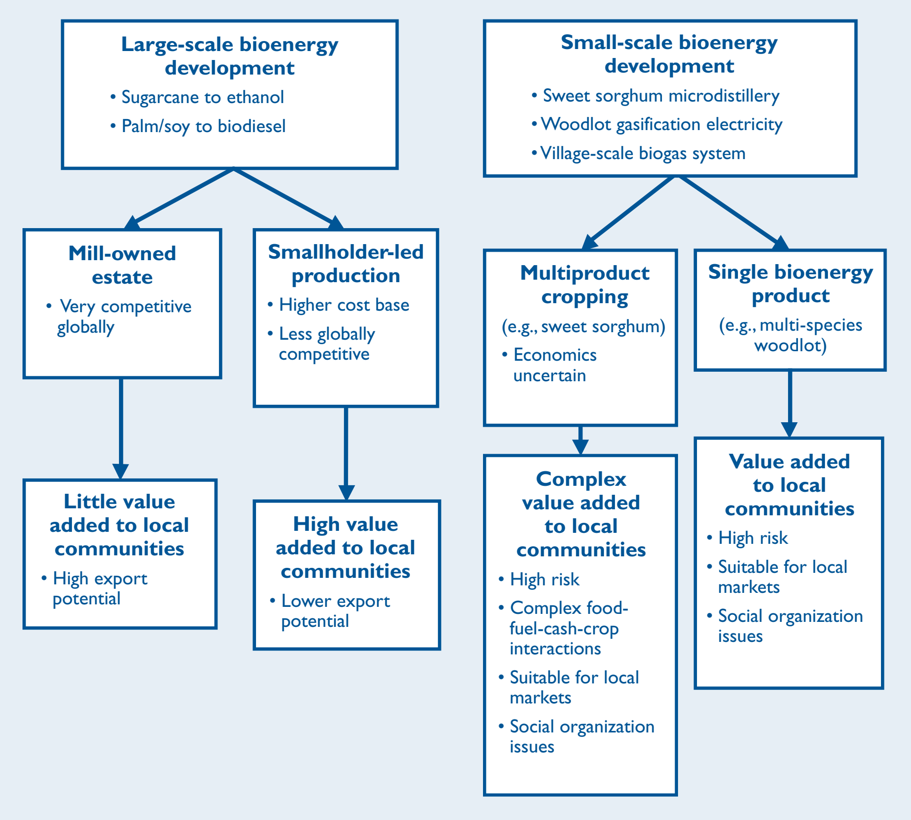
Figure 1—Bioenergy Supply Routes and Technology Options



Second-generation technologies will open up exciting new possibilities, but in most cases are probably 10–15 years away from being commercially viable. The biggest breakthrough for biofuels will come from further developments in the cost-effective conversion of cellulose-rich biomass to usable energy forms. There are two major pathways for converting cellulose-rich biomass. Thermo-chemical processes (gasification and pyrolysis) involve the thermal decomposition of biomass at high temperatures to generate gaseous (syngas) or liquid (bio-oil) fuels that can be used to fuel power plants, for cooking, or as transport fuels. Biochemical conversion relies on enzymatic and fermentation processes to convert cellulose to sugars.

Cellulose conversion technologies will open up enormous potential for broadening the kinds of feedstocks that can be used for bioenergy to include trees and grasses that produce large amounts of usable biomass per hectare and that can be grown in areas where bioenergy is less likely to compete with agricultural production for food and feed supplies. These technologies will enable greater use of existing agricultural waste and crop by-products and will also encourage growth of dedicated feedstock plantations, including fast-growing trees like willow and eucalyptus, tall grasses like switchgrass and *Miscanthus*, and plants rich in non-edible oils like *Jatropha* and *Pongamia* that grow in low-rainfall areas and on poor soils. These new technologies will allow plants and trees to be bred and managed to increase their total energy content with much less regard to its biochemical form.

Figure 2—Small- and Large-Scale Bioenergy Development Options



CONSIDERATIONS FOR DEVELOPING COUNTRIES

Many developing countries may be able to leapfrog first-generation bioenergy technologies, particularly in developing their electricity and transport systems. They may also want to choose scales and technologies for biomass production and processing that can promote pro-poor and employment-intensive patterns of growth (Figure 2).

Given the bulky nature of biomass crops, processing them for transport fuels and electricity generation presents significant economies of scale. This does not mean, however, that small-scale farmers cannot be involved in growing the feedstock. In many developing countries, large-scale and mechanized farms will not be appropriate, and small-farm involvement would help retain value added in rural areas. Small-farm production of cellulose-rich or non-edible oil crops that can be grown in less fertile and low-rainfall areas would also help some of the poorest people improve their livelihoods. Small farmers may need to be organized into producer groups for marketing their feedstock to large-scale processors.

There is also considerable scope for exploiting small-scale options for growing and processing biomass to meet local energy needs in rural areas. Already community biogas projects and the combustion of waste products for small-scale local electricity production abound, and some second-generation technologies (like gasification) will enhance such opportunities. Some of these options require no changes to existing delivery infrastructure and therefore can build on sunk investments—that is, investments that have already been made and cannot be reversed. ■

For further reading see F. Rosillo-Calle et al., eds., *Biomass Assessment Handbook: Bioenergy for Sustainable Development* (London: Earthscan, 2006); J. Woods and D. O. Hall, *Bioenergy for Development: Technical and Environmental Dimensions*, Environment and Energy Series No. 13, ed. G. Best (Rome: Food and Agriculture Organization of the United Nations [FAO], 1994); J. Woods, F. Rosillo-Calle, and S. L. Hemstock, *A Master Development Plan for the Biomass Resources of 6 South Pacific Island Nations*, Biomass Resource Assessment Project, ed. A. Matakiviti and P. Fairburn (Suva, Fiji: SOPAC [South Pacific Geoscience Commission], 2003), http://www.sopac.org; and R. E. Sims, *The Brilliance of Bioenergy: In Business and in Practice* (London: James and James, 2002).

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

2020 VISION
FOR FOOD, AGRICULTURE, AND THE ENVIRONMENT

Bioenergy and Agricultural Research for Development

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Focus 14 • Brief 7 of 12 • December 2006

Converting agriculture to produce energy as well as food has become an important and well-funded global research goal as petroleum reserves fall and fuel prices rise. But the use of crop biomass—both grain and other plant parts—as a raw material for bioenergy production may compete with food and feed supplies and remove valuable plant residues that help sustain soil productivity and structure and avoid erosion. Agricultural research can mitigate these trade-offs by enhancing the biomass traits of dual-purpose food crops, developing new biomass crops for marginal lands where there is less competition with food crops, and developing sustainable livestock management systems that are less dependent on biomass residuals for feeds. Agronomists will need to define the minimum thresholds of crop residues for sustainable production in particular farming systems, especially in low-yield rainfed systems (that produce less than 5–6 metric tons of grain and straw per hectare), and to establish the level of additional residues that may be removed for other purposes, including biofuel production. Enhanced root growth offers another avenue for maintaining soil organic matter. Agricultural research can also help improve the energy efficiency of biomass crops, enhancing their value as renewable energy sources with low net carbon emissions.

CROP-BREEDING OPTIONS TO ADDRESS BIOFUEL NEEDS

Agricultural biofuels are currently based on the generation of ethanol from sucrose or starch derived from vegetative biomass or grain, on biodiesel from the more direct use of vegetable oils and animal fats. Ethanol has a high octane rating and can be blended in low proportions with gasoline for direct use in normal internal combustion engines.

Further down the line, there is enormous potential to develop cellulose-based bioenergy systems. Plant biomass is an abundant and renewable source of hydrocarbons, and crops can generate more cellulose per hectare than sucrose or starch. Plant breeders should aim for high-density biomass production (for example, 15 tons per hectare in maize) rather than competing with crop residues or forest production for supplying materials to cellulosic biorefineries. Preliminary research shows significant genetic variation among maize and sorghum (brown midrib mutants) cultivars for cellulose and lignin content, suggesting that breeders can select for the increased quality of maize and sorghum stover for ethanol conversion. Breeders can also develop cultivars whose biomass lends itself readily to breakdown by fungi, improving ethanol production efficiency.

Breeders can increase cellulose or hemicellulose production by making photosynthesis or nitrogen metabolism more efficient, but they must also select for enhanced water- and nutrient-use efficiency under resource-conserving systems that provide an overall energy savings and cut emissions of carbon dioxide and pollutants. Growing biofuel crops on lands not suitable for food production—for example, those affected by drought, salt, or temperature stresses—would substantially reduce fuel–food competition.

One set of crops with great potential for ethanol production is sweet sorghum, which is similar to grain sorghum but features more rapid growth, higher biomass production, and wider adaptation. The dual-purpose nature of sweet sorghums—they produce both grain and sugar-rich stalks—offers new market opportunities for smallholder farmers and does not threaten food trade for sorghum. Because sweet sorghum requires less water and has a higher fermentable sugar content than sugarcane, which contains more crystallizable sugars, it is better suited for ethanol production than sugarcane or other sources, and sweet sorghum ethanol is cleaner than sugarcane ethanol, when mixed with gasoline.

THE ROLE OF BIOTECHNOLOGY

Reducing lignin in crop biomass will greatly improve biorefinery efficiencies. Genomics, proteomics, and metabolomics are being used to improve our understanding of and ability to manipulate the lignin biosynthesis pathway. For example, before processing, maize stover is currently pretreated to convert lignocellulose to sugars but transgenic technologies may provide *in planta* alternatives to pretreatment.

DNA markers are chromosomal "flags" that facilitate the discovery, understanding, and manipulation of genes. They may be used to accelerate breeding for reduced lignin biosynthesis and increased cellulose content, or enhanced bacterial digestion of plant cell walls. Care must be taken, however, because changes in lignin properties may reduce pest and disease resistance or alter stover nutritional value. Marker-assisted selection has already been used to improve the equally complex characteristic of oil concentration in maize kernels.

ALTERNATIVE CROP SPECIES WITH POTENTIAL FOR BIOFUEL PRODUCTION

Oil crops in South Asia. Many developing countries cannot afford to use edible oils as an energy source because they are already in short supply. Thus, non-edible oils from underresearched plants such as *Jatropha, Pongamia, Neem, Kusum*, and *Pilu* are being advocated. *Jatropha curcas* (ratanjot) and *Pongamia pinnata* (karanja) could be used to supplement traditional, highly polluting fuels and provide employment to landless and marginal people. Both *Pongamia* and *Jatropha* grow in low-rainfall areas and on problematic soils and wastelands in South Asia. They are easy to establish, are fast growing and hardy, and are not browsed by cattle and goats. *Pongamia* and *Jatropha* seeds contain 25 to 40 percent oil of a type that requires little or no engine modification, when blended after esterification with diesel in proportions as high as 20 percent. Additionally, the oilcake left after extraction of oil is rich in macro- and micronutrients, serving as an excellent organic fertilizer. More research is needed on developing these crops for biofuels.

North American wild grass. Switchgrass (*Panicum virgatum*), a perennial grass native to the North American prairies, could provide more than 100 billion gallons of biofuels per year, while allowing food, animal feed, and export demands for other crops to be met. Switchgrass can grow on lands incapable of supporting traditional food crops, with 1/8 the nitrogen runoff and 1/100 the soil erosion of conventional crops. Its deep root system adds organic matter to the soil, rather than depleting it. Breeding programs are aiming at least to double switchgrass yields (currently about 10 tons per hectare) and raise ethanol output from switchgrass to about 100 gallons per ton in the medium term.

Grasses in Europe. The *Miscanthus* genus (including giant Chinese grass, silver grass, silver banner grass, maiden grass, and eulalia grass) is receiving attention as a potential source of biomass for biofuels. Giant *Miscanthus* (*Miscanthus* x *giganteus*) is a hybrid grass that can grow four meters high. Given its rapid growth, low mineral content, and high biomass yield, some European farmers use *Miscanthus* to produce energy. The biomass from one hectare of *Miscanthus* can produce about 3,700 gallons of ethanol. Alternatively, after harvest *Miscanthus* can be burned to produce heat and power turbines or can be mixed with coal in equal amounts for use in coal-burning power plants without modifications. More research is needed in this area.

BIOFUELS AND CONSERVATION AGRICULTURE

Among other cellulose sources considered for ethanol production are the crop residues or straw from grain crops like maize and wheat. These residues are important for many farmers—particularly in rainfed areas—for use as animal fodder, cooking fuel, construction material, and soil amendments. In intensive agricultural systems, the residues can encumber field operations and are often burned, releasing large, sudden flushes of CO_2 into the atmosphere.

The removal of crop residues contributes to soil erosion and, through loss of soil organic matter, long-term degradation. These effects are exacerbated by continuous and extensive tillage, in itself energy consuming and polluting, leading to a gradual loss of crop productivity, even when irrigation and fertilization are increased. The solution is to combine appropriate conservation agriculture practices such as reduced or zero tillage with the retention of adequate levels of crop residues on the soil surface and diversified crop rotations.

Moreover, one of the most serious problems facing many farmers is their rapidly increasing fuel costs related to their high tillage production systems. Converting to reduced- or zero-tillage planting systems can dramatically reduce fuel costs for all crops. The use of sound conservation agriculture practices that emphasize zero tillage with rational residue management, thereby reducing overall fuel requirements, would be a win-win situation both for food and biofuel crop production. Research could help develop rational residue management approaches that could have the added benefit of reducing farmers' use of fuel.

INSTITUTIONAL ARRANGEMENTS FOR BIOFUEL RESEARCH

Biofuel production poses a major new challenge for crop improvement and the sustainable management of cropping systems. For farmers to respond to market changes, they need multipurpose crops combining food, feed, fiber, and biofuel traits. Basic research on crop biofuels may best be undertaken by upstream academic organizations and the private sector. On the other hand, trait-based mining of genetic resources may be the most appropriate niche for public genebanks, particularly those of research centers supported by the Consultative Group on International Agriculture (CGIAR). Clearly there are substantial financial incentives for private investment in developing new cultivars for biofuel production. Private investment, however, also threatens to result in the locking up of a large proportion of enabling technologies under various intellectual property protection mechanisms, as is already happening with, for example, critical enzymes in the biofuel production process.

The breeding of new cultivars for the biofuel market may open the opportunity for a whole new paradigm in public-private partnerships. Public research may focus on tapping potential plant genetic resources and initial trait genetic enhancement that will feed into either public or private breeding programs worldwide. International public organizations, such as the CGIAR, may serve as conduits of new knowledge and technology to small-scale farmers, particularly in resource-poor farming areas of the developing world. Clearly one of the most important roles of the CGIAR in this area will be to find mechanisms to ensure that smallholder farmers (particularly those in resource-poor areas) can benefit from this potentially lucrative new market without significant increasing their vulnerability. ■

For further reading see J. Hill et al., "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels," *Proceedings National Academy of Sciences*, USA (2006) 103: 11206–11210; A. J. Ragauskas et al., "The Path Forward for Biofuels and Biomaterials," *Science* (2006) 311: 484–489; C. C. Laurie et al., "The Genetic Architecture of Response to Long-Term Artificial Selection for Oil Concentration in the Maize Kernel," *Genetics* (2004) 168: 2141–2155; B. V. S. Reddy et al., "Sweet Sorghum: A Potential Alternate Raw Material for Bio-ethanol and Bio-energy," *International Sorghum and Millets Newsletter* (2005) 46: 79–86; C. Schubert, "Can Biofuels Finally Take Center Stage?" *Nature Biotechnology* (2006) 24: 777–784; M. Sticklen, "Plant Genetic Engineering to Improve Biomass Characteristics for Biofuels," *Current Opinion in Biotechnology* (2006) 17: 315–319; S. Wani et al. "Improved Livelihoods and Environmental Protection through Biodiesel Plantations in Asia," *Asian Biotechnology and Development Review* (2006) 8: 11–34.

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

Brazil's Experience with Bioenergy

José Roberto Moreira

2020 VISION FOR FOOD, AGRICULTURE, AND THE ENVIRONMENT

FOCUS 14 • BRIEF 8 OF 12 • DECEMBER 2006

Brazil is the world's largest producer of ethanol, a biofuel used mainly in automobiles as an additive or alternative to gasoline. In the mid-1970s the country undertook a major program to produce ethanol, and since then the industry has had both successes and failures. Although Brazil's program was criticized as being uneconomic during periods of low oil prices, the ethanol industry today is recognized as an efficient sector that brings substantial benefits to the Brazilian economy.

All Brazilian ethanol is produced from sugarcane through the fermentation of sugars contained in sugarcane juice. In the 2005/06 growing season, Brazil harvested about 400 million metric tons of sugarcane on 5.5 million hectares (all tons in this brief are metric tons). Three hundred and thirty privately owned sugar mills each process an average of 1.2 million tons per year. The by-products, bagasse (residues from the sugar manufacturing process) and barbojo (tops and leaves remaining from harvesting), are generally burned. Bagasse in particular is traditionally burned in boilers and used as a source of heat and electricity for sugar/ethanol processing, as well as in other agroindustries, whereas barbojo is burned in the field, yielding no energy value.

PERCEIVED BENEFITS AND REASONS FOR GOVERNMENT SUPPORT

The government's reasons for supporting biofuels, at first purely economic, have expanded to include concerns about the energy security of the country, greenhouse gas emissions and global climate change, rural employment and equity issues, and local air pollution.

Oil import dependence and energy security. The oil shocks of 1973 and 1979 caused oil prices to soar to US$40 a barrel, pushing Brazil's annual expenditures for oil imports to more than US$10 billion and causing a global recession. To pay these high import bills and develop domestic energy alternatives, Brazil borrowed heavily from abroad. In the early 1980s, however, a substantial increase in interest rates worldwide forced Brazil, along with other Latin American countries, to implement strict economic adjustments that led to negative economic growth and rapid inflation.

Ethanol production has thus played an important role in guaranteeing fuel security, with the advantage of not requiring hard currency disposal. Since 1975 ethanol has displaced more than 280 billion liters (1.7 billion barrels) of gasoline and saved more than US$65 billion in the cost of oil imports. When the cost of servicing the debt that such imports would have required is included, the cost savings rise to more than US$100 billion.

Employment. The sugar/ethanol sector has become a major employer: in 2001 it was estimated that ethanol production accounted for roughly 1 million jobs in Brazil, of which about 65 percent were permanent and the remainder seasonal (for harvesting). The indirect creation of employment in manufacturing and other sectors was estimated at about another 300,000 jobs.

Sugarcane plantations create jobs in rural areas, most of them for unskilled workers. Moreover, around 30 percent of sugarcane production is in the hands of 60,000 independent producers, representing a major activity for small farmers.

Local air quality. The introduction of gasohol, a combination of gasoline and ethanol, had an immediate impact on the air quality of Brazil's large cities, particularly São Paulo. Evaluations of ethanol's impact on air quality found that E-10 (gasohol made up of 10 percent ethanol) reduces carbon monoxide, a precursor for ozone formation, by more than 25 percent. When used as an additive, ethanol also displaces highly toxic and volatile components of gasoline (such as lead, benzene, toluene, and xylene).

REASONS FOR THE SUCCESS OF BIOFUELS IN BRAZIL

Synergies with the sugar market. The coupled production of ethanol and sugar, which occurs in almost all sugar mills, is a significant driver of Brazil's successful ethanol program. International sugar prices have been both highly volatile and on a general downward trend. If sugar prices fall, mills may find it more profitable to shift to ethanol production. Experience has shown, however, that it is important to protect the domestic market for ethanol—that is, in order to prevent domestic ethanol shortages, sugarcane producers often have to produce ethanol even when they could make greater profits by selling sugar.

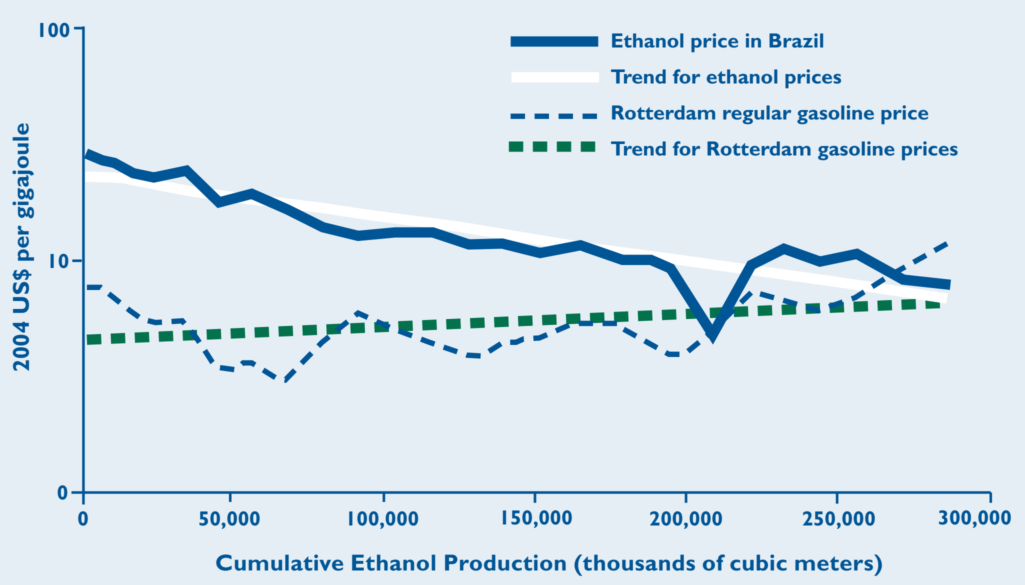
Significant improvements in the productivity of the sugar industry have benefited ethanol production. Between 1975 and 2000, sugarcane yields in the São Paulo region rose by 33 percent, ethanol production per unit of sucrose rose by 14 percent, and the productivity of the fermentation process rose by 130 percent. Thanks to these productivity improvements, the cost of producing ethanol declined by an annual average of 3.8 percent from 1980 to 1985 and 5.7 percent from 1985 to 2005 (see figure next page).

Synergies with electricity and heat production. Another important contributor to the success of biofuels lies in the energy content of sugarcane residues. At present, cogeneration of heat and electricity from bagasse supplies most of the energy needs of the biofuel production process itself, as well as allowing an increasing amount of electricity to be exported to the grid. From 1997 to 2004, the amount of electricity from biomass sold to the grid increased from 80 to 1550 gigawatt-hours (GWh). This surplus electricity came mainly from retrofitting existing energy supply facilities in some 30 sugar mills.

Institutional support. Replacing gasoline with another fuel faces a "chicken-and-egg" problem in the supply chain. Consumers are afraid to buy cars that use a new fuel that may be difficult to find. Service station owners are not interested in investing in a parallel fuel distribution system since the number of potential users is usually very small. Therefore the Brazilian government, at both the federal and state level, had an essential role to play in providing incentives and setting up a clear institutional framework. This role included setting technical standards, supporting the technologies involved in ethanol production and use, providing financial advantages, and ensuring appropriate market conditions.

Geographical aspects. Brazil has abundant agricultural land and an appropriate climate for sugarcane. Its sugarcane industry was already developed, and the dominant state in this industry—São Paulo—

Brazil's Ethanol Prices at Sugar Mill Gate Compared with International Gasoline Prices, 1980–2005



Source: J. Goldemberg et al., "Ethanol Learning Curve: The Brazilian Experience," *Biomass and Bioenergy* 26 (2004): 301–304.

accounted for more than half of the country's car fleet. In other areas of the country, the government subsidized the transport costs of ethanol to ensure wide geographical coverage.

THE OUTLOOK FOR BIOFUELS IN BRAZIL

Ethanol supply and demand have not always been properly balanced in Brazil. In 1989 ethanol supply was not able to fulfill demand because of poor management of supply and demand, and as a result, sales of cars powered by neat ethanol fell from more than 90 percent of new cars in the late 1980s to almost 1 percent in 1996. Thus there was no significant increase in ethanol production during the 1990s and early 2000s. Since flex-fuel cars—capable of running on gasoline, ethanol, or any combination of the two fuels—were launched in early 2003, internal ethanol consumption has increased significantly. At the beginning of 2006, 75 percent of new cars manufactured in Brazil were flex-fuel models. Exportation of ethanol has also increased since 2001, and in 2004 exports reached 2.5 billion liters. In 2005 exports fell to just less than 2 billion liters, owing to intense internal demand for the product.

Recent expansion of internal and external markets has triggered the interest of investors, and many new sugar mills are being built. Sugarcane cultivation is being extended to new areas, and it is expected that 570 million tons of sugarcane will be harvested by 2010, compared with 400 million tons in 2005. About 90 new sugar mills will become operational between 2006 and 2010, most of them designed to handle an average of 3 million tons of sugarcane per year when in full operation. Old refineries are also being retrofitted to become more productive.

Sugar mills are also diversifying their energy outputs. Since 1997, when legislation allowed independent power producers to sell electricity to the grid, the supply of electricity to the grid from sugar mills has grown strongly. Around 600 MW of installed power from sugar mills were delivered to the grid in 2005. Sugar mills are starting to economically compete with conventional sources of electricity to meet the needs of the national power grid, and this activity is expected to increase. In addition, sugar mills are installing biodiesel plants that offer a number of synergies with sugar/ethanol production.

Sugar/ethanol production does raise concerns about land use. Sugarcane production for ethanol competes with production of food and other export crops. Yet the 5.5 million hectares cultivated with sugarcane represent only 8.6 percent of the total area harvested with essential crops. In addition, farmers are increasingly rotating between sugarcane and food crops like tomatoes, soy, peanuts, beans, rice, and maize. This approach has helped maintain the balance between energy and food and has improved land profitability. The expansion of sugarcane plantations could, however, indirectly lead to increased deforestation, as cattle ranching displaced from pastureland by sugarcane production could encroach on forest areas. Until now, most of the cattle ranching activities in the region have continued on a more confined, less land-intensive scale.

POLICY LESSONS

For countries that wish to improve their energy security while promoting rural development, Brazil's experience offers some relevant policy lessons. Among the policies most important to Brazil's success were the following:

- requiring the auto industry to produce cars using neat or blended biofuels;
- subsidizing biofuels during market development until economy of scale allowed fair competition with oil products;
- allowing renewable energy-based independent power producers to compete with traditional utilities in the large electricity market;
- supporting private ownership of sugar mills, which helps guarantee efficient operations; and
- stimulating rural activities based on biomass energy to increase employment in rural areas. ■

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

Bioenergy in Europe: Experiences and Prospects

OLIVER HENNIGES AND JÜRGEN ZEDDIES

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FOCUS 14 • BRIEF 9 OF 12 • DECEMBER 2006

Although Europe is a relatively small producer of ethanol (2.6 percent of world production in 2005), it produces a sizable share of the world's biodiesel (88 percent of world production in 2005). Production started in the early 1990s (well after Brazil and the United States; see Figure 1), when revisions to the Common Agricultural Policy (CAP) first allowed farmers to grow nonfood crops for income on set-aside land. Germany began to produce biodiesel from rapeseed, while France undertook production of bioethanol from sugar beet and wheat. Today, Germany is the world's largest biodiesel producer, with a total existing capacity of more than 2 million metric tons per year, representing more than 5 percent of domestic diesel demand.

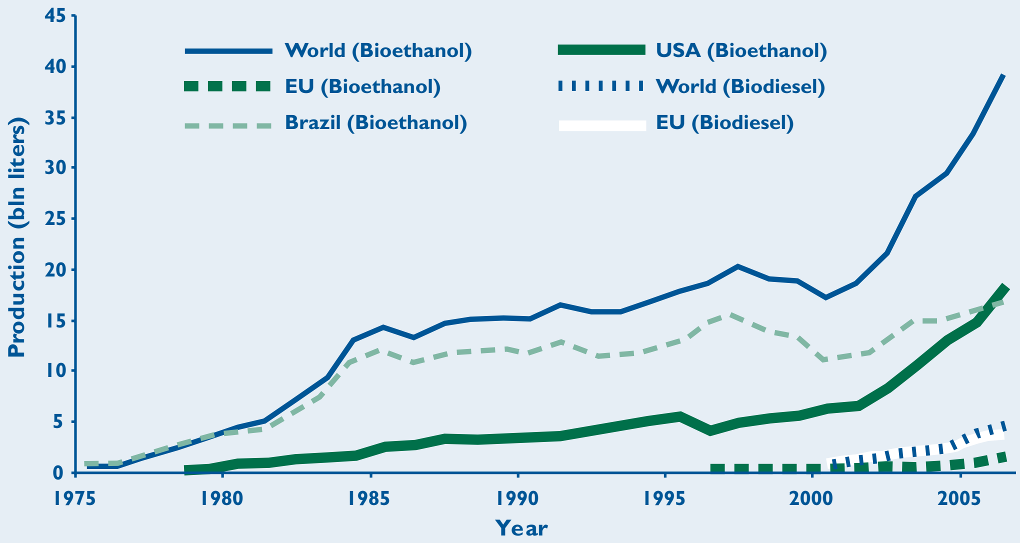
By 2010, the European Union (EU) plans to have doubled the share of renewable energy in its primary energy consumption to 12 percent. This goal includes increasing the share of biofuels from 2 percent of total transport fuel today to 5.75 percent by 2010, as well as making significant increases in the use of biomass in electricity generation. The biofuels target will require an annual production of about 5–6 billion liters of bioethanol and biodiesel. EU member states have already implemented relevant policies. For example, to achieve the biofuels target, 11 member states have implemented tax reductions as their main policy instrument, 9 are using incentives for research and development, 5 are using mandatory blending requirements, and 2 are using investment subsidies.

COSTS OF BIOFUELS

Since Europe is already a net importer of vegetable oils—the primary feedstock for biodiesel production—future growth in biofuel production will probably have to come through increased ethanol production. But Europe is a relatively high-cost producer of ethanol. Figure 2 shows a standardized comparison of the gross and net production costs of ethanol for a 200-million-liter plant. The gross costs include investment costs, variable costs like feedstock and processing, and a risk factor of 5 percent. The net cost is calculated by subtracting the value of co-products, like distillers dried grains with solubles (DDGS) and beet pulp, which are used as animal feeds, from the gross cost, except in the case of sugarcane trash.

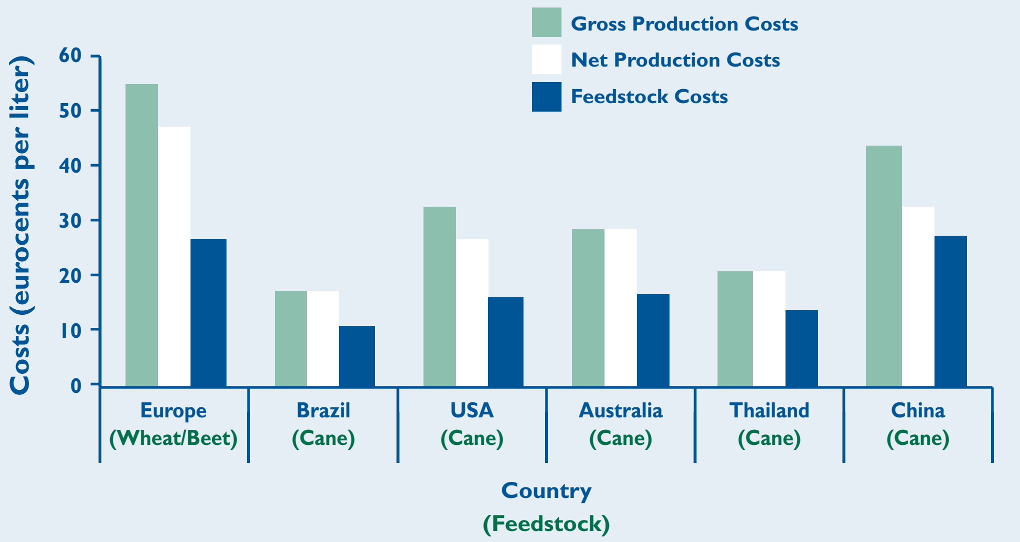
Brazil's low production costs for sugarcane-based ethanol are the result of that country's long-term experience in developing sugar-

Figure 1—Bioethanol Production in Brazil, the European Union, and the United States, 1975–2006



Source: *F. O. Licht's World Ethanol and Biofuels Report*, Vol. 4, No. 16, p. 365 and Vol. 4, No. 17, p. 391 (Tunbridge Wells, U.K.: F. O. Licht, 2006).

Figure 2—Ethanol Production Costs without Subsidies



Source: O. Henniges and J. Zeddies, "Economics of Bioethanol in the Asia-Pacific: Australia – Thailand – China," in *F. O. Licht's World Ethanol and Biofuels Report*, Vol. 3, No. 11 (Tunbridge Wells, U.K.: F. O. Licht, 2005).

growing and processing technologies and its relatively low taxation of the fossil fuels used in biofuel production.

According to the authors' own calculations for EU countries, domestically produced biofuels would not be viable without a subsidy of some kind unless oil prices were consistently higher than US$80 a barrel. Given that such prices are not imminent, the biofuel industry in Europe, as in the United States, is heavily dependent on continuing political support.

POLITICAL SUPPORT

The European Union has supported biofuel production primarily to promote sustainable farming, protect the countryside, create additional value added and employment in rural areas, reduce the cost of farm support policies, and diversify its energy supplies. Reducing emissions of greenhouse gases is only a secondary goal because the net energy efficiency of the biofuel crops grown in Europe is low. Thus the biofuel industry has much higher carbon abatement costs than do some other fields of energy use.

Increasing farm incomes has also not been a primary reason for supporting bioenergy in the European Union. In Germany, for example, political support contributed to a doubling of the land area devoted to renewable feedstocks—from 545,000 hectares in 1998 to 1.05 million in 2004—and the creation of about 120,000 jobs for processing renewable fuels. Yet the income effects on agriculture have been small. In fact, the gasoline tax exemption on biofuels has even been adjusted on occasion to ensure that farm-level incentives for growing bioenergy crops are not too generous.

Nevertheless, farmers have gained in other ways. For example:

1. The revised CAP allows farmers to grow energy crops on set-aside land, and farmers can earn an additional € 100–500 per hectare—depending on location—compared with retaining that land in fallow.
2. In areas with significant animal production, the cultivation of energy crops provides a cost-effective and environmentally acceptable way of disposing of manure by using it as a fertilizer.
3. Biofuel production has led to stronger prices for agricultural commodities used for feedstock (for example, the price of rapeseed increased from about € 180/t in 2000 to approximately € 220/t today).

Despite these benefits, farmers capture only a small share of the total added value from biofuel production. By far the largest share goes to biofuel producers and the gasoline industry.

The support for renewable raw materials, particularly those for liquid biofuels, has also affected trade flows for agricultural commodities. The growth in biodiesel production in Germany, for example, has increased Germany's rapeseed imports, primarily from France and the Czech Republic, but also from North America. On the other hand, diversion of some cereals to biofuel production has helped reduce EU cereal exports and the associated cost of export subsidies.

Some member states of the European Union are considering replacing their tax exemptions for biofuels with a system of mandatory fuel blending. Germany, for example, set an increasing biofuel quota of up to 8 percent in 2015. This system would require transport fuel companies to blend minimum ratios of biofuels with gasoline or diesel fuel. A quandary with this approach is that transport fuel companies would be free to buy biofuels from low-cost producers (like Brazil) in the world market, thereby undercutting the European Union's own biofuel production program and its perceived advantages. Moreover, European consumers would face higher fuel prices because of the removal of the tax exemption, despite the cost savings on imported biofuels.

CONCLUSIONS

Given Europe's high import demand for fuel and its commitments to reduce CO2 emissions under the Kyoto Protocol, political pressure to implement strategies for the use of renewable energy is ever increasing. Thus, Europe aspires to use substantially more biofuels than it currently produces.

Europe has considerable potential to expand its bioenergy program without jeopardizing its food production. This potential is highest in France, Germany, and Spain. Europe, however, is a relatively high-cost producer of biofuels compared with countries like Brazil. Although the existing programs have significant social and environmental benefits, these may be outweighed by their economic costs compared with alternative approaches for supporting rural areas and reducing greenhouse gas emissions. Finding the right balance between supporting a domestic biofuels program and adopting more economically efficient approaches is essential, but any solution will be constrained by the vested interests that have already been created in the domestic industry. Europe can reduce the costs of biofuel production by using set-aside land that has limited alternative uses and by making technological improvements that increase the economic and energy efficiency of biomass crops. ■

For further reading see *F. O. Licht's World Ethanol and Biofuels Report,* Vol. 4, No. 16, p. 365 and Vol. 4, No. 17, p. 391, (Tunbridge Wells, U.K.: F. O. Licht, 2006); German Federal Ministry of Food, Agriculture, and Consumer Protection, *Agrarpolitischer Bericht der Bundesregierung 2005* (Berlin: 2005), <http://www.bmelv.de/cln_045/nn_752130/SharedDocs/downloads/Agrarbericht/gesamte_20Fassung_202006,templateId=raw,property=publicationFile.pdf/gesamte%20Fassung%202006.pdf>; O. Henniges, "Conflict of Objectives in the Use of Biofuels," in *World Sugar Yearbook 2006*, 67th ed. (Tunbridge Wells, U.K.: F. O. Licht, 2005), pp. D24–D32; O. Henniges and J. Zeddies, "Economics of Bioethanol in the Asia-Pacific: Australia – Thailand – China," in *F. O. Licht's World Ethanol and Biofuels Report*, Vol. 3, No. 11 (Tunbridge Wells, U.K.: F. O. Licht, 2005), p. 214–221; D. Thrän et al., *Sustainable Strategies for Biomass Use in the European Context,* Report for the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (Berlin: 2005), http://www.ie-leipzig.de/Biomassenutzung/Biohandel_Final%20Report_EN.pdf; M. Schöpe and G. Britschkat, "Macroeconomic Evaluation of Rapeseed Cultivation for Biodiesel Production in Germany," Preliminary Report from IfO Schnelldienst (Munich: 2002), <http://www.cleanairnet.org/infopool/1411/articles-35678_macroeconomic_munich.pdf>.

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

Bioenergy in Developing Countries: Experiences and Prospects

DANIEL M. KAMMEN

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FOCUS 14 • BRIEF 10 OF 12 • DECEMBER 2006

Biomass energy programs offer a wide range of potential benefits for developing countries. Already traditional biomass products like firewood, charcoal, manure, and crop residues provide the main source of household energy use for some 2–3 billion people in the developing world, and this demand is likely to grow in the years ahead. But new technologies for commercial energy production from biomass are emerging that could lead to dramatic new opportunities for agriculture and the rural sector, as well as help developing countries reduce their dependence on expensive oil imports. Both the traditional and the new options for biomass energy pose challenges that will require technology and policy solutions to ensure efficient, healthy, and environmentally sustainable outcomes.

BIOMASS FOR HOUSEHOLD USE

Biomass fuels are vital to basic welfare and economic activity in developing countries, especially in many African countries, where they meet more than 90 percent of household energy needs. For these people, biomass is generally used in open hearths or simple stoves that are inefficient and polluting, with significant impacts on human health. Combustion of biofuels emits pollutants that currently cause more than 1.6 million deaths globally each year (400,000 in Sub-Saharan Africa alone), mostly among children and women. Thus biomass use is directly or indirectly related to multiple Millennium Development Goals (MDGs), including environmental sustainability, reduction of child mortality, and gender equity.

Traditional sources of biomass are also associated with degradation of forest and woodland resources and soil erosion. Charcoal is a good example. This fuel is in high demand in many rapidly growing urban areas, and to meet this demand, charcoal producers often plunder forest and woodland resources. In Kenya, for example, most charcoal is produced in earthen kilns that typically yield only one kilogram (kg) of charcoal for every six kg of wood harvested. To reach Nairobi, charcoal is frequently brought from 200–300 kilometers away. In one year, an urban household cooking exclusively with charcoal uses between 240 and 600 kg of charcoal, produced using between 1.5 and 3.5 tons of wood.

Despite the inefficiency of its production, charcoal remains an affordable fuel for Kenya's urban consumers in part because the national government owns the forests where charcoal production takes place, but does little to control access to them. Charcoal producers pay no stumpage fees, so urban customers pay only for labor, transportation, and handling of the charcoal, plus the middlemen's mark-ups. They do not pay for the feedstock itself. Instead, the costs of replacing the feedstock and coping with the damage caused by the loss of tree cover are borne by the rural population where the trees are harvested.

Prohibiting charcoal, the government concluded, would be extremely unpopular, likely to fail, and harmful to the poor. An alternative to excessively centralized control that could lead to more sustainable charcoal production is to support local community control of forest resources. This approach would channel charcoal revenues into local communities and promote sustainable land management practices rather than the resource mining that is currently taking place in Kenya and elsewhere. Or, if a central administration is deemed best in a given situation, license fees could be collected for charcoal production, ideally "green" tagged to reward sustainable practices, and then returned to local governance groups based on their vigilance and success in ensuring minimally destructive harvests.

During the past decade a series of studies in Kenya examined programs to design and disseminate improved household stoves, as well as efforts to develop and implement sustainable forestry and fuel (often charcoal) production practices in Africa. The studies found that combined attention to both stove and forestry programs can simultaneously lead to dramatic improvements in human health, ecological sustainability, and local economic development. Furthermore, the work in Kenya revealed something exceptional: shifting from burning wood and dung fuels on simple stoves to burning charcoal on improved stoves can reduce the frequency of acute respiratory infections (ARIs) by a full factor of *two*. This is a tremendous impact, for ARIs are the most common illnesses reported in medical exams in Sub-Saharan Africa. Further, comparatively simple materials and design modifications in household stoves are now known to both dramatically improve energy efficiency and reduce particulate and greenhouse gas emissions. As a result, after childhood immunizations, improved stoves may be the single most cost-effective public health intervention.

These benefits can be achieved at exceptionally low cost—a few dollars per life saved—with the added benefit that atmospheric carbon mitigation is possible, also at a few dollars per ton of carbon. In contrast, carbon now trades for roughly US$15–20 per metric ton on the London exchange, a price that reflects greenhouse gas impacts alone. The potential to address both local health and development needs *and* global environmental protection with such economic efficiency makes efforts to support the dissemination and use of improved cookstoves a natural component of any comprehensive development and assistance strategy in Africa or elsewhere.

COMMERCIAL USE OF BIOMASS

New technological innovations in bioenergy, along with dramatically rising international oil prices and extremely volatile natural gas costs, have opened the door to a revolution in commercial bioenergy production. Improvements have been made in ethanol, methanol, and biodiesel production and in the gasification of biofuels. In most countries these developments have important implications for agriculture and may offer new income-earning opportunities for farmers. In some cases, such as Brazil, they dramatically reduce the need for imported oil.

Residues are an especially important potential biomass energy source in densely populated regions, where much of the land is used for food production. In fact, biomass residues play important roles in such regions precisely because the regions produce so much food; crop production can generate large quantities of by-product residues. For example, in 1996 China generated crop residues in the field (mostly maize stover, rice straw, and wheat straw) plus agricultural processing residues (mostly rice husks, maize cobs, and bagasse) totaling about 790 million metric tons, with a corresponding energy content of about 11 exajoules (EJ). To put this in perspective, if half of this resource were to be used for generating electricity at an efficiency of 25 percent (achievable at small scales today), the resulting electricity generation would be about half of the total electricity generated from coal in China in 1996. Of course, most of China's residue consumption is in traditional combustion devices. Residues yield about 35 percent of the rural population's total household energy consumption and 20 percent of the national total.

There is also significant potential for providing biomass for energy by growing crops specifically for that purpose. In one scenario from the Intergovernmental Panel on Climate Change (IPCC), 385 million hectares globally are planted with biomass energy plantations in 2050 (equivalent to about one-quarter of the present planted agricultural area), with three-quarters of this area in developing countries. Using so much land for bioenergy raises the issue of intensified competition with other important land uses, especially food production. Competition between land use for agriculture and for energy production can be minimized, however, if degraded land and surplus agricultural land are targeted for energy crops. Though these lands are less productive, targeting them for bioenergy plantations can have secondary benefits, including restoration of degraded land and carbon sequestration. In developing countries in aggregate, about 2 billion hectares of land have been classified as degraded, though this land is certainly not entirely unoccupied. Although there are many technical, socioeconomic, political, and other challenges involved in growing energy crops on degraded lands, successful plantations have already been established on such lands in some developing countries.

Biomass-based industries are also a significant source of jobs in rural areas, where high unemployment often drives people to take jobs in towns and cities, dividing families and exacerbating problems of urban decay. Compared with other fossil-fuel and renewable energy production, biomass is relatively labor intensive, even in industrialized countries with highly mechanized industries. Traditional bioenergy provision also creates a significant source of employment. One study reported that 33 percent of randomly selected respondents in one charcoal-producing area claimed charcoal production as a source of income. It should not be assumed, however, that all rural areas in developing countries are characterized by surplus unskilled labor and that labor-intensive bioenergy projects will automatically have a pool of workers from which to select. Employment in rural areas is primarily agricultural and hence, highly seasonal. It also moves in longer cycles coinciding with good and bad harvests, which can have ripple effects extending into the formal economy.

CONCLUSIONS

Biomass energy programs offer a wide range of benefits, but achieving them requires significant public policy guidance. In the household fuel and health sector, tremendous gains in fuel reduction and health improvement are possible through the design and dissemination of improved stoves. At the same time, significant benefits to forest sustainability and biomass production are achievable by enforcing sustainable forest and agricultural waste management strategies.

The dramatic gains, however, exist where an effort is made to integrate both programs: a technically feasible but often politically challenging goal. To make integrated end-use and forest and field production programs the norm, integrated planning is needed across the forestry, public health, and transport sectors.

Commercial energy production from biofuels has also undergone a technological and economic revolution in the past decade. These changes open the door for both advanced, low-carbon electricity production and for dramatic reductions in gasoline use (such as the 40–50 percent decline achieved in Brazil). Developing countries may be particularly interested in this nexus because of biofuels' significant employment benefits compared with fossil-fuel energy systems. Expanded attention to ethanol, biodiesel, and biofuel gasification programs is warranted. Local and international support for research and development is recommended, along with careful attention to developing useful distribution systems for biofuels blended with gasoline. Some of the greatest gains are likely when traditional biomass practices are integrated into ethanol bioenergy schemes in ways that both support local farmers (by providing local solid biomass for cooking) and produce ethanol or biodiesel for local consumption and regional sale. ■

For further reading see M. Ezzati and D. M. Kammen, "Evaluating the Health Benefits of Transitions in Household Energy Technologies in Kenya," ***Energy Policy*** **(2001) 30: 815–826; M. Ezzati and D. M. Kammen, "Indoor Air Pollution from Biomass Combustion and Acute Respiratory Infections in Kenya: An Exposure-Response Study,"** ***The Lancet*** **(2001), 358: 619–24; R. Bailis, M. Ezzati, and D. M. Kammen, "Mortality and Greenhouse Gas Impacts of Biomass and Petroleum Energy Futures in Africa,"** ***Science*** **308 (2005): 98–103; E. Kituyi et al., "Biofuel Availability and Domestic Fuel Use Patterns in Kenya,"** ***Biomass and Bioenergy*** **20 (2001): 71-82; E. Kituyi et al., "Biofuel Consumption Rates and Patterns in Kenya,"** ***Biomass and Bioenergy*** **20 (2001): 83–99; and A. E. Farrell et al., "Ethanol Can Contribute to Energy and Environmental Goals,"** ***Science*** **311 (2006): 506–508.**

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

Bioenergy and the Poor

STEPHEN KAREKEZI AND WAENI KITHYOMA

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AND THE ENVIRONMENT

FOCUS 14 • BRIEF 11 OF 12 • DECEMBER 2006

Biomass is a primary source of energy for close to 2.4 billion people in developing countries. Easily available to many of the world's poor, biomass provides vital and affordable energy for cooking and space heating. Although widespread use of traditional and inefficient biomass energy in poor countries has been linked to indoor air pollution as well as to land degradation and attendant soil erosion, biomass-based industries are a significant source of jobs and income in poor rural areas with few other opportunities

The share of biomass energy in total energy consumption varies across developing countries, but generally the poorer the country, the greater its reliance on traditional biomass resources (see figure). Biomass has considerable potential to become more important in total energy consumption, and this growth could have significant impacts, both positive and negative, on agriculture and the poor. This brief delineates two broad categories for bioenergy development—the exploitation of existing agricultural wastes and the establishment of energy plantations—and suggests high-priority steps for developing bioenergy in ways that benefit the poor.

USE OF EXISTING AGRICULTURAL WASTES

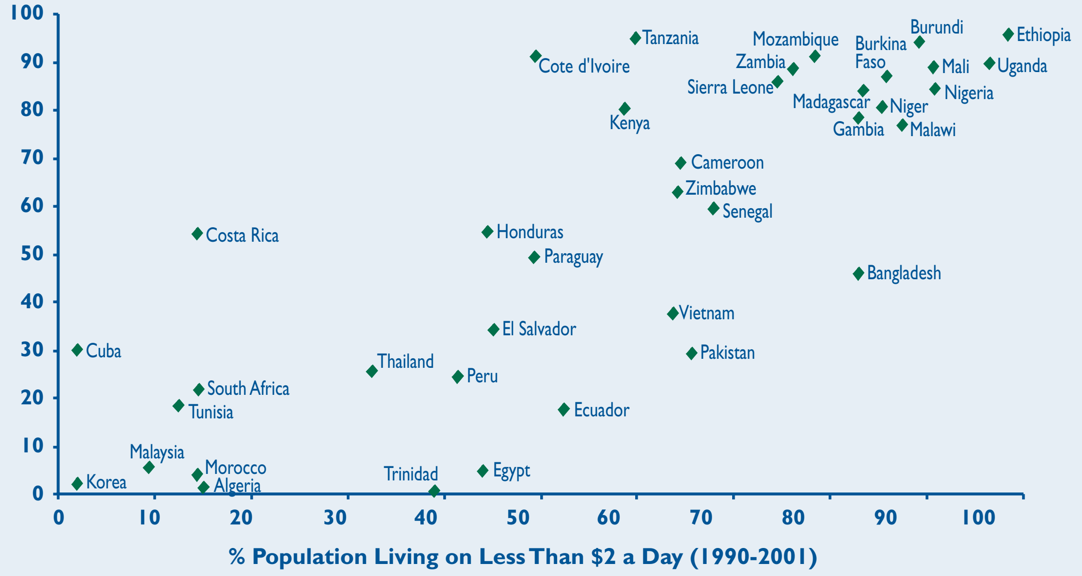
The efficient exploitation of existing agricultural wastes presents significant potential for developing bioenergy without unduly disrupting existing agricultural practices and food production or requiring new land to come into production. Some of the most common crop wastes suitable for bioenergy development include sugarcane bagasse, sisal waste, coffee husks, rice husks, maize cobs, and banana leaves. Unlike many other crop wastes, these waste products are generated during agroprocessing and are rarely returned to the field. Consequently, use of such agricultural wastes for energy generation is unlikely to have a detrimental impact on soil management and food production and could potentially be an additional source of revenue for the poor.

The use of existing agricultural wastes can be further subdivided into the following categories:

- **Centralized energy generation from centralized agricultural waste that is currently not utilized efficiently.** Some industries and sectors, such as sugar factories, use agricultural wastes produced by their processing activities to generate heat and electricity for their own use and for sale. Improving the efficiency of energy production from these wastes could deliver significant benefits to the industries and other stakeholders, including the poor, if the appropriate regulatory and revenue-sharing mechanisms are in place. For example, smallholder cane farmers in Mauritius share the revenues from large-scale bagasse-based cogeneration plants (which meet close to 40 percent of the country's electricity needs).

- **Centralized energy generation from decentralized agricultural waste production.** For effective use of decentralized wastes generated at the farm level during harvesting (like banana leaves), an efficient system for collection, transportation, storage, handling, and fuel preparation is needed. Without such a system, the cost of centralization could limit the potential for energy production. In cases where a cost-effective waste centralization system is in place, the poor can benefit directly from the use of agricultural wastes for energy generation.

Poverty and Traditional Energy Use



Sources: International Energy Agency (IEA), *World Energy Outlook 2000* (Paris: 2000); United Nations Development Programme (UNDP), *Human Development Report: 2003* (New York: 2003).

- **Decentralized energy generation from decentralized agricultural wastes.** Poor, small-scale farmers with substantial agricultural wastes can engage in decentralized energy generation, mainly for their own consumption, but the energy service they obtain from these wastes is often of poor quality. Moreover, in areas where agricultural wastes are typically used to enrich the soil, using them for energy can be detrimental to the long-term health of soil and may even contribute to increased rural poverty. One option that has proven successful in a number of developing countries is household, community, or institutional biogas production. This technology not only provides clean energy for household, community, or institutional use, but its by-product is a rich organic manure that can be recycled in fields to reduce the need for chemical fertilizer and pesticides.

ENERGY PLANTATIONS

Dedicated energy plantations are not yet widespread in developing countries, so there is little empirical basis for evaluating their benefits for the poor. Nonetheless, to better understand how energy plantations might affect the poor, it is useful to distinguish between direct and indirect impacts.

Energy plantations have direct impacts primarily on nearby rural people. Negative impacts include possible dispossession of land among the poor in areas with insecure land tenure, with the result that poverty and food insecurity may increase. Without appropriate, sensitive, and equitable management, large-scale modern biomass energy development can lead to further marginalization of the rural poor. It is, however, possible that the growth and development of these technologies could lead to increased incomes for the poor (such as smallholder sugar farmers) if a well-designed revenue-sharing scheme is established. Positive impacts could also include potential increases in employment (in agriculture or bioenergy production). Management of energy plantations by individual households or community groups can yield significant benefits to the poor. Community-managed energy plantations are particularly attractive, since they allow smallholder farmers to join together and produce energy crops with the advantages of large-scale farming. Another benefit of this approach is the creation of local employment opportunities in the planting, harvesting, and processing of energy crops. Several developing countries are piloting small- and medium-scale energy plantations using a variety of crops, the most common being *Jatropha*. At the local level, small- and medium-scale energy plantations can contribute to poverty reduction through increased incomes for small-scale farmers.

Indirectly, energy plantations affect all types of poor people, including the urban poor. On the positive side, these impacts include potential lower energy costs (and associated lower transportation costs, assuming that the bioenergy resources are local) and increased employment from urban-based bioenergy processing plants and distribution enterprises. On the other hand, higher costs of food might arise where there is competition between food and bioenergy for land or water. Whether these positive and negative impacts result in a net gain or loss for poor people will depend in part on household budget shares for energy and food, as well as the importance of the jobs and enterprises created by the bioenergy subsector.

Options for limiting the competition for land between food and fuel include increasing food production on current agricultural lands and establishing large tree plantations on low-potential and degraded lands not currently used for food. The trade-offs presented by dedicated energy plantations have to be carefully evaluated to ensure optimum use of existing land resources without endangering food supplies.

Existing studies of the impact of dedicated energy plantations on the poor and on food security are still largely speculative. Additional research is needed to better predict the net impacts, which are likely to vary by type of region and household and to depend on the extent to which a viable and competitive bioenergy sector is established.

PRIORITIES FOR DEVELOPING A PRO-POOR BIOENERGY SECTOR

For developing countries with a large number of poor people reliant on agriculture, the first priority should be given to effective use of existing agricultural wastes for energy generation. This option has the least adverse impact on the poor and could provide additional revenue for poor rural communities. It requires, however, establishing effective revenue-sharing mechanisms that ensure that the higher revenues from the exploitation of agricultural wastes are shared in an equitable fashion and flow to all stakeholders, including low-income farmers. It also requires enacting a legal and regulatory framework that allows for the development of modern agro-waste-based bioenergy and that provides, among other incentives, access to the power grid and transport fuel market. In some cases, mechanisms for efficient centralization of agricultural wastes would need to be in place.

Once developing countries have optimized the use of existing agricultural wastes for energy generation and put in place adequate revenue-sharing, regulatory, and policy frameworks, they can consider the option of dedicated energy plantations, while carefully balancing any associated trade-offs between food security and energy generation. Fortunately, the technical, regulatory, and policy expertise needed to promote an equitable agricultural waste energy industry also provides, in many cases, the skills needed to develop and nurture a sustainable dedicated energy plantation sector that does not adversely affect the poor or decrease food security. ■

For further reading see S. Karekezi, K. Lata, and S.T. Coelho, "Traditional Biomass Energy: Improving Its Use and Moving to Modern Energy Use," thematic background paper for the 2004 International Conference for Renewable Energies (Bonn, Germany: Secretariat for the International Conference for Renewable Energies, 2004); E. D. Larson and S. Kartha, "Expanding Roles for Modernized Biomass Energy," ***Energy for Sustainable Development*** **4, no. 3 (Bangalore, India: International Energy Initiative, 2000); UNDP (United Nations Development Programme),** ***Energy and the Challenge of Sustainability*** **(New York: 2000).**

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BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES

Developing Bioenergy: A Win-Win Approach That Can Serve the Poor and the Environment

PETER HAZELL

FOCUS 14 • BRIEF 12 OF 12 • DECEMBER 2006

The promise of bioenergy is that it may help cope with rising energy prices, address environmental concerns about greenhouse gas emissions, and offer new income and employment to farmers and rural areas. In principle, there is a high degree of congruency between these three objectives for bioenergy production and the poverty reduction targets embodied in the Millennium Development Goals. But the development of bioenergy also poses risks and has the potential to result in difficult trade-offs for the poor and the environment. There is, for example, a chicken-and-egg conundrum that makes it difficult for the private sector to grow the industry before sufficient demand is forthcoming, yet demand depends on an ample and well distributed supply. Moreover, because most of the environmental and social benefits and costs of bioenergy are not priced in the market, leaving bioenergy development entirely to the private sector and the market will lead to levels and types of bioenergy production that fail to achieve the best environmental and social outcomes. To ensure better outcomes, the public sector has important roles to play.

GROWING THE INDUSTRY

Launching and developing a new industry like bioenergy poses difficult challenges for the private sector. The substantial investments that must be made up front can yield little return until sufficient scales of production and demand have been achieved to slash unit costs. But achieving those scales depends on complementary investments throughout the market chain, and these investments may not be forthcoming until bioenergy costs have fallen to a level competitive with alternative energy sources. The biofuel industry is a good example. A viable biofuel industry requires large and coordinated investments not only by farmers and processors, but also by car manufacturers, consumers, fuel distributors, and garages. Until these investments are in place, biofuel sales are destined to be low, and economies of scale in production and distribution cannot be exploited. Given higher costs, biofuels may remain uncompetitive with oil.

The solution to this problem is for governments to provide initial incentives to help launch the industry. The public sector can help achieve critical market size by offering tax rebates on biofuels (but not on oil-based gasoline and diesel), by mandating fuel blending requirements (like the European Union's current requirement that diesel contain at least 2 percent biodiesel), by offering investment incentives such as tax exemptions or holidays on bioenergy investments by industry and subsidies to consumers (to buy flex-fuel cars, for instance), and by investing directly in research and development and relevant infrastructures. Brazil began using these kinds of interventions in the mid-1970s and has now built up a viable biofuels industry that not only contributes a significant share of the country's energy requirements for transportation, but also exports to other countries. The European Union and the United States began later and are in the process of building up their own domestic industries. Many other countries seem likely to follow.

BENEFITING THE POOR

Although biofuel production has clear benefits for the agricultural sector, the net impact on poverty and food insecurity in developing countries is less clear. Not all countries have the natural resource base to justify significant production of bioenergy crops, but for those that do, the diversion of land and water away from the production of other agricultural outputs, especially food and feed, needs to be considered. Although current levels of bioenergy production are too small to have much impact on world food prices, any rapid and widespread expansion within the constraints of existing technologies could lead to significant food price increases. Such price increases would be beneficial to farmers who produce a net surplus of food, but they would be detrimental to poor consumers and food-deficit farmers, who would have to balance more expensive food against less costly energy. Since the poor typically spend much larger shares of their consumption budget on food than energy, this trade-off is unlikely to be favorable.

There are several ways to reduce the trade-offs between bioenergy crops and food production:

- Develop biomass crops that yield much higher amounts of energy per hectare or unit of water, thereby reducing the resource needs of bioenergy crops.
- Focus on food crops that generate by-products that can be used for bioenergy, and breed varieties that generate larger amounts of by-products.
- Develop and grow biomass in less-favored areas rather than in prime agricultural lands—an approach that would benefit some of the poorest people. Second-generation technologies that enable cost-effective conversion of cellulose-rich biomass, like fast-growing trees, shrubs, and grasses that can grow in less fertile and low-rainfall areas, will greatly expand this option within the next 10–15 years.
- Invest in increasing the productivity of the food crops themselves, since this would free up additional land and water for the production of bioenergy crops.
- Remove barriers to international trade in biofuels. The world has enough capacity to grow all the food that is needed as well as large amounts of biomass for energy use, but not in all countries and regions. Trade is a powerful way of spreading the benefits of this global capacity while enabling countries to focus on growing the kinds of food, feed, or energy crops for which they are most competitive. Trade would also allow bioenergy production patterns to change in the most cost-effective ways as new second-generation technologies come on line.

The benefits for the poor can also be enhanced by choosing appropriate scales and techniques for producing and processing biomass. So far most attention has been given to large-scale production and processing of bioenergy for the market, which is often the most cost-effective approach for private firms. This is because biomass crops lend themselves to economies of scale in growth and processing. Yet the scale benefits need to be balanced against the costs and energy loss of transporting biomass products, given their bulk and weight. This situation opens up opportunities for smaller-scale and rural-based production and processing, which would be much more beneficial for the poor than large-scale and urban-based processing. In many developing countries it may also be inappropriate to consolidate land into heavily mechanized farms for growing biomass. A better approach is to organize smallholders so that they can grow and market biomass crops to large processing firms. Small-scale processing of biomass to produce, for instance, electricity or biogas already helps meet local energy needs in rural areas in many developing countries, and these options can be expanded in the future. The agricultural research systems in developing countries have a key role to play in addressing these issues to make biofuels pro-poor. This is a promising area for public-private partnership in research. The Consultative Group on International Agricultural Research (CGIAR) could also play a key role in strengthening international knowledge and facilitating the exchange of information on pro-poor development of biofuels.

BENEFITING THE ENVIRONMENT

Even if bioenergy proves to be a cost-effective substitute for oil, it may not necessarily be much better for the environment. Biofuels can, for example, use a great deal of fossil energy in their production, leading to little if any net reduction in greenhouse gases. Different crops and growing and processing technologies lead to different environmental outcomes. For example, ethanol produced from sugarcane not only is competitive with oil at today's prices, but also has favorable energy and carbon balances. In contrast, biodiesel produced from oilseeds and ethanol produced from maize and sugar beets are less competitive on price and have less favorable energy and carbon balances. Second-generation technologies based on cellulose-rich biomass should be more energy efficient, and there remains great scope for developing additional technologies that lead to larger carbon savings. Considerable research is being directed at this problem in Europe and the United States.

Bioenergy feedstocks can also pose environmental risks in the areas in which they are grown. For example, removing all the biomass can exacerbate shortages of organic matter for returning to the soil, leading to nutrient mining and land degradation. Cultivation of bioenergy feedstocks can mine water resources, expose land to greater erosion, pose problems with the intensive use of pesticides and fertilizers, and threaten local biodiversity. On the other hand, grown under the right conditions, bioenergy crops can contribute to better environmental management. For example, dedicated energy plantations grown on degraded lands may actually help restore the soil and biodiversity. As with all crops, bioenergy crops need to be grown and managed responsibly, and farm-level incentives for sustainable farming (such as secure property rights and locally managed externalities) need to be in place.

BIOENERGY AT WHAT COST?

Not all countries can grow bioenergy feedstocks at costs that are competitive with fossil fuels. Brazil, for example, can produce ethanol from sugar at the equivalent of US$30–35 per barrel of oil and is now growing its industry to the point where it is becoming a major exporter of biofuels. Several other countries with favorable climates and abundant resources may well follow suit. Producing ethanol in Europe, however, costs the equivalent of about US$80 per barrel of oil, and in the United States, about US$55 a barrel. The domestic biofuel industries that are being so carefully nurtured in these countries may not be able to compete in the future without trade protection. The cost of achieving net reductions in carbon emissions from biofuels can also be high, and there may be more cost-effective alternatives. A key question for policymakers is how much they are willing to pay to achieve the perceived benefits of bioenergy. These costs should decline over the next 10–15 years as second-generation technologies come on line, but for many countries, especially in temperate climates, it may prove more cost-effective to continue to use fossil fuels and buy carbon offsets, or to import biofuels from countries that can grow them more competitively. Rich-country policymakers can afford to contemplate taking on the higher costs of domestic bioenergy production if this helps reduce the cost of supporting their farm sectors. But even here it is relevant to ask whether there might not be more cost-effective alternatives.

CONCLUSIONS

With oil prices in excess of US$60 a barrel, interest in bioenergy is running high. The energy needs of rapidly growing countries like China and India, together with unstable oil supplies, suggest that the days of cheap oil are over. Bioenergy offers an attractive alternative for many industrial and developing countries, but if its full potential is to be captured, then both the public and private sectors, working as partners, must make long-term commitments and investments in innovation. ■

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