Liquid Biofuels: Background Brief for the World Bank Group Energy Sector Strategy

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Abbreviations

CBI	Caribbean Basin Initiative
CO_2	carbon dioxide
FAO	Food and Agriculture Organization (of the United Nations)
GHG	greenhouse gas
IEA	International Energy Agency
OECD	Organisation for Economic Co-operation and Development
UN	United Nations
UNEP	United Nations Environment Programme

All dollar amounts are U.S. dollars unless otherwise indicated.

Glossary of Terms

Anhydrous ethanol	Ethanol with sufficient water removed to make it suitable for blending with gasoline
B2, B5, B10, B20	Diesel-biodiesel blends containing, respectively, 2, 5, 10, and 20 percent biodiesel
E2, E5, E10, E20, E25, E85	Ethanol-gasoline blends containing, respectively, 2, 5, 10, 20, 25, and 85 percent anhydrous ethanol
Flex-fuel vehicle	A vehicle capable of running on blends with varying ethanol content
Hydrous ethanol	Ethanol with about 95 percent purity, the balance being water, and not suitable for blending with gasoline

A Brief on Liquid Biofuels

Liquid biofuels are being increasingly used to substitute fuels derived from oil. A number of governments have provided incentives for the liquid biofuel industry, prompted by a desire to increase self-sufficiency in fuel supplies against the backdrop of high and volatile oil prices, support domestic agriculture and promote rural development, and reduce greenhouse gas (GHG) emissions in the light of emerging scientific evidence on the pace of climate change.

The World Bank and other United Nations (UN) agencies, the Organisation for Economic Co-operation and Development (OECD), the International Energy Agency (IEA), and numerous other institutions have studied various aspects of liquid biofuels in recent years. Although carried out separately, these studies have arrived at similar conclusions. The purpose of this brief is to inform the forthcoming World Bank Group energy sector strategy by providing a summary of the analyses of liquid biofuels undertaken collectively by UN agencies—notably by the Food and Agriculture Organization (FAO), United Nations Environment Programme (UNEP), and the World Bank—focusing in particular on government policies.

Issues related to liquid biofuels cut across several sectors: agriculture, forestry, water, transport, energy, and environment. Ethanol and biodiesel are the two most common forms of liquid biofuels currently in use. Those in use are also referred to as first-generation biofuels. First-generation ethanol is made from sugarcane, maize, and starch crops, and typically substitutes gasoline; biodiesel is made by reacting methanol with plant oils. Agricultural feedstocks have dominated biofuel production to date, and future feedstocks are likely to be land-based and require water for many years to come. As such, the sector that has been affected more than any other to date and for the foreseeable future is agriculture. Among the critical agricultural issues that have been studied include the effects of biofuel production on food prices, on smallholders, food security, land tenure, and water resource management; trends in crop yields and uptake of agricultural technology in low-income countries; and investment in agriculture. It is not the intention of this brief to examine these agricultural issues in detail, as they are largely outside the energy sector. No new empirical analysis is carried out for this brief, which refers the reader to recent publications.

Context

Historically, interest in liquid biofuels has moved in tandem with world oil prices. Fuel switching is one response to higher oil prices, and one sector in which diversification beyond oil is particularly difficult is transport. Unlike heat and power generation, where natural gas, solid biomass, and such alternative sources as hydroelectric or geothermal power can be commercially viable, the shift from traditional liquid petroleum fuels for vehicles to either gaseous fuels or electricity typically requires costly modifications to vehicles, fuel distribution, and refueling infrastructure. Liquid biofuels are among the few alternatives that can be readily used by vehicles without significant modification in the existing infrastructure, and, for this reason, biofuels have been used primarily in the transport sector to date. In aviation—where the share of global GHG emissions is rising faster than in any other sector save power generation (IEA 2009)—fuel switching away from liquid fuels is ruled out for the foreseeable future for technical reasons. As a result, there is much interest in using jet fuels made from biomass as a means of curbing the growth of GHG emissions.

Global production of liquid biofuels has been growing rapidly, driven primarily by a combination of blending or consumption mandates and subsidies. World fuel ethanol production rose from 17 billion in 2000 to 66 billion liters in 2008. During the same period, fuel ethanol trade rose from 440 million liters to 5.1 billion liters. Biodiesel production rose even faster, although from a low base: from less than 1 billion liters in 2000 to 12 billion liters in 2008 (F.O. Licht 2009a and 2009b; REN21 2009). The IEA estimates that liquid biofuels accounted for 1.5 percent of global transportation fuel, and the volume of liquid biofuels supplied could double by 2015 (IEA 2009).

The United States and Brazil accounted for about 90 percent of global fuel ethanol and the European Union about 70 percent of global biodiesel production in 2008. Biofuel manufacture in the United States and the European Union are heavily subsidized and, in the case of ethanol, protected by large import tariffs in addition.

Brazil is an ethanol pioneer, with blending of 5 percent anhydrous ethanol in gasoline first authorized in 1931 and mandated in 1938. Fuel ethanol no longer receives specific government support from the federal government, but ethanol blending continues to be mandated. At 51 percent by volume in 2008 (ANP 2009), Brazil has achieved a penetration rate of ethanol displacing automotive gasoline that is unmatched by any other country in the world. Brazil remains the world's most competitive ethanol producer as well as the lowest-cost sugarcane producer. Nearly all cane fields in the Center-South of Brazil are rain-fed. This gives a marked advantage to Brazil compared to other cane growers relying on irrigation, such as Australia and India. High productivity in Brazil has also benefited from decades of research and commercial cultivation. More than half of Brazil's sugarcane is devoted to ethanol. Brazilian exports of fuel ethanol rose from 77 million liters in 2000 to 3.2 billion liters in 2008, accounting for 62 percent of global fuel ethanol exports in that year (F.O. Licht 2009b).

The rapid expansion of a global biofuel industry that relies almost exclusively on agricultural crops for feedstock has had important implications for food security in many developing countries. Sugar's importance in food consumption is limited because it does not contain vital nutrients and is not used as animal feed. In contrast, diversion of maize and oilseeds to the biofuel sector has had a significant direct effect on global food prices in recent years. The FAO suggests that new biofuel demands and soaring oil prices together were the major drivers for the record prices for basic foods set in June 2008, pushing an additional 115 million people into chronic hunger. Although food prices have come down since, they are still high by recent historical standards (FAO 2009a). One study estimates that the increased demand for feedstock crops by biofuel industries accounted for 30 percent of the increase in weighted average grain prices from 2000 to 2007, with maize prices seeing the largest impact, estimated to account for 39 percent of the increase in real prices, followed by 22 percent for wheat and 21 percent for rice (Rosegrant 2008). Going forward, a growing concern—more than rising fuel prices pushing up food prices—is the possibility that energy price volatility will be increasingly transmitted to agricultural commodity prices.

Second-generation biofuels, still under development, cover a variety of feedstocks and liquid fuels. An example is cellulosic ethanol, which can be made from non-food crops including dedicated energy crops—switchgrass being one example—as well as and wastes and by-products that are currently not fully utilized, such as maize stover (crop residue not including cobs). An alternative pathway for manufacturing liquid biofuels from biomass is to convert biomass into syngas—a mixture of carbon monoxide and hydrogen—and to make liquid fuels from syngas. A range of liquid fuels can be made from syngas, including synthetic gasoline, (high-quality) diesel, and dimethyl ether (a substitute for diesel). Syngas can also be made from fossil fuels. Coal-to-liquid and gas-to-liquid plants are commercially operating in Malaysia, Qatar, and South Africa. Although some have been operating for decades, coal and gas to liquids are not commercially viable under most circumstances because of cost; biomass to liquids is even more costly.

Fuels derived from algae are referred to as third-generation biofuels. Per unit area, microalgae can produce considerably more oil than palm or any other oil-producing plant. The cost of making biofuel from algae, however, is prohibitively high at present and significant technical barriers remain (Waltz 2009).

Liquid Biofuel Policies and Economics

The production and sale of liquid biofuels are typically regulated by the ministry or agency responsible for establishing fuel specifications and monitoring compliance. The finance ministry, in consultation with the ministry in charge of biofuels, provides fiscal incentives. The first step in promoting liquid biofuels is to legalize their use, typically by setting fuel specifications and a maximum amount of a biofuel that can be blended into a petroleum fuel. Other regulations include safety and other technical standards. Of all the different regions in the world, Africa stands out in lacking policies to regulate biofuels—they do not exist in most African countries, potentially depriving them of commercially viable opportunities to produce and use biofuels. This is despite the fact that land availability and climatic conditions favor biofuel production in many parts of Africa (Mitchell forthcoming).

After legalizing their production and use, some countries have issued policy documents that are not legally binding. Others have promulgated laws that mandate blending, often associated with guaranteed fiscal incentives. Argentina, Australia, Brazil, Canada, China, Colombia, the European Union, Honduras, India, Indonesia, Malaysia, Mexico, New Zealand, Peru, the Philippines, South Africa, Thailand, Uganda, and the United States are among those that have adopted targets—some mandatory—for increasing the contribution of biofuels to their transport fuel supplies. Examples of biofuel blending or consumption mandates are given in Table 1. While developing countries tend to specify the percentage of blended biofuel, [2] the European Union and the United States also specify how biofuel feedstocks are to be grown and are in the process of establishing a framework for distinguishing between sustainable and unsustainable biofuels. Sustainability is based importantly on GHG emissions savings and, in the European Union, restricting land use for growing biofuel feedstocks and setting minimal social standards.

[2] The consumption mandates in developing countries in the table are expressed in terms of bifuel blends of either ethanol and gasoline (these are prefaced with an "E") or biodiesel and petroleum diesel (prefaced with "B"). Thus, E5 is a blend of 5 percent ethanol and 95 percent gasoline; B5 is a blend of 5 percent biodiesel and 95 percent petroleum diesel.

Table 1 Biofuel Blending/Consumption Mandates

Country	*Ethanol*	*Biodiesel*	*Comments*
Argentina	E5	B5	Both effective in 2010
Brazil	E20–E25[a]	B2, B3 effective July 2008	Ethanol blending first mandated in 1938
Canada	E5 starting in 2010	B2 starting in 2012	Nation-wide biodiesel mandate upon successful demonstration of fuel performance under Canada's climatic conditions. Provincial ethanol and biodiesel blending mandates in effect or will come into force in the future.
China	E10 in 10 provinces		Fuel ethanol production began in 2004. Six provinces use E10 throughout the entire provinces.
Colombia	E10 in large cities beginning in 2007	B5 beginning in 2008, increasing to B10 in 2009	Fuel ethanol production began in late 2005 and palm oil diesel production in Nov. 2007.
European Union	10% minimum for the share of biofuels in automotive gasoline and diesel by 2020		Only certified sustainable biofuels for the 2020 target. EU members have country-specific blending mandates.
India	E5 in 20 states and 4 union territories in Nov 2007		Ethanol blending began in Jan. 2003
India[b]	E20 by 2017	B20 by 2017	National Biofuel Policy approved in Sep. 2008
Indonesia	E3 or E7 depending on user starting between 2010 and 2015	B2.5 or B3 (transport), B5 (industry), and B1 (power) between 2010 and 2015	Mandate first in effect in 2009 at lower blending levels.
Peru	E2	B2	Mandate in effect in 2009

Country	*Ethanol*	*Biodiesel*	*Comments*
Philippines	E5	B2 using coconut-based biodiesel	B1 mandated in 2007, E5 and B2 mandated in 2009, and E10 in 2011.
Thailand		B2 in 2008	B5 planned for 2011
United States	9 billion gallons (34 billion liters) of renewable transportation fuel in 2008, rising to 36 billion gallons (136 billion liters) by 2022		There are requirements on shares of cellulosic ethanol and advanced biofuel nationally, and a number of states have state-specific blending requirements.

Sources: Kojima 2009, European Parliament and the Council of the European Union 2009, CRS 2007.
a. The government varies the blending target between 20 and 25 percent, depending on fuel prices and availability.
b. Targets.

A number of price- and tax-based policies are used to promote biofuels. Fuel tax reductions are the most widely used support measures for biofuels. A detailed look at U.S. support for fuel ethanol and biodiesel found that government support was provided at every stage of production and consumption. Tax credits provide the largest level of support, followed by market price support (resulting in consumers paying above-market prices) and crop subsidies. An estimated range for total support in 2007 was between $8.1–$9.9 billion, rising from $6.3–7.7 billion in 2006 (Koplow 2007). An OECD report estimates that the support given to biofuels in North America and the European Union in 2006 amounted to $11 billion, and that net GHG emissions were achieved at a cost of $960–1,700 per tonne of CO_2 equivalent, far in excess of any carbon price considered for the foreseeable future (OECD 2008).

Developing countries have generally adopted similar support policies. Even governments of countries that are low-cost producers of feedstocks have combined blending mandates with tax breaks and other fiscal incentives for biofuel manufacturers. Argentina, which is among the world's lowest-cost producers of soybeans, provides fiscal incentives including tax exemptions for biofuels (USDA FAS 2009a). Thailand, a low-cost producer of sugarcane, uses molasses and cassava as feedstocks for ethanol production and offers one of the largest fuel tax reductions found globally. In mid-December 2009, the reductions in Bangkok amounted to $0.86 a liter of ethanol blended for E85 to as high as $1.80 a liter of ethanol blended[3]—more than triple the ex-refinery price of gasoline—for E10. Large fuel tax reductions have been used for years to price ethanol blends much below pure gasoline. Similarly B5 is granted a large tax reduction, equivalent to $0.86 a liter of biodiesel blended (EPPO 2009).

The effectiveness of fuel tax reductions depends on the magnitude of excise taxes levied on petroleum fuels. Taxes on petroleum products are often a critical source of government revenue in low-income countries. The reason is that taxing fuel is one of the easiest ways to get revenue: collecting fuel taxes is relatively straightforward, and the consumption of fuels as a group is relatively price inelastic and income elastic, ensuring buoyant revenue as income rises and tax

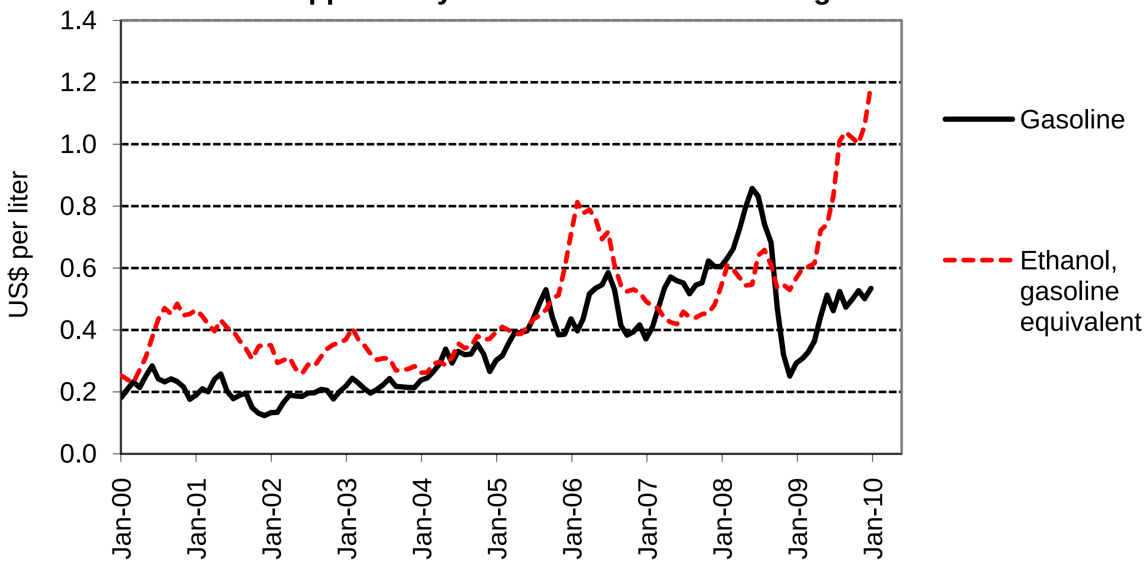
[3] The tax reduction per liter of ethanol *blended* is equal to the tax reduction for the blended fuel divided by the percentage of ethanol blended.

rates are increased (Bacon 2001). Taxes on gasoline are also progressive. Where the government's reliance on fuel taxes is significant, offering fuel tax reduction as a financial incentive to promote biofuels could have a large negative effect on government revenue. At the same time, a number of developing countries tax diesel lightly or subsidize it because diesel is an important intermediate good in the economy. In those countries, even waiving diesel tax altogether might not provide a sufficient incentive for biodiesel producers.

Other support policies include various fiscal incentives provided to manufacturers, minimum price guarantees, and mandating a minimal fraction of new domestically manufactured vehicles that have flex-fuel capability. Honduras has approved laws and regulations for both biodiesel and ethanol production, and its Biofuels Law provides funds—which are exempt from customs tariffs, income tax, and other related taxes for 12 years—for production of biodiesel, provided that at least 51 percent of the feedstock is grown in the country (USDA FAS 2009b). The government of China provides subsidies to five fuel ethanol producers, amounting to approximately $258 per tonne of ethanol in 2008, over and above waiving the consumption tax and value-added tax entirely for fuel ethanol (USDA FAS 2009c). The government of Colombia—a country that is the world's second largest ethanol producer from sugarcane—issued a decree in March 2009, requiring 60 percent of all new vehicles with an engine size of 2 liters or smaller to operate as flex-fuel vehicles compatible with E85 beginning in 2012. The government's 2008 policy framework guarantees a minimum price to producers and provides tax exemptions for feedstock growers (USDA FAS 2009d).

Financial incentives are needed because, despite high oil prices in recent years, biofuel feedstock prices have also risen, thus increasing the cost of biofuels. The economics of ethanol production from sugarcane—by far the most efficient and the lowest-cost pathway for ethanol manufacture at present—since 2000 for price takers in the sugar market are shown in Figure 1. Ethanol is economic if the solid line for gasoline (indicating its price) is above the dotted line for the gasoline-equivalent cost of ethanol. Of the 121 months between January 2000 and January 2010, there were only 25 months when ethanol was more economic than gasoline, mostly in 2007 and 2008 and none in 2009. In the remaining months, a subsidy would have been needed to make ethanol cost-competitive with gasoline. This means that, absent incentives, farmers would have preferred to sell sugarcane to sugar producers rather than to ethanol manufacturers.

Figure 1 International Market Prices of Gasoline and Opportunity Costs of Ethanol from Sugarcane

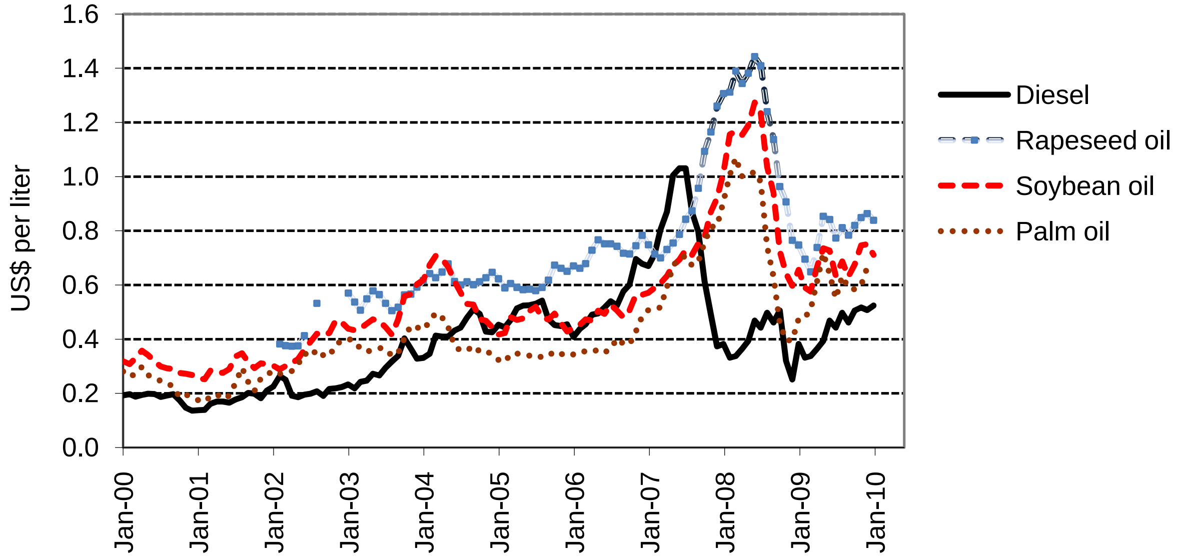


Sources: World Bank calculations, premium unleaded gasoline in northwest Europe from Energy Intelligence 2010, raw cane sugar prices from the International Sugar Organization.
Notes: The opportunity cost of ethanol is calculated based on the following parameters used to compute the equivalency between sugar and ethanol in Brazil: 1.0495 kg of sucrose equivalent to 1 kg of sugar, and 1.8169 kg sucrose equivalent to 1 liter of anhydrous ethanol. Sugarcane is assumed to yield 83 percent sugar and 17 percent molasses. Prices of molasses are assumed to be equal to 25 percent of sugar prices on a weight basis, and the sucrose content of molasses is 55 percent that of sugar. A liter of ethanol is assumed to achieve the same distance traveled as 0.8 liters of gasoline, on account of its energy content being a third less. Gasoline prices are northwest Europe monthly spot prices, barges, free on board for premium unleaded. Sugar prices are raw, free on board, and stowed at greater Caribbean ports.

In practice, the economics of ethanol production from sugarcane are more complex. In the short run, there is not much flexibility for switching back and forth between ethanol and sugar; even hybrid sugar/ethanol complexes in Brazil have only a limited range in which to shift between the two. From a business point of view, producers look at returns on a risk-adjusted basis. Optimal portfolio theory would suggest that having a portfolio of goods with volatile prices, with returns that are imperfectly correlated, can be more profitable than selling a single product, in this case sugar. Indeed, this is how Brazilian producers today are trying to optimize their portfolios, which now include cogeneration. And in the case of Brazil, which splits sugarcane almost equally between ethanol and sugar, ethanol manufacturing has allowed the industry to basically double its output of sugarcane without putting undue downward pressure on the world sugar price.

Biodiesel economics have been even more unfavorable—biodiesel *feedstock costs alone* have generally been higher than petroleum diesel prices. Figure 2 compares prices of petroleum diesel with those of rapeseed oil (used in Europe), soybean oil (Argentina, Brazil, United States) and palm oil (Indonesia, Malaysia). In the 121 months between January 2000 and January 2010, there were 39 months when palm oil prices were lower than diesel prices, only 7 months when soybean oil prices were lower, and none when rapeseed oil prices were lower.

Figure 2 Comparison of International Market Prices of Diesel and Vegetable Oils



Sources: Energy Intelligence 2010, World Bank Development Economics Prospects Group, USDA, and USDA FAS.
Notes: A nominal density of 0.92 kilogram per /liter is assumed to convert prices from US$ per metric tonne to US$ per liter. Diesel prices are Northwest Europe monthly spot prices, barges, free on board; rapeseed oil prices ex-mill, free on board in the Netherlands; soybean prices in Decatur, Illinois; crude palm oil prices in Malaysia.

Biofuel economics can be more favorable in petroleum-importing landlocked or remote areas, or in any other situation where transportation costs for imports are high and there are indigenous sources of biofuel feedstocks that can be grown at reasonable costs. If there is surplus sugar or any other biofuel feedstock that is being exported, the economics will be based on the export-parity prices of the feedstock—which are lower than world prices by the cost of transporting it to the nearest external market—and import-parity prices of the petroleum fuel—which are correspondingly higher than world prices by the cost of importing the fuel into the country. Sample calculations examining the economics of ethanol from sugarcane in a gasoline-importing, sugar-exporting market are given in Kojima, Mitchell, and Ward (2007).

Biofuel economics also are more favorable where, instead of primary commodities, surplus byproducts such as molasses are used as feedstocks. Wastes as feedstock could also have low costs, but the economics of using wastes depend critically on the cost of collecting and transporting the wastes to a biofuel manufacturing plant, which can be high. In addition, wastes may fetch higher prices in other markets (for example, waste oils and greases can be sold to rendering companies).

Concerns about food security have prompted some governments to direct efforts for biofuel production away from food-based feedstocks. In 2007, the government of China stopped approving new plants processing grains, including ethanol plants. India's biofuel strategy focuses on the use of nonfood feedstocks: molasses for ethanol and nonedible oilseeds for biodiesel. South Africa's biofuels industrial strategy, issued in December 2007, excluded maize—an important staple among the poor—from the government's biofuel policy (DME 2007). Mexico prohibits the use of domestically produced maize to make fuel ethanol unless there is a national surplus, and stopped providing financial support to maize-based biofuel projects in 2008 (BBC 2009).

Some governments provide incentives for certain feedstocks or manufacturers. Argentina's biofuel regulations of 2007 give priority to small and medium enterprises, farmers, and entities operating in nontraditional production areas; the legislation passed in January 2008 extended the incentives to ethanol produced from sugarcane (USDA FAS 2009a).

Trade barriers have had significant effects on the economics of the global biofuel industry. The two largest biofuel markets—the European Union and the United States—protect their own biodiesel and fuel ethanol industries, respectively, with high import tariffs. Some developing countries have been granted duty-free entry to both markets—a large number of countries, in fact, in the case of the European Union—and the duty-free status is generating significant investment in some. But this has, on occasion, led to further distortions. One example is the Caribbean Basin Initiative (CBI), under which countries in Central America and the Caribbean have had duty-free access to the United States since 1989 for ethanol produced from at least 50 percent local feedstocks. Limitations apply if the local feedstock content is lower, but duty-free ethanol is permitted up to 7 percent of total U.S. ethanol consumption for ethanol containing no local feedstock. This duty-free access has historically prompted hydrous ethanol produced in Brazil to be shipped to dehydration plants in CBI countries for re-export to the United States. This otherwise inefficient export route is economic solely because of the provisions of the CBI. Costa Rica, El Salvador, Jamaica, and Trinidad and Tobago have built and operate dehydration plants to take advantage of the CBI. These ethanol producers have recently warned that proposed provisions for new U.S. renewable fuel standards—requiring verification of the origin of the sugarcane for ethanol to certify that it was grown on land currently under cultivation—would virtually shut down their industry (*Platts Oilgram Price Report* 2009). Some developing country governments levy high import tariffs on biofuels also, such as 27 percent imposed in India (USDA FAS 2009e).

A few major producers of biofuel feedstocks assess large export taxes on feedstocks, biofuels, or both. Argentina, which produces biodiesel almost exclusively from soybean oil, levies high export taxes on both soybean oil and biodiesel. The tax on soybean oil at 32 percent is much higher than that on biodiesel at 16.6 percent, lowering the feedstock cost domestically and encouraging exports of biodiesel rather than soybean oil (USDA FAS 2009a).

Drivers for Biofuel Policies

Expanded biofuel production and use have been pursued for several reasons:

- "**Energy security**." This somewhat amorphous term has come to mean increased reliance on domestic energy resources to many governments. It also can refer to efforts to combat high and volatile oil prices through diversification of fuel consumption (not necessarily production).
- **Rural development**. Expansion of biofuels has been seen as a way to increase demand for agricultural commodities, create jobs in more impoverished rural areas, and otherwise enhance rural development. This has been one of the main drivers in all countries promoting domestic production of biofuels through government support.
- **Environmental Sustainability**. Substitution of biomass energy for fossil energy in liquid fuels has been seen as an important means of reducing GHG emissions. As discussed below, this depends on the extent to which net global GHG emissions, and not just

project-based emissions, are reduced. Other reasons cited for environmental sustainability include reducing local air pollution.

Energy security

Energy security, in the form of greater self-sufficiency, has been one of the most important drivers of biofuel policies around the world, as typified by the title of the legislation setting out the U.S. policy for biofuels: "Energy Independence and Security Act of 2007." The level of interest in biofuels has historically risen in oil-importing countries with each oil shock. An underlying assumption essential to this approach is that domestically produced energy is "more reliable" and less affected by price volatility on the world market.

A related reason for considering liquid biofuels is diversification of energy sources. As long as prices are not closely correlated, having a portfolio of different energy sources can help cope with rising prices of certain forms of energy. In the case of liquid biofuels, the objective in this context would be to reduce reliance on oil, thereby being in a better position to cope with the next oil shock.

Fuel prices have historically been more volatile than agricultural commodity prices. Consistent with this general trend, price volatility in the last decade, as measured by the coefficient of variation, has been smaller for biofuel feedstocks than their corresponding petroleum products. For example, the coefficients of variation for sugar (0.38) and maize (0.35) are smaller than 0.47 for gasoline, and similarly for palm oil (0.47) and soybean oil (0.45) are smaller than 0.54 for diesel. Had biofuel production been economic, lower price volatility might have been one benefit of switching to biofuels.[4]

Because global biofuel production will remain small in contrast to petroleum fuel production, biofuels will continue to be price-takers in the market rather than drivers of transportation fuel prices. As a result, average biofuel prices on the international market are unlikely to be much lower than those of petroleum for long. This trend will be reinforced as countries try to force biofuel production to higher levels, thereby potentially pushing up feedstock prices further. The OECD and FAO, in their *Agricultural Outlook 2009–2018*, cite the emergence of the biofuel industry—and in particular use of maize, oilseeds, and sugar feedstocks—as one of the factors contributing to much greater interdependence between energy and agricultural prices (OECD and FAO 2009).

That said, agricultural crop production—and thus the cost of biofuels relative to petroleum-based fuels—also depends on weather. Too little rain in India—India's sugar production fell by almost half in 2008/09, turning the country from the second-biggest producer to the biggest importer—and too much rain in Brazil led to world sugar prices continuing to rise in 2009, even as gasoline prices stagnated. The simple correlation coefficient between sugar and gasoline prices is 0.7 over the period between January 2000 and December 2008, but it falls to 0.6 once 2009 is included in the calculation.

The possibility of serious disruptions to feedstock supply due to unfavorable weather would argue for flexible biofuel policies, particularly with respect to quantitative mandates. The ethanol

[4] Price volatility can always been reduced if one is prepared to accept higher prices. In the extreme, for example, zero price volatility could historically have been achieved without any energy diversification if retail gasoline and diesel prices had been set constant at $2 a liter.

mandate in Brazil allows for such flexibility by varying the blending proportion between 20 and 25 percent. For example, the government reduced the required blend level from 25 percent to 20 percent in March 2006 after the world sugar price reached a historic high; after raising it to 23 percent several months later and eventually to 25 percent in July 2007, the government again reduced the blend level to 20 percent in February 2010. This flexibility is further enhanced by widespread use of flex-fuel vehicles, which accounted for 95 percent of all new passenger vehicle sales in October 2009. These vehicles are capable of running on both hydrous ethanol (containing no gasoline) and any gasoline-ethanol blend. Thus, if world sugar prices soar as a result of crop failure in Brazil or elsewhere, domestic consumption of fuel ethanol can be substantially reduced by a combination of a shift away from hydrous ethanol to a gasoline-ethanol blend and lowering the mandated blending ratio.

Biofuels will be price takers as long as they comprise a small share of total fuel supply, but they can still influence world petroleum prices if they can contribute to sufficient additional supply. For example, if—after adjusting for fuel efficiency differences and incremental energy used in biofuel production—biofuels could meet 3 percent of global gasoline and diesel fuel demand, or about 1.5 percent by volume of total oil consumption, this would amount to 1.3 million barrels per day of petroleum oil today. While such substitution would not reduce the long-term demand for petroleum oil, which has been growing at 1.4 percent annually during the last decade, it would delay the time at which any given level of demand is reached, with associated price implications. And if biofuel production increases over time, then this will moderate petroleum demand growth and petroleum price increases.

The argument for relying on domestic resources is stronger in small markets where petroleum fuels are imported at high costs. Costs can be high for a variety of reasons: small market size not achieving minimal scale economy for shipping, pipelines, and refining; poor conditions of infrastructure for transporting fuels (pipelines, rail, or roads in a state of disrepair); and frequent power failure disrupting pipeline and refinery operations; to mention a few. These markets tend to suffer from shortages of all forms of modern energy. Where consumers are already paying high prices for energy (typically for electricity and petroleum products), production of liquid biofuels from locally grown feedstocks could be attractive. That said, the most economic may not be ethanol or biodiesel, but direct use of plant oils in stationary sources for power or heat generation; converting the oils into biodiesel requires importation of methanol, which could be expensive.[5]

Second-generation technologies—using agricultural residues, forestry products, dedicated energy crops, or municipal and other wastes—or third-generation algae-based technologies could, under certain circumstances, transform the biofuels industry away from one competing for land and water needed for food production, and thus make a larger contribution to energy security with much smaller adverse effects than today's industry. It is worth noting, however, that crop residues are not without value. A sizable fraction are usually returned to the soil to manage organic matter and soil fertility. Some crop residues are used as animal feed (maize stover being an example), and, especially in low-income developing countries, they are burned as fuel.

One example arises in the context of feedstocks that have attracted much attention in recent years: Jatropha curcus, Pongamia pinnata, and other oil-bearing, non-food shrubs that can grow on marginal land with little rainfall. As concerns about competition between food and fuel have

[5] If ethanol can be manufactured cost-effectively, ethanol can be used instead of methanol for transesterification.

heightened in recent years, some have seen these plants as enabling energy needs to be met without compromising food security. However, questions about possible yields and required inputs and about the economics of growing these perennial poisonous shrubs for fuel production remain. BP and D1 Oils have planted 200,000 hectares of Jatropha, or 25 percent of worldwide planting, including a large-scale pilot scheme in India. At a biofuel conference in Africa in April 2009, D1 Oils reported that, when Jatropha is grown on arid and infertile soil, the oil yields are too low to be economic: "If you grow Jatropha in marginal conditions, you can expect marginal yields." Growing Jatropha as a cultivated crop in fertile, irrigated land increases yield and oil content but competes for resources that would otherwise go to other agricultural activities. It also makes the plant more susceptible to pests, further complicating the economics.[6] Having announced a plan to invest $160 million in Jatropha several years earlier, BP exited the Jatropha business in mid-2009. D1 Oils plans to release second-generation seeds with much improved characteristics in 2010 or 2011 (*Wall Street Journal* 2009; *In Africa* 2009).

Rural development, job creation, and support to agriculture

The high food prices of 2007 and 2008, attributed in part to the growth in biofuel production, provide clear evidence that the biofuel industry can have a measurable impact on demand and raise prices of agricultural commodities. To the extent that the majority of the rural poor are net buyers of food, the poor have been adversely affected; the FAO estimates that 1.09 billion people were under-nourished worldwide in 2009, representing more hungry people than at any time since 1970 (FAO 2009b).

Many crop producers are rural, poor, and in developing countries. Years of low and stable agricultural prices gave farmers little incentive to invest in means of production. This disinvestment has had serious adverse effects on productivity. During the Green Revolution of the 1960s, staple-crop yields were rising by 3 to 6 percent a year. Since then, they have been rising by only 1 to 2 percent annually. In poor countries, including those in Africa, yields have stagnated. For most of the past 25 years, investment in agriculture has declined (World Bank 2008, FAO 2009a, *Economist* 2009).

High agricultural prices should provide incentives to reverse this trend. Productivity-led increases in agricultural production will increase farm incomes and stimulate backward and forward linkages in the rural economy, reducing poverty. Concerned particularly to uplift small-scale farmers and producers, biofuel policies in some countries give priority to small-scale operations, as discussed above.

In this respect, an important lesson from the high food price episode of the last two years is that high commodity prices alone are not sufficient. Many farmers in developing countries did not seize the opportunity to invest and raise their production and productivity, because the high international prices were not transmitted through national borders and marketing chains to them, their access to affordable inputs and modern technology were limited, necessary infrastructure and institutions were lacking, and some policy responses—such as price controls and tariff reductions—actually reduced incentives.

[6] The challenge is illustrated by an effort Brazil once pursued to use cassava for making ethanol as a way of lifting the rural poor out of poverty. Cassava grows under a variety of soil and climatic conditions and has a less clearly defined harvest period, creating a reasonably constant demand for labor throughout the year. But developing large-scale farming of cassava proved to be difficult because pests and diseases plagued the crop.

Smallholders in developing countries need to overcome these constraints if they are to deliver a significant supply response in food or energy crops based on productivity improvement. Proper policy interventions are needed to break out of this vicious circle that has trapped small producers in poverty for decades, especially in Africa. Whether biofuels can benefit poor smallholder farmers by generating employment and increasing rural incomes should be viewed in the context of these broader challenges (FAO 2009a, *Economist* 2009).

With the exception of first-generation biodiesel production to meet local fuel demand, there are large economies of scale in processing feedstocks into biofuels, especially with second-generation biofuels. The scale economy requires that a large amount of feedstock be transported to the processing plant at a low cost, and this in some cases has translated into large farms, particularly when the harvest product is perishable. If well-fertilized and irrigated land is required for Jatropha, for example, medium- to large-scale commercial farm enterprises are likely to produce oil at a cost that farmers producing a few tonnes a year using inter-cropping are not able to match, diminishing the chances of small-scale rural farmers benefiting from the global biofuel industry.

Higher food prices have increased acquisition of farmland in developing countries—not only for food but also for biofuel crop production—by large foreign firms. In principle, these land deals can increase investment in agriculture. However, there are concerns about the terms of acquisition, particularly when the land acquired by foreign investors has been operated under customary tenure arrangements by smallholders with no formal title to the land. Even when land deals—whether by foreign or domestic investors—are justified on the grounds that the land being acquired is "unproductive" or "under-utilized," there is some form of land use in most cases, often by the poor. Protests have broken out in Asia after government reclassified village commons—widely used for grazing livestock—as "wastelands" targeted for biofuel crop plantation, mostly Jatropha, in one country and as Jatropha plantations began to displace rice, bananas, maize, and root vegetables in another (von Braun and Meinzen-Dick 2009; *Yale Environment 360* 2009; Cushion, Whiteman, and Dieterle 2010).

Where large farms are more economic, as with any large-scale agriculture and especially in countries with weak institutions and governance, increased demand for land can affect security of tenure and land use; powerful interests may seek land currently used by smallholder farmers or held in communities to convert it to large-scale biofuel plantations. These risks are illustrated in a recent study in Tanzania, where biofuel projects involving several billion U.S. dollars have been proposed for the next 10–20 years. The study finds that some land acquisitions for biofuels are targeting land currently used for forest-based economic activities on which villagers depend heavily. The compensation process is fraught with problems: local people do not understand the process, their rights, or opportunities; land valuations are carried out using inadequate criteria; and benefits are promised by companies but not incorporated into a written contract. Of particular concern is the high level of risk taken by communities where the proposed investment relies on the transferred land to be used as collateral for bank loans, prior to compensation being paid (Sulle and Nelson 2009).

These concerns point to the importance of designing and managing investment projects to ensure that local communities benefit through ensuring transparency in negotiations; respect for existing land rights, including customary and common property rights; benefit-sharing measures such as contract farming and out-grower schemes where possible; environmental sustainability; and adherence to national trade policies (World Bank 2009; von Braun and Meinzen-Dick 2009).

Inter-cropping with food crops can limit the negative impact of biofuel feedstock production on food security, although the gender construct in play on the land needs to be understood so as not to marginalize women further or even worsen food insecurity. Questions include what incentives to provide to women tending, for example, an oilseed while inter-cropping, where the income stream goes, and possible threats to food security if women are displaced from food crop land. In Sub-Saharan Africa, it is highly likely that an oilseed, if produced for cash, would be controlled by men, although it may require significant amounts of female household labor input. If grown on food land, the crop is largely tended by women, who may have little incentive to look after it given their lack income from it. If women are displaced from their food crop land, or their labor is redirected to oilseed production at the expense of their foodcrop production, and they have no alternate income streams, food and nutrition security may suffer even as total household income increases (Haddad, Hoddinott, and Alderman 1997; Quisumbing et al. 1999; World Bank, FAO, and IFAD 2009).

Environmental sustainability

Reducing GHG emissions through the use of renewable fuel is frequently cited as an important reason to support biofuels. Researchers differ on the magnitude of the prospective reduction in GHG emissions as a result of greater biofuel use. The extent of GHG reduction depends on the entire cycle of biofuel production, from the cultivation of feedstocks and the biofuels production process to transport of biofuels to markets. Estimates of gains vary, depending on the type of feedstock and production process used, with ethanol from established sugarcane fields ranking among the highest in net GHG emission reduction and ethanol from maize among the lowest because of the high energy-intensity of its production.

An important, and often overlooked, source of additional GHG emissions is land use change. If increased feedstock production in one area prompts changed land use in another area, global GHG emissions may actually rise. For example, increased maize use for biofuels in the United States decreases U.S. maize exports and raises the price of maize, with knock-on effects that increase the incentives for clearing land to produce crops in other countries. A general equilibrium model examining the impact of implementing the U.S. and EU biofuel mandates on global land use in 2015 suggests crop cover rising sharply in Latin America, Africa, and Oceania at the expense of pasturelands, followed by commercial forests (Hertel, Tyner, and Birur 2010).

The world population is projected to increase from six billion in 2000 to eight billion in 2030, but the World Bank estimates that cereal production will have to increase by nearly 50 percent and meat production by 85 percent during the same period. There is significant scope for yield improvement in many parts of the developing world, but that alone is unlikely to be able to meet this projected demand, indicating that new land will have to be put into cultivation. To exacerbate these problems, it is generally agreed that climate change will tend to reduce global agricultural production. By 2050, climate change may increase the number of people at risk of hunger by 10–20 percent (World Bank 2008; WFP 2009).

Increased demand for agricultural feedstocks for biofuels will add to the growing competition for land.[7] If there is land use change, net GHG emissions will be higher, rather than lower, over the near to medium term. Indirect effects of incremental biofuel production through land conversion somewhere else in the world is difficult to pinpoint, but a recent analysis by the U.S. Environmental Protection Agency that calculates the indirect effects of higher biofuel production estimates that, per unit of energy contained in each fuel, global land use changes offset GHG emission reduction benefits the most for biodiesel from soybeans, followed maize ethanol, switchgrass ethanol, and finally sugarcane ethanol. UNEP suggests that project-based standards for biofuels alone may be inadequate for the purpose of avoiding displacement and related direct and indirect effects of biofuel production, as long as the global cropland required for agricultural based consumption grows (UNEP 2009; U.S. EPA 2010).

The environmental cost of cultivating some types of biofuels could be high. A recent assessment of 26 different biofuels showed that many of them generate GHGs at a volume more than a third lower than gasoline. However, these benefits fall after accounting for environmental effects associated with production of biofuels: depletion of natural resources, razing of forests and peat surfaces to open land for cultivation, and damage to ecosystems. Nearly half of these biofuels, including the commercially most important ones—such as U.S. maize ethanol, soy diesel, and Malaysian palm-oil diesel—may even have greater environmental costs than fossil fuels (Zah et al. 2007). Another looming shortage is that of fresh water. Agriculture uses 85 percent of fresh water withdrawals in developing countries, and irrigated agriculture accounts for about 40 percent of the value of agricultural production in the developing world.

The environmental effects of biofuel production from algae are not yet clear. Some lifecycle studies have found unfavorable environmental effects of producing algae (Clarens et al. 2010) and algae-based biodiesel (Lardon et al. 2009). More detailed analysis using the most recent data—the work by Clarens et al., which used publicly available information, has been criticized by the industry for using outdated data (*New York Times* 2010)—could help identify the areas requiring technology breakthroughs for developing efficient and sustainable production pathways.

Stationary use of biomass may hold greater promise, for both efficiency of conversion to energy—for example, for heat or combined heat-and-power applications—and reducing net GHG emissions, particularly in developing countries. For environmental sustainability, it may be better to use bioenergy to replace coal in the power sector, rather than convert it to a liquid vehicle fuel. Aside from GHG emissions, other environmental concerns associated with the production of liquid biofuels include the effects on biodiversity, eutrophication, and acidification (UNEP 2009; WBGU 2009).

Even in the transport sector, a recent comprehensive analysis of lifecycle GHG emissions comparing two pathways—converting maize (first generation) and switchgrass (second generation) to ethanol to fuel conventional spark ignition engines and for electricity to run

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[7] There will be individual circumstances where incremental biofuel production does not have to lead to land use changes elsewhere. For example, changing from extensive to intensive cattle-raising could improve productivity significantly in Brazil and free up large amounts of land for sugarcane or other crops, which in turn could be used to make biofuels. Replacing an additional 2 percent of projected world gasoline consumption in 2030 with Brazilian ethanol would require the area of sugarcane grown in Brazil to expand by approximately 6 million hectares, which in turn would involve a transfer of only 3 percent of Brazil's current pasture area into sugarcane production (World Bank forthcoming).

electric vehicles—concluded that the latter would reduce GHG emissions more. The study took into account GHG emissions not only from fuel and electricity manufacture and ethanol combustion but also during vehicle manufacture (Campbell, Lobell, and Field 2009).

The steady improvements made in the last two decades in vehicle and transportation fuel technology are such that biofuels do not provide a clear advantage over petroleum fuels for reducing the emissions of harmful local pollutants. In those developing countries with markedly less stringent fuel specifications, biofuels may offer some benefits. Historically, ethanol was used in some countries as an octane enhancer when lead—a harmful additive, particularly damaging to the intellectual development of children—was phased out of gasoline.

One concern is that some feedstocks for biofuels run the risk of becoming invasive species. In 2007, the Invasive Species Council of Australia cautioned that most plants being promoted as biofuels in the country were serious weeds and should not be grown (Low and Booth 2007). The Global Invasive Species Programme similarly warned in 2008 that importation of alien species of plants known for their fast and productive growth would increase two risks: clearing and conversion of natural areas for monocultures, and invasion by non-native species (GISP 2008).

Observations

Rapid growth of liquid biofuel production and consumption has had negative unintended consequences. Questions are being raised about possible competition for land and water resources even in growing energy crops for second-generation biofuels. In this uncertain situation, use of wastes, residues, and under-utilized byproducts will continue to receive priority.

The pace of technological progress will influence the future potential of liquid biofuels. A large number of companies and research groups are directing efforts at developing new pathways for producing liquid fuels. Those focusing on microalgae alone include such major oil companies as BP, Chevron, Royal Dutch Shell, and ExxonMobil; chemicals companies such as Dow Chemicals; and various biofuel companies, large and small. Technology is rapidly evolving not only on the fuel front but also for engines. For example, in early 2009, U.K. engine manufacturer Ricardo announced development of technology that optimizes ethanol-fueled engines to exceed spark ignition (gasoline) engine efficiency and approach levels previously reached only by compression ignition (diesel) engines. Ricardo's technology takes advantage of ethanol's higher octane and higher heat of vaporization and optimizes the engine for both gasoline and ethanol, thereby eliminating the large fuel-economy penalty suffered by current flex-fuel vehicles (*Automotive World* 2009). If such technology can be commercialized, this would change the economics of ethanol.

The biofuel industry's current dependence on subsidies, especially in the United States and the European Union, distorts market behavior and hides real costs. Direct and indirect policy-induced price distortions greatly affect the financial attractiveness of ethanol and biodiesel production and trade. The resulting price distortions are large, and the forward and backward links with other price-distorted markets are strong. A level playing-field for biofuels would resolve some of the dilemmas, attenuate the risks, and clarify the choices for policymakers seeking welfare gains from biofuels. The importance of basing biofuel policies on a more solid base (FAO 2008) and in particular reconsidering mandates, targets, and quotas (UNEP 2009) is now generally accepted. The German Advisory Council on Global Change has called for "a swift phase-out of promotion of biofuels for transport purposes" (WBGU 2009). Equally important is the need to consider the cost-effectiveness of all options for enhancing energy security and limiting environmental effects of energy use, and assessing liquid biofuels in that overall context.

But policy changes take time. For the foreseeable future, liquid biofuel markets are likely to continue to be driven by mandates and subsidies. As such, policy uncertainties—including how governments in developed countries will judge the environmental sustainability of biofuel production and modify their policies accordingly—will affect the financial attractiveness of biofuel production around the world. Some developing countries may have a comparative advantage in producing biofuels for export, but whether it would make sense to pursue such exports would depend on a substantial reduction in tariffs or duty-free access granted by the importing countries, blending mandates and even subsidies being retained in these markets, and, increasingly, sustainability certification of biofuel production.

The pursuit of liquid biofuels as an environmentally sustainable source of energy is increasingly questioned. There is a worldwide move to establish criteria for sustainable land use and protection of biodiversity. The need to consider and limit emissions caused by land-use changes is now widely acknowledged. These include not only the clearing of virgin land for the explicit purpose of growing biofuel feedstocks—among the most damaging of which is clearing tropical rainforests (palm, soybeans) or draining and burning peatlands (palm) to grow feedstocks—but also indirect effects, which seem unavoidable given the need to clear new land just to meet incremental demand for food in the coming decades. Even restricting biofuel production to degraded land—whereby biofuel crop production could restore such land—risks acceleration of land degradation through forest fires started explicitly to increase the amount of degraded land. Because currently available lifecycle analyses tend to be product- or project-specific and do not take indirect land use change into account, they need to be complemented with other assessments (Cushion, Whiteman, and Dieterle 2010; UNEP 2009). In this context, providing subsidies to, or mandating use of, biofuels just because they are renewable seems questionable in many situations in the near to medium term. If and when markedly different production pathways for biofuels become commercial, the role for biofuels in responding to global climate change may grow.

There is greater scope for economic production of biofuels in developing countries, because conditions are more favorable for growing feedstocks—Brazil's ethanol program from sugarcane is a celebrated case—while shortages of all forms of modern energy abound in many parts of the developing world. Regions with plentiful land, such as Africa and Latin America, are particularly promising.

Where expanding production of liquid biofuels makes economic sense, a challenge is to find means of sharing benefits broadly and contributing to equitable rural and agricultural development. There is a serious risk of marginalizing subsistence farmers and smallholders, especially those with no formal title to land. The risks exist even when "unproductive" lands are selected for biofuel crop production, as experience in Asia and elsewhere shows. The large economies of scale required in emerging biofuel technologies and associated capital costs exacerbate these challenges. For example, the FAO, Ecofys, and the Global Bioenergy Partnership point out that one barrier to commercializing biofuels derived from algae in developing countries is its significant requirement for upfront capital investment (FAO 2009c).

An economically viable biofuel industry will require a commercially dynamic and well-coordinated supply chain with a minimum efficient size. While there is an active debate on the relative production costs of smallholdings and of large commercial farms, economies of scale at the marketing end of the supply chain—except in limited local applications—may eventually favor larger enterprises, except where smallholders are supported by effective collective organizations. Where cost-competitive, biofuel companies using outgrower and other contracted smallholder arrangements may represent a positive model for local livelihoods and the environment. Governments need to develop policies that encourage sustainable and beneficial biofuel investments and that provide safeguards against negative effects on land access, environmental conservation, and food security.

Alternative uses of biomass merit serious consideration. Absent a dramatic technology breakthrough, an emerging consensus is that biomass, generally, is better used in stationary applications (UNEP 2009, WBGU 2009). As an illustration, local use of oilseeds may provide an economically viable opportunity for power generation, running stationary engines, and for household energy use. In Mali, the Garalo Jatropha Producers' Cooperative supports small-scale farmers growing Jatropha, and ACCESS, a private power company, provides a guaranteed market for the farmers. ACCESS currently supplies electricity to about 250 households. Households pay for connection and consumption, and make a contribution towards street lighting. Payment defaults are less than 10 percent, enabling ACCESS to cover all its recurring costs from income (*In Africa* 2009). The fuel is used also for lighting and cooking, and is not only cheaper but, being local, is available during the rainy seasons when impassable roads can block the delivery of petroleum fuels (*Yale Environment 360* 2009).

For developing-country governments considering incentives for liquid biofuels, a final challenge is to ensure that the required government support not displace alternative activities that may deliver higher returns in energy security, rural employment, or climate change mitigation. Other—often more cost-effective—ways of delivering environmental and social benefits also need to be considered. Two examples are improvements in energy efficiency—one obvious area is reducing large technical and commercial losses in electricity transmission and distribution—and alternative uses of biomass. Governments need to carefully assess the economic, environmental, and social implications and risks, as well as the potential energy security benefits, of different paths for clean energy development.

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