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Biofuels in Africa

Opportunities, Prospects, and Challenges

Donald Mitchell

THE WORLD BANK

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Foreword

Biofuels offer new opportunities for African countries. They can contribute to economic growth, employment, and rural incomes. They can become an important export for some countries and provide low-cost fuel for others. There is also a potentially large demand for biofuels to meet the rapidly growing need for local fuel. Abundant natural resources and low-cost labor make producing biofuel feedstocks a viable alternative to traditional crops; and the preferential access available to most African countries to protected markets in industrial countries provides unique export opportunities.

Biofuels also bring challenges and risks, including potential land-use conflicts, environmental risks, and heightened concerns about food security. These challenges and risks can be effectively dealt with through governmental policies. However, biofuel policies are lacking in most African countries, resulting in limited opportunities for biofuel production. Without established policies, investors are reluctant to produce biofuels; and land-users' rights, environmental impacts, food security issues, and consumer concerns may not be adequately addressed.

This book examines the potential of African countries to produce biofuels for export or domestic consumption and looks at the policy framework needed. It is part of the effort by the World Bank's Africa Region to examine critical issues that affect the region and to recommend policies that effectively address these issues while providing an enabling environment for the private sector. The book is intended to inform policy makers and the larger development community of the global and domestic market opportunities facing biofuel producers, as well as the challenges of producing biofuels, in the Africa Region.

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Any errors or omissions are the sole responsibility of the author.

About the Author

Donald Mitchell was a lead economist in the World Bank's Africa Region Agriculture and Rural Development Department when this book was written. He received a Ph.D. in agricultural economics from Iowa State University in 1976, and was on the faculty of the Department of Agricultural Economics at Michigan State University from 1976 to 1983. In 1983 he joined the World Bank, headquartered in Washington, D.C. As a member of the Global Economic Prospects Department, he was primarily involved in research and policy analysis on commodity markets and related issues, and he advised on policy reforms in more than 20 commodity-exporting and commodity-importing countries. From 1999 to 2008, he was head of the Global Economic Prospect's Commodities Team, which was responsible for monitoring global commodity markets and preparing price projections for major energy and nonenergy commodities.

Mitchell has coauthored two books on commodities and related issues, the most recent being *The World Food Outlook,* published by Cambridge University Press in 1997. *Grain Export Cartels,* published in 1981 by Ballinger Press, was awarded the Outstanding Research Award by the American Agricultural Economics Association. He also coauthored the World Bank's *Global Economic Prospects 2009: Commodities at the Crossroads.*

Recently his work has focused on the impact of biofuels on commodity prices and the potential for developing countries to produce biofuels for export and domestic use. This work has been widely quoted in the international press. He moved to the World Bank's Tanzania country office in 2008 to research the potential of biofuels in the Africa Region. Having retired from the World Bank at the end of 2009, Mitchell continues to live in Dar es Salaam, Tanzania, consulting for the World Bank and others on biofuels and commodity market issues of importance to developing countries. He can be contacted by e-mail at don.mitchell09@gmail.com.

Abbreviations

CDM	Clean Development Mechanism [under the Kyoto Protocol]
D1	D1 Oils plc
DFID	Department for International Development (United Kingdom)
Diligent	Diligent Tanzania Ltd.
EBA	Everything but Arms
EPA	economic partnership agreements
EU	European Union
FAPRI	Food and Agricultural Policy Research Institute
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO database
GHG	greenhouse gas
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Agency for Technical Cooperation)
IEA	International Energy Agency
PPP	purchasing power parity
RFS	Renewable Fuel Standard
SEKAB BT	SEKAB BioEnergy Tanzania Ltd.

SVO	straight vegetable oil
T Sh	Tanzania shilling
US$	U.S. dollar

Executive Summary

The rapid rise in energy prices over the past decade is seen as the beginning of a new era in which energy prices will remain high for an extended period. Several factors drive this situation, including the rapid growth in demand for energy in developing countries such as China and India; the depletion of easily accessible supplies of oil; and the higher cost of extracting oil from deep oceans, remote areas, and politically unstable regions. The situation has contributed to renewed interest in biofuels as an alternative and renewable supply of transport fuels and to policies in many countries that encourage production and mandate consumption of biofuels. Concerns over global climate change have also contributed to the renewed interest in biofuels as a way of reducing greenhouse gas emissions, as have other factors such as the desire for increased energy security and the desire to support the rural sector. The effect of expanded biofuel production on the rural sector will be substantial. Biofuels will not only provide opportunities for farmers to grow new cash crops, but will also cause the relative prices of all agricultural commodities to rise because of the increased competition for resources. The latter is expected to break the decades-long trend of declining real prices for agricultural commodities. African countries can participate in this new era as both producers of traditional agricultural commodities and as producers of biofuels to meet domestic and export demand.

The global demand for ethanol and biodiesel is expected to grow rapidly until at least 2020 because of consumption mandates and high energy prices. Most of the growth is expected to come from the United States and the European Union (EU) because both have mandated large increases in biofuel consumption. However, many other countries have also mandated consumption of biofuels and will contribute to global demand growth. The EU has mandated that 10 percent of transport fuels come from renewable sources by 2020, and that mandate requires almost tripling the approximately 15 billion liters of biofuels consumed in 2009. The United States has mandated that 36 billion gallons (136 billion liters) of biofuels be consumed by 2022, which requires more than tripling the 11.1 billion gallons (42 billion liters) of biofuels consumed in 2009. Most of the increase in U.S. biofuel consumption will be for ethanol because that is the dominant transport fuel in the United States, and the mandate for biodiesel consumption is comparatively small at 1.0 billion gallons (3.8 billion liters). The EU demand for biofuels to meet the consumption mandate will also require larger increases in ethanol than in biodiesel because current biodiesel production is larger and therefore nearer the mandated consumption than ethanol.

The rapid increase in the global demand for biofuels, especially ethanol, over the next decade or more will provide opportunities for African exporters because neither the EU nor the United States is expected to be able to meet its consumption mandates completely from domestic production. The EU ethanol market is especially attractive for African biofuel producers because of duty-free access afforded most African countries under various preferential trade agreements and the high EU tariff on ethanol imports. The U.S. ethanol market also gives African exporters preferential access, but it has lower tariffs and is not expected to be the target market for African producers. Biodiesel exports offer less of an opportunity for African producers because EU and U.S. import duties are lower and duty-free access offers less of an advantage over low-cost Southeast Asian producers. Ethanol production for export will need to be large scale to reduce production costs and will most likely be from sugarcane because that proven technology can be adapted to African conditions. Smallholders will be able to participate as outgrowers, but they will need government assistance to establish their sugarcane fields. Large-scale biodiesel production for export is less attractive for African producers because production costs are expected to be higher than for Southeast Asian producers and tariff advantages to the EU or U.S. markets are low and do not offset higher production costs. However, smallholders may be able to produce biofuel feedstocks, such as jatropha seeds, for export to the EU for processing into biodiesel, taking advantage of the EU's already established large-scale processing capacity.

The domestic market for biofuels is also expected to be attractive in many African countries because of high fuel prices and rapid demand growth, and it may offer better opportunities for smallholder participation in producing biofuel crops. The prices of fuel in sub-Saharan African countries are about double those in the most competitive markets, and landlocked countries face even higher prices. Demand for transport fuels is projected to grow by more than 5.0 percent per year in sub-Saharan African countries during 2005–20, and that growth will provide opportunities for domestic use of biofuels. Household cooking is another potentially large and important market in Africa, where biofuels can replace charcoal and wood fuels in urban areas. The demand for such fuels is expected to increase as populations and incomes grow and supplies of traditional cooking fuels become more costly because of depletion of forests near urban centers. In addition to the environmental benefit of biofuels from replacing charcoal and wood fuels, a substantial health benefit could accrue as clean-burning biofuels and vegetable oils replace traditional biomass and reduce indoor air pollution, which contributes to respiratory illness. A third opportunity for biofuel use in domestic markets is as straight vegetable oil (SVO) to fuel stationary power plants and provide power to rural communities not connected to the national grid. Such use already exists in several countries, and it provides both a market for local biofuel feedstocks and electricity for rural communities. Heavy industry in rural areas, such as mining, provides yet another marketing opportunity, where biofuels can replace imported diesel fuel in remote areas.

Most of the increase in demand for biofuels over the next decade will need to be met from first-generation technology unless second-generation technology develops more rapidly than expected. First-generation technology includes producing ethanol from sugar crops, such as sugarcane or sweet sorghum, and from starchy crops, such as cassava, and producing biodiesel from animal fats or vegetable oils. This technology is mature, and large increases in efficiency are not expected. Second-generation technology uses a different process and can use waste from food crops and feedstocks, such as agricultural residue, timber waste, and specialty crops including fast-growing grasses or trees. The basic conversion technologies of second-generation technology are not new, and their commercial development has been pursued for many years. The main reason they are not used commercially is that the necessary conversion technology from feedstock to finished fuel is not technically proven at commercial scale. Second-generation technologies are not expected to contribute significantly to biofuel production for at least a decade, and that means food crops will remain the dominant feedstocks for biofuels. Third-generation biofuels are still at the research and development stage; they include a group of technologies described as "advanced biofuels." Algae are perhaps the best known of these, and certain species can store large amounts of carbohydrates or oil. Algae oil yields per hectare are much higher than those of vegetable oils and require much less water. However, production of large volumes of oil from algae requires large ponds and large capital investments, which increase production costs.

Opportunities for Biofuels in Africa

African countries are well placed to benefit from the increased demand for biofuels because many have large areas of land suitable for producing biofuels as well as abundant labor. Sub-Saharan Africa has more than 1 billion hectares of land with potential for rain-fed crop production according to the Food and Agriculture Organization of the United Nations, of which less than one-quarter is being cultivated. Biofuels offer the prospects of a new cash crop for farmers, increased employment in rural areas, reduced fuel import costs, and foreign exchange earnings. Liquid biofuels, such as ethanol, biodiesel, and SVO, account for a very small share of total energy supplies in Africa, but small quantities of biofuels have been produced and used for almost three decades. Malawi, for example, has produced ethanol from molasses and used it as a substitute for imported gasoline since the early 1980s. However, large-scale production of liquid biofuel to substitute for imported fossil fuel or for export is just beginning. Most countries do not have policies for biofuels. This situation is changing as high fuel prices have encouraged many countries to develop biofuel policies and many investors to focus on Africa as a biofuel producer for export.

Although biofuels can be produced from a wide range of crops, sugarcane and molasses to produce ethanol, and jatropha to produce biodiesel or to be used as SVO seem to be attracting the most interest in Africa. Sugarcane production is well known in Africa, and the technology for producing ethanol from sugarcane and molasses has been refined in Brazil over the past 30 years and can be readily adapted to Africa. Much less is known about jatropha and its suitability for biofuel production, but high labor requirements and low yields are major concerns. Many other crops may have potential as biofuel feedstocks, including cassava and sweet sorghum for ethanol and croton and oil palm for biodiesel or SVO fuel. However, because the widespread interest in biofuel production in Africa is a recent phenomenon, the basic research has not been done to identify suitable crops under alternative conditions.

Biofuel markets are heavily distorted by government subsidies, tariffs, and consumption mandates, and such distortions lead to large variations in biofuel prices among countries and regions. Although such distortions are undesirable from a global welfare perspective and have often led to trade disputes, they do create export opportunities for most African countries because most have preferential access to these protected markets under various trade agreements. The value of these preferences can be very large, especially for ethanol, which has high tariffs in both the EU and the United States. Biodiesel, SVO, and feedstocks used to produce these biofuels have relatively low tariffs, and duty-free access offers less of an opportunity to African exporters for these products. Biofuel producers such as Brazil, Indonesia, Malaysia, and South Africa do not receive the same trade preferences. However, if preferential access were granted to those countries, then the preferences would likely erode and the trade advantage currently available to African producers would be reduced or eliminated.

Challenges Posed by Biofuels

Along with new opportunities for biofuel production come new challenges that must be met if such production is to be sustainable. These challenges include the environmental impact of expanded crop production and manufacturing of biofuels, the land use conflicts that arise from expanded crop production, the impact on food security, and the need for government support to smallholders so they can participate in and benefit from expanded biofuel production. Research programs will also be needed to evaluate alternative crops for their suitability as biofuel feedstocks and to develop improved varieties of the most suitable crops. Possibly this work could be undertaken at the regional level.

Expanding crop production, whether for biofuels or other purposes, poses risks to the environment, including loss of biodiversity, pollution from fertilizers and pesticides, and additional stress on land and water resources. These effects can be reduced by following best practices in the production and harvesting of crops, and policies should be formulated to ensure that best practices are adhered to. Sugarcane burning, for example, is one of the largest sources of air pollution from biofuel production: the smoke, fine particles, and nitrogen gases in the atmosphere cause acid rain that contributes to human health problems. An obvious trade-off exists between employment and the environment, but mechanical cane harvesting is increasing in Brazil and that method will probably become the standard in all countries. Environmentally sensitive areas can be protected from development, and wildlife corridors can be left to allow animal migration between protected areas and wildlife sanctuaries. Opportunities also exist to improve the environment by restoring degraded areas through planting crops such as jatropha that can tolerate conditions where food crops cannot be grown. The manufacturing of biofuels adds the additional challenges of properly disposing of large amounts of organically contaminated wastewater and large volumes of by-products that may have little economic value.

Land laws in many African countries need to be strengthened to protect the rights of local people with insecure land tenure and of communities that agree to long-term land leases with no recourse if biofuel projects fail. Land allocations for biofuels should be transparent, involve all stakeholders, and provide just compensation to those who give up their land for biofuel production. Legal support should be provided to local communities and those with land use claims to help them negotiate with investors and protect their rights. Investors need to be given clear information on criteria for decision making and conditionality. Decision making should be open to public scrutiny and done in a timely manner. Mechanisms should be developed to discourage purely speculative acquisitions of land and to encourage closer ties between local communities and investors so that communities have an ongoing stake in the success of biofuel projects. Possibly local communities and existing land users could be granted equity in biofuel projects. Investors have a strong interest in the fair treatment of local land users and communities to avoid the hostility of local populations, which can lead to myriad problems. Land leases of 50 or 99 years, as are often available in Africa, are unsustainable unless some level of local support exists.

Food security is a major concern of all governments, and recent increases in food crop prices have led many African governments to restrict production of biofuel feedstocks in an effort to improve food security. However, such restrictions raise serious equity considerations because they limit the income opportunities of farmers, who are often among the poorest members of society. These restrictions also limit employment opportunities and wages in rural areas where poverty is often pervasive by limiting production of potentially profitable biofuel feedstocks. A better policy approach is to address food security directly through targeted social safety nets and investments in infrastructure, crop breeding research, and other public goods that increase food production and lower costs. Maintaining low import tariffs can also allow food crops to be imported from neighboring countries or world markets when domestic production is reduced by drought or other factors. Raising incomes of the poor is the most effective way to improve food security, and recent research has shown that increasing biofuel production can contribute not only to economic growth and poverty reduction but also to food security through enhanced purchasing power resulting from economic growth and employment.

Government support to smallholders will be needed if they are to produce new crops for biofuels, such as jatropha. Production practices are not well established for these crops, and farmers will require assistance to grow them. Investment incentives may be required for smallholders to encourage them to plant such crops when those crops will not produce significant yields until the third or fourth year following planting. Improved varieties will need to be developed that are high yielding and tolerant to pests, disease, and drought. Planting materials will need to be produced and disseminated, along with guidance on the appropriate planting procedures and husbandry practices. Following planting, disease and pest control will be needed to protect the plantings, and information on harvesting methods and postharvest handling will need to be provided. Ongoing research will be needed to address new problems that arise, such as new diseases. Such support will stretch the abilities and budgets of many countries that are already doing crop research and providing extension assistance on existing food and cash crops. Delivering these additional services and support will require cooperation between the private and public sectors to identify priorities, carry out the necessary research, and provide other services. Existing policies may need to be changed if they raise feedstock costs to uncompetitive levels by establishing high minimum prices.

Managing price risk is likely to be a major challenge for first-generation biofuel producers because both input and output prices can be very volatile. Hedging this price risk is difficult because financial instruments are not available for some biofuels or their feedstocks. Even when such instruments are available, large variations can exist between local prices and the international prices that are the basis of financial instruments. Managing price risk with financial instruments is difficult even when financial instruments are available, as illustrated by the recent bankruptcy of a large U.S. biofuel producer caused by a failed hedging strategy. Second-generation biofuels should have less price risk because the feedstocks will be less closely linked to food or feed crop prices. However, output prices will still provide volatility and price risk. Biofuel producers should consider several strategies to manage price risk. Purchase agreements for feedstocks should be negotiated, when possible, at favorable terms, and marketing agreements that dampen price volatility and sales should be considered. Producers may be able to reduce price risks by producing for markets that are insulated from international markets by high transport costs. Diversification of both feedstocks and outputs should be considered to allow flexibility to purchase the lowest-cost feedstock and to shift production to the most profitable output. Producing sugar, ethanol, and electricity is an example of output diversification that is widely practiced in Brazil.

Production Costs in Africa

Biofuel producers in the African region are unlikely to be as low cost as Brazilian producers of ethanol or Southeast Asian producers of biodiesel on large-scale projects. However, unique opportunities exist to produce ethanol in Africa at very low cost from molasses, because that feedstock has low opportunity costs. Small-scale production of jatropha oil for local use is also possible from existing farmstead hedges and wild trees. The generally higher costs of biofuel production in Africa are caused by poor infrastructure, weak national agricultural research systems, high import costs on equipment and inputs, and an often unfavorable business environment. In contrast, the lowest-cost biofuel producers in Brazil and Southeast Asia are well established with large rain-fed areas suitable for biofuel crops, decades of management experience, effective research systems that produce high-yielding varieties suited to the region, economies of scale in production, installed infrastructure that reduces transport and export costs and spreads such costs over a large number of producers, abundant land for expansion, supportive government policies, and a favorable business environment.

The African region has little actual experience with producing biofuels, and historical production costs are not available. However, production costs were estimated from models developed for ethanol produced from sugarcane and molasses and for SVO and biodiesel from jatropha using cost estimates from studies by consultants, costs from producers in other countries, and interviews with firms developing biofuel projects in Africa. The focus was on estimating the financial costs of producing biofuels, which are the actual costs incurred in production, rather than the economic costs, which are the full costs to society. Sensitivity tests were performed on the models to identify critical variables, and alternative cases were examined to explore the effect of changes in technology, wage rates, yields, and other variables on production costs. The results are summarized in table ES.1 but should be viewed as indicative.

Ethanol produced from molasses was found to be the lowest-cost biofuel in Africa. Molasses is a by-product of sugar production and an excellent feedstock for ethanol. The ex-factory price of molasses in many African countries has been as low as US$20 per ton because of limited demand for its use as livestock feed and high transport costs that make exporting it unprofitable. Ethanol can be produced for US$0.20 per liter or less when the ethanol distillery is integrated into the sugar factory, and that is usually half the cost of imported gasoline after adjusting for the lower energy content of ethanol. Substantially higher costs would occur if an ethanol plant bought molasses from several factories and transported it to a central site for processing. Ethanol produced from sugarcane is estimated to cost about US$0.50 per liter to produce in large-scale, state-of-the-art factories using mostly company-grown cane. Alternative cases resulted in costs that ranged from US$0.41 to US$0.56 per liter depending on land development costs, yields, and smallholder participation. Smallholder involvement usually raises production

Table ES.1 Estimated Biofuel Production Costs in Sub-Saharan Africa
US$ per liter

Biofuel	*Production cost*
Ethanol from molasses in an integrated plant	0.20
Ethanol from sugarcane in a state-of-the-art plant	0.50
Jatropha oil from the following sources:	
Collected seeds for village processing and use	0.42
Collected seeds for central processing	0.80
Plantation at US$2.00/day wages	0.63
Plantation at US$3.00/day wages	0.75
Plantation at US$4.00/day wages	0.87
Biodiesel from jatropha oil in a small-scale plant	0.11
Biodiesel from jatropha oil in a large-scale plant	0.08

Source: Author's calculations.

costs because of lower cane yields and higher production costs. Second-generation technology could reduce ethanol production costs from sugarcane by about 20 percent, based on current estimates, and allow ethanol production to increase about 50 percent compared with production using only first-generation technology.

Jatropha oil can be produced in small quantities for village use for about US$0.42 per liter, assuming seeds are collected from farmstead hedges and wild jatropha plants and are delivered to a village processing plant for US$0.10 per kilogram of dry seed (as is now being done in several countries). Processing by a mechanical press can extract about 24 percent of the oil from the dry seeds. These costs are very competitive with international vegetable oil prices and local fuel prices; however, such low costs are possible only for small quantities of oil produced from locally collected seeds. When large quantities of seed are collected and transported to a central site for processing, collection and transportation costs can equal the prices paid to producers, causing jatropha oil prices to rise to about US$0.80 per liter. Plantation jatropha is more costly to produce than collected seeds primarily because of costs for hiring labor, and production costs would range from an estimated US$0.63 to US$0.87 per liter depending on wage rates. Producing biodiesel from jatropha oil would cost an additional US$0.08–$0.11 per liter depending on plant scale. Transporting liquid biofuels or jatropha oil to the EU would cost approximately US$0.07–$0.10 per liter. With these costs, jatropha oil would be competitive with high-quality oils such as rapeseed when wage rates are US$2.00 per day but not when wage rates are US$4.00 per day. Sensitivity analysis shows that increasing labor productivity is a high priority whether by increasing the oil content of jatropha seeds, which reduces labor costs per liter of oil, or by increasing harvesting rates per day through crop research, partial mechanization, or other means. Without improvements in labor productivity, firms will have difficulty attracting the labor needed for harvesting and maintenance at wages that can be paid.

Second-generation technology and improved crop varieties should allow production costs to decline in the future. Ethanol from sugarcane is especially well placed to benefit from second-generation technology because the sugarcane residue (bagasse) is already collected and transported to the sugar factory as part of sugar or first-generation ethanol production, and the opportunity cost of the bagasse is low for cogeneration of electricity. The large investment in jatropha currently being made in the region could also benefit from crop improvements that increase labor productivity and raise yields. Synchronized flowering to allow mechanical harvesting or more efficient manual harvesting would have the greatest effect, but higher yields and increased oil content would also lower production costs. Carbon credits have not generally been available for biofuels, but they could become an important source of revenue in the future. The carbon market has grown rapidly, and efforts to reduce greenhouse gas emissions under the Kyoto Protocol or national programs are expected to lead to further growth and higher carbon prices. Biofuels have not benefited because they have been certified as eligible for the Clean Development Mechanism of the Kyoto Protocol only under very limited conditions, but that situation could change in the future, and other opportunities to generate carbon credits may develop.

Policy Framework and Development Strategy for Biofuels

The policy framework necessary for producing biofuels depends on the scope and scale of the industry. If crops that are already being produced and marketed are to be used as feedstocks for biofuels, then a biofuel policy may not be required and the use of crops for biofuels can be treated as an additional demand for existing crops. If production of feedstocks for biofuels is large scale, however, then policies to protect the environment and the rights of current land users with informal rights as well as policies to address other considerations, such as food security, research, and programs to support smallholder involvement, are necessary. When biofuel manufacturing is considered desirable, then environmental policies may need to be strengthened to prevent damage from toxic waste and large volumes of by-products. And when biofuels are to be used as domestic transport fuels, rather than being exported, the policy requirements increase substantially and include the need to establish biofuel standards, mandates on blending, and pricing, taxing, and tariff policies.

A prudent biofuel development strategy would develop biofuels in phases. That process would allow policy support, institutional capacity, and regulatory requirements to be developed as required for each phase rather than all at once, as has been attempted in most countries. Each country's particular situation could determine the progression from one phase to the next. During each phase, preparation for the next phase could begin with the benefit of experience gained. This phased approach would permit the benefits of biofuels to be achieved at each phase while preparations are under way for the next phase. Such a phased development strategy has fewer risks because implementation of each phase builds on the success of the previous phase. The phased approach would also allow countries to better consider their comparative advantage at each phase. Some countries may have a comparative advantage in production of feedstocks but not in manufacture of biofuels, and the phased approach would allow them to evaluate each activity before developing policies.

The first phase could be the production of crops for biofuels for export and the use of SVOs as fuel in stationary power plants and specially modified vehicles. Policy would provide the legal authority to produce crops for biofuels and the use of SVOs for fuels to remove uncertainty for investors and commercial users. The production of crops for biofuels would give farmers new opportunities to produce crops such as jatropha for biofuels. Crops not already grown in the country should require government approval to avoid introducing invasive species, but existing crops could be grown for biofuels at the discretion of the producer. SVO fuel would most likely be produced and consumed in remote areas where imported fuel is costly. It could be used by industries such as mining and other natural resources extractive industries as well as by rural communities to provide electricity to community centers, clinics, and schools, and in diesel engines to power farm machinery such as pumps, crop-processing equipment, and small tractors. The positive rural development effects could be very substantial if such fuel allowed irrigation of food or cash crops. The oils could also be used for home cooking in place of fuel wood and would benefit health by reducing indoor air pollution. Collection and crushing of oilseeds could be community based or done by the private sector and could provide both income and power to rural communities. Institutional support would be required for training, assistance to purchase processing equipment, and research to improve feedstock varieties. Fuel sales to the general public would not be authorized in this phase to prevent possible engine problems when such fuels are used in vehicles not specially adapted for them.

The second phase of a biofuel development strategy could be the manufacture of biofuels for export to take advantage of the preferential access most African countries have to the EU and other markets. This strategy would have the advantage of providing income, employment, and a market for feedstocks without the need for the policy support and institutional capacity to regulate the consumption of biofuels. The private sector would handle production, most likely using production platforms such as the Brazilian model for producing ethanol from sugarcane or the large-scale production and processing of oilseeds for export as vegetable oils or biodiesel. The institutional support and policy requirements would be much larger than for phase one, but still much less than would be required to support consumption of biofuels. Land use, property rights, environmental impacts, and health and safety issues would need to be addressed. Research should be focused on improving feedstock varieties for smallholder production so that benefits can be widely shared. The institutional capacity could be developed to monitor and regulate feedstock production, and the tax revenues would be available to support the industry. Because sale of SVO would be permitted in phase one, it should also be permitted in phase two, but only for commercial use, not for retail use. The private sector would need to accept responsibility for product quality and perform necessary testing for appropriateness for their application.

The third phase would require the greatest level of institutional capacity and government support and would include production and retail sale of biofuels for transport. Biofuel standards would need to be defined, monitored, and enforced. Regulations would need to be developed on handling, storage, transport, and distribution. Blending facilities would be needed, and procedures, regulations, and investment incentives would need to be agreed on. Pricing, taxing, and tariff policies would be needed. Limits on blending levels of biofuels with fossil fuels must be established. This final phase could be economically justified in countries that have sufficient quantities of low-cost feedstocks, such as molasses, that could be used to produce ethanol. However, this final phase involves considerable risk because it also is likely to require consumption mandates, price incentives, and tariff protection. That has been the case in all countries that have developed biofuels for domestic use, and it would probably be required in most African countries. Without such policy support, the private sector may be unwilling to make the investments in production facilities and distribution networks needed to support biofuel production.

The international community, multilateral organizations, and donors can support the development of a sustainable biofuel industry in African countries by providing financial support, policy guidance, and opportunities for capacity building. Research will be needed to identify and improve suitable crops for biofuels, which could be undertaken at the regional level with donor support. Smallholder participation will require training, access to technology, and credit, which could be supported by donor-funded programs. Assistance with identification of areas with high biodiversity that will not meet the sustainability criteria of importing countries will be needed, so these areas can be excluded from biofuel production. Foreign investors can also contribute to the development of a sustainable biofuel industry by providing investment capital, technology, and management experience.

Conclusions

Biofuels offer an opportunity for African countries to produce new cash crops for domestic use or export. High energy prices and large consumption mandates already agreed to in many countries suggest that these opportunities will exist for an extended time. The entire rural sector will feel the effects of expanded production of crops for biofuels as resources are shifted away from traditional crops and prices of all agricultural commodities rise. African biofuel producers are well placed to produce biofuels because of their relatively abundant land resources and preferential access to protected markets with higher-than-world-market prices for biofuels. The rights of current land users must be protected, and equitable methods of revenue sharing with local communities must be found if production is to be sustainable. Protecting the environment and biodiversity are also vital to the sustainability of biofuel production; this can be done by using best crop production and harvesting practices and establishing protected areas. Policies needed for biofuels depend on the scope and scale of the industry, and countries should take a phased approach rather than approving all aspects of biofuels at one time. Institutional capacity will need to be expanded, and new regulations and procedures developed. Countries new to biofuel production can benefit from the experience of other countries in the region and elsewhere in designing their biofuel strategies. Multilateral institutions, donors, the development community, and investors can contribute to the development of a sustainable biofuel industry in Africa by providing financial support, technology, policy guidance, and an opportunity for shared learning among those involved in developing biofuel policies.

CHAPTER 1

Introduction

The rapid rise in energy prices over the past several years is seen as the beginning of a new era in which energy prices will remain high for an extended period. Several factors drive this situation, including the rapid growth in demand for energy in developing countries such as China and India following their sustained rapid per capita income growth over many years. More available income has led to an increase in the demand for transport fuel for both personal and commercial use, and that trend is expected to continue as more consumers achieve middle-income status. The supply of energy is also expected to be more costly to produce than in the past because of the depletion of easily accessible supplies of crude oil as major oil fields age and production declines. New oil fields are being located and developed, but many are in remote areas, politically unstable regions, and deep oceans. Thus, interest in biofuels as an alternative and renewable supply of transport fuels has revived, which in turn has led many countries to adopt policies encouraging production and mandating consumption of biofuels.

Concern over global climate change has also contributed to the renewed interest in biofuels as an alternative to fossil fuels as a way of reducing greenhouse gas emissions. The debate over the effectiveness of biofuels as a way of reducing greenhouse gases is ongoing, but both the

European Union and the United States have recently approved legislation that requires large increases in consumption of biofuels over the next decade or more. These mandates seem unlikely to be abandoned, although they may be tempered if adequate supplies of biofuels are not available to meet these mandates without disrupting other markets, such as food. For both the European Union and the United States, meeting these mandates will be difficult if domestic production of food crops is used as feedstocks for biofuels, unless second-generation biofuel technology develops quickly. However, the contribution of second-generation technology for producing biofuels is uncertain, and a large portion of these mandates will likely need to be met with first-generation technology that relies on food crops such as grains, sugarcane, and oilseeds as feedstocks. Imports are expected to be needed to meet these mandates, thus providing new opportunities to African countries and other developing countries that can produce biofuels or the feedstocks for biofuels competitively. Rapid growth in demand for transport fuels in African countries and high fuel prices also create opportunities for biofuel production and domestic use.

Biofuels are a relatively new economic activity for most African countries, even though the diesel engine was designed to run on biofuels more than a century ago and several African countries have produced ethanol for several decades. Moreover, because they are relatively new, much is still to be learned about feedstocks and technology. Jatropha has a long history of production in sub-Saharan Africa but a short history of commercial production, and many of the projects that use jatropha as the primary feedstock are still searching for good plant varieties and uses for the by-products. Projects that pass the initial start-up phase may look very different in a decade or more as production techniques are tried and refined. Other crops, such as sugarcane for ethanol production, are tried and tested in other regions and should be adaptable to Africa. However, low-cost producers in Latin America and Asia will be formidable competitors for the export markets.

The objective of this book is to deepen understanding of the potential of biofuels in the African region and to examine the domestic and foreign policies that influence that potential. The book examines the important characteristics of biofuels within the African context, evaluates the market opportunities and economic viability of biofuels, and examines domestic and foreign policies. The focus is on the production of liquid biofuels, such as ethanol and biodiesel, for export or domestic use in transport or household energy requirements such as cooking and lighting. The book also considers the potential of using straight vegetable oil in stationary power plants and specially modified vehicles. The time frame is the period to 2020. The book examines the experience of countries and companies to learn lessons that can improve the performance of the biofuel sector and avoid costly mistakes. Policy recommendations are presented for a multistage biofuel development strategy that will allow countries to begin to benefit from biofuels while developing the institutional capacity and policies to expand the role of biofuels in the economy. The intended audience for this book is policy makers in African countries, the development community, and investors. It will also be of interest to other developing countries that face many of the same issues as African countries.

The book begins by examining the characteristics of biofuel production, consumption, trade, pricing, and use in chapter 2, as well as related topics such as alternative feedstocks, biofuel standards, and opportunities to obtain credits for biofuel production as clean development mechanisms under the Kyoto Protocol. The importance of by-products is discussed, and the implications for exports of feedstocks and manufactured biofuels are examined. Chapter 3 looks at the cost of producing biofuels in Africa and other major producers, focusing on sugarcane and molasses to produce ethanol and on jatropha under both smallholder and plantation production for use both as raw vegetable oil fuel and as a feedstock for biodiesel production. Chapter 4 looks at the regional and global demand for biofuels and projects the growth of demand for gasoline and diesel for selected countries in the African region based on an econometric model. Preferential access to the European Union and U.S. biofuel markets is compared, and policies of other major biofuel-producing and biofuel-consuming countries are examined. Chapter 5 looks at three case studies to learn the lessons from their experience in producing jatropha and sugarcane ethanol. One of the studies presents the experience of D1 Oils plc, a U.K. share company that is the world's largest jatropha producer with more than 220,000 hectares of jatropha trees. Chapter 6 looks at policy issues related to biofuels, including environmental, land, food security, agricultural support, and the effect of protection on competitiveness. The policy framework needed to legalize and regulate biofuels is also discussed, and a phased development approach is recommended. Appendix A looks at the Brazilian experience and the lessons learned, and appendix B presents selected data on African countries for population and income, food consumption and nutrition, land availability and use, and agricultural production and productivity. The data reflect some of the factors to consider in evaluating food security and resources potentially available for biofuels.

This book does not cover important global issues, such as the effect of biofuels on greenhouse gas emissions, global food security, or global welfare and resource allocation. Although such topics are important, they are covered elsewhere or are beyond the scope of this book. The effect of biofuel production on greenhouse gas emissions has been estimated in a number of studies, and the current research focuses heavily on the impact of direct and indirect land use changes on greenhouse gas emissions. Food security at the national and global levels is the focus of two multiyear studies under way by the Food and Agriculture Organization of the United Nations and the International Food Policy Research Institute; final results from those studies will be available soon. The global welfare implications of biofuel policies are not considered in this book, but the evidence from previous work on distortions in agriculture suggests that such policies distort trade, impose large global welfare costs, affect food crop prices, and limit exports from lower-cost biofuel producers. Efforts to reduce such distortions are among the most contentious trade issues and are one of the important reasons why the Doha Round of multilateral trade negotiations has not been concluded. The classification of ethanol as an agricultural good within the World Trade Organization has allowed such high tariff protection to occur, whereas tariffs on biodiesel are low because it is not classified as an agricultural good. Such tariffs will probably become important in future trade talks. Such policies are most often designed to protect domestic producers from lower-cost exporters, but they also provide preferential access to certain groups such as the least-developed countries. More direct support to such countries would be more beneficial and have lower costs because it would not impose such large global welfare costs or distort resource allocations and trade.

CHAPTER 2

Understanding Biofuels in Africa

Biomass is the primary source of energy in African countries, used mostly as wood fuel and charcoal for home cooking, lighting, and heating. Liquid biofuels, such as ethanol, biodiesel, and straight vegetable oil (SVO), account for a small share of total energy supplies, but they have been used for almost three decades, and production is increasing. Malawi and Zimbabwe, for example, have produced ethanol from molasses and used it as a substitute for imported petrol since the early 1980s. Ethiopia currently exports ethanol produced from molasses, and Sudan recently acquired equipment to produce ethanol from molasses. Mali has used jatropha oil to power stationary power plants in rural villages since the mid-1990s. However, large-scale production of liquid biofuels to substitute for imported fossil fuels or to export is just beginning. Most countries do not have policies that allow biofuels to be sold as fuel, and the lack of such policies partly accounts for their limited use, along with low fuel prices during most of the 1980s and 1990s, which discouraged biofuel production. This situation is changing, because high fuel prices have encouraged many countries to develop biofuel policies and many investors to focus on Africa as a biofuel producer. Biofuels offer the prospects of increased employment, a new cash crop for farmers, reduced fuel import costs, and increased foreign exchange earnings. They also raise concerns about the impact on the environment, potentially raise land-use conflicts, and have led to concerns about their impact on food prices and food security. This chapter briefly reviews the important elements of biofuels in Africa, including aspects of production, consumption, pricing, and trade. Other issues, such as biofuel standards, the potential for biofuel production to generate carbon credits, and the potential for greenhouse gas emissions savings from biofuels, are also discussed.

Production

Biofuels can be produced from almost any biomass or animal fat; however, they can be economically produced only from a few of these products (referred to as *feedstocks*). For biofuels to be profitably produced, the concentration of sugars, starches, or fats in the feedstock must be high enough, relative to the cost of the feedstock and the price of the biofuel, to justify processing. This situation can occur when the biomass produced per hectare is very high (the case with sugarcane) or when the concentration of sugar, starches, or oils used to produce the biofuel is very high per unit (the case with many oilseeds, such as jatropha). The feedstock must also be available in sufficient quantity to achieve economies of scale in biofuel production. Animal fat, for example, is usually a low-cost feedstock for producing biodiesel, but it is available only in small quantities from slaughterhouses and cannot be used for large-scale biofuel production. Used cooking oil is more viable as a biofuel feedstock because it can be animal fat or vegetable oils and because it is more readily available. However, it is still not available in sufficient quantities to allow a significant contribution to local fuel requirements. Transport costs can often determine whether biofuel production is economically viable from a particular feedstock. In general, the shorter the distance from the field to the factory and from the factory to the consumer, the lower the transport costs will be; thus, crops that have high yields per hectare will have lower transport costs and greater potential for profitable biofuel production. The technology used to produce biofuels is also important and determines how much biofuel can be produced per unit of a given feedstock.

Technology

Producing biofuels from food crops is generally referred to as *first-generation technology* and includes producing ethanol from sugar crops, such as sugarcane or sweet sorghum, and starchy crops, such as maize or cassava. It also includes producing biodiesel from animal fats or vegetable oils. Straight vegetable oil can also be used as a biofuel in certain types of diesel engines without processing, and it can be used in most diesel engines (including light vehicles) with only minor modifications to the engine and pretreatment of the SVO prior to use. The properties of ethanol are independent of the feedstock used in production, whereas the properties of biodiesel or SVO depend on the feedstock.

First-generation technology for producing ethanol is to ferment sugars into ethanol. This process is easiest from sugar crops because the sugars (such as sugarcane juice) are already available in the plant material. Producing ethanol from starchy crops requires an additional step of first converting the starches into sugar and then fermenting them into ethanol. This process is generally more costly than producing ethanol from sugar crops. First-generation technology also includes producing biodiesel from animal fats or vegetable oils through a process called *transesterification*, whereby the fat or oil is mixed with alcohol and a catalyst to produce biodiesel. This relatively simple process can be done on a small scale; however, many unwanted reactions and chemical substances can develop during the process that can contaminate the fuel and make the quality of the biodiesel from small-scale plants variable in energy content, viscosity, and lubricity properties (IEA 2008a). Quality is less of a problem in large automated biodiesel plants because of better controls and testing facilities, and those plants can consistently produce biodiesel to acceptable final product standards.

Although first-generation technology is considered mature, the two largest producers of first-generation ethanol, Brazil and the United States, have experienced significant gains in production efficiency and significant cost reductions over the past several decades. Brazil produces ethanol from sugarcane and has seen sugarcane yields rise by one-third in the main São Paulo producing region from 1975 to 2000. Ethanol production per unit of sucrose has increased by 14 percent, and productivity in the fermentation process has increased by 130 percent. These efficiency gains allowed the cost of ethanol production to decline by an average of 5.7 percent per year from 1985 to 2005 (Moreira 2006). The United States produces ethanol mainly from maize and has also seen efficiency gains from larger-scale plants and several new processing techniques that reduced input requirements and improved process yields. Energy-saving technologies, such as the reuse of liquefaction and scarification energy for removing water from ethanol in the distillation column, have led to a more than 70 percent decline in the thermal and electrical energy used to produce ethanol. Process automation and distributed control systems have reduced labor requirements, and several improvements in fermentation technology, the most important of which was simultaneous scarification and fermentation, have improved yields. Plants are now able to produce more than 2.8 gallons of ethanol per 56-pound bushel (0.417 liter per kilogram) of maize compared to less than 2.5 gallons in 1980 (Shapouri and Gallagher 2005), and maize yields in the United States increased 48 percent from 1979–81 to 2004–06. Further gains in first-generation technologies from higher crop yields, larger scale, and improved manufacturing processes are possible; however, large advances in efficiency are not expected.

Second-generation technology uses different processes, and a wide array of feedstocks can be used, including agricultural residue, timber waste, and specialty crops such as fast-growing grasses or trees (BR&Di 2008). Second-generation technology should offer substantial advantages over first-generation technology, including greater reductions in greenhouse gas emissions, reduced land-use requirements, and less competition for land, food, fiber, and water. The basic conversion technologies of second-generation biofuels are not new, and their commercial development has been pursued for many years. They are not used commercially because the necessary conversion technologies from feedstock to finished fuel are not technically proven at commercial scale, and their costs of production are estimated to be significantly higher than for many first-generation biofuels. Significant research, development, and design challenges remain before widespread use is possible, but several pilot-scale plants are in operation and larger demonstration plants are planned or under development. In addition to high costs and the unproven conversion technologies, second-generation biofuels require large volumes of biomass, which presents a logistical challenge for some feedstocks.

Second-generation technology for producing biofuels would use cellulose and hemicellulose components of the biomass. The production of biofuels from lignocellulosic feedstocks can be achieved through two different processing routes, both of which are currently at the demonstration phase:

- Biochemical enzyme hydrolysis—in which enzymes and other microorganisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol
- Thermochemical biomass to liquid—where pyrolysis or gasification technologies produce a synthesis gas ($CO + H_2$) from which a wide

range of long-carbon-chain biofuels, such as synthetic diesel or aviation fuel, can be re-formed.

These are not the only second-generation biofuel pathways, and several variations and alternatives are under evaluation in research laboratories and pilot plants, including dimethyl ether, methanol, or synthetic natural gas. However, at this stage these alternatives do not represent the main thrust of research and development investments (IEA 2008a).

Biochemical enzyme hydrolysis could be expected to produce up to 300 liters of ethanol per dry ton of biomass, whereas the thermochemical route could yield up to 200 liters of synthetic diesel per ton but with a higher energy density by volume. The thermochemical routes can also be used to produce a range of longer-chain hydrocarbons from the synthesis gas. These hydrocarbons include biofuels better suited for aviation and marine purposes. Only time will tell which conversion route will be preferred. Whereas alternative drives may become available for light vehicles in the future (including hybrids, electric plug-ins, and fuel cells), such alternatives for airplanes, boats, and heavy trucks are less likely, and liquid fuels will continue to dominate those uses.

Production of first-generation biofuels, particularly sugarcane ethanol, will continue to improve through increased cane yields and process improvements and is expected to play a continuing role in biofuel production. The transition to integrated first- and second-generation biofuel production will, therefore, most likely encompass the next one or two decades as the infrastructure and experience gained from using first-generation technology are transferred to support and guide second-generation biofuels (IEA 2008a). When second-generation technologies are fully commercialized, they will likely be favored over first-generation technologies because of their superior environmental benefits and reduced competition for food and feed. Several first-generation production paths appear to offer natural transitions to second-generation production, with sugarcane ethanol being a good example. Sugarcane ethanol has attained efficiency and cost competitiveness in first-generation ethanol production, and the availability of sugarcane residue (bagasse) already at the factory as part of the sugar or ethanol production process provides a ready feedstock for second-generation technology. Other first-generation feedstocks, such as cereals, may also offer opportunities for second-generation biofuels by using the stalks or straw that is normally left in the field as feedstocks, but this approach would entail the added cost of collecting and transporting the biomass to the factory for processing. Projections of when second-generation biofuels will become commercial are wide-ranging, with the first fully commercial-scale operations possible as early as 2012. However, widely deployed commercial plants are not expected before 2015 or 2020 (IEA 2008a). The Intergovernmental Panel on Climate Change's fourth assessment report did not expect second-generation biofuels to be commercialized before 2030 (IPCC 2007).

Production costs for first-generation biofuels are well understood and depend on the cost of the feedstock, the efficiency and scale of the processing plant, and the value of the by-products. Feedstock costs dominate; they account for about 80 percent of the cost of producing biodiesel, for about two-thirds of ethanol production costs from sugarcane in Brazil, and for about half of production costs of ethanol from maize in the United States. The share of feedstocks in production costs rises as the price of the feedstock rises because manufacturing costs do not rise in proportion to feedstock costs. The cost of second-generation biofuels remains uncertain, but the International Energy Agency estimates that ethanol costs would range from US$0.80 to US$1.00 per liter of gasoline equivalent and at least US$1.00 per liter of diesel equivalent for synthetic diesel (IEA 2008a). These estimates broadly relate to gasoline and diesel wholesale prices in the United States when crude oil prices are between US$100 and US$130 per barrel. These prices are higher than for alternative energy sources, such as heavy oil, tar sands, gas-to-liquid and coal-to-liquid, that can compete with oil at around US$65 per barrel, excluding any penalty imposed for higher carbon dioxide emissions. Widespread deployment of second-generation technology is expected to lead to technology improvements, reduced costs of plant construction, and lower operating costs as experience is acquired. These developments could lead to costs of between US$0.55 and US$0.60 per liter of gasoline equivalent for both ethanol and synthetic diesel in the next 20 years if second-generation commercialization succeeds in the 2012–15 period and rapid deployment occurs beyond 2020.

Third-generation biofuels are still at the research and development stage. They include a group of technologies described as "advanced biofuels," and algae are perhaps the best known of these. Algae are the fastest growers of the plant kingdom, and certain species can store large amounts of carbohydrates or oil. Algae oil yields per hectare are claimed to be 16 times higher than palm oil, and algae consume 99 percent less water. But to produce large volumes of oil from algae requires large ponds and large capital investments. Algae's potential has been understood for many years. Research was widely undertaken in the 1970s, was abandoned in the 1990s, and has only recently revived. The cost of production is thought to be around US$5 per liter, but researchers say uncertainty remains about when algae biofuels will become commercially viable (IEA 2008a). Most third-generation technologies are expected to be more evolutionary than revolutionary, with biorefineries, for example, producing multiple products from varying biomass feedstocks in much the same way that a petroleum refinery produces more than 2,000 products from crude oil.

Feedstocks for Biofuels

Many different feedstocks can be used to produce biofuels. The ones receiving the greatest interest in Africa are sugarcane or molasses to produce ethanol and jatropha to produce biodiesel or to be used as SVO. Other promising feedstocks in Africa are cassava and sweet sorghum to produce ethanol, oil palm to produce biodiesel, and croton to be used as SVO. Mozambique recently approved sugarcane and sweet sorghum for ethanol production and coconut and jatropha for biodiesel production (Locke 2009). Maize and other grains could also be used to produce ethanol as they are in the United States and Europe; however, grains are not expected to be an attractive feedstock in most African countries because of high production costs and limited demand for the by-product feed. Soybean, rape, and sunflower seeds are used to produce biodiesel in Europe and the United States, but they are generally not well suited to production in tropical climates and have not received widespread attention as feedstocks for biofuels in Africa. South Africa, however, which has a more temperate climate, approved soybean, rape, and sunflower seeds for biodiesel production in its biofuel strategy approved in December 2007.

Sugarcane and molasses are generally considered to be the lowest-cost feedstocks for biofuel production, and they are the primary feedstocks used in Brazil's ethanol program. Africa has a number of established low-cost sugar-producing countries, including Malawi, Swaziland, Zambia, and Zimbabwe, as well as newcomers, such as Mozambique. Sugarcane has several advantages as a feedstock: high yields of biomass per hectare, sugars that can be fermented directly into ethanol, and bagasse for powering the factory. Sugarcane also has the advantage of providing an easy progression path to second-generation technology because the bagasse that would be used as feedstock to produce second-generation cellulosic ethanol is already transported to the factory as part of the sugar production process. Molasses is usually a cheaper feedstock than sugarcane juice because it has low opportunity costs in Africa and has a high sugar content.[1]

Jatropha (*Jatropha curcas* L.) has only recently been viewed as a feedstock for biofuels, although it has been grown in Africa and other regions for centuries as hedges. This drought-resistant shrub is native to Central America but found its way to Africa for use as farm hedges because the leaves are toxic and animals avoid them. The seeds from jatropha are not edible and have traditionally been used for making soap and for medicinal purposes. The oil content of the dry seeds is between 30 and 40 percent, and the oil is well suited for biodiesel production, use as an SVO fuel, or as a replacement for kerosene in lamps. Biodiesel made from jatropha oil can meet the European Union (EU) standard for biodiesel, which few other oils can. The press cake is high in nitrogen and can be used as fertilizer. Jatropha's recent popularity stems from its perceived ability to grow on degraded land and the fact that it is not a food crop. Thus, it does not compete directly for resources used for food production. However, as more is learned about jatropha, its desirability as a feedstock for biofuels is questionable. Yields under marginal conditions are low, and more intensive production practices on better-quality soils risk competition with food crops. A major constraint is high labor costs in harvesting because jatropha flowers over an extended growing period and the fruit does not ripen simultaneously and must be handpicked. Yields on mature shrubs are reported to range from 0.4 to 12.0 tons of dry seed per hectare, and potential yields of 7.8 tons per hectare are thought to be possible under good conditions (Jongschaap and others 2007). The oil production would range from 0.13 ton of oil per hectare at the low end of the yield range to 2.5 tons under maximum expected yields. Research is under way in a number of locations to collect plants from various locations and conditions, select for yield and desirable properties, and then produce improved varieties that can become the plant material for large-scale production. Such research is expected to take 5 to 10 years or more.[2] Previous attempts at commercial production of jatropha were unsuccessful in Nicaragua (Foidl and others 1996) and Brazil (von Braun and Pachauri 2006).

Jatropha may have better potential for use as a biofuel in niche markets and in remote areas where diesel to power generators is not available or is expensive because of high transport costs. It may also have potential for use on marginal or degraded soils to prevent erosion, enrich the soil, and rehabilitate degraded areas that have been used for charcoal production. Estimated plantings of jatropha in Africa totaled 73,000 hectares in 97 projects in mid-2008 (GEXSI 2008), but yield and production data for these projects are not available. Many of these projects may have been scaled back because of the decline in crude oil prices in the second half of 2008 and the global recession, which reduced funding for such investments.

Sweet sorghum may have potential as an important feedstock for ethanol production in Africa while providing human food from the grain and animal fodder from the leaves (ICRISAT 2007). Sweet sorghum can be grown in dry or semiarid tropics as a rain-fed crop in areas with more than 700 millimeters of rainfall. A crop of sweet sorghum takes four to five months to grow and can be followed by a ratoon crop (the natural second regrowth from stubble after the first crop is harvested). Sweet sorghum requires comparatively less fertilizer, water, and labor than sugarcane and is planted from seeds that require less labor than planting sugarcane cuttings. It also has the advantage of mechanized sowing and harvesting. The ethanol yield per ton of feedstock for grain sorghum is lower than for sugarcane, but lower production costs and water requirements make it cost competitive with sugarcane for ethanol production. Sweet sorghum grain yields are about 25 percent lower than those of grain sorghum.

The cellulose in the sweet sorghum stalks can be burned to power the factory, used as animal feed, or used as feedstock for second-generation ethanol production. Uganda began commercial production of ethanol using sweet sorghum in 2007 with technical support from the International Crops Research Institute for the Semi-Arid Tropics (Kojima, Mitchell, and Ward 2007), but sweet sorghum is not widely grown in Africa and research is needed to improve varieties. Research at the University of Zambia (Kalaluka n.d.) suggests that sweet sorghum can be used to supplement sugarcane and can be processed in existing sugar mills without any modifications (Woods 2001). One of the challenges of sweet sorghum is that it matures at one time and must be processed within a few weeks of harvesting. Unless other feedstocks are available, ethanol production facilities would be underused or idle for several months each year. However, when sweet sorghum is used to supplement sugarcane, the same factory can process both crops. Some sweet sorghum varieties were found to be competitive with sugarcane, with yields of 2–4 tons of grain, 5–7 tons of dry leaves, 15–20 tons of bagasse, and 5–9 tons of syrup, or 3,000–4,000 liters of ethanol per year (Nimbkar and Rajvanshi 2003). These varieties could be grown in between sugarcane crops to boost ethanol production.

The African oil palm is a tropical tree native to West Africa that produces oils well suited as a feedstock for biodiesel production or SVO fuel. It has the potential to grow well in the more tropical parts of Africa and has been grown successfully in West Africa and within about 20 degrees of the equator. A mature tree grows to 20 meters and produces clusters of fruit (bunches) that can weigh 40–50 kilograms and consist of an oily, fleshy outer layer (the pericarp) with a single seed (kernel). Palm oil is derived from the pericarp and is used mainly as cooking oil; palm kernel oil is derived from the seeds and is used in processed foods. Palm oil also is used in the manufacture of soap (such as the American brand Palmolive) and cosmetics. The palm fronds and kernel meal are processed for livestock feed. One hundred kilograms of fruit bunches produce about 22 kilograms of palm oil and 1.6 kilograms of palm kernel oil. One hectare of oil palm can produce more than 20 tons of fruit bunches that can yield more than 4 tons of oil. Oil palm from West Africa was planted in Indonesia in the mid-1800s and in what is now Malaysia in the early 1900s; those two countries now account for about 85 percent of global production.

Both smallholders and plantations in Southeast Asia grow oil palm. It costs the least to produce of the major vegetable oils, with production costs estimated to be about 20 percent lower than for soybean oil, which has the next-lowest cost of the major vegetable oils (Carter and others 2007). Oil palm is very responsive to fertilizers; about one-third of production costs in Southeast Asia are for fertilizer. Because palm oil is relatively high in saturated fats, it becomes semisolid at room temperature. Biodiesel produced only from palm oil has limitations in colder climates because it has a high cloud point (begins to form solids). However, it can be used year-round in warmer climates and during the summer months in colder climates.

Environmental concerns have been raised about the clearing of tropical forests to plant oil palms in Southeast Asia. According to recent research (Koh and Wilcove 2008), more than half the oil palm expansion occurred between 1990 and 2005 in Malaysia and Indonesia at the expense of forests. Despite such concerns, clearing continues to expand rapidly because of palm oil's high profitability and strong support from both national and local governments in Southeast Asia. Governments recognize palm oil production's contribution to employment, income, and foreign exchange earnings.

As grown by smallholders in West Africa, the oil palm is largely sustainable according to the United Nations Development Programme

(UNDP 2007, 144, box 3.9), and the Food and Agriculture Organization (FAO) of the United Nations has encouraged small farmers across Africa to grow oil palm because of its opportunity to improve livelihoods and incomes of the poor. Oil palm fruit yields in many African countries are low relative to those of Southeast Asia, with average yields of only 3.7 tons of fruit bunches per hectare compared with more than 20 tons in Malaysia and 17 tons in Indonesia. The largest African producers are in West Africa, led by Cameroon, Côte d'Ivoire, Ghana, and Nigeria. According to FAOSTAT (the FAO statistics database), yields vary greatly among these producers: Nigeria produces only 2.6 tons of fruit bunches per hectare, whereas Cameroon produces more than 22 tons per hectare, and Ghana and Côte d'Ivoire produce 6–7 tons per hectare.[3] If produced using intensive practices similar to those in Southeast Asia, oil palm could become the low-cost feedstock for biodiesel in Africa. However, environmental concerns would need to be addressed and sustainability criteria of importing countries met.

Cassava may have potential as a low-cost feedstock for ethanol production in Africa. It is better suited to smallholder production than sugarcane. Cassava is already widely grown in Africa by smallholders as a basic staple food crop, and it could be grown as a cash crop. It is drought tolerant, can grow on marginal soils, and has the potential for continuous harvesting because the crop does not mature as do most crops. Continuous harvesting would allow better use of the ethanol production facility because production would be less seasonal than would be the case with an annual crop that matures. Yields are high, with an estimated 12 tons per hectare in Nigeria—the world's largest producer (FAOSTAT). Ethanol production costs from cassava were estimated to be US$0.45 per liter in Thailand during 2002–05, with cassava yields averaging 18.5 tons per hectare, cassava prices averaging US$30 per ton, and the scale of ethanol production capacity at 50 million liters per year (Yoosin and Sorapipatana 2007). However, these costs may not be representative because sugarcane bagasse from a nearby sugar factory provided power and reduced costs.[4] Ethanol production from cassava in Africa would need to use a mix of plantation and outgrower production to ensure a steady supply to operate the factory at full capacity and contain overhead costs (Caminiti and others 2007). Collection costs from outgrowers could be high because fresh cassava tubers are 60–70 percent water and deteriorate if not processed within two or three days. Cassava could be chipped and sun dried in villages to reduce transport costs, as is done in Thailand. FAO estimated that a typical cassava ethanol system in Africa could be competitive with fossil fuels when crude oil prices were US$45 per barrel (FAO 2008).

Many other crops could potentially be used as feedstocks for biofuels; one of the more promising is croton. The croton tree (*Croton megalocarpus*) is native to Africa and grows wild in the area around Lake Victoria at altitudes of 1,200 to 1,600 meters, where it receives at least 800 millimeters of rainfall per year. Local farmers use it primarily as a shade and ornamental tree. Croton trees begin to produce seeds at 3 years, reach maturity at about 11 years, and continue to produce for at least 45 years. The seeds contain about 32 percent oil, which is similar to jatropha oil and can be processed into biodiesel or used as SVO for stationary power plants, marine engines, or farm machinery. The cake is not toxic like jatropha and can be used as feed. The seeds fall from the tree when ripe, unlike jatropha, making harvesting croton less labor intensive than harvesting jatropha. The crop is unproven for use as biofuel, but testing of croton oil and field surveys suggest it has potential in remote areas, such as western Tanzania, where importing diesel is expensive because of high transport costs. Yields are estimated to be 1,720 liters of croton oil per hectare (Africa Biofuels 2006; GTZ and Kenya Ministry of Agriculture 2008).

Yields of Biofuels per Hectare

Biofuel yield per hectare is one criterion by which biofuel feedstocks could be measured. Using that criterion, sugarcane, oil palm, and cassava rank highest among crops that could be used for biofuels in Africa. Sugarcane is the highest-yielding feedstock globally for biofuel production, with an estimated 5,376 liters of ethanol per hectare based on global average sugarcane yields of 66 tons per hectare (table 2.1). As much as 8,000 liters per hectare could be expected under irrigated conditions in many African countries because of higher cane yields. Oil palm is the second-highest yielding feedstock globally, with an estimated 3,136 liters of biodiesel per hectare based on global average yields and approximately 4,400 liters in the highest-yielding Southeast Asian countries. Cassava is the highest-yielding of the starchy crops, with more than 2,000 liters of ethanol per hectare based on global average yields of 11.5 tons, and more than double that could be expected under more intensive production techniques in the African region. The ethanol yields per hectare for maize are similar to cassava based on global average yields, but yields are much higher in the United States because U.S. yields are more than double the global average. In contrast, maize yields in the African region are only one-third of the

Table 2.1 Biofuel Yields of Major Feedstocks

Crop	*Biofuel*	*Conversion efficiency (liter/ton feedstock)*	*Global average crop yield (ton/hectare)*	*Yield of biofuels (liter/hectare)*
Cassava	Ethanol	180	11.5	2,071
Castor	Biodiesel	393	0.9	364
Coconut	Biodiesel	130	5.3	690
Groundnuts	Biodiesel	309	1.6	484
Jatropha	Biodiesel	340[a]	—	—
Maize	Ethanol	410	4.8	1,988
Oil palm	Biodiesel	223	14.1	3,136
Potato	Ethanol	110	16.9	1,860
Rapeseed	Biodiesel	392	1.8	704
Rice	Ethanol	430	4.1	1,754
Sesame	Biodiesel	440	0.5	200
Sorghum	Ethanol	402	1.3	532
Soybean	Biodiesel	183	2.3	419
Sugarcane	Ethanol	81	66.4	5,376
Sunflower	Biodiesel	418	1.3	538
Wheat	Ethanol	389	2.9	1,118

Sources: Johnston and others 2009; FAOSTAT for global average yields 2004–06.
Note: — = not available.
a. Author's estimate, assuming a 30 percent oil extraction rate.

global average. At that amount, ethanol yields would be about 700 liters per hectare. Oilseeds (for example, rape, soybean, and sunflower) that are used to produce biodiesel in the EU and the United States yield about 400–700 liters of biodiesel per hectare at global average yields, which is less than one-quarter of the yield of biodiesel from palm oil. Yields of biodiesel from jatropha are not available on a comparable basis to the other crops in table 2.1. However, based on yields of 5 tons of seed per hectare, the yield of biodiesel from jatropha would be 1,650 liters per hectare.

By-Products of Biofuel Production

Biofuel production results in large quantities of by-products that can add economic value or become waste that must be disposed of, depending on the by-product and market conditions. In many cases, African countries' domestic economies will not support the profitable use of by-products, and those countries will thus incur costs for by-product disposal. Export may also be unprofitable because of low volumes and high transport costs. These circumstances can influence the types of biofuels that can be produced profitably and may favor the export of unprocessed feedstocks, such as raw vegetable oil, rather than processed biofuels, such as biodiesel. Unprocessed feedstocks could offer greater opportunities for marketing the by-products in industrial countries. The quantities of by-products will often exceed the quantities of biofuel and can present a challenge for biofuel producers in Africa.

The by-products of ethanol production depend on whether sugar crops or starchy crops are used as feedstock. Sugar crops produce by-products, such as bagasse, whereas starchy crops produce residues that can be used as feed. The bagasse is burned to power the factory and can be used to produce surplus electricity when high-pressure boilers and high-efficiency turbines are used. Bagasse also has other uses, such as in the manufacture of particleboard for construction. Feed by-products can be used as animal or poultry feed and are valued for their high protein content. Carbon dioxide is also a by-product of ethanol production during the fermentation stage, and some larger ethanol plants collect, clean, compress, and market it for use in carbonated beverages, manufactured dry ice, or flash-frozen meat.

Cogeneration of electricity for sale to the power grid is an important by-product of ethanol production from sugarcane. Cogeneration may qualify for carbon credits under certain conditions and can provide an additional source of revenue for ethanol producers. It can contribute to rural power supplies because sugar factories are often located in rural areas. Bagasse has traditionally been used very inefficiently to power sugar factories because it had few alternative uses and unused bagasse had to be disposed of. But with more efficient turbines and high-pressure boilers, surplus electricity can be produced and sold. In Mauritius, for example, almost all sugarcane factories cogenerate electricity for sale to the national grid (Deepchand 2005). The capital costs of equipment to cogenerate surplus electricity are high, and a cane crush of at least 200 tons per hour is required to justify the investment. Production of approximately 125 kilowatts of electricity is obtained per ton of cane in Mauritius using high-pressure boilers and matching turbines.

When starchy crops are used to produce ethanol, only the starch is used for ethanol; the protein, fat, vitamins, and fiber in the feedstock remain in more concentrated levels in the by-product. These by-products are used as feed, and the nutritional content and quantity of the by-product will depend on the feedstock and production process. When maize is used as the feedstock, approximately 30 percent of the maize remains as distiller grains, and the protein content increases from approximately

10 percent in the maize kernel to 30 percent in the distiller grain by-product. When wheat is used, the resulting distiller grain by-product has 45 percent protein because wheat kernels contain more protein than maize kernels. The value of distiller grains from maize is approximately 20 percent of the total value of products sold by U.S. ethanol producers. The value of distiller grains will depend on the demand from the local livestock and poultry industries, and a small fed-livestock or poultry industry could constrain large-scale production of ethanol from some types of starchy crops, but less so with others. Cassava, for example, is approximately 73 percent starch, 5 percent sugar, and 3–4 percent protein on a dry-matter basis (International Starch Institute 2009), making cassava more attractive for ethanol production than maize in Africa with its small fed-livestock and poultry industries because less of the value is in the by-products.

Glycerol is a by-product of the transesterification process that produces biodiesel. For every 10 tons of biodiesel produced, 1 ton of glycerol is also produced. Crude glycerol is about 50 percent pure and contains a significant amount of contaminants, including methanol, soap, and catalysts. It can be refined relatively easily to 80–90 percent purity by adding hydrochloric acid, and it has often been sold in that form as crude or raw glycerol. Refined glycerol is purified to 99.7 percent for industrial use, and that requires either vacuum distillation or ion-exchange refining, both of which require capital-intensive technology, making it more practical for large-scale plants than for small- or medium-scale biodiesel plants (Van Gerpen and others 2006). Once refined, glycerol has many uses, including in food products, cosmetics, toiletries, toothpaste, explosives, drugs, animal feed, plasticizers, emulsifiers, and tobacco. However, a glut of crude glycerol developed in the United States and Europe as biodiesel production surged in 2006 and 2007 and prices fell to US$0.02 per pound, which made even refining to 80 percent purity uneconomic. That surge led to dumping into waterways and fields in the United States. Dumping could be a concern in Africa where the by-product is unlikely to be marketed. The discharges are hazardous to fish and birds and can alter existing soil nutrients, depending on what contaminants remain in the glycerol.

The second major by-product of biodiesel or SVO production is the press cake that remains after the oil is extracted from the oilseed. Press cake can be used for animal feed, fertilizer, and other purposes, depending on the feedstock and market opportunities. Press cake from soybeans, for example, is a high-value animal feed that contains about 44 percent

Table 2.2 Oil Content of Oilseeds Used for Biodiesel
percent

Oilseed	*Oil content*
Castor	45
Copra (dry coconut)	60
Cottonseed	20
Groundnuts	50
Jatropha kernel	55
Jatropha seed	35
Mustard seed	32
Oil palm	22
Oil palm kernel	50
Rapeseed	40
Safflower	35
Soybean	18
Sunflower	45

Sources: Author's estimates based on various sources.

protein and is priced at almost twice maize. Press cake from jatropha is toxic to animals and is used as fertilizer or as cooking fuel (although D1 Oils, a British public company, has developed and patented a process to remove toxicity, which could make it suitable for feed). The approximate oil content of various crops is shown in table 2.2; however, the oil content can vary greatly depending on varieties and growing conditions. The oil extraction rate depends on the technology used to remove the oil from the oilseeds, with less oil extracted from screw-type presses and nearly all the oil removed using solvent extraction technology.

Consumption

Biofuels can be used as transport fuel and for household purposes, such as cooking, lighting, and heating. They can also be used to provide power to rural communities and heavy industries, such as mines located in remote areas. Ethanol has been used for industrial purposes and beverage consumption for decades. Vodka, for example, is typically 40 percent ethanol.[5] Biodiesel is also especially well suited to certain uses, such as underground mining where workers are exposed to high levels of diesel exhaust. Using biodiesel can eliminate as much as 90 percent of air toxins. One of the advantages of using biofuels for transportation is that they can be blended with fossil fuels using simple splash-blending techniques, delivered to retail outlets, and dispensed using the same equipment as that used for gasoline and diesel.

Ethanol has a higher octane rating than gasoline, which improves engine performance, but a lower energy content, which results in less distance traveled per unit of fuel.[6] Biodiesel has lubricating properties that improve diesel engine operation but also a lower energy content than fossil diesel.[7] SVO has a higher energy content than biodiesel and can be used in most diesel engines without modification if it is preheated to a lower viscosity. Without preheating, incomplete combustion and carbon buildup will occur that could ultimately damage the engine. Preheating is typically done with an electric heater before the engine is started or with engine heat once the engine is running. SVO can also be used for household cooking in specially designed stoves or for lighting and heating.

One of the potentially substantial uses of ethanol in African countries is for home-cooking fuel as an alternative to charcoal or kerosene. Ethanol can be used directly in specially designed stoves or mixed with a thickening agent (such as cellulose) to convert it to a gel for use as a cooking fuel. It has the potential to partially replace charcoal in urban areas and thus reduce the pressure on forests. Ethanol would also have health benefits because it is a clean-burning fuel; it reduces indoor air pollution that contributes to respiratory illnesses. The potential demand for this use is great because roughly two-thirds of African households use wood fuels for their daily cooking and heating needs. Wood-fuel use places a huge burden on forests, and that burden will likely increase as populations expand. If gel fuels replaced only 10 percent of African household energy consumption for cooking, more than 3 billion liters of ethanol would be required (based on Utria 2004), which would entail about 370,000 hectares of sugarcane. The retail cost of gel fuel is higher than that for ethanol, and subsidies would currently be necessary. However, the health benefits and reduced pressure on forests may justify such subsidies. Gel fuels produced from ethanol made from molasses in small-scale distilleries could be sold competitively with charcoal in some cases (Zuzarte 2007).

Biofuels may also be used to provide power to rural communities, as is currently being done in Mali. The Malian Ministry of Mines, Energy and Water is promoting the use of jatropha oil for rural electrification and vehicle fuel and for reducing poverty among rural women. The German Agency for Technical Cooperation began a jatropha scheme at five sites in 1993, and the Mali Folkecenter Nyetaa more recently helped communities set up local biofuel systems in four additional localities. In one village, 20 hectares of jatropha supply the energy needs of villages within a

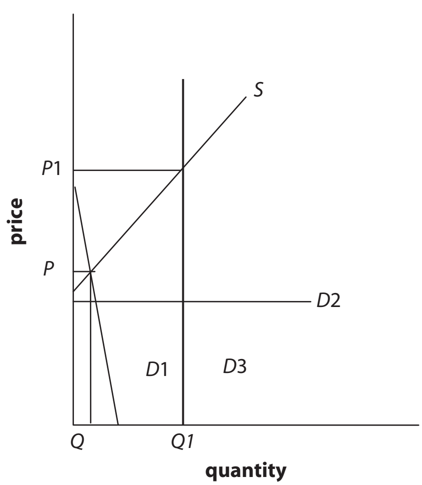
20-kilometer radius. The second stage of the project involves planting 1,000 hectares of jatropha to provide electricity for 10,000 rural inhabitants. Villagers provide communal lands for jatropha in exchange for improved access to energy (Cotula, Dyer, and Vermeulen 2008). Mozambique has also begun small-scale jatropha projects for rural energy, and five West African countries are participating in a United Nations Development Programme project to provide electricity from jatropha oil to power simple multiplatform diesel engines.

Biofuels as Transport Fuel

The largest current demand for biofuels is for use as liquid transport fuels: (a) as fuel enhancers, (b) as fossil fuel substitutes, and (c) to satisfy government use mandates or environmental regulations. Biofuels are in demand as fuel enhancers because of their properties; for example, they have a higher-octane content (ethanol) than gasoline and greater lubricity (biodiesel) than diesel that gives them value for blending with fossil fuels. This demand is small in most countries because other fuel enhancers provide similar benefits at lower costs and because the demand for fuel enhancers depends on many factors, including the age and technology of the vehicle fleet. The demand for biofuels as fossil fuel substitutes depends on the price of biofuels relative to the price of fossil fuels. If biofuel prices are lower than the fuel-equivalent price of fossil fuels, the demand for biofuels will be perfectly elastic, and consumers will switch to biofuels to the extent their vehicles can use the biofuels without damaging the engine or fuel system and as long as the vehicle manufacturer's warranty is not voided (assuming consumers are afforded a choice). Most countries restrict the maximum ethanol content of the ethanol-gasoline blend to 10 percent because major vehicle manufacturers do not warrant their cars for higher blends. However, Brazil has used blends of 20–25 percent ethanol for decades, and its experience has been that ethanol blends of up to 26 percent ethanol with gasoline can be used in conventional vehicles without modification (Coelho 2005). The U.S. Department of Energy has studied various ethanol blends and has found no operability or drivability issues with blends of up to 20 percent (BR&DB 2008). For vehicles that are no longer under warranty, ethanol blends of up to 20 percent are judged to be safe, but for vehicles under warranty in the United States the maximum blend allowed is 10 percent. Vehicle manufacturers in Brazil have developed flex-fuel engines that can operate on any mixture of ethanol and gasoline, and vehicle manufacturers in North America have produced E85 engines that can operate with a fuel mixture of 85 percent ethanol and 15 percent gasoline.[8] More than half the fueling stations in Sweden offer E85, and 15–25 percent of new car sales were E85 in 2007–09.

Biofuels are also demanded for transport fuel to satisfy government consumption mandates or environmental regulations. Environmental regulations could include air quality requirements that specify an oxygen enhancer, such as ethanol blended with gasoline, or a ban on the use of lead as an oxygen enhancer in gasoline because of its environmental and health hazards. Consumption mandates could specify the share of liquid transport fuels that must come from renewable energy, as is the case in the EU, or a certain quantity of biofuels that must be consumed, as is the case in the United States. The demand for biofuels to satisfy a consumption mandate is perfectly inelastic and thus does not vary with price. If supply is large enough to more than satisfy the mandate and prices are low enough, the mandate may have little effect on biofuel demand. That is the case in Brazil, where the government sets the ethanol consumption mandate at 20–25 percent of gasoline consumption. However, ethanol consumption is equal to gasoline consumption and more than satisfies the mandate. In the EU, the consumption mandate is higher than the biofuel demand, so biofuel consumption must rise to satisfy the mandate. In that case, the price of biofuels will rise along the supply curve until the quantities specified by the mandates are reached. This situation is shown in figure 2.1, where the

Figure 2.1 Consumption Mandates for Biofuels



Source: Author's analysis.

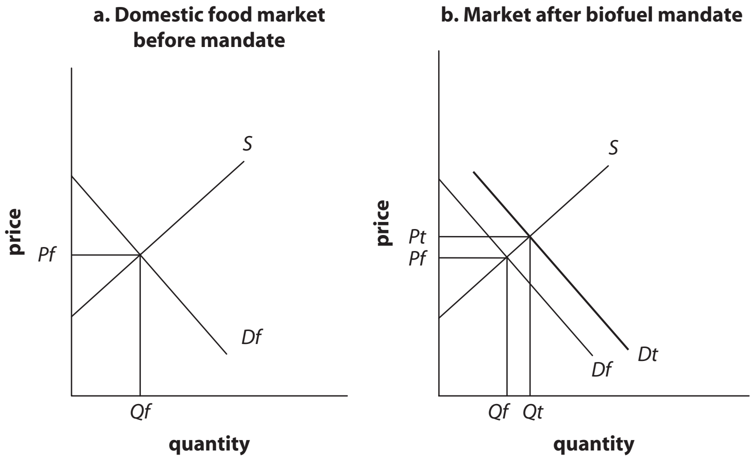
consumption mandate is represented by the perfectly inelastic demand curve *D*3, the demand for biofuels as fuel enhancers is depicted by demand curve *D*1, and the demand for biofuels as fuel substitutes is shown as *D*2. With the supply of biofuels represented by the supply curve, *S*, the quantity of biofuels consumed without the consumption mandate would be Q at price *P*. The price of biofuels exceeds the fuel-equivalent price, and the demand for biofuels as a fossil fuel substitute is zero. If the government imposes a consumption mandate, *D*3, the quantity of biofuels consumed will rise from Q to Q1, and the price of biofuels will rise from *P* to *P*1.

To meet the consumption mandate, the government must either legislate the consumption of biofuels (in which case the consumer pays for the production through higher prices for blended transport fuel) or provide sufficient price subsidies to producers to ensure that the price is low enough to meet mandated consumption. If the government provides a price subsidy, the required subsidy would be (*P*1 – *P*) and the cost of the subsidy would be (*P*1 – *P*) Q1. The supply curve would shift right until the consumption mandate was met at price *P*. Lapan and Moschini (2009) have shown that a biofuel consumption mandate is equivalent to taxing fossil fuels and subsidizing biofuels.

The Effect of Biofuels on Food Crop Prices

The effect of biofuels on food crop prices depends on the feedstock used to produce the biofuels, whether dedicated supplies of feedstocks are used to produce the biofuels, and trade. If jatropha is the feedstock used and is grown on land not used for food crops, the effect on food crop prices could be minimal and would come primarily through the competition for labor to produce jatropha and food crops and the increased demand for food crops caused by the increased incomes of jatropha producers. However, if a food crop is used to produce ethanol to satisfy the mandate and if the food crop is purchased from the local market rather than being produced specifically for ethanol production, the effect on food crop prices could be significant. Panel a of figure 2.2 depicts a domestic food market, such as cassava, that has no imports or exports (a typical situation in the cassava market because cassava is bulky to transport and deteriorates quickly once harvested). Food demand is reflected by *Df*, food supply by *S*, and the equilibrium price and quantity by *Pf* and *Qf*, respectively. If a biofuel mandate is introduced and is met by producing the biofuel from cassava, it can be shown as increased demand for cassava in panel b. This mandate adds to the demand for cassava for food to

Figure 2.2 The Impact of Biofuel Mandates on Food Crop Prices



Source: Author's estimate.

create a new total demand curve *Dt*. The price of the food crop will rise from *Pf* to *Pt*, with the magnitude of the actual increase dependent on the size of the biofuel mandate relative to the food demand and the demand and supply elasticities of the food crop. The food use of cassava will decline in response to the higher price and is given by the intersection of the food demand *Df* and the price *Pt*. Because the biofuel mandate does not depend on prices, all demand adjustments must be made in the food market. In the longer run, the supply of cassava will increase because the long-run supply elasticity is greater than the short-run supply elasticity, and the price effect of the biofuel mandate will diminish.

Biofuel mandates can greatly affect global food crop prices when they are raised quickly or established at high levels. This has been the case with both the U.S. and EU mandates, when sufficient feedstock supplies were not available to meet the increased demand without large price increases. In the United States, the use of maize to produce ethanol increased from 34 million tons in 2004 to 89 million tons in 2008 (FAPRI 2009), and the U.S. share of global maize production for biofuels increased from 4.8 percent to 11.3 percent. Maize acreage in the United States rose by 22 percent in 2007–08, which led to a 14 percent decline in soybean acreage and contributed to price increases in soybeans and other oilseeds. During the same period (2004–08), biodiesel production in the EU increased from 2.3 billion liters to 7.6 billion liters, and the share of global vegetable oil production used for biodiesel increased from 1.7 percent to 4.8 percent. The rapid increase in ethanol and biodiesel production depleted maize and vegetable oil stocks and caused maize and vegetable oil prices to rise (Mitchell 2008).

The Effect of a Consumption Mandate in Africa

The effect of a biofuel consumption mandate in an African country would depend on several factors. If the biofuel could be produced at less than the fuel-equivalent (wholesale) cost of the imported fossil fuel (the typical case when molasses is used as the feedstock to produce ethanol), and the supply was large enough to satisfy the mandate, then the price of the blend fuel could fall and a foreign exchange saving could result as the biofuel displaced imported fossil fuel. However, the actual fuel price paid by the consumer would depend on pricing policies. If the price of the blend fuel were determined by formula, then the price should fall as the lower-cost biofuel is included in the blend. But if the fuel price were determined by market forces, then the price of the biofuel would most likely rise to the level of the fossil fuel (because the biofuel would be a small share of the total fuel volume), and the consumer would not pay a lower price. Trade and tax policies could change this outcome. If free trade were allowed in biofuels, the locally produced biofuel might be exported to a higher-priced market (such as the EU), and biofuels could be imported to meet the consumption mandate (as occurs in sugar).[9] Under this alternative, fuel prices could rise because of the higher price of imported biofuels or fall if the imported biofuel was less costly than the imported fossil fuel. Tax policies could also change the effect of a biofuel consumption mandate. If the domestically produced biofuel were exempt from fuel taxes, the cost of producing biofuels could be higher, but the price at which they are sold to the consumer could be lower and the blend fuel price could be reduced. This situation would not only result in foreign exchange savings but also lower fuel tax revenues. The effect on food crop prices would depend on the factors considered in the previous section. To the extent these various factors can be generalized, foreign exchange savings and lower consumer fuel prices should be possible when the cost of producing biofuels is less than the cost of imported fossil fuels. In reality, fluctuations in fossil fuel prices would probably lead to biofuel prices' being sometimes higher and sometimes lower than fossil fuel prices.

If biofuels were more costly to produce than imported fossil fuels, the price of fuel to the consumer would tend to rise as the blend to meet the mandate included the higher-cost biofuel. A foreign exchange saving would still occur as the biofuels displaced the imported fossil fuels, but this saving would occur at the expense of the consumer who would pay more for transport fuel. As in the case when biofuel production costs were lower than the imported wholesale fossil fuel price, tax and trade policies could change these effects. With free trade in biofuels, imported biofuels could be priced lower than domestically produced biofuels and could be imported to meet the consumption mandate. Either locally produced biofuels would be exported to a protected market with higher prices or production would be unprofitable.

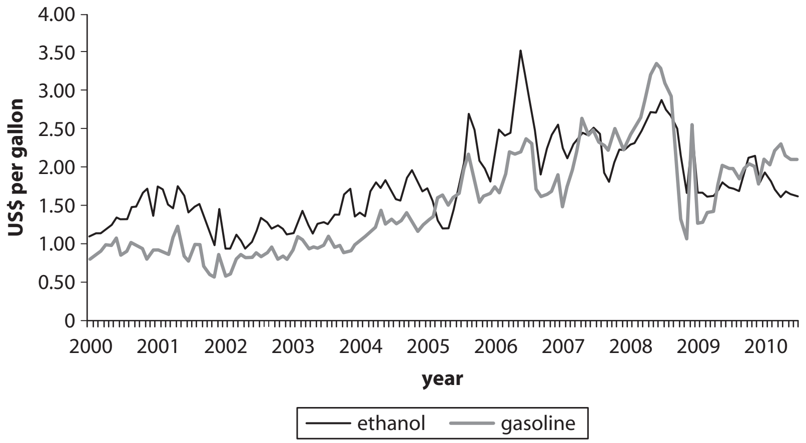
Prices

Biofuel prices are heavily distorted by government policies, such as import tariffs, producer subsidies, and consumption mandates. Such policies increase demand, distort trade, and raise consumer prices. In the absence of such policies or selling practices that do not afford consumers a choice of fuels to purchase, biofuel prices should equal their fuel-equivalent value relative to fossil fuels after allowing for their lower energy content and enhanced performance characteristics.[10] Moreover, because biofuels account for a small share of liquid transport fuels—about 1.5 percent of global transport fuels in 2008—they can be viewed as price takers in the liquid transport fuel market. Even if their share increases to 5 percent by 2030 as the International Energy Agency expects (IEA 2008b), they will still be a relatively small share of transport fuels and should have a limited effect on fossil fuel prices. They account for a larger share of liquid transport fuels in individual countries such as Brazil (50 percent of passenger car fuel) and the United States (7 percent) and can exert a greater effect on prices in those countries—at least in the short run.

U.S. Ethanol and Gasoline Prices

Figure 2.3 shows the relationship between monthly U.S. wholesale prices of ethanol and gasoline, from 2000 to 2010, for the midwestern state of Nebraska where ethanol is produced. Ethanol prices were typically higher than gasoline prices until mid-2007 and have fluctuated around the gasoline prices since then. As supplies of ethanol have increased, the price has occasionally dipped below that for gasoline, but it has been roughly equal to the gasoline price since mid-2007. The fact that ethanol prices were above their gasoline-equivalent values from 2000 to 2004 suggests that factors other than their fuel-equivalent value supported prices. Those factors included (a) a blender's tax credit of US$0.51 per gallon

Figure 2.3 Monthly U.S. Ethanol and Gasoline Prices, 2000–10



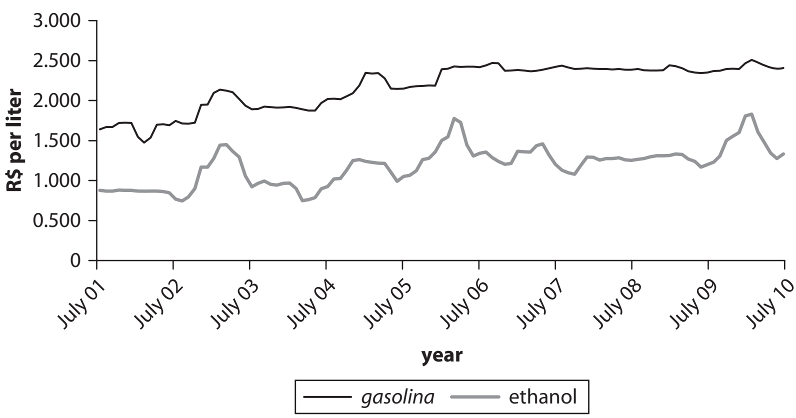
Source: Nebraska State Government Web site, Ethanol and Unleaded Gasoline Average Rack Prices, F.O.B. Omaha, Nebraska, August 2010, http://www.neo.ne.gov/statshtml/66.html.

(US$0.135 per liter); (b) environmental regulations that required gasoline to be blended with oxygen enhancers, such as ethanol, to reduce air pollution; and (c) the lack of choice afforded consumers.[11] The blender's tax credit allowed fuel blenders to pay more than the fuel-equivalent value of ethanol. The environmental regulations increased the demand for ethanol, and the lack of consumer choice allowed ethanol to be sold at the same price as gasoline. During 2000–04, ethanol prices averaged US$1.40 per gallon (US$0.37 per liter), compared to gasoline prices of US$0.97 per gallon (US$0.26 per liter). The market price of ethanol should equal the price of gasoline plus the blender's tax credit because of competition among refiners and blenders (de Gorter and Just 2009), assuming perfect substitutability between gasoline and ethanol in consumption. The margin between ethanol and gasoline prices averaged US$0.43 per gallon (US$0.11 per liter) during 2000–04, suggesting that gasoline and ethanol were less than perfect substitutes. Ethanol prices increased even more, relative to gasoline, in 2005 and 2006 as the petroleum-based oxygen enhancer methyl tertiary butyl ether was phased out because of concern over groundwater pollution. By 2007, ethanol supplies had increased enough to meet this additional demand, and from 2007 to 2009, ethanol and gasoline prices were equal, on average, suggesting that ethanol was no longer a close substitute. This situation could have occurred because ethanol supplies in Nebraska increased relative to the maximum blend allowable of 10 percent in the United States, and ethanol had to be exported to other regions.

Brazilian Ethanol and Gasolina *Prices*

In Brazil, consumers can purchase either ethanol or the government-mandated blend of ethanol and gasoline (called *gasolina*), which is between 20 and 25 percent ethanol, depending on the domestic market conditions. The introduction of flex-fuel cars in 2003 made it possible for owners of those vehicles to use any combination of ethanol and *gasolina* in their vehicles, while non-flex-fuel vehicles can use only *gasolina*. The "rule of thumb" for consumers with flex-fuel vehicles is that they buy ethanol when the price is less than or equal to 70 percent of the *gasolina* price and they buy *gasolina* when the ethanol price is greater than 70 percent of the *gasolina* price. This rule of thumb is very close to the fuel-equivalent price of ethanol relative to *gasolina*, estimated at 73 percent.[12] Figure 2.4 shows the monthly prices of ethanol and *gasolina* in São Paulo, Brazil, from July 2001 to July 2010. Ethanol prices averaged 55 percent of the *gasolina* price during this period, indicating that ethanol was cheaper than gasoline on a fuel-equivalent basis. This could be because São Paulo is the largest ethanol-producing region in Brazil and ethanol prices are lower than in other regions. The ratio of ethanol to *gasolina* prices has increased over time as flex-fuel cars have become more widely available. For example, during July 2001 to July 2005, the ratio of ethanol

Figure 2.4 Monthly Brazilian Ethanol and *Gasolina* Prices, 2001–10



Source: Plinio Nastari, CEO of DATAGRO, pers. comm., 2010.
Note: R$ = Brazilian reais.

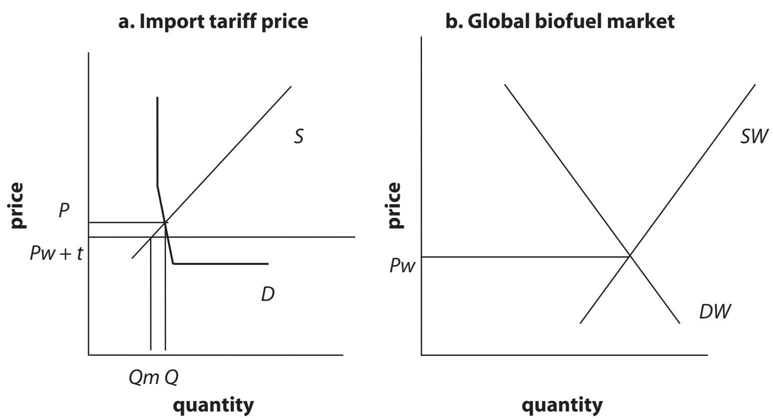
to *gasolina* was .52 compared to .56 from July 2005 to July 2010. The relationship between ethanol and *gasolina* prices in Brazil is reversed compared to the relationship between ethanol and gasoline prices in the United States, that is, ethanol prices were lower than *gasolina* prices in Brazil but generally higher than gasoline prices in the United States over the same periods. This disparity reflects partly different choices afforded American and Brazilian consumers and partly the relative supply of ethanol compared to demand caused by tariffs that limit imports in the United States.

Trade

Trade policies affect the price of biofuels, and tariffs are often used to raise the price of imported biofuels (see figure 2.5). Both the United States and the EU have tariffs on ethanol and biodiesel imports.

The aggregate demand and supply of biofuels in a particular country are depicted in panel a of figure 2.5 by *D* and *S*, with equilibrium price and quantity, *P* and Q. The demand curve is the aggregate of the demand for alternative uses (see figure 2.1). The world market price for ethanol is *Pw* in panel b, which is lower than the domestic price *P*. An import tariff, *t*, is imposed to raise the international price and provide protection to domestic producers. The domestic price falls from *P* to *Pw* + *t*, and imports are equal to Q minus *Qm*. This scenario represents the situation in both the United States and the EU, as an import tariff is used to restrict

Figure 2.5 Import Tariff on Biofuels



Source: Author's estimates.

imports and protect domestic producers. It would also represent the situation in an African country that had higher biofuel production costs than the price of imported biofuels. In the absence of other taxes or subsidies, the consumer would pay higher prices for biofuels, which would most likely be reflected in higher blend-fuel prices. The depiction in figure 2.5 reflects the EU's ethanol tariff of 0.192 euro(€) (US$0.25) per liter applied to imports from major producers, such as Brazil. However, most African countries are afforded duty-free access to the EU market by virtue of their status as least-developed countries or other designations and receive $Pw + t$ instead of Pw.

Biofuel Standards

Major biofuel producers have historically used different standards for biofuels. The standards reflect different feedstock availability and different vehicle requirements. Among the three major producers (Brazil, the EU, and the United States), ethanol specifications are more closely aligned than biodiesel specifications, partly because ethanol is a single chemical compound whereas biodiesel varies, depending on the feedstock used. The most fundamental difference for ethanol is water content. The EU has the lowest maximum limit of 0.24 percent by volume, the United States has the highest at 1.0 percent by volume, and Brazil has no maximum water content in its specification. These differences are primarily because of varying ethanol concentrations permitted in gasoline and differences in gasoline distribution systems. The differences among biodiesel specifications are greater because of difference in use, blending requirements, and feedstocks. The EU has a much larger diesel passenger car fleet, while the United States and Brazil use diesel primarily in heavier-duty engines. The biodiesel standards of Brazil and the United States are used to describe a product that is blended in conventional fossil diesel, whereas the EU biodiesel standard describes a product that can be used either as a standalone diesel fuel or as a blending component in fossil diesel fuel.

In 2006, a tripartite task force composed of representatives of these three countries was formed to develop compatible standards for biodiesel and ethanol. It produced a white paper on internationally compatible biofuel standards in December 2007 (Tripartite Task Force 2007). The report identified 16 specifications for ethanol and 24 for biodiesel. It concluded that 9 of the 16 specifications for ethanol were considered aligned and all but one of the remaining specifications could be aligned in the short term. Despite modest differences, the report concluded that existing specifications for ethanol presented no impediment to global trade in ethanol. Six of the 24 biodiesel specifications were considered aligned, and the report suggested that many differences could be dealt with by blending various types of biodiesel to create an end product that would meet regional specifications for fuel quality and emissions. An International Biofuels Forum—composed of Brazil, the EU, and the United States, as well as China, India, and South Africa—is working to make biofuel standards compatible worldwide.

Greenhouse Gas Emissions, Carbon Credits, and Biofuels

Biofuels have the potential to reduce greenhouse gas (GHG) emissions compared to fossil fuels. However, the amount of reduction varies greatly, depending on the biofuel and feedstock, and some biofuels may result in increased levels of GHG emissions relative to fossil fuels. Considerable controversy exists within the scientific community on how large the savings are from using various biofuels relative to fossil fuels and what factors should be considered when calculating the emission savings. Recent work by Searchinger and others (2008) has highlighted the importance of secondary land-use changes on GHG emissions caused by expanding biofuel production. If the expansion of biofuel production results in secondary land-use changes as existing crops are displaced by biofuel crops and then resumed in another location, the emissions released from the land-use changes should be considered in calculating the GHG emission savings. If the land was previously in a natural state, such as grassland or forest, the GHGs released from converting this land to biofuels may not be offset for many decades.

These calculations and scientific debates are important to African countries, not only because they are a guide to reducing their own GHG emissions but also because they could ultimately determine which biofuels can be used to meet consumption mandates aimed at reducing GHG emissions in importing countries and which biofuels can generate carbon credits. The EU, for example, has calculated the GHG emission savings for a range of biofuels under various technologies, and the United States requires biofuels that can be used to meet its advanced biofuels mandate to have GHG emission savings of at least 50 percent (USEPA 2010). Biofuels that do not meet these criteria will not be eligible for subsidies or benefit from demand increases resulting from these mandates and would have limited export opportunities.

The Kyoto Protocol

The main international agreement addressing GHG emissions is the Kyoto Protocol of 1997 that entered into force in 2005 (UN 1998). This agreement committed 37 industrial countries and the EU (referred to as Annex B countries) to reduce their overall GHG emissions by at least 5 percent from 1990 levels during 2008–12. Countries can meet their commitments by reducing GHG emissions directly or by acquiring the rights to emit GHGs. The Kyoto Protocol established three market-based mechanisms to facilitate achieving these emissions reductions: (a) emission trading, which allows the international transfer of national allocations of emission rights between Annex B countries; (b) the Clean Development Mechanism (CDM), which allows Annex B countries to implement emission reduction projects in developing countries to generate certified emission reductions credits; and (c) joint implementation, which allows the creation of emission reduction credits through transnational investment between Annex B countries or companies in these countries.

Efforts to reduce GHG emissions have led to a large and rapidly growing market for carbon credits, with each carbon credit equal to 1 metric ton of carbon dioxide or its equivalent of other specified GHGs.[13] Carbon credits are created by a project that reduces GHG emissions relative to a predefined baseline; for biofuels to generate carbon credits, agreement must exist on the GHG savings from using biofuels relative to fossil fuels. The two most important criteria that need to be considered when calculating the GHG emission savings from biofuels are (a) the savings from using a particular biofuel rather than fossil fuels and (b) the prior use of the land on which the biofuel is produced. Sugarcane, for example, is generally accepted as having GHG emissions of at least 80 percent from existing fields (Macedo, Seabra, and Silva 2008). However, if production was on land previously in tropical forests, the GHG savings would be greatly reduced (Searchinger and others 2008), and under the EU's sustainability criteria (discussed in chapter 4), production from such lands would not be eligible to meet consumption mandates in the EU. Projects started before 2008 will be largely exempt from the sustainability criteria, but projects begun in or after 2008 will need to meet the new criteria. Not all crops have been rated for their GHG emissions. Jatropha, for example, does not yet have a GHG savings estimate from the EU, and producers of jatropha must submit their own estimates for EU acceptance or wait until the EU rating is available. Until then, jatropha oil or biodiesel made from jatropha oil could not be used to meet the EU's renewable fuel mandate for transport fuels and would likely face low demand for use in the EU.

The EU has most aggressively implemented policies to reduce GHG emissions, and it introduced an emissions-trading scheme in January 2005. Under this scheme, the emissions of specified industries are capped, and companies in those industries are forced to meet the emissions caps or to buy EU emission allowances to offset their additional emissions. Most other countries with commitments under the Kyoto Protocol have not yet established market-trading systems but could become active buyers of carbon credits to meet their GHG emission reductions targets. The United States did not sign the Kyoto Protocol, but legislation is being considered that would require reducing GHG emissions from their 2005 levels. Demand from the EU for carbon credits along with demand from other Kyoto Protocol signatories and potential demand from the United States could result in further increases in what is already a large and rapidly growing carbon market. Transactions in global carbon markets totaled US$126 billion in 2008, with the EU accounting for the majority of the trades (Capoor and Ambrosi 2009). Carbon credits are traded on more than a dozen exchanges. The price of carbon credits, as reflected by the certified emission reductions credits traded on the European Climate Exchange, has ranged from €10 to €25 (US$13 to US$33) per ton since trading began in 2005 (Brohé, Eyre, and Howarth 2009).

The Potential Value of Carbon Credits

The potential value of carbon credits produced from biofuels depends on the price of carbon and the savings in GHGs relative to fossil fuels. The carbon emissions from transport fuels and electricity produced from coal are shown in table 2.3 and give some indication of the potential value of carbon credit sales. One liter of gasoline emits 2.322 kilograms of carbon; a carbon credit to offset this emission would have a potential value of US$0.046 per liter if a carbon credit was US$20 per ton.[14] If carbon prices rose to US$100 per ton, a possibility suggested by the International Energy Agency (IEA 2008b), the value of a carbon credit to offset the emissions from gasoline would have a value of US$0.232 per liter, which could represent about 40 percent of current ethanol production costs in Africa. Likewise, electricity cogenerated from sugarcane bagasse could reduce GHG emissions relative to coal-fired plants, and the value of carbon emissions per kilowatt-hour would be US$0.018 with carbon credits priced at US$20 per ton.[15] This value would equal roughly one-third of

Table 2.3 Carbon Dioxide Emissions from Transport Fuels and Electricity
kilograms

Fuel/power	*Carbon dioxide emissions*
Gasoline (liter)	2.322
Diesel (liter)	2.664
Electricity (kilowatt-hour)	0.881

Sources: USEPA (2005) for gasoline and diesel and USDOE and USEPA (2000) for electricity.
Note: The calculations of carbon dioxide (CO_2) emissions from gasoline and diesel are based on the average carbon content of the fossil fuel multiplied by the oxidation ratio multiplied by the molecular weight of CO_2 (MW 44) to the molecular weight of carbon (MW 12). The CO_2 emission per kilowatt-hour of electricity is the average for coal-fired power plants in the United States for 1998 and 1999.

current electricity prices. As previously noted, the value of the carbon credit would be reduced in proportion to the reduction in GHGs provided by biofuels relative to their fossil fuel counterparts.

The difficulty of obtaining carbon credits for biofuel production is reflected in the slow progress in achieving certification under the Kyoto Protocol CDM (see box 2.1). This situation is credited to the rigorous project requirements established by the CDM Executive Board, the lack of approved methodologies, the high abatement costs of biofuel projects, and the difficulty of proving additionality and calculating the GHG emission reductions of a project (Bakker 2006).[16] In a 2007 decision related to a CDM project for the manufacture of biodiesel from crude palm oil and jatropha (Case NM0224), the Executive Board did not approve the proposed project because it had no provision to identify and monitor emission reductions from the final consumer, to whom the biofuel was to be sold; therefore, the potential existed for double counting. Specific restrictions—such as "No biofuel production exported to Annex I countries is eligible to claim [certified emissions reductions] under the CDM" (IGES 2009a)—further limit the opportunities to use the CDM for biofuels. The only approved methodology for production of biofuels is AM0047, "Production of Biodiesel Based on Waste Oil and/or Waste Fats from Biogenic Origin for Use as Fuel." Despite these restrictions, the *World Development Report 2010* (World Bank 2010) argues that new approaches are needed to deal with climate change, and biofuels seem to offer an important opportunity.

Several opportunities also exist to get carbon credits for related activities. Wastewater treatment at an ethanol plant in the Philippines was approved in 2006 (IGES 2009b). The project avoids the emission of methane from the ethanol plant's wastewater treatment system for

Box 2.1

Clean Development Mechanism

The Clean Development Mechanism (CDM) is an arrangement under the Kyoto Protocol that allows industrialized countries with a GHG reduction commitment to invest in projects in developing countries that reduce emissions.[a] The CDM has the twin objectives of (a) contributing to stabilizing GHG concentrations in the atmosphere and (b) assisting developing countries in achieving sustainable development. An industrialized country that wishes to get credit from a CDM project must obtain the consent of the developing country that the project will contribute to sustainable development. Then, using methodologies approved by the CDM Executive Board, the applicant industrial country must (a) establish additionality by making the case that the carbon project would not have happened anyway and (b) establish a baseline estimating the future emissions in the absence of the project. The case is then validated by a third-party agency, called a Designated Operational Entity, to ensure the project results in real, measurable, and long-term emissions reductions. Next, the Executive Board decides whether or not to register (approve) the project. If the project is registered and implemented, the Executive Board issues credits, called certified emissions reductions, commonly known as carbon credits, where each unit is equivalent to the reduction of 1 metric ton of carbon dioxide to the project participants based on the monitored difference between verified baseline and actual emissions. These carbon credits can then be used by the project developer to offset emissions from its own operations or sold to other companies or governments in international markets.

Every proposed CDM project has to use an approved methodology that establishes steps to determine the baseline and monitoring parameters for quality assurance and the equipment to be used to obtain data to calculate emissions reductions. If a project developer cannot find an approved methodology that fits its case, it can submit a new methodology. If the methodology is approved, it will be converted to an approved methodology for others to use. All approved methodologies are listed on the Web site of the United Nations Framework Convention on Climate Change.

a. The CDM is defined under Article 12 of the 1997 Kyoto Protocol. The CDM is supervised by the CDM Executive Board under the guidance of the Conference of the Parties of the United Nations Framework Convention on Climate Change.

vinasse, the wastewater effluent of ethanol plants. Vinasse is one of the strongest industrial effluents, having extremely high chemical oxygen and biochemical oxygen demand values that could result in methane emissions from the traditional lagoons that could offset a significant portion of the GHG emission reductions from the use of biofuels. An approved methodology (AM0015) also exists for bagasse-based cogeneration of power that displaces grid electricity. This methodology is based on Vale do Rosário Bagasse Cogeneration in Brazil and requires that (a) the bagasse used as feedstock for cogeneration is supplied by the same facility, (b) documentation is provided stating that the project would not have been implemented by the public sector or other developers, (c) the implementation of the project will not increase bagasse production, and (d) the bagasse will not be stored for more than one year.

Summary and Conclusions

Biofuels can be produced from a wide variety of crops, but sugarcane and molasses to produce ethanol, and jatropha to produce biodiesel or to be used as SVOs are attracting the most interest in Africa. Sugarcane production is well known in Africa. The technology for producing ethanol from sugarcane and molasses has been refined in Brazil over the past 30 years and can be readily adapted to Africa. Much less is known about jatropha and its suitability for biofuel production, but high labor requirements and low yields are major concerns. Many other crops may have potential as biofuel feedstocks, including cassava and sweet sorghum for ethanol, and croton and oil palm for biodiesel or SVO fuels. However, because the interest in biofuel production in Africa is a recent phenomenon, the basic research to improve varieties and to identify suitable crops under alternative conditions has not been done. Private companies are experimenting with various crops, but most lack the resources or the expertise to do basic research and many are reluctant to share the results of their research. Public sector research is needed to improve varieties and identify characteristics of biofuel crops that are suitable for different countries and conditions. Labor requirements, for example, may become the limiting factor in producing jatropha from wild varieties, but research to synchronize flowering and develop harvesting machinery could make production profitable. Such research should not be viewed as a quick fix to biofuels in Africa, but it is essential to the development of a sustainable industry that can raise incomes and contribute to energy supplies and economic growth in the future.

Improvements in the technology of biofuel production may hold the key to the future of biofuels in the African region. First-generation technology—which includes producing ethanol from sugar crops, such as sugarcane or sweet sorghum, and from starchy crops, such as maize or cassava, and biodiesel from animal fats or vegetable oils—is mature, and large increases in efficiency are not expected. Nonetheless, steady gains have occurred in both the efficiency of the manufacturing process and the feedstock yields, and those are expected to continue and lower the cost of biofuel production in the future. Second-generation technology uses a different process and can utilize waste from food crops and feedstocks. A wide array of feedstocks can be used with second-generation technology, including agricultural residue, timber waste, and specialty crops such as fast-growing grasses or trees. Second-generation technology should offer substantial advantages over first-generation technology, including improved energy balances, greater reductions in GHGs, reduced land-use requirements, and less competition for food and fiber. The basic conversion technologies of second-generation technology are not new, and their commercial development has been pursued for many years. The main reasons they are not used commercially are that the necessary conversion technologies from feedstock to finished fuel have not been proved technically on a commercial scale and their costs of production are estimated to be significantly higher than for many first-generation biofuels. Significant research, development, and design challenges remain before widespread use is possible, but several pilot-scale plants are in operation, and larger demonstration plants are planned or under development. Second-generation technology is not expected to make a significant contribution to biofuel production for at least a decade; during that period, food crops will continue to be the primary feedstocks for biofuels.

Biofuel markets are heavily distorted by government subsidies, tariffs, and consumption mandates, and such distortions lead to large variations in biofuel prices among countries and regions. Although such distortions are undesirable from a global welfare perspective and have often led to trade disputes, such distortions create export opportunities for most African countries because they have preferential access to these protected markets under various trade agreements. The value of these preferences can be very large, especially for ethanol, which has high tariffs in both the EU and the United States. Biodiesel, SVO, and feedstocks used to produce these biofuels have relatively low tariffs, and duty-free access affords less of an opportunity to African exporters of these products. Other major biofuel producers, such as Brazil, Indonesia, Malaysia, and South Africa, do not receive the same trade preferences. However, if preferential access were granted to these producers, the preferences would likely erode and the trade advantage currently available to African producers would be reduced or eliminated.

Biofuel production results in large volumes of by-products. The economic value or cost of their disposal can strongly influence the profitability of production and the choice of feedstock for biofuel production. Ethanol produced from sugarcane results in large volumes of cane residue (bagasse), which has historically had low value and was used only to fuel boilers to power the factory. However, bagasse has become a valuable by-product because it can be used to produce surplus electricity that can be sold to the national grid when high-pressure boilers and more efficient turbines are used. Bagasse is also likely to be the feedstock for second-generation cellulosic ethanol when it becomes commercially available and could allow a 50 percent increase in ethanol production per ton of sugarcane processed. The by-products of biodiesel production are the press cake that remains after the oil is extracted from the oilseeds and the glycerol from biodiesel production. The value of the press cake varies, depending on the oilseed. If the press cake can be used as animal feed, it often has high value because oilseeds are generally high in protein, which is a valuable nutrient. However, if the press cake cannot be used as animal feed, which is the case with jatropha because it is toxic, then the press cake may have low value as an organic fertilizer or for charcoal. A process to remove the toxicity from jatropha press cake has been patented. If it is economically viable, it could significantly increase the potential for profitable jatropha production. An additional by-product of biodiesel production is glycerol, and each liter of biodiesel produced results in one-tenth of a liter of glycerol, which has many industrial uses. However, the large increase in biodiesel production has turned this once-valuable by-product into a waste product for most producers. This change has led to cases of dumping of glycerol into waterways or fields where it can be a hazardous pollutant. Biofuel producers will need to find profitable uses for it, such as animal feed or bunker fuels, or to develop ways to dispose of it without polluting streams or fields.

Biofuel standards for production differ among major producers, but they are not a significant barrier to trade because they can usually be accommodated with blending or additional processing. Standards for ethanol have fewer differences than for biodiesel because ethanol is a single chemical compound regardless of the feedstock used, whereas biodiesel retains some of the properties of the feedstock used in its production. Efforts are under way to harmonize standards, and they should improve the ease with which biofuels can be traded. However, African exporters should plan to produce biofuels that meet the standards of their target market to prevent price discounts that can be expected when additional processing or careful blending is required.

Carbon credits have not generally been available for biofuels, but they could become an important source of revenue in the future. The carbon market has grown rapidly, and efforts to reduce GHG emissions under the Kyoto Protocol or national programs are expected to lead to further growth and could lead to higher carbon prices. Biofuels have not benefited because they have only been certified as eligible for the CDM of the Kyoto Protocol under very limited conditions, but that could change in the future. The potential value of carbon credits at current carbon prices of approximately US$20 per ton of carbon or equivalent GHGs is about US$0.04–$0.05 per liter of ethanol. That price could rise to several times that value if carbon prices rise as some project, and the GHG savings of biofuels relative to fossil fuels are certified. The potential value of electricity cogenerated from sugarcane bagasse would be approximately US$0.018 per kilowatt-hour at carbon prices of US$20 per ton or equivalent GHGs.

Notes

1. The sugar content of cane molasses is about 62 percent, consisting of 32 percent sucrose, 14 percent glucose, and 16 percent fructose (LMC International 2003).
2. Hong Yan, Director of TEMASEK Lifesciences Laboratory, National University of Singapore and Nanyang Technological University, pers. comm., March 30, 2009; S. S. Goyal, University of Santa Barbara, pers. comm., 2009; D1 Oils corporate executives, pers. comm., 2009.
3. See http://faostat.fao.org/default.aspx.
4. Plinio Nastari, CEO of DATAGRO, pers. comm., 2009.
5. Undenatured ethanol is suitable for human consumption. It is denatured by adding toxic solvents to make it unsuitable for human consumption when it is to be used for transport fuel.
6. Ethanol has an octane rating of 98 compared to gasoline, with an octane rating of 80, but it has only 67 percent of the energy of gasoline. Thus, about 40 percent more fuel is required per distance driven than for gasoline. This lower fuel efficiency could be partially overcome because of the higher octane rating, which allows ethanol to be used in engines with higher compression ratios. That could increase engine efficiency by about 15 percent and reduce the fuel-efficiency penalty of ethanol from about 30 percent in conventional engines to 20 percent in engines adjusted to operate at higher compression ratios of 12 to 1 instead of 8 to 1 in gasoline-fueled engines (Goldemberg 2008).
7. Biodiesel has 92 percent of the energy content of diesel (USDOE 2006); SVO has approximately 95 percent of the energy content of diesel.
8. Ethanol is produced as either anhydrous ethanol, which is 99.6 percent ethanol and 0.4 percent water, or hydrous ethanol, which is 95.5 percent ethanol and 4.5 percent water. Anhydrous ethanol is blended with gasoline for

use in unmodified conventional automobiles, and hydrous ethanol can be used as pure ethanol in specially designed flex-fuel vehicles.

9. Domestic sugar production is often exported to the protected EU market under duty-free preferences. Lower-cost Brazilian sugar is imported to satisfy domestic demand.
10. This analysis ignores any additional costs associated with mixing and distributing biofuels blended with fossil fuels.
11. A blender's tax credit is given to the blender of gasoline and ethanol for every gallon of ethanol blended with gasoline. The blender's tax credit was reduced to US$0.45 per gallon in 2009.
12. *Gasolina* is 25 percent ethanol and 75 percent gasoline. The price relative to gasoline should be equal to the share of gasoline plus the share of ethanol times its fuel-equivalent value (ignoring any differences in performance). Assuming the fuel-equivalent value of ethanol is two-thirds that of gasoline, the ethanol price should be 0.67 of the gasoline price. The price of ethanol should equal $1.0 \cdot 0.75 + 0.67 \cdot 0.25 = 0.918$ of the gasoline price. Thus, the price of ethanol relative to gasoline should equal $0.67/0.918 = 0.73$, or 73 percent.
13. The Kyoto Protocol recognizes six main greenhouse gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Each of these GHGs has a different global-warming potential relative to carbon dioxide, but they are expressed in carbon dioxide equivalents to facilitate trading in global carbon markets.
14. Calculated as the carbon emitted per liter of gasoline times the price of a carbon credit: $(2.322/1{,}000) \times$ US$20.
15. Calculated as the carbon emitted per kilowatt-hour multiplied by the price of a carbon credit: $(0.881/1{,}000) \times$ US$20.
16. Additionality is usually discussed in terms of whether the project is reducing emissions in a way that is beyond business as usual.

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CHAPTER 3

Biofuel Production Costs

Understanding biofuel production costs is essential to decision making at the individual, firm, or national level. It is especially important at this time because many firms seem to be rushing into biofuels without a full understanding of the production costs or the factors that determine them. Governments and local communities in African countries are being asked to grant land to companies on long-term leases for biofuels. Jatropha, for example, is a crop that has been grown in Africa as hedges for centuries, but growers have little experience with its commercial production for biofuels. If jatropha production costs are high relative to returns, production will be uneconomic and unsustainable. Moreover, those local communities that have provided long-term land leases to jatropha producers for little more than the promise of employment opportunities may be left without access to their lands or the promised jobs. Understanding the volatility of production costs is also important. If biofuel production costs are very volatile, as appears to be the case for some feedstocks, dependence on biofuel production has implications for employment and the macroeconomy, as well as for the profitability of biofuel-producing firms. Conversely, if prospects are good for profitable industries that provide employment and growth, governments need to understand those opportunities.

This chapter examines the financial costs of producing biofuels in Africa at different scales of plant, with different production systems and different feedstocks. This information can then be used to understand firm behavior under alternative conditions and to guide both investment decisions and government policy. The firms are assumed to be greenfield operations, with a given plant scale, and are price takers for purchased inputs. Fixed, variable, and total costs are estimated to allow examination of the firm's economic decision making. Costs for biofuel production are expressed in U.S. dollars per liter. The approach is based on the work of Shapouri, Gallagher, and Graboski (2002); Tiffany and Eidman (2003); and Shapouri and Gallagher (2005)—all of whom estimated production costs for ethanol producers in the United States. The focus is on the financial costs of producing biofuels, which are the actual costs incurred in production, rather than on the economic costs, which are the full costs to society. The differences can be substantial because the economic costs could include environmental impacts, such as the loss of biodiversity or soil degradation resulting from biofuels production, and the costs of government policies, such as consumption mandates, that raise the cost of fuel to consumers but are not reflected in the financial costs. Financial costs can be used to estimate the profitability of biofuel production to a firm but not the economic cost to society.

The prices of the production factors and the technical conversion factors needed to estimate production costs were obtained from interviews with biofuel firms, published estimates, feasibility studies, private sector studies of biofuel production costs from LMC International (2008; 2009), and published reports from *F. O. Licht's World Ethanol and Biofuels Report* (agra-net.com 2009). A formal survey of producers is a commonly used approach to estimate factor prices and technical coefficients and was planned in this study, but it could not be done because producing biofuels in most African countries is a recent activity and few firms have actual production costs. Therefore, this chapter relies more on data from established producers in other countries rather than on actual data from African biofuel producers. Key inputs and conversion factors were verified through discussions with African biofuel firms when possible. Cost categories used in this chapter include land acquisition and development, plant and equipment, interest, depreciation, return-to-investor capital, labor, purchased inputs, taxes, insurance, licenses, and fees. Technical conversion factors are explicitly stated, and sensitivity analysis is done to identify critical variables. The convention of treating biofuel production costs as net of by-product sales is followed.

Market prices are used to value resources when they exist, and costs of production are used when resources are produced only for biofuels—as is the case with jatropha. Variation of production costs among firms cannot be adequately reflected in a model of production costs, which tends to use averages of values obtained from different firms. Thus, the cost-of-production estimates may not apply to all firms.

Although a range of feedstocks are being used to produce biofuels, most of the investors in Africa have focused on either ethanol from sugarcane or molasses, or straight vegetable oil (SVO) or biodiesel from jatropha, which are the focus of this chapter. Sugarcane and molasses are well suited to biofuel production in Africa because many countries already have well-established sugar industries, and some are among the lowest-cost producers in the world. Molasses offers unique opportunities for ethanol production because it has few alternative uses in many African countries and, therefore, has low opportunity costs. Jatropha oil may become the dominant SVO or biodiesel feedstock in Africa, with 97 projects planned according to a recent survey (GEXSI 2008). However, production of jatropha oil is still minor because many projects are in the planning or development stage and few have begun significant production. This chapter begins by examining jatropha production costs under alternative production schemes and then looks at ethanol production from sugarcane and molasses. Models are developed and sensitivity tests are performed. The variability of production costs and the implications for biofuel producers are examined, and a final section offers a summary and conclusions.

Straight Vegetable Oil Production Costs and Prices

The average prices of major vegetable oils used to produce biodiesel are shown in table 3.1 for 2003–09. Palm oil was the least costly, with an average price of US$0.55 per liter, soybean oil averaged US$0.69 per liter, and rapeseed oil averaged US$0.77 per liter. Good estimates of jatropha oil prices are not available because of the limited quantities produced and sold. However, jatropha oil is a high-quality oil for biofuel production, and its value for biofuels would compare to rapeseed oil because both can be used to produce biodiesel that meets the European Union (EU) standard, whereas neither palm oil nor soybean oil can (Sarin and others 2007; Woods 2001).[1]

The ex-factory cost of producing jatropha oil comprises the costs of seed production, collecting and transporting the seeds for processing, and

Table 3.1 Prices of Major Vegetable Oils Used for Biodiesel, Northern Europe, 2003–09

Vegetable oil	*US$/ton of oil*	*US$/liter*
Palm oil	596	0.55
Soybean oil	747	0.69
Rapeseed oil	840	0.77

Source: World Bank Commodity Price Data, average of monthly prices from January 2003 to July 2009.
Note: Assumes the density of vegetable oils is 0.92 gram per milliliter, which yields 1,087 liters per ton of vegetable oil (Demirbas 2008).

crushing the seed to separate the oil and meal. These costs can vary widely depending on the methods of production, the efficiency of the crushing equipment, and transport and collection costs. Smallholders who collect seeds from wild trees using surplus and family labor were being paid approximately US$100 per ton for dry seeds in eastern Africa in 2009.[2] That amount roughly reflects the costs of smallholder harvesting, shelling, drying, and delivering the seeds to a local collection point. The costs of buying the seeds and transporting them to a central processing point can be more than double the price of the seed, according to companies buying seed from smallholders. The estimated cost of crushing the seeds is US$35 per ton of oil in a small-scale crushing facility using mechanical presses that extract 24 percent oil from the seeds (Econergy 2008). Thus, 1 ton of jatropha oil would require crushing 4.17 tons of seed at a seed cost of US$417 plus crushing costs of US$35 per ton of oil and would result in a cost for jatropha oil of US$452 per ton (US$0.42 per liter), as shown in table 3.2 (ignoring collection and transport costs). The by-product of crushing jatropha seeds for oil is the press cake, which would be 76 percent of the seed weight. This by-product would contribute little to reducing costs and is assumed to be returned to farmers for use as fertilizer.

If more efficient (and more costly) crushing equipment were used, the cost of oil would be lower because less seed would be required to produce 1 liter of oil. For example, a high-quality mechanical press can extract 30 percent of the seed as oil and would require only 3.33 tons of seed to produce 1 ton of oil. The cost of seed would decline to US$333 per ton of jatropha oil and, assuming similar extraction costs of US$35 per ton of oil,[3] would result in a cost of US$368 per ton (US$0.34 per liter). The higher-efficiency mechanical presses have obvious cost advantages, but capital constraints and small-scale facilities limit their use.

Table 3.2 Smallholder Jatropha Oil Production Costs for Local Use

Indicator	*Percentage*	*US$/ton*	*US$/liter*
Seed price paid to farmer	n.a.	100	n.a.
Oil extraction cost (per ton oil)	n.a.	35	n.a.
Extraction rate	24	n.a.	n.a.
Cost of jatropha oil	n.a.	452	0.42
Extraction rate with more efficient presses	30	n.a.	n.a.
Cost of jatropha oil	n.a.	368	0.34

Sources: Author's calculations based on jatropha prices currently paid to outgrowers in Malawi, Tanzania, and Zambia, and oil extraction costs estimated by Econergy (2008) and D1 Oils (corporate executives, pers. comm., 2009).
Note: n.a. = not applicable.

These costs are very competitive with international vegetable oil prices and local fuel prices; however, such low costs are possible only for small quantities of oil produced from locally collected seeds. When large quantities of seed are collected and transported to a central site for processing, collection and transport costs can be substantial. Diligent estimates that collection and transport can cost as much as 150 percent of the prices paid to producers of jatropha in Tanzania, which implies a cost of production starting at US$0.80 per liter for jatropha oil from smallholders.[4] However, if smallholders produced for local use and delivered the seeds to the processing facility, small quantities of jatropha oil could be produced at prices that would be lower than imported diesel costs. The oil could be used to power generators for lighting and operating small equipment. This possibility is a practical alternative in remote areas where feedstock supplies are small and processing costs are high. Stationary power plants, such as those used to supply electricity to rural communities or to operate equipment for mining or other industries, are designed to operate on heavy fuels, such as furnace oil, but can operate on SVOs or a combination of SVO and furnace oil (Takavarasha, Uppal, and Hongo 2005). SVO can also be used in most diesel engines at low blends of 10–20 percent with minor engine modifications (Radich 2004).

An alternative jatropha production model is the plantation, where hired labor is used to do the fieldwork on company-owned or company-leased land. The plantation model provides greater control over production and harvesting and a more regular supply of seeds for processing that allows better use of equipment. Yields per hectare are expected to be higher than for smallholder production because of better management and higher, and more timely, input use. Transport costs are lower because production is concentrated on the plantation. Labor costs are an important component of plantation production costs. In India, crop maintenance (weeding, irrigation, fertilization, and pruning) reportedly requires 22 days per hectare in the first year and 70 days in the sixth year (Sharma and Sarraf 2007). Harvesting is even more labor intensive, and estimates of the amount of seed that can be harvested per worker-day vary from less than 20 to more than 60 kilograms of dry seed. Reinhard Henning, who has worked with jatropha in Africa for more than 20 years, reports that women in the KAKUTE jatropha project in Tanzania collected 2 kilograms of seed per hour, which implies 16 kilograms in eight hours (Henning 2009). The manager of D1-BP Fuel Crops in Zambia expects a worker to harvest 30 kilograms of seed per day,[5] and Nielson (2009) reports that workers in Mozambique can collect and shell only 1–3 kilograms of seed per hour (8–24 kilograms per day).

If yields were 3 tons of seeds per hectare, and 30 kilograms of seed were harvested per worker per day, the labor required for harvesting 1 hectare would be 100 days per year. Labor for maintenance could add another 40–60 days per year, causing the labor requirements per hectare to total approximately 150 days per year. A survey of 115 small-scale jatropha growers in Zambia in 2007 found labor requirements to be even higher (Freim 2008). Weeding, pruning, and harvesting required the most time, and the average number of days of labor per year per hectare of jatropha was 275 during the first four years. Harvesting and peeling the fruit from the seeds took 45 minutes per kilogram of seed, meaning a worker could harvest only 10.5 kilograms of seed per day. With such wide-ranging estimates of labor requirements, little certainty can be attached to plantation production costs. Several companies report working on mechanical harvesters for jatropha, and such machinery could significantly affect the profitability of the crop if it becomes available.

Jatropha Plantation Production Model

To explore jatropha plantation production costs, a model is developed for a rain-fed plantation of 6,000 hectares with annual yields of 3 tons of jatropha seed per hectare (case I in table 3.3). This scale would allow the use of efficient solvent extraction equipment. The annual production would be 18,000 tons of seed and 7 million liters of jatropha oil, assuming a 36 percent oil extraction rate using a solvent extraction process. The press cake is assumed to be used as organic fertilizer, and no credit is given for

Table 3.3 Jatropha Plantation Oil Production Costs, Alternative Cases

Jatropha oil production costs	*Case I: Greenfield base case*	*Case II: High yield and low wages*	*Case III: High yield and high wages*	*Case IV: Genetic improvements*
Hectares of jatropha	6,000	6,000	6,000	6,000
Processing capacity (million liters per year)	7.0	11.7	11.7	11.7
Investment costs				
Land acquisition (US$/hectare)	50	50	50	50
Land clearing and preparation (US$/hectare)	500	500	500	500
Land clearing and preparation (US$ millions)	3.0	3.0	3.0	3.0
Land development total (US$/hectare)	550	550	550	550
Land development total (US$ millions)	3.3	3.3	3.3	3.3
Factory costs ($/liter capacity)	0.40	0.40	0.40	0.40
Factory costs (US$ millions)	2.82	4.70	4.70	4.70
Building and equipment (US$/hectare)	100	100	100	100
Building and equipment (US$ millions)	0.60	0.60	0.60	0.60
Total investment cost (US$ millions)	6.72	8.60	8.60	8.60
Total investment cost (US$/hectare)	1,120	1,433	1,433	1,433
Total investment cost (US$/liter capacity)	0.95	0.73	0.73	0.73
Working capital (US$ millions)	0.67	0.86	0.86	0.86
Operation and maintenance (US$ millions)	0.50	0.50	0.50	0.50
Management and overhead (US$ millions)	0.50	0.50	0.50	0.50
Depreciation on capital equipment (years)	20	20	20	20
Depreciation on capital equipment (US$ millions)	0.17	0.26	0.26	0.26
Debt-to-equity ratio	0.60	0.60	0.60	0.60
Interest on capital (percent)	6.0	6.0	6.0	6.0
Interest on capital (US$ millions)	0.27	0.34	0.34	0.34

(continued next page)

Table 3.3 *(continued)*

Jatropha oil production costs	*Case I: Greenfield base case*	*Case II: High yield and low wages*	*Case III: High yield and high wages*	*Case IV: Genetic improvements*
Return on investor capital (percent)	12.0	12.0	12.0	12.0
Return on investor capital (US$ millions)	0.35	0.45	0.45	0.45
Total capital costs (US$ millions)	2.46	2.92	2.92	2.92
Contribution to jatropha oil production costs (US$/liter)	0.35	0.25	0.25	0.25
Jatropha seed production				
Yields (tons of seed/hectare)	3.0	5.0	5.0	5.0
Production (tons of seed)	18,000	30,000	30,000	30,000
Labor requirements				
Maintenance (days/hectare/year)	45	45	45	45
Harvesting (kilograms of seeds/day/worker)	30	30	30	60
Labor costs				
Wage rate (US$/day)	2.0	2.0	3.3	3.3
Maintenance (US$/hectare/year)	90.0	90.0	148.5	148.5
Maintenance (US$ millions)	0.5	0.5	0.9	0.9
Harvesting ($ per kg seed)	0.07	0.07	0.11	0.06
Harvesting (US$ millions)	1.20	2.00	3.30	1.65
Total labor costs (US$ millions)	1.74	2.54	4.19	2.54
Total labor costs (US$/hectare)	290	423	699	424

Total labor costs (US$/kg seed)	0.10	0.08	0.14	0.08
Total labor costs (US$/liter)	0.25	0.22	0.36	0.22
Labor requirements (full-time equivalent years)	3,480	5,080	5,080	3,080
Labor requirements at harvest	5,000	8,333	8,333	4,167
Other variable costs (US$/hectare)	50	70	70	70
Other variable costs (US$ millions)	0.30	0.42	0.42	0.42
Crushing				
Jatropha oil extraction rate (percent)	36	36	36	36
Jatropha oil produced (million liters)	7.0	11.7	11.7	11.7
Processing costs (US$/metric ton of seed)	10.8	10.8	10.8	10.8
Processing costs (US$/liter)	0.03	0.03	0.03	0.03
Total costs (US$ millions)	0.21	0.35	0.35	0.35
Variable costs (US$ millions)	2.79	3.86	5.51	3.86
Total costs (US$ millions)	4.41	5.81	7.46	5.81
Cost per liter of jatropha oil (US$)	0.63	0.49	0.64	0.50
Labor share of total costs (percent)	39.4	43.7	56.2	43.7
Variable share of total costs (percent)	63.2	66.5	73.9	66.5
Cost per metric ton of jatropha oil (US$)	681	538	691	538
Cost per metric ton of jatropha oil northern Europe (US$)	790	647	800	647

Source: Author's estimates.

by-product sales. Land acquisition, clearing, and preparation are significant costs of establishing a plantation and are estimated at US$550 per hectare (US$3.3 million) based on discussions with firms developing greenfield operations in Africa. However, these costs vary with the situation and could exceed US$1,000 per hectare. The cost of factory equipment, farm machinery, and buildings is estimated at US$3.4 million, including crushing equipment costing US$0.40 per liter of crushing capacity. Interest, depreciation, return-to-investor equity, operation and management, and working capital costs total an additional US$2.46 million per year, bringing the total fixed costs of jatropha oil production to US$0.35 per liter.

Fieldwork and harvesting are done by unskilled labor assumed to earn US$2 per day. Crop maintenance is assumed to require 45 days per hectare per year, and workers are assumed to harvest 30 kilograms of seed per day. Total labor costs would be US$290 per hectare and US$1.74 million per year. Labor would contribute US$0.25 per liter to jatropha oil production costs. Processing costs add another US$0.03 per liter, in addition to factory costs, bringing the total cost of production of crude jatropha oil to US$0.63 per liter. The cost per ton of jatropha oil would be US$681 ex-factory and US$790 including cost, insurance, and freight to northern Europe based on expected transport costs of US$0.10 per liter. These production costs compare favorably with other vegetable oils used for biodiesel, such as rapeseed oil, which averaged US$840 per ton in northern Europe during 2003–09. Unskilled labor accounts for 39 percent of total costs in case I, and the 6,000-hectare plantation would require 3,480 full-time-worker equivalents per year. If the crop were harvested in a four-month period, the labor requirement during harvest would be 5,000 workers. The large labor requirements present several challenges, including the difficulty of attracting such a large number of workers for fieldwork at the low wage of US$2 per day and the food and lodging requirements for such a large workforce. Wages of US$2 per day are lower than wages paid for other fieldwork. Kilombero Sugar Company in Tanzania, for example, pays US$3.30 per day to its casual fieldworkers, and tea pickers in Tanzania earn US$4.40 per day in wages and benefits (box 3.1). If a wage of US$3.30 per day were paid, the cost of labor would rise to US$2.87 million per year, and the cost of jatropha oil would rise by US$0.16 per liter to US$0.79 per liter. At a wage of US$4.40 per day, jatropha production costs would rise to US$0.92 per liter. As previously noted, the confidence with which plantation production costs can be estimated is not high because of the wide range of estimates of labor requirements.

Box 3.1

Comparison of Wages for Harvesting Jatropha and Tea

Tea and jatropha have similar labor requirements. The well-established tea industry in Tanzania provides some useful lessons for jatropha plantation production. Tea plantations require 1.5–2.0 fieldworkers per hectare compared with an estimated 1.0–1.5 fieldworkers for jatropha. Harvesting both tea and jatropha requires hand harvesting of only the ripe fruits or green leaves. The green-leaf tea and jatropha seeds have similar values at US$0.08–$0.10 per kilogram. A tea picker can harvest about 40 kilograms of green-leaf tea per day compared to an estimated 30 kilograms of jatropha seed. One important difference is that jatropha harvesting occurs over a period of four to five months compared to year-round harvesting of tea, which makes keeping a permanent labor force possible for tea but not for jatropha.

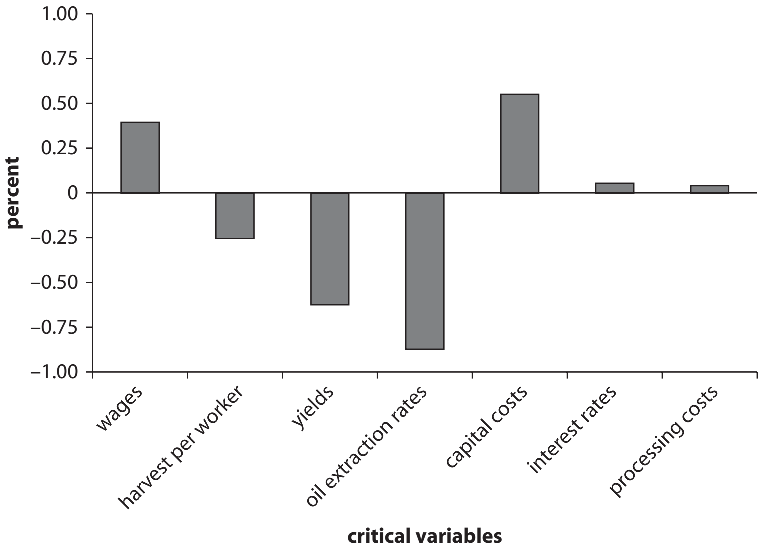
Tea workers in Tanzania are unionized and work under a collective-bargaining agreement. The cash wage averages approximately 3,000 Tanzania shillings per day (US$2.20), and companies provide an equal value in nonmonetary benefits. These benefits include company-provided housing for the 60 percent of workers who are permanent, plus water, electricity, medical care for the workers and their families, schools and day care for the children, and garden plots when the tea plantation has land available. Workers are provided lunch on days when they work more than eight hours. Despite these relatively good wages and benefits, finding workers is increasingly difficult, and the tea plantations are gradually shifting to mechanical harvesting, which reduces quality.

Jatropha plantations could expect to pay similar wages and benefits if they are to attract a large permanent labor force. However, because the harvesting season for jatropha is only four to five months long and labor requirements during nonharvesting periods are low, relying on seasonal workers and paying even higher wages may be necessary.

Source: Executive director, Tea Association of Tanzania, pers. comm., March 2010.

The sensitivity of plantation jatropha oil production costs to wages, seed harvested per day, crop yields, oil extraction rates, and other variables is shown in figure 3.1 as elasticities estimated from the levels in case I of table 3.3. The elasticities show the percentage change in jatropha oil production costs for a 1.0 percent change in critical variables. For example, a 1.0 percent increase in wage rates would increase production

Figure 3.1 Elasticities of Jatropha Oil Production Costs to Critical Variables



Source: Author's estimates.

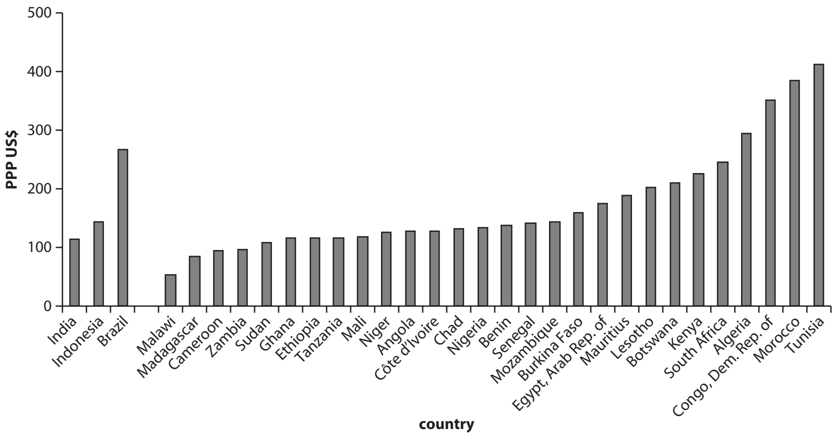
costs by 0.39 percent, and a 1.0 percent increase in seed harvested per worker (that is, from harvesting 30 kilograms of seed per day to harvesting 30.3 kilograms) would lower production costs by 0.25 percent. The largest elasticity is for increasing the oil extracted per kilogram of seed either by raising the oil content of the seed or by increasing the extraction rate. This occurs because the labor costs required to harvest the seeds do not change, and only a small change occurs in processing costs. Increasing crop yields are seen to have a lower elasticity than increasing oil extraction because the gains from higher yields are partially offset by higher harvesting costs. Capital investment costs have a lower elasticity than variables that change yields or labor costs, which suggests that investments that raised yields, such as supplemental irrigation, could be profitable, as could investments that raised worker productivity, such as increasing tree spacing to allow partial mechanization for harvesting or crop maintenance.

The greatest uncertainties about jatropha plantation production appear to be the seed yield per hectare and the labor requirements for harvesting and crop maintenance. To explore these alternatives, case II (see table 3.3) considers a high-yield alternative with yields per hectare of 5 tons of dry seed. The cost of producing jatropha oil would fall to US$0.49 per liter if wage rates remained at US$2 per day. Labor requirements would rise to 5,080 full-time workers per year, and harvest-time labor requirements would rise to 8,333 workers. Attracting such a large workforce to a rural area for seasonal harvesting seems a challenge in most countries. Consequently, case III considers the effect of raising the wage rate to US$3.30 per day, in addition to higher yields. This scenario would cause production costs to rise to US$0.64 per liter compared with US$0.63 per liter in case I. Higher yields offset higher wages, and production costs are similar to those in case I.

Labor availability appears to be a significant constraint on jatropha production because of the large number of low-wage workers required to harvest and maintain the crop. If labor productivity could be raised through genetic modification of the plant to allow synchronized flowering or if harvesting could be partially mechanized, jatropha could become a viable crop for use as SVO or biodiesel production and could provide employment at competitive wages. To explore this alternative, case IV assumes that seed harvested per worker rises to 60 kilograms from the case I alternative of 30 kilograms per worker per day. That increase would cause jatropha oil production costs to fall to US$0.50 per liter at a wage of US$3.30 per day and a yield of 5 tons per hectare. If yields could also be raised to 7 tons per hectare, the cost per liter of jatropha oil would fall to US$0.45, and jatropha could be very competitive with other high-quality vegetable oils used for biodiesel, such as rapeseed oil.

These simulated model results indicate that increasing labor productivity is a high priority, whether by increasing the oil content of jatropha seeds, which reduces labor costs per liter of oil, or by increasing harvesting rates per day through crop research or other means. Without improvements in labor productivity, firms will have great difficulty attracting the labor needed for harvesting and maintenance at wages that can be paid. Some countries with very low wages may be able to supply the labor required for plantation jatropha, but higher-wage countries will find it difficult. Figure 3.2 shows the minimum wages in African countries in 2007 based on International Labour Organization data expressed in purchasing power parity rates. Minimum wages are shown for Brazil, India, and Indonesia for comparison because these countries produce jatropha for biofuels. For this period, Malawi has the lowest minimum wage, followed by Madagascar.

Figure 3.2 Monthly Minimum Wages in African Countries



Source: ILO 2008, appendix table A2.
Note: PPP = purchasing power parity.

Producing Biodiesel from Jatropha Oil

Raw jatropha oil is unsuitable for processing into biodiesel without refining it to remove gums, waxes, and other impurities. The oil is first degummed by adding phosphoric or citric acid and sending it through a separator. It is then bleached and filtered, and the free fatty acids are removed by passing the oil through a deacidification column before it can be made into biodiesel. The cost of oil refining is estimated at US$45 per ton (US$0.042 per liter) of oil produced in a small-scale plant and US$30 per ton (US$0.027 per liter) in a large-scale plant (Econergy 2008). Producing biodiesel from refined oil is estimated to cost an additional US$75 per ton (US$0.066 per liter) in a small-scale plant and US$59 per ton (US$0.052 per liter) in a large-scale plant, making the entire cost of producing biodiesel from crude jatropha oil in a small-scale plant about US$0.11 per liter compared with US$0.08 per liter in a large-scale plant.

The by-products from biodiesel production from jatropha oil are glycerin and fatty acids. Glycerin was historically the most valuable of these by-products, but its value has declined as global biodiesel production has increased and prices have fallen off. It is unlikely that crude glycerin can be sold without further processing, which would be uneconomic for small firms. Fatty acids can be sold as animal feed, but the value is slight. The combined value of by-products is usually only 1.0–3.0 percent of the value of biodiesel in the United States; the value is likely to be nil in most African countries.

Ethanol Production Costs

Ethanol is less costly to produce than biodiesel because of lower feedstock costs, which more than offset higher factory costs (see box 3.2 for directly comparable ethanol and biodiesel production costs in the U.S. state of Iowa). The most common feedstocks for ethanol in Africa are sugarcane and molasses. Examples of these feedstock costs and their contribution to ethanol production costs are shown in table 3.4, with costs in Brazil for comparison. Sugarcane contributed approximately US$0.20 per liter to ethanol production costs in Brazil compared with US$0.35 per liter in Tanzania (based on cane payments to outgrowers in both cases). Molasses is the lowest-cost feedstock in most African countries, contributing about US$0.10 per liter to ethanol production costs. By comparison, the lowest cost of the major vegetable oils used for biodiesel was palm oil, with an average cost of US$0.55 per liter of biodiesel produced.

Ethanol from Molasses

Molasses is a by-product of sugar production and an excellent feedstock for ethanol production. The ex-factory price in many African countries has been as low as US$20 per ton because it has limited demand as livestock feed and high transport costs that make exporting unprofitable. It is often used as road tar by sugar plantations or dumped as refuse. Each ton of sugarcane crushed for sugar production yields approximately 35 kilograms of molasses. A ton of molasses contains approximately 60 percent sugar and can yield 250 liters of ethanol. When molasses is US$25 per ton, it contributes about US$0.10 per liter to ethanol production costs.

Table 3.4 Prices and Feedstock Costs of Major Ethanol Feedstocks, 2008

Feedstock	*Price (US$/ton)*	*Feedstock costs (US$/liter of ethanol)*
Sugarcane (Brazil)	19	0.26
Sugarcane (Tanzania)	28	0.35
Molasses (East Africa)	25	0.10
Molasses (northern Europe)	147	0.59

Sources: Board official, Sugar Board of Tanzania, pers. comm., 2009; USDA 2009; World Bank 2009.
Note: Sugarcane prices are outgrower prices in São Paulo, Brazil, and Tanzania. Molasses prices are estimated prices in eastern Africa.

Box 3.2

Ethanol versus Biodiesel: Production Costs in Iowa

Iowa is a low-cost producer of both maize and soybeans and a major producer of biodiesel from soybean oil and of ethanol from maize. Because Iowa produces both biodiesel and ethanol, comparisons can be made of biofuel production costs under very similar conditions. The cost estimates are from Iowa State University's Agricultural Marketing Resource Center for a typical biodiesel and ethanol plant in Iowa for 2008 (see table). The production costs per liter of biodiesel were more than double those for ethanol. However, on a fuel-equivalent basis (adjusting for energy content[a]), the difference is smaller, and biodiesel costs about 60 percent more than ethanol to produce.

The capacity of the typical biodiesel plant was 114 million liters (30 million gallons) per year compared to 380 million liters (100 million gallons) per year for the ethanol plant. Construction costs per liter of nameplate capacity were US$0.42 per liter (US$1.57 per gallon) for the biodiesel plant and US$0.52 per liter (US$1.97 per gallon) for the ethanol plant. The biodiesel plant had 28 employees; the ethanol plant had 39. Total production costs were US$1.17 per liter of biodiesel and US$0.55 per liter of ethanol. Variable costs accounted for 94 percent of biodiesel production costs and 87 percent of ethanol production costs. Net feedstock costs (crediting the sale of by-products) were 83 percent of biodiesel production costs compared to 53 percent of ethanol production costs.[b]

Table B3.2 Comparison of Typical Biodiesel and Ethanol Plants in Iowa, 2008

Plant characteristics	*Biodiesel*	*Ethanol*
Capacity (million liters)	114	380
Plant costs per liter of capacity (US$)	0.42	0.52
Employees	28	39
Production costs total (US$/liter)	1.17	0.55
Fixed	0.07	0.07
Variable	1.10	0.48
Feedstock (net of by-product credits)[c]	0.97	0.29
Other	0.13	0.15
Share of variable costs of total (percent)	94.0	87.3
Share of net feedstock costs of total (percent)	82.9	52.7
Share of other variable costs of total (percent)	11.1	27.2

Source: Agricultural Marketing Resource Center, Iowa State University, http://www.agmrc.org/commodities__products/.

Box 3.2 *(continued)*

Note: Brazilian ethanol production costs were estimated at US$0.35–$0.38 in 2008 (chief executive officer of DATAGRO, pers. comm., 2009) compared to US$0.55 in Iowa. The difference of US$0.17–$0.20 per liter was roughly equivalent to the tariff on ethanol of US$0.14 per liter.

a. Assuming the energy content of biodiesel is 92 percent of diesel and ethanol is 70 percent of gasoline, the fuel-equivalent cost of producing biodiesel is US$1.27 per liter and of producing ethanol is US$0.79 per liter, making biodiesel 60 percent more costly than ethanol.

b. Note that variable costs and their share of total costs are not comparable to the estimates in this chapter for African producers. In the United States, the feedstock is purchased and thus is treated as a variable cost, whereas in Africa, feedstock is produced for purpose and treated as a combination of fixed and variable costs.

c. Feedstock costs are typically computed net of by-product sales.

Processing costs for ethanol from molasses are an additional US$0.07–$0.10 per liter, depending on plant scale, input costs, and factory efficiencies, which result in an ex-factory price of about US$0.17–$0.20 per liter of ethanol. This price is between 25 and 50 percent of the pretax wholesale gasoline prices in many countries. In Tanzania, for example, the imported wholesale price of gasoline was US$0.35 per liter in March 2009. But in Malawi, the landed import price was US$0.65 per liter because of high transport costs, and the fuel-equivalent price of ethanol (after adjusting for the lower energy content of ethanol compared to gasoline) produced from molasses was less than 40 percent of the imported gasoline price.[6]

To achieve such low costs, ethanol production from molasses must be located adjacent to the sugar factory to reduce transport costs and to take advantage of surplus (often free) power from the sugar factory.[7] When ethanol production is not integrated with sugar production, production costs can rise substantially, as is the case in Kenya, where production costs are US$0.51–$0.61 per liter because producers buy and transport molasses from various sugar companies and because production is inefficient (GTZ and Kenya Ministry of Agriculture 2008, 59). However, large sugar companies in Kenya, such as Mumias, should be able to produce ethanol from molasses at costs comparable to those in Malawi. Supplies of molasses for ethanol production are limited because molasses is only a by-product of sugar production. The African region produces about 90 million tons of sugarcane per year and about 3.5 million tons of molasses. The potential ethanol production from this molasses is about 875 million liters, which would be sufficient to provide a 2–3 percent blend with gasoline.

Ethanol from Sugarcane

Several companies in Africa plan to produce ethanol from sugarcane. A model was developed based on typical investment costs, yields, and conversion factors for a hypothetical project. Production costs rather than market prices are used to value sugarcane because sugarcane is highly perishable and is not traded. Four alternative estimates of ethanol production costs were considered and are presented in table 3.5. They represent different production systems and assumptions. All alternatives are based on a large-scale, greenfield facility to produce ethanol and to cogenerate surplus electricity for sale. Combinations of plantation and outgrower production are specified with different yields and cane prices. The ethanol factory is assumed to be state of the art with high-pressure boilers and efficient turbines for power production.

Case I in table 3.5 is the base case and assumes 25,000 hectares of sugarcane for processing into ethanol. Total investment costs are US$262 million, and processing capacity is 230 million liters of ethanol per year. Land development costs, including irrigation, total US$51.3 million, or US$2,050 per hectare, and factory costs are assumed to be US$0.90 per liter of capacity, which are representative of projects being developed in the region. Factory costs exceed those per liter in Brazil, but they reflect higher costs in Africa that include irrigation systems and imported equipment. Total factory costs are US$207.0 million and represent 79 percent of project investment costs. Working capital is assumed to be 10 percent of total investment costs. Straight-line depreciation for 20 years is charged on irrigation equipment, factory buildings, and other equipment. The debt-to-equity ratio is 0.5, and interest on borrowed capital is 6 percent. The return on investor equity is assumed to be 12 percent. Outgrower production is 25 percent; outgrowers are assumed to have yields that are 80 percent of company yields. Sugarcane yields are assumed to be 110 tons per hectare per year on company lands, which are consistent with yields currently obtained in Malawi, Tanzania, and Zambia in eastern and southern Africa. The sugarcane price paid to outgrowers is US$28 per ton, which is the outgrower price being paid in Tanzania.[8] The cost to grow plantation cane is assumed to be US$20 per ton, which reflects production costs in the region and is similar to costs in Brazil. Ethanol production is assumed to be 85 liters per ton of sugarcane, and total annual production is 222 million liters. The company is assumed to cogenerate electricity and sell 100 megawatts at a price of US$0.05 per kilowatt-hour, which is credited to reduce ethanol production costs.[9] The net cost of ethanol production per liter is US$0.50. Variable costs are 66 percent

Table 3.5 Ethanol Production Costs from Sugarcane, Alternative Cases

Ethanol production costs from sugarcane	*Case I: Greenfield project*	*Case II: High-productivity outgrowers*	*Case III: All-outgrower model*	*Case IV: Cellulosic production*
Hectares of sugarcane	25,000	25,000	25,000	25,000
Ethanol capacity (million liters/year)	230	230	200	345
Investment cost				
Land acquisition (US$/hectare)	50	50	50	50
Land clearing and preparation (US$/hectare)	500	250	250	500
Land clearing and preparation (US$ millions)	12.5	6.25	6.25	12.5
Irrigation systems (US$/hectare)	1,500	750	750	1,500
Irrigation systems (US$ millions)	37.5	18.8	18.8	37.5
Land development total (US$/hectare)	2,050	1,050	1,050	2,050
Land development total (US$ millions)	51.3	26.3	26.3	51.3
Factory costs (US$/liter capacity)	0.90	0.60	0.90	0.90
Factory costs (US$ millions)	207.0	138.0	180.0	310.5
Building and equipment (US$/hectare)	150	150	150	150
Building and equipment (US$ millions)	3.8	3.8	3.8	3.8
Total investment cost (US$ millions)	262.0	168.0	210.0	365.5
Total investment cost (US$/hectare)	10,480	6,720	8,400	14,620
Total investment cost (US$/liter capacity)	1.14	0.73	1.05	1.06
Working capital (US$ millions)	26.2	16.8	21.0	36.6
Operation and maintenance (US$ millions)	2.0	2.0	2.0	2.0
Management and overhead (US$ millions)	3.0	3.0	3.0	3.0
Depreciation on capital equipment (years)	20	20	20	20

(continued next page)

Table 3.5 *(continued)*

Ethanol production costs from sugarcane	*Case I: Greenfield project*	*Case II: High-productivity outgrowers*	*Case III: All-outgrower model*	*Case IV: Cellulosic production*
Depreciation on capital equipment (US$ millions)	12.4	8.0	10.1	17.6
Debt-to-equity ratio	0.5	0.5	0.6	0.6
Interest on capital (percent)	6.0	6.0	6.0	6.0
Interest on capital (US$ millions)	8.6	5.5	8.3	14.5
Return on investor capital (percent)	12.0	12.0	12.0	12.0
Return on investor capital (US$ millions)	17.3	11.1	11.1	19.3
Total capital costs (US$ millions)	43.4	29.7	34.5	56.4
Contribution to ethanol costs (US$/liter)	0.20	0.13	0.18	0.17
Cane production				
Share of outgrowers (percent)	25	25	100	25
Plantation yields (metric tons/hectare)	110	110	0	110
Outgrower yields (metric tons/hectare)	88	110	88	88
Plantation cane costs (US$/metric ton)	20	20	0	20
Outgrower cane price (US$/metric ton)	28	20	28	28
Cane produced by outgrowers (thousand tons)	550	688	2,200	550

Cane produced by estate (thousand tons)	2,063	2,063	-	2,063
Total cane produced (thousand tons)	2,613	2,750	2,200	2,613
Cost of cane production (US$ millions)	56.7	55.0	61.6	56.7
Contribution to ethanol costs (US$/liter)	0.26	0.24	0.33	0.17
Feedstock share of total costs (percent)	51	57	59	42
Factory operation				
Ethanol per ton cane (liters)	85	85	85	128
Ethanol produced (million liters)	222	234	187	334
Processing costs (US$/liter)	0.07	0.07	0.07	0.07
Total processing costs (US$ millions)	15.5	16.4	13.1	23.4
Contribution to ethanol costs (US$/liter)	0.07	0.07	0.07	0.07
Variable costs	75.8	74.4	78.0	84.3
Total costs	115.5	101.0	109.2	136.4
Cogenerated electricity (megawatts)	100.0	100.0	100.0	0.0
Price per kilowatt-hour (US$)	0.05	0.05	0.05	0.05
Revenue from electricity (US$ millions)	5.0	5.0	5.0	0.0
Credit to ethanol costs (US$/liter)	0.02	0.02	0.03	0.00
Cost per liter of ethanol produced (US$)	0.50	0.41	0.56	0.41
Variable share of total costs (percent)	66	74	71	62

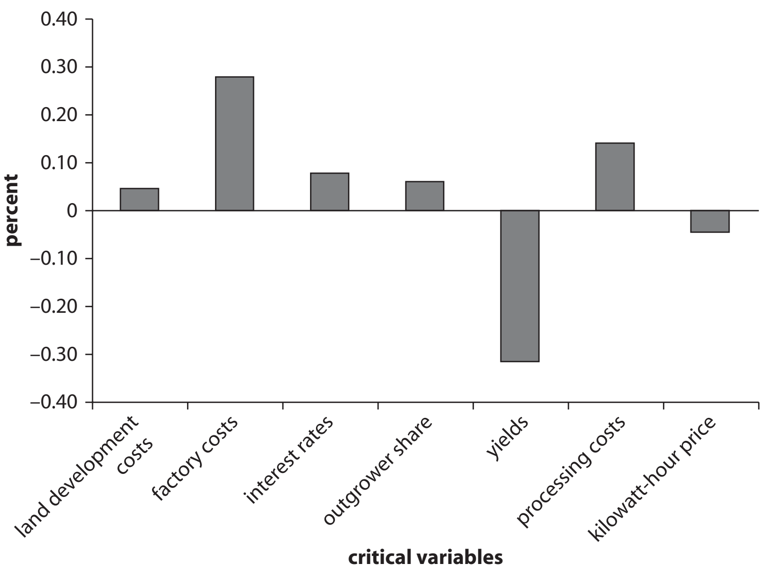
Source: Author's estimates.

of total production costs. Capital costs contribute US$0.20 per liter to ethanol production costs, cane production contributes US$0.26 per liter, and ethanol processing contributes US$0.07 per liter. Cogeneration contributes a credit of US$0.02 per liter.

Sensitivity of Production Costs to Critical Variables

The sensitivity of ethanol production costs to critical variables such as land development costs, factory construction costs, interest on capital, outgrower share of cane production, yield processing costs, and price of cogenerated electricity is shown in figure 3.3 as elasticities estimated from the levels in case I of table 3.5. The elasticities show the percentage change in production costs for a 1.0 percent change in key variables. For example, a 1.0 percent increase in land development costs would increase ethanol production costs by 0.05 percent. This relatively small elasticity is because of the small share of land development costs in total investment costs (21 percent) and the low interest rate on borrowed capital. In contrast, a 1.0 percent increase in factory construction costs would increase ethanol production costs by 0.28 percent because of the large share of

Figure 3.3 Elasticities of Ethanol Production Costs to Critical Variables



Source: Author's estimate.

factory costs of total costs (79 percent). Interest rates and the outgrower share of total cane production have low elasticities, whereas cane yields have the largest elasticity at –0.32 of variables tested. This difference indicates that increasing cane yields would reduce ethanol production costs more than an equivalent improvement in other factors of production. Processing costs have the next-largest elasticity, 0.14, indicating that a 1.0 percent increase in processing costs would increase ethanol production cost by 0.14 percent.

Case II considers the effect of lower land development and factory costs, improved outgrower yields, and lower outgrower cane prices. This alternative is intended to more closely reflect the situation in Brazil and provide a comparison of costs in Africa and Brazil. In this case, land development costs were halved, and factory investment costs were reduced by one-third. Outgrower yields and cane prices were the same as for plantation production. Under this alternative, ethanol production costs would decline to US$0.41 per liter compared to production costs in Brazil of US$0.35–$0.38 per liter in 2008.[10] Thus, a large part of the difference in production costs between Africa and Brazil appears to be explained by higher development costs and lower outgrower yields and higher cane prices for outgrowers. Separating these two effects indicates that lower development costs account for US$0.06 per liter of the reduction in production costs, and higher cane yields and lower prices for outgrowers account for US$0.03 per liter of costs. Efforts to lower development costs and raise outgrower productivity would reduce the gap in production costs between African and Brazilian producers.

Case III considers an industry based on outgrowers. It is analogous to the situation in Kenya, which has 100,000 outgrowers who account for the bulk of cane production (Mitchell 2005). Such an industry would differ from one based primarily on plantation production because yields would be lower and cane prices higher if recent experience is a guide. Land development costs would decline because smallholders would provide a portion of the labor. Factory costs would remain unchanged (per liter) compared to plantation-led production but would decline in the aggregate because of reduced output. As an initial estimate, land development and irrigation costs were reduced by half, yields were 80 percent of plantation yields, and cane prices were 40 percent higher than for plantation production, resulting in an ethanol production cost of US$0.56 per liter (compared with US$0.50 in case I). Greater government support for outgrowers would be required, but the rural development effects would be larger than for plantation production.

Case IV considers the effect of cellulosic production from sugarcane bagasse on ethanol production costs. Although not yet commercially viable, cellulosic production is expected to become economic in the next 5–10 years. Sugarcane bagasse is one of the most attractive feedstocks for cellulosic ethanol production because it is a by-product of sugar or ethanol production from sugarcane and has low opportunity costs for other uses (primarily cogeneration of electricity). A modern sugar or ethanol factory would be constructed with high-pressure boilers and efficient turbines that would require only one-third of the bagasse to power the factory. The remaining two-thirds of the bagasse could be used to produce cellulosic ethanol. Thus, the amount of ethanol produced per ton of cane would increase by 50 percent—from 85 liters per ton to 128 liters per ton.[11] Although the potential cost of producing ethanol from bagasse is not yet known, discussion with industry experts suggests it could be the same as for current ethanol production from sugarcane juice, allowing for higher manufacturing costs but lower feedstock costs. Factory costs and ethanol production are both increased by 50 percent, and bagasse is not used to cogenerate electricity for sale. Factory investment costs would rise from US$207 million to US$311 million, and ethanol production costs would decline by US$0.09 per liter to US$0.41 per liter, as shown in case IV.

The results of these four scenarios suggest that African producers' costs will not be as low as those of Brazilian producers because of higher equipment and land development costs, lower outgrower yields, and higher cane prices for outgrowers. However, African producers can be competitive for exports to the EU and for domestic use in countries with high fuel prices. The cost of a production system that relies exclusively on outgrowers is estimated to be about 12 percent higher than one that has a large share of plantation production, but it still might be preferred because of the development effects from having a large number of outgrowers. If cellulosic ethanol production from sugarcane bagasse becomes economically viable with production costs similar to current ethanol costs from sugarcane, it will reduce ethanol production costs by approximately 18 percent. This development could become very important for African ethanol producers and outgrowers who supply sugarcane to the plants.

Because large-scale ethanol production has not yet been undertaken, these cost estimates are only indicative of expected production costs in the region. However, on the basis of these estimates and discussions with firms planning to produce ethanol from sugarcane, exports to the EU would be marginally profitable at 2009 ethanol prices of approximately US$0.60 per liter and profitable at average ethanol prices during 2007 and 2008 of US$0.80 per liter.

Summary of Biofuel Production Cost Estimates

Table 3.6 summarizes the estimates of biofuel production costs in sub-Saharan Africa. Ethanol produced from molasses is the lowest-cost biofuel and can be produced for US$0.20 per liter or less when the ethanol distillery is integrated into the sugar factory. Substantially higher costs would occur if the ethanol plant bought molasses from several factories and transported it to a central site for processing. Jatropha oil can be produced in small quantities for village use as biofuel for about US$0.42 per liter, assuming seeds are collected from hedges and wild jatropha plants and are delivered to a village processing plant for US$0.10 per kilogram of dry seed (as is now being done). Processing would be by a mechanical press that can extract 24 percent of the oil from the dry seeds. If seeds are collected in larger quantities and transported to a central site for processing, the costs could more than double because of collection and transport costs. However, this increase could vary greatly based on the dispersion of the collection area, distance to the central processing site, and transport costs per kilometer.

Plantation jatropha is more costly to produce than collected seeds primarily because of hired labor costs, and production costs would range from an estimated US$0.63 to US$0.87 per liter, depending on wage

Table 3.6 Estimated Biofuel Production Costs in Sub-Saharan Africa
US$ per liter

Biofuel	*Production cost*
Ethanol from molasses in an integrated plant	0.20
Ethanol from sugarcane in a state-of-the-art plant	0.50
Jatropha oil from the following sources:	
Collected seeds for village processing and use	0.42
Collected seeds for central processing	0.80
Plantation at US$2.00/day wages	0.63
Plantation at US$3.00/day wages	0.75
Plantation at US$4.00/day wages	0.87
Biodiesel from jatropha oil in a small-scale plant	0.11
Biodiesel from jatropha oil in a large-scale plant	0.08

Source: Author's estimates.

rates. Producing biodiesel from jatropha oil would cost an additional estimated US$0.08–$0.11 per liter depending on plant scale. Transporting liquid biofuels or jatropha oil to the EU would cost approximately US$0.10 per liter, and jatropha oil would be competitive with high-quality oils such as rapeseed oil when wage rates are US$2 per day, but not when wage rates are US$4 per day (refer to table 3.1 for rapeseed oil prices).

Ethanol produced from sugarcane is estimated to cost about US$0.50 per liter to produce in large-scale, state-of-the-art factories using company-grown cane. Ethanol could be exported to the EU for an additional US$0.07–$0.10 per liter and would be profitable for sale in the EU because of the duty-free access and high tariffs. Smallholder involvement raises production costs because of lower cane yields and higher costs, but it would probably not make ethanol exports unprofitable unless the productivity gap was very large. Second-generation technology could reduce ethanol production costs by about 20 percent based on current estimates and could become available in the next 5–10 years.

Volatility of Production Costs and Managing Price Risk

Managing price risk is one of the biggest challenges facing the biofuel industry. Both input and output prices are volatile and subject to large cyclical swings as well as shorter-term price shocks from changes in demand or supply. The relatively large share of feedstock costs of the total biofuel production costs makes costs sensitive to fluctuations in input prices, and biofuel output prices are closely linked to global energy prices. Government policy changes can add an additional element of price risk, but they may also reduce price risk by insulating domestic markets from global price changes. Traditional financial instruments, such as futures and options, can sometimes be used to moderate price risk, but these instruments are costly, difficult to manage, and unable to hedge basis risk, which results when futures prices do not reflect local prices. In addition, some biofuel feedstocks may not have futures prices, and hedging would require using financial instruments for crops that only proxy biofuel feedstocks.

Even when financial instruments are available, they do not remove price risk, as the recent bankruptcy of U.S. ethanol producer VeraSun illustrates (see box 3.3). In that case, futures and options were available on maize and ethanol with little basis risk; however, the company made poor decisions in the application of these instruments and incurred large losses, which led to bankruptcy.

Box 3.3

Ethanol Producer VeraSun Bankrupt after Failed Hedge

VeraSun was one of the largest U.S. ethanol producers, with 16 plants in eight states. It filed for bankruptcy on October 21, 2008, because of a failed hedge on corn prices. VeraSun had listed assets of US$3.45 billion, had the capacity to produce 1.64 billion gallons of ethanol (6.2 billion liters), and had high-profile investors, such as Bill Gates and major hedge funds (Bloomberg 2008).

It reported losses of US$99 million during the second quarter of 2008 to cover margin calls on short positions (positions that lose value if prices rise) in corn futures as corn prices spiked higher from the flooding that threatened U.S. midwestern corn production (Piller 2008). However, VeraSun abandoned its short position as corn prices spiked to near US$8 per 56-pound bushel amid concerns that prices would rise even further, and VeraSun's traders locked in corn prices near the peak while prices quickly fell to US$4 per bushel. With corn prices accounting for approximately two-thirds of production costs, the disparity between input costs and ethanol prices created a severe cash-flow problem. Other factors, such as the global recession, made obtaining financing difficult and contributed to the bankruptcy. But the failure to manage price risk was the main cause of the bankruptcy, and it illustrates the severity of the problem for biofuel producers.

The choices of feedstock, technology, and marketing strategy can all influence price risk and should be considered in plant design and production decisions. Feedstocks that have few alternative uses, such as jatropha, would be expected to have less price volatility than feedstocks that can be used for food or feed. Likewise, second-generation feedstocks, such as sugarcane bagasse, have few alternative uses besides production of ethanol or electricity and would not be expected to exhibit as much price volatility as food or feed crops. The choice of technology can influence the range of feedstocks that can currently be used, as well as the ease with which future technologies can be adopted. Multifeedstock factories reduce input price risk by allowing the lowest-cost compatible feedstock to be selected, and multioutput factories (such as sugar and ethanol) adjust production in response to output prices. Marketing can also be an important strategy for dealing with price risk by targeting markets with high importing costs or policy-protected prices. Feedstocks that supply the by-products for second-generation technology provide a transition path to new technologies as they become available.

The Brazilian ethanol industry has effectively dealt with biofuel price risk by focusing mostly on the domestic market where fossil fuel prices are controlled by government policy and by developing an industry that can shift between producing ethanol and sugar in response to market signals. African biofuel producers can learn from Brazil's experience, but they will need to adapt their strategy to country conditions. Local markets for biofuels will be somewhat insulated from international energy markets by high import costs; however, these markets are small and unable to absorb large production. Thus, most African biofuel producers will need to focus on global or regional markets, and many of those will face competition from international energy prices. Feedstock prices will depend mostly on local conditions because of policies that protect local producers and high import costs.

Summary and Conclusions

Biofuel production costs are dominated by feedstock costs. This fact derives from the relatively simple nature of first-generation biofuel production, especially for biodiesel. Low-cost producers of biofuels will typically be low-cost producers of feedstocks, and the African region is well placed to be a low-cost producer of biofuel feedstocks. Sugarcane, the primary feedstock for ethanol production in tropical countries, has been produced in the African region for decades, and some of the world's lowest-cost producers are located in the region. Molasses has low opportunity costs in the region for domestic use or export and is an excellent feedstock for ethanol production. Jatropha, which is labor intensive with as much as 40 percent of production costs coming from manual labor for harvesting and crop maintenance, is well suited to the African region because of low wage rates. However, the crop has never been commercially produced and its economic viability is uncertain.

Molasses is the most attractive biofuel feedstock in the African region because it has low opportunity costs and can be used to produce ethanol at less than half the cost of imported fuel in many countries. However, molasses supplies are limited because molasses is a by-product of sugar production and large-scale production of ethanol will require both sugarcane and molasses, as is done in Brazil. Use of both should be possible in countries where suitable land and water are available, such as Angola, Mozambique, and Tanzania. Production costs are expected to be higher than in Brazil because of higher plantation development costs, the need to irrigate, and poor infrastructure that is common in African countries.

However, these high costs will be partially offset by high yields from irrigated cane and low land acquisition costs. Policies that protect existing sugarcane producers with border measures, such as those in Kenya and Tanzania, will raise the cost of outgrower production and could limit outgrower opportunities. Such policies could even limit the development of sugar ethanol industries if large outgrower participation is needed to gain the political support necessary for project approval.

Jatropha is very labor intensive, requiring as much as one full-time worker per hectare. Attracting sufficient labor will be difficult at the wages that can be paid for harvesting and maintaining the crop. An inadequate workforce could limit the intensive production necessary to contain transport and processing costs to make jatropha oil or biodiesel made from jatropha competitive with fossil fuels. Yields are also a major uncertainty since actual experience with commercial production is limited. Byproduct values are also unknown and could be key if they add value as charcoal, fertilizer, or animal feed as some investors believe. However, their value is not market tested and remains uncertain. Jatropha may have better potential as a smallholder crop in remote areas where fuel import costs are high and surplus and family labor can harvest and maintain the crop. In such cases, it could be used in raw vegetable oil form to power stationary power plants for rural electrification or industrial equipment for mining or other industries. It is also likely to find demand in niche markets, such as safari camps that find it well suited to powering diesel vehicles and satisfying their demand for green fuels. Jatropha oil will probably be too costly to replace a significant share of domestic supplies of diesel in most countries unless production limitations are eased through crop-breeding research. These limitations include continuous flowering over multiple months and low yields. Continuous flowering makes mechanical harvesting difficult because the fruit does not all ripen at the same time. If these limitations can be overcome, jatropha may become a viable biofuel crop for widespread use. It is a high-quality oil for biodiesel production and can be used to meet the EU standard for biodiesel.

Second-generation biofuel technology and improved crop varieties should allow production costs to decline in the future. Ethanol from sugarcane is especially well placed to benefit from second-generation technology because the sugarcane residue (bagasse) is already collected and transported to the sugar factory as part of sugar or first-generation ethanol production. Moreover, the opportunity costs of the bagasse are low for cogeneration of electricity. The large investment in jatropha currently being made in the region could also benefit from crop improvements that increase labor productivity and raise yields. Synchronized flowering to allow mechanical harvesting would have the greatest effect, but higher yields and increased oil content would also lower production costs.

Managing price risk is likely to be a major challenge for first-generation biofuel producers because both input and output prices can be very volatile. Hedging this price risk is difficult because financial instruments are not available for some biofuels and their feedstocks. Even when such instruments are available, variations could be large between local prices and international prices that are the basis of financial instruments. Managing price risk with financial instruments is also difficult, as the recent bankruptcy of a large U.S. biofuel producer illustrates. Second-generation biofuels should have less price risk because feedstocks will be less closely linked to food or feed crop prices. However, output prices will still provide volatility and price risk. Biofuel producers should consider several strategies to manage price risk. Purchase agreements for feedstocks should be negotiated when possible at favorable terms, and marketing agreements that dampen price volatility and sales should be considered. Producers may be able to reduce price risks by concentrating on markets that are insulated by transport costs from international markets. Diversification of both feedstocks and outputs should be considered to allow the flexibility to purchase the lowest-cost feedstock and to shift production to the most profitable product. Producing both sugar and ethanol is an example of output diversification that is widely practiced in Brazil.

Notes

1. Corporate executives, D1 Oils, pers. comm., 2009.
2. Bio Energy Resources Ltd., pers. comm., 2009; Tyson Chisambo, director of Biofuels Association of Zambia, pers. comm., 2009; chief executive officer, Diligent Tanzania Ltd., pers. comm., 2009.
3. The cost of equipment would be higher, but less jatropha would be crushed to obtain 1 ton of oil, resulting in similar costs per ton of oil.
4. Chief executive officer, Diligent Tanzania Ltd., pers. comm., 2009.
5. Jacob Mukupa, Country Manager, D1 Oils Zambia, pers. comm., June 2009.
6. Malawi Energy Regulatory Authority, pers. comm., June 15, 2009.
7. Ethanol Company of Malawi, pers. comm., 2009.
8. Board official, Sugar Board of Tanzania, pers. comm., 2009.

9. The cost received per kilowatt-hour may be higher depending on electricity prices and distance of the ethanol factory from the national grid. In Brazil, producers receive US$0.10 per kilowatt-hour.
10. Chief executive officer of DATAGRO, pers. comm., 2009.
11. Company officials, SEKAB, pers. comm., 2009.

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CHAPTER 4

Global and Regional Demand for Biofuels

The global demand for liquid biofuels (ethanol and biodiesel) is expected to grow rapidly over the next two decades because of consumption mandates and high energy prices. Most of the growth is expected to come from Brazil, the European Union (EU), and the United States, and the share of road transport fuels (adjusted for energy content) provided by liquid biofuels globally is expected to rise from 1.5 percent in 2006 to 5.0 percent by 2030 (IEA 2008) according to the International Energy Agency (IEA). Much of this growth will need to be met from first-generation biofuels because second-generation biofuels are expected to become commercially viable and to make a significant contribution to total biofuel supplies only toward the end of the projection period. Ethanol is expected to remain the dominant liquid biofuel, accounting for almost 80 percent of total production by 2030, although biodiesel is expected to have more rapid growth, albeit from a lower base. Imports are expected to be required to meet a significant portion of demand in the EU and United States if consumption mandates are met, because domestically produced feedstocks will not be available in sufficient quantities to satisfy those mandates.

The African region's demand for biofuels will depend on the growth in the transport fuel market, the demand for household uses, and the demand from niche markets. Transport fuel demand has been growing rapidly and is projected to grow at 5–6 percent per year in the 2010s if historical trends in income growth, population, and urbanization continue. Biofuel demand for household uses such as cooking, heating, and lighting is currently small but could grow rapidly as charcoal and wood fuel become more costly following depletion of forests near population centers. Niche markets such as green fuel for safari companies, demand from heavy industry in remote areas, and power for rural communities located far from the national grid could provide additional demand for biofuels.

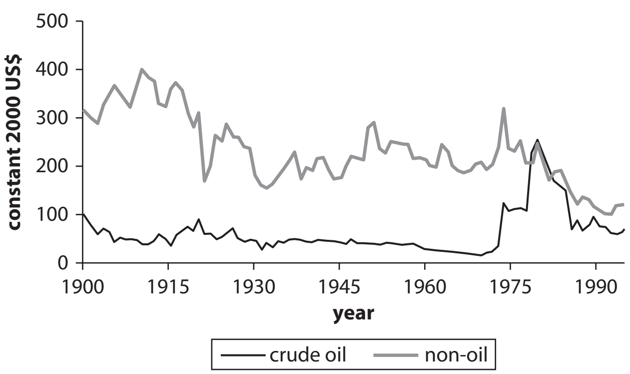
Energy Prices

Energy prices will play an important role in the future demand for biofuels. If energy prices remain high relative to historical levels, that will provide stronger incentives for larger biofuel demand and increase the likelihood that consumption mandates will be met. However, if energy prices fall to the levels of the past several decades, biofuel demand will fall and mandates will most likely go unmet. The sharp decline in crude oil and biofuel prices in 2008 and 2009 because of the global recession slowed the growth of biofuel production capacity and led to plant closures and consolidation among the major biofuel producers. Financing for biofuel projects was also abundant while crude oil prices were rising but scarce once prices began to fall. The long-term outlook is for much higher energy and crude oil prices, according to the IEA, which declared that "the era of cheap oil is over" (IEA 2008, 3). The IEA baseline assumes that crude oil prices will average US$100 per barrel in constant 2007 dollars over the 2008–20 period and then rise to over US$120 per barrel in 2030. The sharply higher prices are caused by a rapid decline in the output from mature fields (which largely offsets additional production from new fields), rapid growth of demand in developing countries, and too little investment in new capacity to keep up with growing demand for oil despite adequate global oil reserves. China and India are expected to account for just over half of the increase in global primary energy demand between 2006 and 2030 because of their continuing strong economic growth. According to the IEA, policies to mitigate greenhouse gas (GHG) emissions could push energy prices lower and increase carbon prices to over US$100 per ton by 2030, resulting in greater demand for low-carbon biofuels.

The U.S. Department of Energy, in its *Annual Energy Outlook 2009* (USDOE/EIA 2009), shares the IEA view that energy prices will be sharply higher in the future because of growing demand for energy—particularly in China, India, and other developing countries—and efforts by many countries to limit access to oil resources in their territories. In the report's reference case, world oil prices will rise to US$130 per barrel in real 2007 dollars in 2030. However, the report notes significant uncertainty in its estimates and projects a range of oil prices from US$50 to US$200 per barrel in alternative scenarios. The low-oil-price scenario represents an environment in which many of the major oil-producing countries expand output more rapidly than in the reference case and increase their share of world production beyond current levels. In contrast, *Annual Energy Outlook 2009*'s high-price scenario represents an environment in which the opposite occurs, with major oil producers maintaining tight control over access to their resources and developing them slowly. Other organizations generally share the view that energy prices will be higher in the future because of strong growth in demand and dwindling supplies of easily accessible crude oil. The World Bank projects nominal crude oil prices of US$80 per barrel in 2020 and real prices of US$74 per barrel in 2007 constant dollars, which is more than double the average price during 2000–05 (World Bank 2010).

Sustained high oil prices would be a break with the trend of declining real oil prices since the 1970s and the trend of generally declining prices for real primary non-oil commodities over the past century (figure 4.1). Such trends have been occasionally interrupted by sharp price increases, but those have quickly dissipated. However, the rapid growth in demand

Figure 4.1 Real Primary Commodity Prices, 1900–2009



Source: World Bank 2010.
Note: Index of prices deflated by the manufactures unit value index, 2000 = 100.

in developing countries; the declining production of mature oil fields; and the concentration of known oil reserves in remote locations, unstable regions, and deep oceans present a formidable challenge to increasing supplies. In addition, the increasing concerns over global climate change may make oil more expensive to use, if not more costly to produce. Given these challenges, oil prices are unlikely to fall to the lows of the past decade. Even if oil prices fall well short of the large increases projected by the IEA, the U.S. Department of Energy, and the World Bank, the likelihood is that they will be higher than during the past two decades and will provide incentives for biofuel production.

Mandates and Subsidies

Mandates and subsidies will also play an important role in determining future biofuel production; both have been instrumental in the development of most biofuel industries to date. Brazil and the United States, the two largest biofuel producers, have provided subsidies to producers since the 1970s, and both now mandate consumption. Government support to the biofuel industry has declined in Brazil in recent years, but Brazil still has tax incentives in certain states and a national mandate on consumption of both ethanol and biodiesel. The United States provides tariff protection and tax credits to fuel blenders, and certain states have additional incentives. Many other developed and developing countries have announced some type of biofuel incentive program.

The policies tend to be of two types: (a) mandates (binding) or targets (nonbinding) on biofuel consumption and (b) subsidies to producers, which are often combined with tariffs to limit imports (Kojima, Mitchell, and Ward 2007). For example, Brazil, the EU, and the United States have all mandated biofuel consumption levels; Australia, China, India, Indonesia, and Malaysia have set targets on biofuel consumption. In addition, the EU and the United States provide subsidies or tax credits and tariffs for biofuels. The United States has a tax credit available to blenders of ethanol of US$0.45 per gallon (US$0.119 per liter) and an import tariff of US$0.54 per gallon (US$0.143 per liter), as well as a biodiesel blender's tax credit of US$1.00 per gallon (US$0.26 per liter). The tax credits are reflected in higher biofuel prices. The EU has a specific tariff of €0.192 (US$0.25) per liter on ethanol, plus other incentives, such as a subsidy of €45 (US$59) per hectare of cropland used to produce biofuel feedstocks. Table 4.1 summarizes biofuel policies in major countries and regions.

Table 4.1 Biofuel Mandates and Targets, Production Incentives, and Trade Policy for Major Consumers and Selected African Countries

Country	*Use mandate or target*	*Production incentives*	*Trade policy*
United States	Mandates 15 billion gallons of ethanol (56.8 billion liters) from conventional sources by 2015 (about 10 percent of total gasoline use) and 1 billion gallons (3.78 billion liters) of biodiesel by 2012. Mandates an additional 21 billion gallons (79.5 billion liters) of advanced biofuels by 2022.	Tax credit of US$0.45/gallon ($0.12/liter) for ethanol blenders and US$1.00/gallon ($0.26/liter) for biodiesel blenders from agricultural feedstocks.	Ethanol tariff of US$.54/gallon ($0.143/liter) plus 2.5 percent. Ethanol tariff exempt under Caribbean Basin Initiative. Ad valorem duty of 1.9 percent on biodiesel.
EU	Mandates 10 percent of transport fuel from renewable fuels by 2020.	Member states permitted to exempt or reduce excise taxes on biofuels or provide production incentives.	Specific tariff of €0.192/liter of ethanol ($0.25/liter). Ad valorem duty of 6.5 percent on biodiesel.
Brazil	Mandates ethanol blend of 20–25 percent. Biodiesel blend of 2 percent by 2008 and 5 percent by 2013.	State tax incentives.	Tariff of 20 percent on ethanol imported from outside the Southern Cone Common Market (temporarily suspended).
Canada	Mandates 5 percent ethanol by 2010 and 2 percent biodiesel by 2012. Some provinces have higher mandates.	Production incentives.	Ethanol tariff of Can$0.05 per liter except for North American Free Trade Agreement countries.
India	Government approved National Biofuels Policy in 2009 with target of 20 percent ethanol and biodiesel blend by 2017.	No direct financial assistance or tax incentives for ethanol or biodiesel.	Ethanol tariff of 29 percent on ethanol and biodiesel.
China	Target of 15 percent of fuel consumption to be nonfossil by 2020.	Production subsidies on ethanol and biodiesel.	Duty of 30 percent on ethanol.

(continued next page)

Table 4.1 *(continued)*

Country	*Use mandate or target*	*Production incentives*	*Trade policy*
Malawi	Mandates 10 percent ethanol dependent on availability.	Fuel tax exemption.	Regulated price and tax incentives.
South Africa	Biofuels strategy approved in 2007. Proposed 2 percent biodiesel and 8 percent ethanol blend by 2013.	Government support to research and production in government-owned facilities.	—
Mozambique	Blend mandate approved but not yet specified.	Producer support not yet specified.	Trade policy not yet specified.

Sources: Author's compilation from various sources including Kojima 2010; Kojima, Mitchell, and Ward 2007; LMC International 2009; Renewable Fuels Association 2008 data (http://www.ethanolrfa.org/); U.S. Department of Agriculture, Global Agriculture Information Network (GAIN) biofuels reports, various countries and years.
Note: Can$ = Canadian dollars; — = not available.

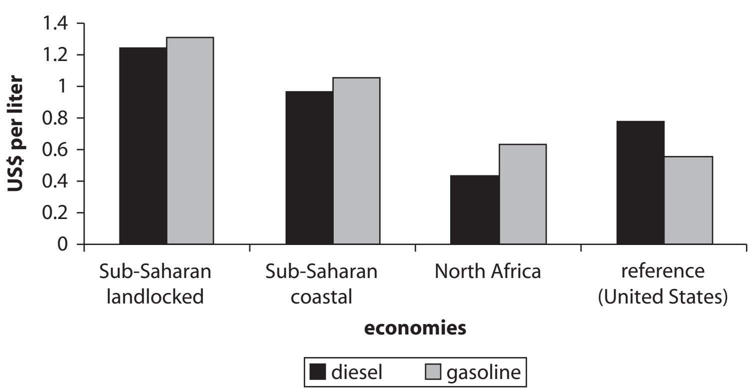
Meeting consumption mandates from domestic production will be a challenge for many countries, but that shortfall will provide opportunities for low-cost exporters. Both the United States and the EU have recently mandated large increases in biofuel consumption that are expected to be met, at least in part, by imports. In its Directive on the Promotion of the Use of Energy from Renewable Sources (Directive 2008/16), agreed to in December 2008, the EU mandated 10 percent renewable energy in transport fuels by 2020, compared with the voluntary target of 5.75 percent biofuels by 2010 in its previous directive (CEC 2008). Many African countries will have preferential access to the EU under the Everything but Arms (EBA) initiative, the Cotonou Agreement, and the super Generalized System of Preferences, and their least-developed country status, giving them an advantage over existing large biofuel producers such as Brazil, Indonesia, and Malaysia. The U.S. legislation, the Energy Independence and Security Act of 2007, mandated consumption of 15 billion gallons (56.8 billion liters) of ethanol from conventional sources (primarily ethanol from maize) by 2015 and 1.0 billion gallons (3.78 billion liters) of biodiesel by 2012 (compared with its previous mandate of 7.5 billion gallons [28.4 billion liters] of ethanol in 2012 established by energy legislation in 2005). The act also mandated consumption of an additional 21 billion gallons (79.5 billion liters) of renewable fuels (excluding ethanol produced from maize) by 2022. A substantial portion of this mandate may come from imports of ethanol from sugarcane, unless second-generation technology becomes commercially viable sooner than many expect.

Biofuel Demand in the African Region

High fuel prices make biofuels a more attractive alternative to fossil fuels, and most sub-Saharan Africa countries have very high fuel prices. Most countries in the region import gasoline and diesel rather than refine it from crude oil, and they have high import costs because of poor infrastructure, limited volumes, and high domestic transport costs. In addition, many countries impose high taxes on fuel. According to a November 2008 survey of retail fuel prices by the German Agency for Technical Cooperation (GTZ 2009), African gasoline prices were double those in the United States, which are taken as the benchmark.[1] At that time, crude oil prices were US$48 per barrel, the average retail gasoline price in Africa was US$1.12 per liter, and the average retail diesel price was US$1.02 per liter. Considerable disparity exists in fuel prices within Africa; North African countries generally had lower fuel prices than sub-Saharan Africa countries because many of the former are oil exporters and subsidize fuel prices. Oil-exporting countries in sub-Saharan Africa, such as Angola, also had low fuel prices (see annex table 4A.1), but most sub-Saharan Africa countries had high prices (figure 4.2).

Landlocked countries had even higher average fuel prices than coastal countries in sub-Saharan Africa, with gasoline prices and diesel prices

Figure 4.2 Retail Fuel Prices in Africa, 2008



Source: GTZ 2009.

averaging 24 percent and 28 percent higher, respectively, in the 2008 survey. Malawi, for example, is a landlocked country that imports all of its fuel through either Mozambique or Tanzania by rail and truck. The inbound landed cost of gasoline in Malawi doubles from the port in Dar es Salaam, Tanzania, because of the high transport costs, and it more than doubles again within Malawi because of high levies, taxes, and duties (table 4.2). When the distribution and marketing margins are added, the cost of gasoline was more than four times the free on board price in Dar es Salaam, at US$1.55 per liter in March 2009.[2] Such high gasoline prices make ethanol competitive with gasoline, and Malawi has been producing and using ethanol from sugarcane molasses continuously since 1982.

Demand for Gasoline and Diesel in Africa

Growth in demand for fuel could be an important factor influencing the domestic use of biofuels in African countries with higher growth, encouraging biofuel consumption as a means to reduce import costs.[3] The rapid growth in energy demand seen in China and India could also occur in Africa if income growth remains high and if the income elasticities rise, as they have in Asian countries with higher income levels. Kshirsagar, Mitchell, and Streifel (2010) developed an econometric model of fuel demand based on cross-regional aggregate data and used it to explore potential fuel demand growth in Africa. The factors determining per capita fuel consumption are well known and include per capita income, fuel prices, and urbanization rates (ExxonMobil 2008; McKinsey Global Institute 2007; Small and Van Dender 2007).

Table 4.2 Gasoline Prices in Malawi, 2009
US$ per liter

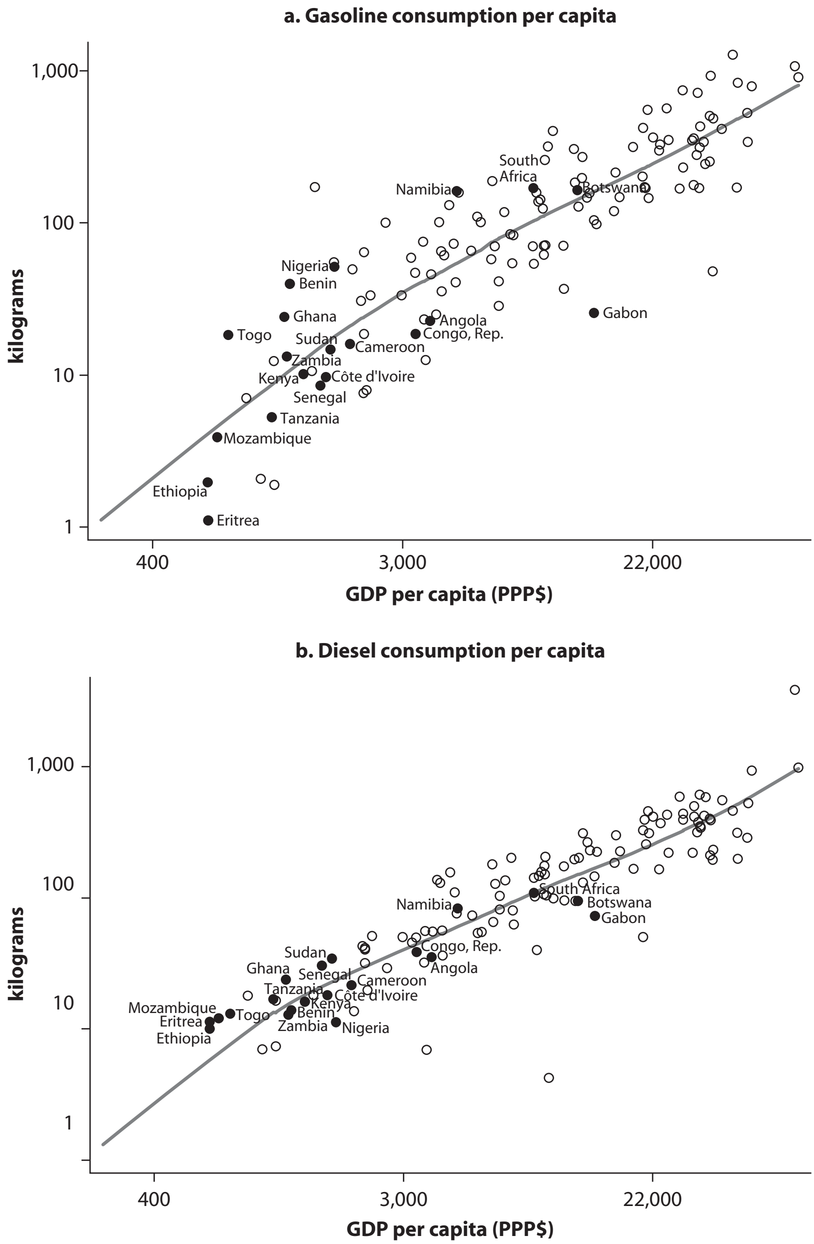
Pricing method	*Gasoline price*
Dar es Salaam free on board prices	0.35
Inbound landed costs	0.64
Levies and fees	0.46
Duties	0.24
Total levies, fees, and duties	0.70
Duty-paid price	1.33
Retail pump price	1.55

Source: Malawi Energy Regulatory Authority, pers. comm., June 15, 2009.
Note: The March 2009 exchange rate was 138 kwacha = US$1.

As incomes rise, the demand for gasoline and diesel increases for both personal vehicles and commercial activities. Increased urbanization is associated with a greater need for transport and with the attendant higher demand for transport fuel as a larger fraction of the population moves away from an agrarian existence. Countries in sub-Saharan Africa typically have lower rates of urbanization in addition to lower income per capita than other developing countries. Despite the lower levels of urbanization, a given percentage increase in the urban share of the population is associated with a greater need for transport and the attendant higher demand for transport fuel. These factors are shown for sub-Saharan Africa and other low-income countries in figures 4.3 through 4.5 for gasoline and diesel based on data from the IEA, the World Bank, and GTZ's survey of retail fuel prices. Per capita income (expressed in purchasing power parity, or PPP) and per capita consumption of gasoline and diesel (figure 4.3) are seen to be broadly consistent across low-income countries for gasoline and diesel. The relationships between fuel prices and per capita consumption are more complex (figure 4.4), with no apparent systematic relationship between fuel price and per capita consumption if other factors are not held constant. Sub-Saharan Africa countries are below the fitted price curves because they have lower per capita income and lower levels of urbanization. However, consumption per capita is negatively related to price after controlling for income per capita, as regressions show. The relationship between urbanization and diesel consumption is shown to be broadly consistent across sub-Saharan Africa and other low-income countries (figure 4.5), but per capita gasoline consumption is lower for sub-Saharan Africa than for other low-income countries.

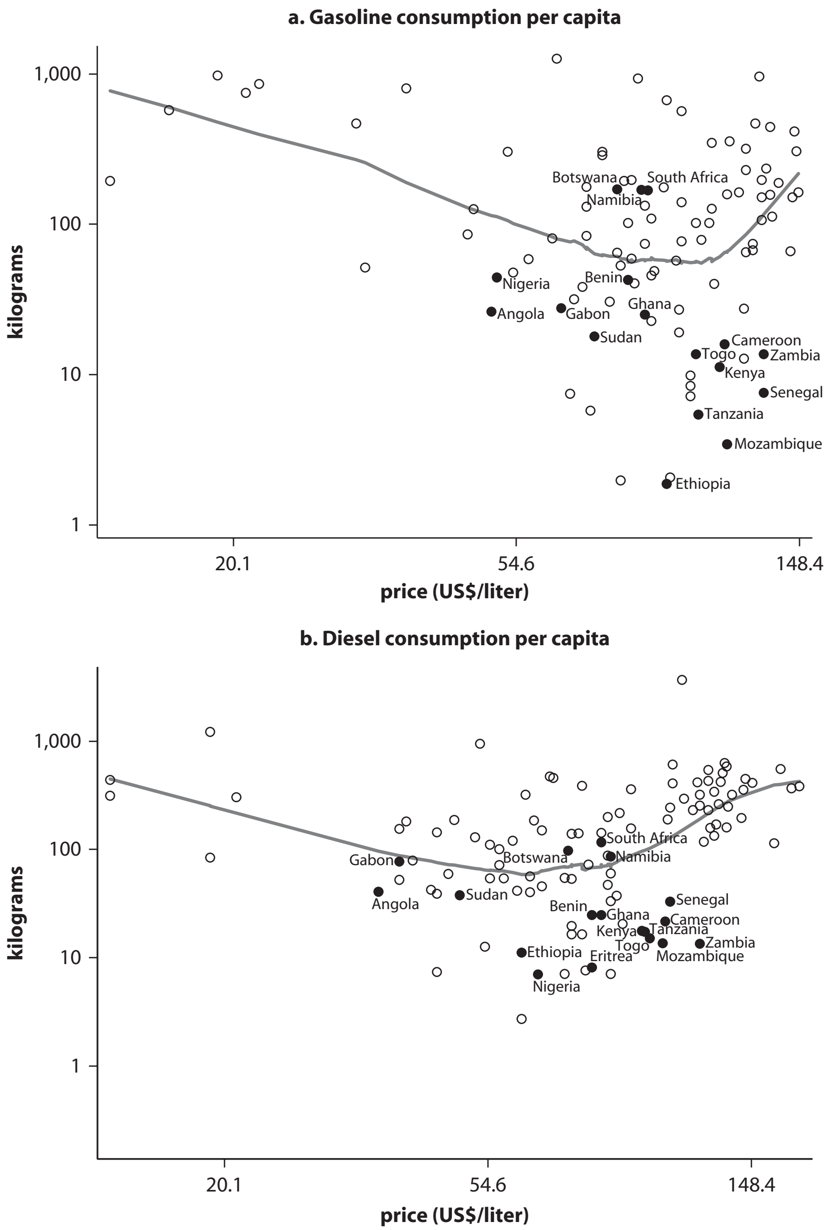
Comparing factors determining per capita fuel consumption across regions shows that sub-Saharan Africa has had similar rates of growth in urbanization as the East Asia and Pacific and the South Asia regions but more rapid population growth (table 4.3). Real per capita income growth has not been as rapid as in other regions but has been rapid by historical comparison for sub-Saharan Africa (for example, real per capita income declined from 1990 to 2000 for the median country in sub-Saharan Africa). Per capita fuel consumption in sub-Saharan Africa grew faster than in the East Asia and Pacific, and South Asia regions, although from a smaller base, and has not received as much attention (the median country in the region witnessed an average annual growth rate of 4.6 percent for gasoline and 5.0 percent for diesel oil between 2000 and 2007).

Figure 4.3 Fuel Consumption versus GDP in Low- and Middle-Income Countries, 2005



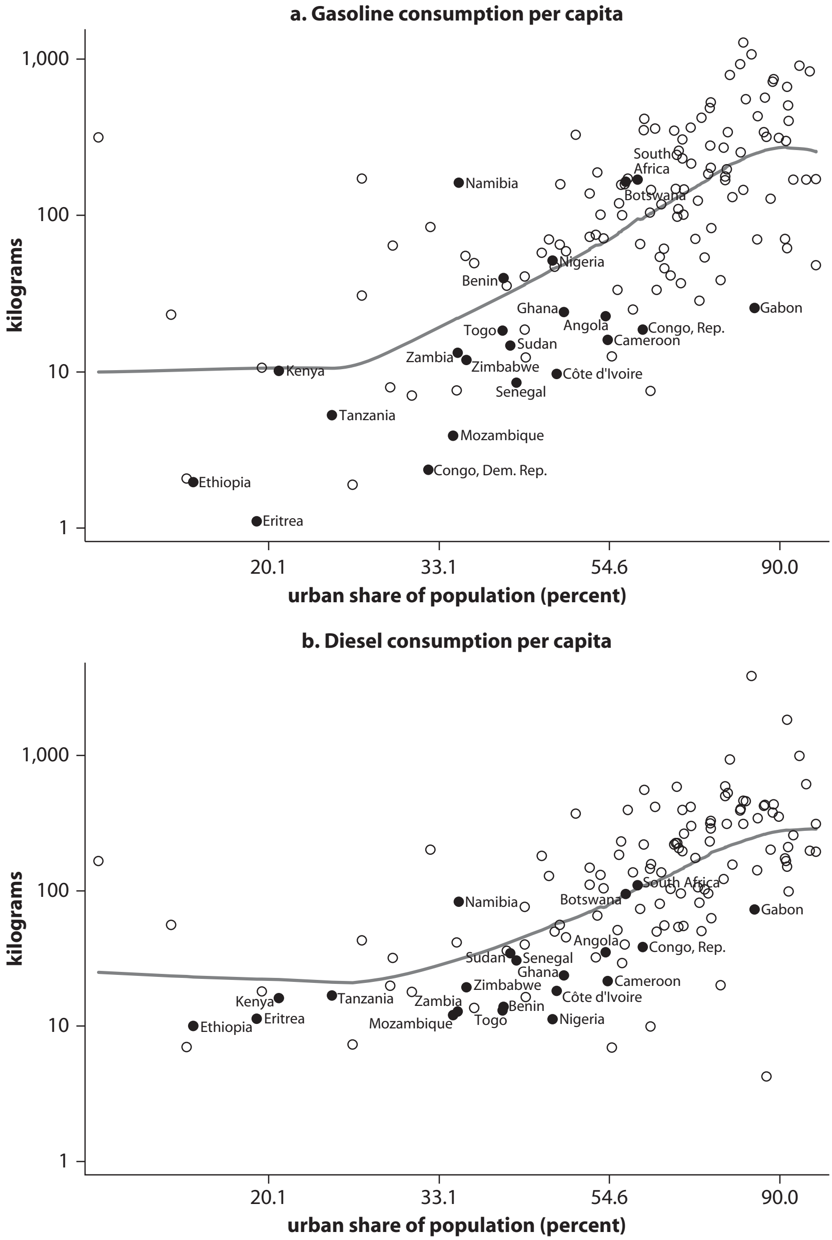
Source: Kshirsagar, Mitchell, and Streifel 2010.
Note: Black dots represent countries in sub-Saharan Africa. GDP per capita is measured in PPP (purchasing power parity) dollars. Graphs are on a log scale. The fitted line is a lowess curve.

Figure 4.4 Fuel Consumption versus Price in Low- and Middle-Income Countries, 2006



Source: Kshirsagar, Mitchell, and Streifel 2010.
Note: Black dots represent countries in sub-Saharan Africa. Graphs are on a log scale. The fitted line is a lowess curve.

Figure 4.5 Fuel Consumption versus Urbanization in Low- and Middle-Income Countries, 2005



Source: Kshirsagar, Mitchell, and Streifel 2010.
Note: Black dots represent countries in sub-Saharan Africa. Graphs are on a log scale. The fitted line is a lowess curve.

Table 4.3 Recent Trends in Urbanization, Economic Growth, and Population, 2000–07

	Average annual growth rate				
Region (median country)	*Urban share (percent)*	*Population (percent)*	*Real income per capita (PPP$)*	*Per capita gasoline consumption (percent)*	*Per capita diesel consumption (percent)*
Sub-Saharan Africa	1.4	2.5	2.9	4.1	5.2
South Asia	1.6	1.8	4.7	1.8	–4.1
East Asia and Pacific	1.4	1.6	3.4	2.0	1.8
Europe and Central Asia	0.2	–0.1	6.5	0.0	8.4
Latin America and the Caribbean	0.5	1.4	3.5	1.0	3.1
Middle East and North Africa	0.6	1.8	2.6	5.5	5.0
Developed countries	0.1	0.7	2.9	0.0	4.8

Sources: IEA 2008; World Bank 2009b.
Note: PPP$ = purchasing power parity dollar.

To quantify the effects of each of the key determinants of per capita demand for transport fuel, the study estimated a fuel transport model using panel data from 1980 to 2006 for 134 countries (see box 4.1 for model specifications). The model was estimated for each World Bank income group separately, because the reduced-form model of transport fuel consumption would likely yield different estimates of elasticity for countries that are at different stages of development. The results are broadly consistent with the literature (for example, Espey 1998; Hamilton 2009). Per capita consumption was multiplied by the relevant population estimates to obtain an estimate for aggregate transport fuel consumption for a given country. The results suggest that diesel consumption is more sensitive to changes in income than gasoline across all income groups, and the income elasticity for diesel increases for higher income groups (table 4.4). In part, the results reflect greater trade in goods within (and across) countries that are more developed. For the highest income group, diesel is less heavily taxed in Europe, and consequently diesel consumption is more sensitive to income increases (Pock 2009). In contrast, gasoline demand is most sensitive to income for countries that are in the low- to middle-income range. Countries in this income range will have the largest fraction of consumers who are willing and able to purchase passenger vehicles for the

Box 4.1

Econometric Model of Transport Fuel Demand

The model for estimating transport fuel demand per capita (T_{ic}) is described by the following reduced-form dynamic equation:

$$Ln\ (TFCpc_{it}) = B_i + B_{TFC}\ Ln\ (TFCpc_{it-1}) + B_y\ Ln\ (real\ GDPpc_{it})\ (PPP\$)$$
$$+ B_U\ Ln\ (fraction\ of\ the\ urban\ population_{it}) + B_p\ Ln\ (real\ crude\ oil\ price_{it}).$$

A comprehensive, unbalanced panel of data from 134 countries for the period 1980–2006 is used to estimate the model, and country dummies are used to eliminate any time-invariant unobserved heterogeneity. Because the period is long, the model assumes that the costs associated with the well-known dynamic fixed effects bias are small relative to the efficiency loss from using a more involved technique that requires, for instance, first differencing and using several lagged dependent variables as instruments. Because the fixed effects only allow for identification through intertemporal variation, the possibility of heterogeneous slopes (that is, elasticities) is handled by splitting the sample into four groups based on the World Bank's income classification.

Figure B4.1 Transport Fuel Consumption Elasticity Estimates from Panel (Fixed-Effect) Regressions

	Income group			
Indicator	*Low*	*Lower middle*	*Upper middle*	*OECD*
Log(gasoline consumption per capita)				
Lagged dependent variable	0.789***	0.707***	0.843***	0.957***
	[0.026]	[0.023]	[0.021]	[0.01]
Log(real GDP per capita [PPP$])	0.135**	0.287***	0.108***	–0.033
	[0.054]	[0.039]	[0.031]	[0.014]
Log(fraction of urban population)	0.166**	0.100	0.032	0.165**
	[0.068]	[0.068]	[0.066]	[0.076]
Log(real crude oil price lcu)	–0.003	–0.026**	–0.066***	–0.027***
	[0.015]	[0.012]	[0.01]	[0.004]
Groups	22	34	25	27
Observations	459	685	470	677
R-squared (within)	0.751	0.741	0.873	0.959
Log(diesel consumption per capita)				
Lagged dependent variable	0.662***	0.880***	0.683***	0.851***
	[0.037]	[0.017]	[0.033]	[0.018]
Log(real GDP per capita [PPP$])	0.286***	0.159***	0.425***	0.282***
	[0.079]	[0.039]	[0.054]	[0.035]

Box 4.1 *(continued)*

Figure B4.1 *(continued)*

	Income Group			
Indicator	*Low*	*Lower middle*	*Upper middle*	*OECD*
Log(diesel consumption per capita)				
Log(fraction of urban population)	0.353***	0.080	–0.056	–0.192*
	[0.092]	[0.070]	[0.082]	[0.105]
Log(real crude oil price lcu)	–0.005***	–0.029**	–0.039***	–0.017***
	[0.018]	[0.012]	[0.013]	[0.006]
Groups	20	32	25	27
Observations	424	661	460	677
R-squared (within)	0.629	0.872	0.783	0.955

Sources: Author's calculations based on IEA 2008; World Bank 2009b.
Note: lcu = local currency units; OECD = Organisation for Economic Co-operation and Development; PPP$ = purchasing power parity dollar. The standard errors are reported in brackets below the coefficients. Income classification is based on official World Bank classification.
* 10 percent level of significance; ** 5 percent level of significance; *** 1 percent level of significance.

first time, and vehicle penetration rates are expected to respond more strongly to per capita income changes for this set of countries and to decline thereafter.

Diesel consumption growth rates are sensitive to urbanization rates for countries at earlier stages of development because of the greater amount of fuel required to transport freight. The model cannot capture the long-run relationship between diesel consumption and urbanization for more-developed countries, in part because these countries have not experienced an adequate measure of urbanization during the period for which data were available. Gasoline consumption and diesel consumption have a similar relationship to urbanization across most income groups, with developed countries being the exception. Although it is not clear why the model estimates a large value for the elasticity of this factor for this set of countries (it may reflect greater use of multiple cars per family), this number is not relevant for this chapter's transport fuel projections for countries in sub-Saharan Africa.

Because an adequate time series of local prices is not available, this model uses temporal variation in internationally traded prices (adjusted for inflation and exchange rate movements) to estimate price elasticities. As expected (for example, Hamilton 2009), the short-run price elasticity

Table 4.4 Estimated Elasticities for Factors Determining Transport Fuel Demand

	Per capita gasoline demand for transportation						*Per capita gas, oil, and diesel demand for transportation*					
	Income per capita elasticity		*Price elasticity (with respect to international prices)*		*Urbanization elasticity*		*Income per capita elasticity*		*Price elasticity*		*Urbanization elasticity*	
Income	*Short run*	*Long run*	*Short run*	*Long run*	*Short run*	*Long run*	*Short run*	*Long run*	*Short run*	*Long run*	*Short run*	*Long run*
Low	0.14	0.64	0.00*	–0.02*	0.17	0.79	0.29	0.85	–0.01*	–0.02*	0.35	1.05
Lower middle	0.29	0.98	–0.03	–0.09	0.10*	0.34*	0.16	1.34	–0.03	–0.25	0.08	0.67
Upper middle	0.11	0.70	–0.07	–0.43	0.03*	0.21*	0.43	1.34	–0.04	–0.13	–0.06*	–0.18*
OECD	–0.03	–0.80	–0.03	–0.64	0.17	3.94	0.28	1.91	–0.02	–0.12	–0.19	–1.30

Source: Kshirsagar, Mitchell, and Streifel 2010.
Note: Estimated using dynamic fixed effects. OECD = Organisation for Economic Co-operation and Development.
* Not statistically significant at 1 percent level.

is very low. The long-run price elasticity for gasoline demand is higher than for diesel demand, because diesel is used for freight, which has fewer substitution possibilities. Often, opaque policies determine the (sometimes negligible) extent to which changes in international prices translate into changes in local prices (IMF 2008), and the low estimates of price elasticity partially reflect that factor. However, controlling for variation in international prices (along with the requisite exchange rate and inflation adjustments) allows better estimates of income and urbanization elasticities to be obtained.

The estimated model is used to project consumption of transport fuels in 2020 for 18 countries in sub-Saharan Africa for which data were available (table 4.5). The projections assume that the population growth rates, urbanization, and economic growth remain the same as during 2000–07. The model predicts rapid increases in transport fuel demand in sub-Saharan Africa. These increases will likely be driven by a combination of rapid urbanization, economic growth, and population growth. The most rapid growth is expected to occur in Ethiopia and Mozambique. Both countries have higher rates of growth of all three key drivers (population, urbanization, and real GDP) than the regional averages for these variables. The average growth rate for gasoline consumption in Ethiopia and Mozambique is 5.28 percent per year from 2005 to 2020, with an even more rapid rate of growth for diesel (6.44 percent).

Rapid growth for transport fuels will result in proportionate increases in imports for many countries because many do not have domestic production capacity. Fuel imports in 2005 as a share of GDP and projected in 2020 are shown in table 4.6 assuming that the increase in demand is met by imports. Ghana, Kenya, and Tanzania are all projected to spend at least 4 percent of their GDP on transport fuel imports in 2020 if recent trends in urbanization, GDP, and population growth continue—per capita GDP growth of more than 4 percent per year, urbanization rates of more than 1.5 percent per year, and population growth rates of more than 2 percent per year. In comparison, the median developed country will continue to spend less than 1.0 percent of their GDP on transport fuel imports.

Demand for Biofuels for Household Energy Use

A currently small, but potentially large, market for biofuels exists as a replacement for charcoal for home cooking. Charcoal is used for cooking primarily in urban areas. In Tanzania, an estimated 1 million tons are consumed annually (World Bank 2009a), and at the regional level, the Food

Table 4.5 African Transport Fuel Consumption: Actual 2005 and Forecast 2020

	Gasoline			*Diesel*		
Country	*2005 consumption (mmt)*	*2020 consumption (mmt)*	*2005–20 growth rate (%/year)*	*2005 consumption (mmt)*	*2020 consumption (mmt)*	*2005–20 growth rate (%/year)*
Benin	0.34	0.58	3.72	0.12	0.21	3.88
Botswana	0.30	0.55	4.05	0.17	0.42	6.12
Cameroon	0.28	0.43	2.87	0.38	0.64	3.45
Congo, Dem. Rep.	0.14	0.35	6.47	0.01	0.03	7.55
Congo, Rep.	0.07	0.21	7.81	0.14	0.57	9.98
Côte d'Ivoire	0.18	0.26	2.56	0.34	0.51	2.85
Eritrea	0.01	0.01	4.46	0.05	0.10	4.62
Ethiopia	0.15	0.60	9.76	0.75	4.17	12.08
Ghana	0.54	1.27	5.86	0.53	1.49	7.07
Kenya	0.36	0.80	5.46	0.57	1.45	6.38
Mozambique	0.08	0.25	8.00	0.25	1.01	9.89
Namibia	0.33	0.70	5.18	0.17	0.46	6.93
Nigeria	7.22	16.46	5.65	1.59	4.20	6.71
Senegal	0.10	0.21	4.93	0.36	0.82	5.69
South Africa	7.91	14.30	4.03	5.10	12.75	6.30
Tanzania	0.20	0.55	6.94	0.64	2.15	8.37
Togo	0.11	0.18	3.17	0.08	0.13	3.31
Zambia	0.15	0.28	4.09	0.15	0.30	4.82
Average	n.a.	n.a.	5.28	n.a.	n.a.	6.44

Source: Author's calculations based on estimated elasticities from the dynamic panel data econometric model.
Note: mmt = million metric tons; n.a. = not applicable.

Table 4.6 Transport Fuel Net Import Costs as a Share of GDP: Actual 2005 and Forecast 2020
percentage of GDP

Country	*2005*	*2020*
Botswana	2.8	2.9
Cameroon	–2.5	–3.0
Côte d'Ivoire	–0.9	–1.4
Ghana	4.7	5.1
Kenya	3.9	4.1
Mozambique	1.8	2.2
Namibia	0.6	0.7
Senegal	3.4	3.8
South Africa	2.7	2.9
Tanzania	4.9	5.8
Zambia	2.3	2.1

Source: Kshirsagar, Mitchell, and Streifel 2010.

and Agriculture Organization of the United Nations estimates that charcoal production in the African region was 24.7 million tons in 2007. Charcoal is generally unsustainably harvested from woodlands within 200 kilometers of urban markets, and this is leading to a gradual degradation of forest resources. In Tanzania, for example, rapid income growth, continued urbanization, and rising prices of alternative fuels are expected to keep demand growing rapidly and have contributed to rapid price increases for charcoal in Dar es Salaam. The retail charcoal price increased from 5,000 Tanzania shillings (T Sh) per bag in 2003 to over T Sh 25,000 per bag in 2008 (US$4.95 to US$20.71). The weight of a bag varies, which makes estimating the price per kilogram of charcoal difficult. At the defined weight, the charcoal price was US$0.67 per kilogram in 2008, but the actual price was probably closer to half that because the bags are overfilled. In Malawi, the dependence on fuel wood and charcoal has contributed to the overexploitation of forests and the reduction in the areas of protected forest cover from 45 percent to 25 percent in the past 25 years (Ethio Resources Group 2007). Collection distances for charcoal have increased for rural households, with the burden of wood gathering falling disproportionately on women.

Ethanol and ethanol gel fuel, made by mixing ethanol with a thickening agent, are an alternative to charcoal (Utria 2004). Ethanol gel fuel is easy to use and burns with a carbon-free flame that does not cause respiratory problems such as asthma, which can be caused by emissions from paraffin, coal, and wood fuels (World Bank 2009a). Cooking tests done in Malawi have shown that 1 liter of ethanol can replace 2 kilograms of charcoal, which means that the potential market for gel fuel as a replacement for charcoal in the African region is 12.3 billion liters (18 percent of global ethanol production in 2008). Ethanol gel fuel is sold in Dar es Salaam under the brand name Moto Poa ("cool flame") for T Sh 1,400 per liter (US$1.07), which is more costly than the cooking equivalent in charcoal (about US$0.60–$0.75 for 2 kilograms). The ethanol to manufacture the Moto Poa gel fuel is imported from South Africa. A single-burner stove costs an additional T Sh 15,000 (US$11.50) and therefore is a constraint to use by poor families. Sales of the gel fuel have been growing at 25 percent per year but are small compared with sales of charcoal. However, as incomes and population rise, and as charcoal becomes more costly, the demand for gel fuel is expected to increase and potentially become a large market for ethanol.

Global Demand for Biofuel Imports

The EU and the United States are both expected to become large biofuel importers in the 2010s because of consumption mandates. African biofuel producers are expected to supply a portion of these imports and have the advantage of duty-free and quota-free market access. Because ethanol tariffs are significantly higher than tariffs on biodiesel or biodiesel feedstocks, the advantage will primarily be for ethanol exports. However, the EU is expected to require large imports of biodiesel or feedstocks to produce biodiesel, and African producers may be able to supply a portion of that import demand, even though they do not enjoy significant tariff advantages over other exporters. The United States is expected to require large imports of ethanol rather than biodiesel, and African exporters may be able to supply a portion of that market if supplies from Central and South America are not large enough to satisfy U.S. import demand. Other countries, such as Japan and the Republic of Korea, will also become significant biofuel importers if they meet their biofuel mandates, which will offer opportunities for African exporters. China, India, and other Asian and Latin American biofuel consumers are expected to rely mostly on domestic production.

The EU Market

The EU Directive on the Promotion of the Use of Energy from Renewable Sources (Directive 2008/16, "Renewable Energy Directive") was agreed to in December 2008 (CEC 2008). It established an overall EU target of 20 percent renewable energy to be used in electricity generation, heating, and cooling by 2020. It also set a mandatory target for individual member states to deliver 10 percent renewable energy in transport by 2020.[4] The directive repeals and amends Directive 2001/77/EC and Directive 2003/30/EC, which had voluntary targets of 5.75 percent by 2010 and a 2020 goal of 10 percent, with mandatory minimum targets to be achieved individually by each member state. The mandatory targets ensure consistency in transport fuel specifications and availability, provide certainty for investors, and encourage the development of technologies that generate energy from all types of renewable sources, according to the directive. Member states were advised to work toward an indicative trajectory that traces a path to achievement of their final mandatory targets—with 2005 as a starting point—and to prepare national renewable energy action plans. The mandatory targets can be met by biofuels, biogas, hydrogen, and electricity. However, biofuels are expected to account for the largest share of the renewable fuels used as transport fuel and are expected to be met through a combination of domestic production and imports. The incentives provided for in the directive are expected to encourage increased production of biofuels and bioliquids worldwide;[5] therefore, the directive establishes criteria to encourage the sustainable production of biofuels and bioliquids worldwide. The European Commission will prepare guidelines on the implementation of the biofuels and bioliquids sustainability scheme, and the instruments and laws with respect to the directive must be in place by November 2010, according to the EU's energy and transport director general.

The EU consumption mandate will require a large increase in biofuel consumption, and how that mandate will be met is not clear. Ethanol consumption was approximately 4 billion liters in 2009, and biodiesel consumption was 10.9 billion liters (FAPRI 2010), for a combined consumption of 14.9 billion liters of biofuels (12.3 million tons of oil equivalents). Assuming that diesel is 55 percent of transport fuels and gasoline is the remaining 45 percent in 2020, the European Commission estimated total biofuels required to meet the 10 percent mandate at 34.6 million tons of oil equivalent (EC DG-AGRI 2007), which requires almost a tripling of biofuel consumption between 2009 and 2020. This required level of consumption would equate to approximately 21 billion liters of ethanol and 22.4 billion liters of biodiesel in 2020 if diesel maintains its 55 percent share and gasoline a 45 percent share of transport fuels. The European Commission estimated that the import share of biofuels would equal 20 percent in 2020, assuming that second-generation biofuels would supply 30 percent of required consumption. However, that assumption appears optimistic, and other studies (for example, Banse and others 2008) estimated the import share at 53 percent. The mandated EU targets for renewable energy in transport fuels can be met by either biodiesel or ethanol in most member states, allowing blenders to decide how to meet the obligation. EU production of biodiesel is below capacity, with less than one-third of production capacity operating in 2008. This is expected to create strong demand for imported feedstocks rather than refined biodiesel. Concern over the use of genetically modified vegetable oils for human consumption will also encourage the EU to use domestically produced oils for human consumption and import vegetable oils for biodiesel production (LMC International 2009).

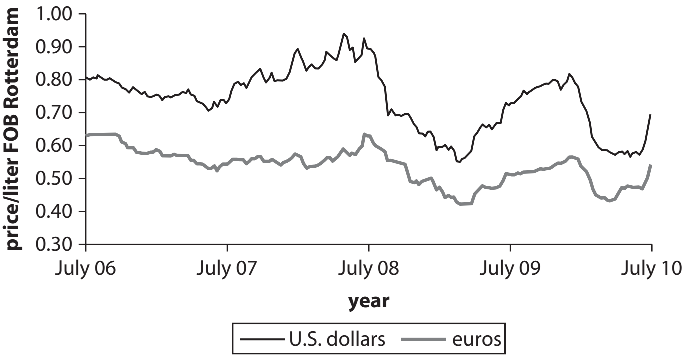
EU Biofuel Import Tariffs and Prices

Ethanol is imported into the EU under two tariff codes, denatured and undenatured, but fuel ethanol does not have a separate tariff code. Denatured ethanol is ethanol that is blended with a chemical additive to prevent human consumption, and the tariff is €0.102 (US$0.133) per liter. Undenatured ethanol has not been blended with a chemical additive to make it unsuitable for human consumption, and the tariff is €0.192 (US$0.25) per liter. Most member states require that undenatured ethanol be used for blending with gasoline, but exceptions exist. The United Kingdom and the Netherlands allow denatured ethanol to be used as well, and Sweden is allowed to import ethanol for use in E85 or E95 blends under a separate tariff code for chemical products, which has a lower tariff. Biodiesel is imported under several different tariff codes, with most imported under the most-favored-nation import tariff of 6.5 percent. Vegetable oils for technical or industrial uses face a most-favored-nation tariff ranging from 3.2 percent to 5.1 percent. Oilseeds have duty-free access on the EU market. Monthly EU ethanol prices averaged €0.54 (US$0.75) per liter from July 2006 to July 2010 (figure 4.6).

African Countries with Duty-Free Access to the EU for Biofuel Exports

All African countries, except those bordering the Mediterranean, were given preferential access to the EU because of their inclusion in the group of Africa, Caribbean, and Pacific countries under the Lomé Convention and later by the Cotonou Agreement of June 2000, which replaced the Lomé Convention. The Cotonou Agreement lapsed at the end of 2007 and was to be replaced by economic partnership agreements (EPAs),

Figure 4.6 EU Ethanol Prices, July 2006–July 2010



Source: Bloomberg database 2010.
Note: FOB = free on board.

which are being negotiated by several regional groups. However, progress on EPAs has been slow, and as of mid-2009, no African region had managed to reach a full agreement. Provisional EPAs with the EU have been agreed to with several countries or regions (table 4.7), which allows temporary duty-free access. With the exception of the Republic of Congo, Gabon, and South Africa, all African Cotonou Agreement countries still enjoy duty-free access to the EU on biofuel exports. In addition, least-developed countries are guaranteed duty-free access to the EU's markets under the EBA initiative, which includes 34 African countries (table 4.8). The duty-free access provided by the EBA has no time limit and is not subject to the periodic review of the European Community's scheme of generalized preferences.

The EU Sustainability Criteria

The EU Renewable Energy Directive of December 2008 introduced sustainability criteria that stipulated that feedstocks used to produce biofuels to meet the EU-mandated targets cannot come from land with high biodiversity value status as of January 1, 2008. Article 17 requires that raw materials cultivated inside or outside the European Community fulfill sustainability criteria for the energy from biofuels and bioliquids to be taken into account for meeting the mandatory targets. The criteria are summarized as follows:

- The GHG emissions savings from the use of biofuels and bioliquids shall be at least 35 percent, and at least 50 percent beginning

Table 4.7 Non-EBA Countries with Duty-Free EU Access under Provisional EPAs

Botswana	Kenya	Swaziland
Cameroon	Mauritius	Zimbabwe
Côte d'Ivoire	Namibia	
Ghana	Nigeria	

Source: LMC International 2009.

Table 4.8 African Countries with Duty-Free Access to the EU under the EBA Initiative

Angola	Ethiopia	Rwanda
Benin	Gambia, The	Senegal
Burkina Faso	Guinea	Sierra Leone
Burundi	Guinea-Bissau	Somalia
Cape Verde	Lesotho	Sudan
Central African Republic	Liberia	Tanzania
Chad	Madagascar	Togo
Comoros	Malawi	Tuvalu
Congo, Dem. Rep. of	Mali	Uganda
Djibouti	Mauritania	Zambia
Equatorial Guinea	Mozambique	
Eritrea	Niger	

Source: LMC International 2009.

January 1, 2017, for installations producing prior to January 1, 2017, and at least 60 percent for installations that begin producing on or after January 1, 2017.

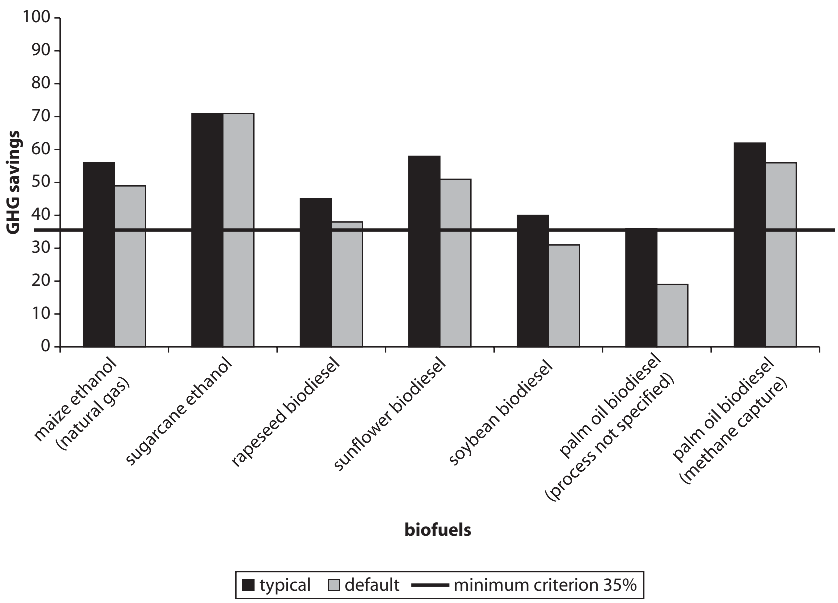
- Biofuels and bioliquids shall not be made from raw materials obtained from land with high diversity value status in or after January 1, 2008 (including primary forests and other wooded land, areas designated for nature protection or the protection of rare, threatened, or endangered ecosystems or species, and highly diverse grasslands).
- Biofuels and bioliquids shall not be made from raw materials obtained from land with high carbon stock, namely, land with one of the following statuses in January 2008: wetlands, continuously forested areas, land spanning more than one hectare with trees higher than five meters and a canopy cover of between 10 and 30 percent, or trees able to reach those thresholds in situ.
- Biofuels and bioliquids shall not be made from raw materials obtained from peatland as of January 1, 2008.
- Agricultural raw materials cultivated in the Community and used for the production of biofuels and bioliquids shall be obtained in

accordance with the environmental requirements and standards and in accordance with minimum requirements for good agricultural and environmental conditions.

Default values for GHG savings for biofuels and bioliquids are provided for common biofuel production pathways, and economic operators should always be entitled to claim those values. When the GHG savings from a production path lies below the required minimum level of GHG savings, producers wishing to demonstrate their compliance with this minimum level should be required to show that actual emissions from their production processes are lower than the default values. The directive provides default and typical values for GHG emissions savings relative to fossil fuel comparators with no net carbon emissions from land use changes.

Figure 4.7 shows, for example, that sugarcane ethanol has a default and typical value of 71 percent GHG savings and would exceed the EU criterion of 35 percent shown. The default value for palm oil biodiesel with an unspecified production path is only 19 percent GHG savings and

Figure 4.7 EU Greenhouse Gas Savings from Biofuels
percent



Source: CEC 2008, 2008/0016 (COD), annex V.

would not meet the EU criterion. However, the typical value for GHG savings is 36 percent, and that would meet the EU criterion, suggesting that an individual producer would be encouraged to submit evidence that it can meet the EU criteria. Many of the biofuel and bioliquid pathways that African producers would use are not included and will either need to be supplied by the economic operator or need to wait for additional estimates from the EU. The directive notes that the GHG emissions savings will be revised as new information becomes available.

The directive would largely prevent expansion of palm oil into new areas in Southeast Asia or Africa after January 1, 2008, to meet the EU-mandated targets but would not preclude using land in palm oil prior to that date if the 35 percent GHG emissions savings could be demonstrated. Thus, existing palm oil production could possibly be used to meet a portion of the EU biodiesel demand, and production in new areas could be devoted to the rapidly growing global food demand. Clearly, not all of the increase in biodiesel required to meet the EU target would come from palm oil, because the properties of palm oil biodiesel are not well suited to the EU market and cannot meet the European Standard for biodiesel, EN 14214. However, palm oil biodiesel can be blended with other biodiesel and still meet the standard, and a portion of the EU-mandated targets would be met by palm oil biodiesel because it is the lowest cost of the major feedstocks used to produce biodiesel. The demand for other oilseeds, such as rapeseed and sunflower, could be used to produce biodiesel for the EU and would increase prices of all vegetable oils.

The EU's environmental sustainability criterion could be challenged in the World Trade Organization. The criterion can be defended successfully only if the EU can show that it is nondiscriminatory and scientifically based and that it has been imposed only after meaningful negotiations with the EU's main suppliers to develop international standards (Swinbank 2009).

The U.S. Biofuel Market

The United States is not expected to be the preferred market for African biofuel exporters because ethanol prices and tariffs are lower than in the EU and transport costs are higher. The import tariff in the United States is US$0.54 per gallon (US$0.143 per liter) compared to €0.192 (US$0.25) per liter tariff in the EU. Fuel prices are also higher in the EU compared with the United States, and that allows greater opportunity for EU member states to provide fuel tax exemptions to biofuels. However, the large increase in U.S. consumption mandates for first- and second-generation biofuels legislated in 2007 will make the United States a large producer and importer of biofuels (primarily ethanol), which will influence the world market for biofuels. If second-generation biofuel production is competitive and production develops more quickly than expected, the increase in imports may slow. However, if the commercialization of second-generation biofuels develops more slowly, then the United States is expected to be a large ethanol importer (primarily of sugarcane ethanol) to meet its mandates, and it could rival or surpass the EU in ethanol imports.

The U.S. Energy Independence and Security Act of 2007 set a renewable fuel consumption mandate, called the Renewable Fuel Standard (RFS), of 9 billion gallons (34.1 billion liters) for 2008 from conventional sources (primarily ethanol derived from maize), that have at least a 20 percent reduction in GHG emissions. The RFS from conventional sources steadily increases to 15 billion gallons (56.8 billion liters) by 2015 (table 4.9). A biodiesel RFS of 1.0 billion gallons (3.8 billion liters)

Table 4.9 U.S. Renewable Fuel Standard Mandates, by Source
billion gallons

Year	*Renewable biofuels*	*Advanced biofuels*	*Cellulosic biofuels*	*Biomass-based diesel*	*Total RFS*
2008	9.00	n.a.	n.a.	n.a.	9.00
2009	10.50	0.60	n.a.	0.50	11.10
2010	12.00	0.95	0.10	0.65	12.95
2011	12.60	1.35	0.25	0.80	13.95
2012	13.20	2.00	0.50	1.0	15.20
2013	13.80	2.75	1.00	—[a]	16.55
2014	14.40	3.75	1.75	—[a]	18.15
2015	15.00	5.50	3.00	—[a]	20.50
2016	15.00	7.25	4.25	—[a]	22.25
2017	15.00	9.00	5.50	—[a]	24.00
2018	15.00	11.00	7.00	—[a]	26.00
2019	15.00	13.00	8.50	—[a]	28.00
2020	15.00	15.00	10.50	—[a]	30.00
2021	15.00	18.00	13.50	—[a]	33.00
2022	15.00	21.00	16.00	—[a]	36.00

Sources: U.S. Energy Independence and Security Act of 2007 (http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf) and USEPA 2010.
Note: n.a. = not applicable; — = not available; 1 gallon = 3.785 liters.
a. To be determined by the U.S. Environmental Protection Agency through a future rulemaking, but no less than 1.0 billion gallons.

by 2012 was established by the 2007 legislation. Separate RFSs were introduced for advanced biofuels and cellulosic biofuels to achieve a total RFS of 36 billion gallons (136.3 billion liters) by 2022. Advanced biofuels are renewable fuels, other than ethanol from maize, that are derived from renewable biomass and achieve at least a 50 percent reduction in GHG emissions. They include cellulosic biofuels, biomass-based diesel, and ethanol from sugarcane. Advanced biofuels are scheduled to grow to 21 billion gallons (79.5 billion liters) and account for 58 percent of overall renewable fuels in 2022. In addition to the RFS on advanced biofuels (which can include cellulosic biofuels), a separate consumption mandate exists for cellulosic biofuels, which are renewable fuels derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass that achieves at least a 60 percent GHG emission reduction. They are scheduled to grow to 16 billion gallons (60.6 billion liters) in 2022 and would be counted as part of the RFS for advanced biofuels.

The renewable biofuel RFS from conventional sources is expected to be met primarily from maize and is projected to use 37.5 percent of domestic maize production in crop year 2015/16 (FAPRI 2010). The advanced biofuel RFS is expected to be met mostly from imported sugarcane-based ethanol. The administrator of the U.S. Environmental Protection Agency is authorized to waive the renewable fuels mandate if he or she determines that implementing the requirement would severely harm the economy or the environment or domestic supply is inadequate to meet the requirement. A separate waiver provision applies for cellulosic biofuels if the minimum volume requirement is not met.

Other Biofuel Producers and Consumers

Brazil is expected to be the primary competitor to African ethanol exporters and a strong competitor of biodiesel exports and feedstocks, with large installed production capacity for ethanol and large production of biodiesel feedstocks such as soybeans. Brazil produced about 26.2 billion liters of ethanol in 2009 (FAPRI 2010) and had net exports of 3.8 billion liters, with the remainder going into the domestic market for blending with gasoline or for direct use in flex-fuel vehicles. It also produced 1.5 billion liters of biodiesel, primarily from soybean oil. Brazil has vast areas of rain-fed land in the Centro-Sul (center-south) region that are well suited to producing sugarcane, oilseeds, and maize for use as biofuel feedstocks. Sugarcane is the primary feedstock for ethanol, and approximately one-half of the sugarcane crop is used to produce ethanol. Sugarcane production grew by almost 9 percent per year from 2000 to

2008 and could continue growing at that rate for many years, based on the amount of land suitable for rain-fed sugarcane in the Centro-Sul region. Exports have been primarily to the United States, the EU, and Japan.

Many other countries have also mandated biofuel consumption and could provide export opportunities for African producers or alternative export markets for Brazilian producers. These countries include Canada, Japan, and Korea. Canada has mandated a 5 percent blend of ethanol in gasoline by 2010 and a 2 percent renewable fuel mandate for biodiesel and heating oil by 2012. Ethanol consumption is expected to rise to approximately 2 billion liters by 2020, and biodiesel consumption is expected to rise to about 790,000 liters. Ethanol would be produced from domestically grown grains and from imported maize. Biodiesel would rely on domestically produced oilseeds such as rapeseed (which would reduce exports to the EU for use in their biodiesel industry) and on imported oilseeds or vegetable oils such as soybean and palm (USDA 2007). The Food and Agricultural Policy Research Institute (FAPRI) estimates that Canada's ethanol imports will exceed 1.0 billion liters in 2019 (FAPRI 2010).

Japan has few prospects for producing biofuels from domestic feedstocks, but its interest in meeting its Kyoto Protocol commitment to reduce carbon dioxide emissions from the 1990 level by 6 percent, by 2010, has led the government to commit to importing ethanol. Japan's first biomass plan was unveiled in December 2002 and updated in 2008, and the strategy is to focus on cellulosic biofuel. The government also supports an ethanol blend of up to 3 percent and is engaged in a number of feasibility studies for the production and distribution of ethanol (USDA 2008a). FAPRI (2010) projects Japan will have net imports of more than 900 million liters of ethanol in 2019.

Korea could also become a significant biofuel importer because of its desire to meet its Kyoto Protocol commitments through increased use of biodiesel. In particular, the government has announced plans to gradually increase the biodiesel blend ratio from the current level of 1 percent to 3 percent by 2012. In an effort to meet these targets, the government has extended industry tax breaks and has taken steps to increase local feedstock production to minimize import dependency. Meanwhile, the biodiesel industry has begun efforts of its own and has secured feedstock plantations in Southeast Asia (USDA 2008b). FAPRI (2010) projects ethanol imports in Korea of nearly 800 million liters in 2019.

Other countries in Asia have biofuel consumption mandates, but many are either suspended because of concern over the effect on food crop prices or not being met because of the higher cost of biofuels compared with fossil fuels. China, India, Indonesia, Malaysia, the Philippines, and Thailand all have biofuel consumption mandates. China and India have the potential to become large biofuel producers and consumers, and both see biofuels as a way to cut dependence on fossil fuel imports as well as to provide rural employment and environmental benefits. However, concern over the effect on food prices will likely limit the production of biofuels. China had previously set a target of almost 19 billion liters of ethanol consumption in 2020; however, the government suspended plans to expand grain-based ethanol because of concerns over the effect on food prices. Biodiesel is also being targeted for production from nonfood crops. India approved a National Biofuels Policy in 2009 with targets of 20 percent ethanol and biodiesel by 2017. Jatropha has been targeted as the feedstock for biodiesel, but production of jatropha has not expanded as expected. Indonesia and Malaysia have mandated biodiesel consumption, but those mandates are unmet. The Philippines has mandated a 10 percent ethanol blend by 2011, and Thailand has mandated a 10 percent ethanol blend as standard and a 2 percent biodiesel blend.

A number of countries in Central and South America, in addition to Brazil, have introduced biofuel policies. Colombia is steadily increasing both production and consumption; it has a 10 percent ethanol mandate in major cities and is gradually extending the mandate to other areas. Argentina, Paraguay, Peru, Uruguay, and the República Bolivariana de Venezuela are also introducing or have announced plans to introduce ethanol mandates with a combined consumption of 2 billion liters of ethanol by 2020 (LMC International 2009). Biodiesel use is also increasing in South America. Brazil first mandated biodiesel consumption in 2008 and is targeting a 5 percent blend by 2010.

Summary and Conclusions

The global demand for liquid biofuels (ethanol and biodiesel) is expected to grow rapidly over the next two decades because of consumption mandates and high energy prices. Most of the growth is expected to come from the EU and the United States. The EU has mandated that 10 percent of transport fuels come from renewable fuels by 2020, which requires almost tripling the approximately 15 billion liters of biofuels consumed in 2009. The United States has mandated that 36 billion gallons (136 billion liters) of biofuels be consumed by 2022, which requires more than tripling the 11.1 billion gallons (42 billion liters) of biofuels consumed in 2009. Most of the increase in U.S. biofuel consumption will be for ethanol because that is the dominant transport fuel in the United States; the mandate for biodiesel consumption is comparatively small, at 1.0 billion gallons (3.8 billion liters). The EU demand for biofuels to meet the consumption mandate will also require larger increases in ethanol than biodiesel, because current biodiesel production is larger and therefore nearer the mandated consumption than ethanol. The contribution of second-generation technology will be critical to meeting the biofuel consumption mandates of both the EU and the United States. Therefore, if this technology does not develop as rapidly as projected, then large imports of first-generation biofuels would be required to meet the mandates. The United States specifically mandates 16 billion gallons (60.6 billion liters) of cellulosic biofuels by 2022 (44 percent of biofuel consumption), whereas the EU does not establish a specific mandate for cellulosic biofuels. Given the uncertainty about second-generation biofuels and the large mandates, both the EU and the United States will likely require large imports to meet their consumption mandates.

Most African countries have preferential trade access to the EU and the United States under various trade agreements such as EBA, provisional EPAs, and the Africa Growth and Opportunity Act. The agreements allow African exporters duty-free and quota-free access to EU and U.S. biofuel markets and favor ethanol over biodiesel exports because tariffs on ethanol imports are higher. The EU tariff on ethanol imported for fuel is €0.192 (US$0.25) per liter in most member states, compared with the U.S. import tariff on ethanol of US$0.54 per gallon (US$0.143 per liter) plus a 2.5 percent ad valorem tariff. Biodiesel is imported into the EU under several different tariff codes, with most imported under the most-favored-nation import tariff of 6.5 percent. Vegetable oils for technical or industrial uses face a most-favored-nation tariff ranging from 3.2 percent to 5.1 percent. Oilseeds have duty-free access to the EU market. Biodiesel imports to the United States also have low import duties of 1.9 percent ad valorem and offer African biofuel exporters little advantage over other exporters.

The domestic market for African biofuel producers may provide an attractive alternative to exporting for many African countries because of high fuel prices and rapid growth in fuel demand. Sub-Saharan African countries have fuel prices that are about double those in the United States, and landlocked countries face even higher prices. Oil-exporting countries in Africa tend to have low fuel prices because of government subsidies and are less attractive biofuel producers for domestic consumption. Demand for transport fuels is projected to grow at more than 5.0 percent annually in sub-Saharan African countries during 2005–20, and fuel import costs are expected to increase substantially. Household cooking is another potentially large and important market for biofuels in Africa to replace charcoal and wood fuels in urban areas. The demand for such fuels is expected to increase as population and incomes grow and as supplies of these traditional cooking fuels become more costly because of the depletion of forests near urban centers. In addition to the environmental benefit of biofuels to replace charcoal and wood fuels, a substantial health benefit could result as clean-burning biofuels replace traditional biomass and reduce indoor air pollution, which contributes to respiratory illness.

A growing consensus holds that biofuels should be economically, socially, and environmentally sustainable if plans to increase consumption are to achieve their multiple objectives. In response, industry associations such as the Roundtable on Sustainable Biofuels have drafted global principles and criteria for sustainable biofuel production, and the EU established sustainability criteria for biofuel production in its 2008 Renewable Energy Directive. The directive did not establish social and human rights standards or provisions to protect soil, water, or air, or to safeguard agricultural diversity or ecosystems. The verification scheme is based on self-reporting by companies or on bilateral or multilateral agreements or voluntary certification schemes. Nevertheless, the provisions of the directive are a step toward sustainability criteria that will balance the often conflicting goals of biofuel production and use.

The large increase in EU mandates, the granting of duty-free access to most African countries, and the EU sustainability criteria are favorable to most African biofuel exporters. Ethanol produced from sugarcane or molasses directly benefits from duty-free access and should meet the EU's default minimum criterion for reducing GHGs. Biodiesel exporters and biodiesel feedstock exporters are less favorably advantaged because the import tariffs on these products are low. However, the sustainability criteria will most likely hinder Southeast Asian oil palm producers in exporting palm oil or biodiesel made from palm oil to the EU to meet the mandate's targets. The criteria also indirectly favor producers of other biodiesel or biodiesel feedstocks. Jatropha was not assigned a GHG-saving default value but could potentially benefit from the limits placed on palm oil exports if it meets the EU minimum criterion. The large surplus capacity for biodiesel production in the EU will favor imports of biodiesel feedstock rather than biodiesel, which benefits many African exporters for several reasons. First, reaching the scale of production required to process oilseeds at low cost with high oil recovery rates will be difficult for many African producers. Second, the scale and quality of the production plant required to produce biodiesel that meets the EU standard will be capital intensive to build and operate. Third, transporting biodiesel in small quantities will be costly, and most producers would be better able to export oilseeds or crude oil. Offsetting these costs is the potential lost value of the by-products, such as press cake, which can be used as organic fertilizer.

The implication of the new U.S. RFS is that it significantly increased the mandate for maize-based ethanol and introduced a large mandate for advanced biofuels that cannot be met by maize-based ethanol. The advanced biofuels mandate can be met by cellulosic biofuels, biodiesel, or sugarcane ethanol as long as they reduce GHG emissions by at least 50 percent. The intent is that cellulosic ethanol will provide a significant part of that mandate. However, if cellulosic ethanol does not become commercially viable, sugarcane-based ethanol is very likely to be the biofuel used to meet that RFS, which provides both opportunities for African ethanol exports and an alternative market for Brazilian ethanol. Some provisions allow the mandates to be waived, however, which adds an element of uncertainty to the mandate.

(*Chapter continues on the following page.*)

Annex

Table 4A.1 Retail Fuel Prices in Africa, November 2008
U.S. cents per liter

Region/country	*Super gasoline*	*Diesel*
North Africa		
Algeria	34	20
Egypt, Arab Rep.	49	20
Libya	14	12
Morocco	129	83
Tunisia	96	84
Average	64	44
Sub-Saharan Africa		
Landlocked		
Botswana	88	102
Burkina Faso	138	133
Burundi	139	123
Central African Republic	144	144
Chad	130	132
Lesotho	79	93
Malawi	178	167
Mali	130	110
Niger	99	97
Rwanda	137	137
Sudan	159	125
Uganda	130	122
Zambia	170	161
Zimbabwe	130	105
Average	132	125
Coastal		
Angola	53	39
Benin	103	103
Congo, Dem. Rep.	123	121
Congo, Rep.	81	57
Côte d'Ivoire	133	120
Eritrea	253	107
Ethiopia	92	89
Gabon	114	90
Gambia, The	79	75
Ghana	90	90
Guinea	102	102
Kenya	120	114
Liberia	77	103
Mauritania	149	106
Mozambique	171	137

Table 4A.1 *(continued)*
U.S. cents per liter

Region/country	*Super gasoline*	*Diesel*
Namibia	78	88
Nigeria	59	113
Senegal	135	126
Sierra Leone	91	91
Somalia	112	115
South Africa	87	95
Sudan	65	45
Swaziland	86	93
Tanzania	111	130
Togo	89	88
Average	106	97
Island		
Cape Verde	184	143
Madagascar	155	143
Average	170	143
United States	56	78

Source: GTZ 2009.

Notes

1. The U.S. average retail price level, less a deduction for highway taxes, is used as the reference for retail fuel prices because the United States is considered to have a competitive and efficient fuel distribution system.
2. Malawi Energy Regulatory Authority, pers. comm., June 15, 2009.
3. This section is based on a study led by Varun Kshirsagar, consultant, Africa Region, World Bank (Kshirsagar, Mitchell, and Streifel 2010).
4. The total amount of energy consumed in transport includes only gasoline, diesel, biofuels consumed in road and rail transport, and electricity, according to the Renewable Energy Directive, Article 3, paragraph 4a.
5. According to Article 2 of the directive, *biofuels* means liquid or gaseous fuel used for transport and produced from biomass, and *bioliquids* means liquid fuel for energy purposes other than transport, including electricity and heating and cooling produced from biomass.

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CHAPTER 5

Case Studies

This chapter presents three case studies to point out lessons from the experience of biofuel producers. The material is based on company reports and interviews with senior officials. The first case study is of D1 Oils plc (D1), a U.K. share company that has produced jatropha oil for export and domestic use since 2005. It is the world's largest jatropha producer, with approximately 220,000 hectares of jatropha plantings on company-leased land and outgrowers' farms in Asia and Africa. The largest plantings are in India. It has ongoing activities in Malawi and Zambia in the African region. The company has restructured twice, first to stop its biodiesel refining and trading activities and a second time to reduce its production activities and focus on research and consultancy services. It plans to sell jatropha oil for direct use in diesel engines or to other companies for the production of biodiesel.

The second case study describes Diligent Tanzania Ltd. (Diligent), a privately held Dutch company that has produced jatropha oil in Tanzania since 2005. It was one of the first companies to rely exclusively on outgrowers. It contracts with farmers to buy their seeds in exchange for free planting materials and technical advice; it guarantees to buy seeds at a minimum price for a period of 10 years. It has 5,000 farmers registered in Tanzania.

The third case study is of SEKAB, which is a Swedish company planning to produce ethanol from sugarcane grown on leased land and from outgrowers in Mozambique and Tanzania. It has ambitious plans to develop a cluster of private investments in a limited area that would mutually support and strengthen each other, as well as to reinforce parallel investments in public sector development in the surrounding communities. The whole cluster was expected to take 15–20 years to develop and involves 250,000 hectares of sugarcane. The plans for the project were largely complete and funding was being sought, but the decline in energy and ethanol prices and the shortage of capital following the financial crisis of 2008 have made raising capital difficult. The company has continued its development on a slower pace during the crisis and was taken over by the minority owner in the SEKAB group and is now EcoEnergy. It continues to seek strategic industrial partners and investor capital for its ambitious long-term development plans.

D1 Oils Plc

D1 is focusing on renewable energy crops, primarily *Jatropha curcas* L., or jatropha. Initially formed as a biodiesel-producing company in the United Kingdom, the company was then transformed to focus primarily on jatropha in Asia and Africa. It is involved in several activities, including jatropha oil production, plant science research, processing of jatropha oil, and development of coproducts. D1 has learned a number of lessons about jatropha production and the characteristics of the *Jatropha curcas* L. plant, which place the company in the forefront of knowledge on jatropha. The lessons it has learned are shared in this case study, which is based on company material and interviews with senior staff and executives.

Jatropha Production

D1 was involved in jatropha production through its subsidiary, D1-BP Fuel Crops, which was a joint venture with BP International. This joint venture accounted for approximately 20 percent of the documented global jatropha plantings. D1-BP Fuel Crops has closed its operations in Malaysia, the Philippines, and Thailand and scaled back operations in Madagascar and Swaziland. It still has operations in India, Indonesia, Malawi, and Zambia. Attempts to market a substantial interest in D1-BP Fuel Crops to a third party resulted in insufficient interest from potential investors, and D1 became the sole owner of the production activities when the joint venture was dissolved in mid-2009.

Plant Breeding Platform

D1 has a plant selection and breeding program that focuses on increasing jatropha grain yields and oil content.[1] The program has identified cultivars that have 25 percent higher yields and up to 38 percent oil content on a grain-weight basis. Breeding and development centers are located in Cape Verde, India, Indonesia, Thailand, and Zambia. Cultivars have been collected from various countries to build a genetic base on which to begin a plant breeding program. The company's collection has shown that little genetic variation occurs in jatropha plants outside of Central America, where the plant originated. That observation suggests that only a few plants were taken to other locations, and those became the parents for all other jatropha plants. Plants collected from Central America show much wider genetic variation and provide much richer genetic material from which to develop improved varieties. Plant breeding research is in the early stages, and initial efforts are to improve yields and oil content using both conventional and advanced breeding techniques. Breeding programs to develop hybrids and to synchronize flowering are being developed in parallel. Improvements are being developed continuously, but a doubling of yield is unlikely to be developed exclusively through plant breeding within the next decade, according to D1 plant breeders.

Plant Agronomy Knowledge Platform

Initial beliefs were that the jatropha plant was a wonder crop that grew under harsh conditions and required very little care. D1 has demonstrated that it is like any other crop, and production practices as well as climatic conditions are important to the health and performance of the jatropha plant. Properly caring for the plant is essential in the first two years to give it a healthy start and protect it from weeds, pests, and disease. The plant must develop a deep taproot to allow it to withstand drought; that requires careful planting to avoid bending the taproot upward in a J, which prevents deep rooting. Pests and disease are a potential problem in the first two years, and treatments are advisable. The specific pests and diseases vary by region, and in Africa, the major pests are the golden flea beetle, leaf miner, and termites, and the major disease is powdery mildew. Beyond the second year, the jatropha plant is less susceptible to pests and diseases and develops a canopy that reduces weeds. D1 is working with chemical companies to identify suitable chemicals to minimize the effect on beneficial organisms that protect the plant. Beginning in the third year, the focus of plant care shifts from control of weeds, diseases, and pests more toward pruning and harvesting.

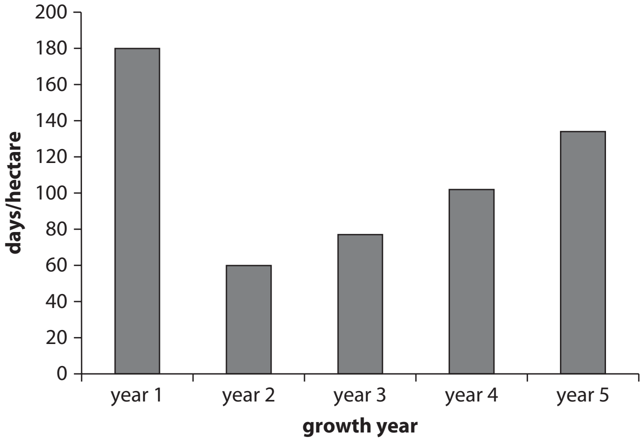
The jatropha plant is very hardy even when it is not properly planted; it survives but does not thrive when it is improperly planted. However, the resulting plant is not vigorous and does not produce large amounts of fruit. Almost all plants may survive in a field that is improperly planted, but many would be small and perform poorly. Time of planting is important; planting at the beginning of the rainy season gives the best chance of developing a healthy plant. If planting is delayed to the end of the rainy season, or if planting is done at other times, the chances of obtaining a healthy plant are reduced. Yields are expected to be 5 tons of grain per hectare from a properly planted field by the fifth year on plantations and 2.5 tons of grain per hectare for outgrowers. Seed germination is 80–90 percent for recently harvested seeds, but that can drop by half for seeds kept for a year (depending on storage practices). Planting seedlings generally results in better branching, canopy diameter, and plant height than planting cuttings. The plant seems to have some natural pesticide characteristics.

Determination of the ideal growing locations for jatropha in Africa is under continuous development. Coastal areas are currently seen to be more favorable for jatropha because they have warm temperatures, which are well suited to jatropha. Large areas in Africa are suitable for growing jatropha—along the eastern coastal belt (Kenya, Mozambique, and Tanzania); in the central region (Angola, the Central African Republic, Ethiopia, and Uganda); and in the western coastal areas (Côte d'Ivoire, Liberia, Nigeria, Sierra Leone, and Togo). Swaziland was initially one of the countries with D1 plantings, but it was found to be too far south of the equator for jatropha and had periods of cold that were too extreme for the plant.

Working with outgrowers requires regular visits to build confidence and keep the farmers interested in the crop, especially during the first two years when the plant is not so productive. Many small farmers are not familiar with perennial crops and require more technical support than those who have previously raised perennial crops. The crop must fit into the farmer's cropping plan to allow the necessary care to establish a healthy crop. Jatropha can be intercropped so that the weeding and maintenance of the intercrop support the development of the jatropha plants. The government could assist jatropha producers by training extension agents so that they could work with outgrowers to grow jatropha.

The estimated labor requirements per hectare for jatropha are shown in figure 5.1, based on D1's medium-variant estimates. The yield profile is assumed to be 2 tons of grain per hectare in the second year, with yields

Figure 5.1 Jatropha Labor Requirements



Source: D1 Oils plc.

rising 1 ton per year until the fifth year and then remaining at that level. The first year is the most labor intensive, with an estimated 160–200 workdays required per hectare of jatropha. Labor is mostly for nursery activities, seedbed preparation, and planting, with weeding, pruning, and chemical treatments accounting for approximately 20 percent of labor needs. Land clearing is not included in this estimate and could require additional unskilled labor if mechanized land clearing is not used. The second year has lower labor requirements, with labor needed primarily for weeding, pruning, and chemical applications and harvesting of the first crop. Labor requirements decline in the third year as weeding, pruning, and chemical applications decrease, then they increase in the fourth and fifth years as jatropha yields rise and labor for harvesting increases. Labor needed for weeding and chemical treatments decreases to near zero in the third year, but pruning and harvesting requirements increase. Labor requirements in the fifth year total 134 days per hectare (approximately 0.5 worker per hectare on a full-time-equivalent basis). However, most of the labor would be required at harvest time, and employment during the remainder of the season would be small and mostly for pruning. The number of seasonal workers required for harvesting would depend on the length of the harvest season. If the harvest season lasted five months, harvesting would require 1.3 workers per hectare to harvest 5 tons of grain.

The jatropha crop calendar for Zambia is shown as an example in figure 5.2. Seedbed preparation begins in October, and planting occurs from December to March following the first rains. Flowering occurs in the second year during November to April, with fruiting following with a one-month delay and harvesting following with a two-month delay.

Processing Platform

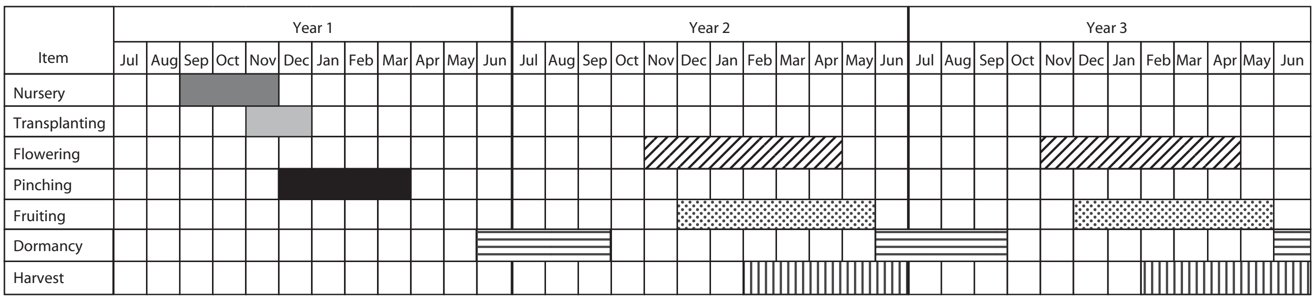
Adding value to jatropha by-products is a critical need if the plant is to be economically viable as a biofuel crop in many countries, and D1 has been at the forefront of such efforts. For every ton of jatropha oil produced, there are also 1.00–1.25 tons of prunings and cuttings, 1.00 ton of hulls, and 0.80 ton of seedcake. The prunings and cuttings are usually left on the farm as a soil-conditioning fertilizer and organic material. Where appropriate, the hulls can be transported to the central processing site and used as the factory energy source, and the seedcake can be used as organic fertilizer or processed to be used as animal feed if the antinutritional factors can be removed.

The oil can be extracted from the grain using a range of technologies from simple mechanical presses that extract about two-thirds of the oil in the grain to more sophisticated mechanical presses that can extract about 90–95 percent of the oil. Solvent extraction processes can extract almost all of the oil from the grain but require larger capital investments and higher daily volumes to be economical. The approximate cost of equipment, volume of grain required per day, and extraction rates are shown in table 5.1.

The crude oil produced from the processing plants can be used directly in some engines (low-speed engines or farm vehicles and nontransport applications), but some degree of processing is required to ensure engine longevity. At the most basic level, processing will include drying and filtering, but degumming and neutralizing will refine the oil to a higher quality that can be used as a feedstock for conversion to biodiesel. Biodiesel production can be done on a range of scales, from 50-kilogram batch reactors to multiton production factories. D1 has proved, using conventional biodiesel facilities, that crude jatropha oil can be refined and transesterified to meet international specifications for biodiesel and is comparable to other oilseed crops used for biofuels.

The meal that remains after the oil has been extracted has a chemical composition of 3.5–5.0 percent nitrogen (N), 0.2–2.8 percent phosphate (P), and 0.75–1.90 percent potassium (K), depending on the type of processing. The N:P:K composition of other seedcakes is similar, with

Figure 5.2 Jatropha Crop Calendar, Zambia



Source: D1 Oils plc.

Table 5.1 Jatropha Oil Extraction Processes, Equipment Costs, and Efficiency

Process	*Recommended minimum daily grain volume (tons)*	*Equipment costs (US$)*	*Percentage of oil extracted*
Manual feed screw press	< 2	<1,000	50–75
Automated screw press	> 5	10,000–100,000	75–95
Solvent extraction	> 500	5 million–20 million	> 98

Source: D1 Oils plc estimates.

cottonseed meal at 7:3:2 and soybean meal at 7:2:1. Trials using jatropha seedcake as an organic fertilizer on vegetables and jatropha plantings showed beneficial effects on plant development and yields; however, more testing is needed to determine the value of jatropha seedcake as fertilizer.

If jatropha seedcake could be used as a high-protein animal feed, its value would increase from US$50–$100 per ton when used as organic fertilizer to US$300–$500 per ton when used as an animal feed. The crude protein content of jatropha seedcake is about one-third higher than soybean meal, according to D1's analysis, and the total digestible nutrients are about 5–10 percent higher. D1 has developed and patented a thermochemical process for removing the toxicity from the seedcake, and if feeding trials confirm the value of jatropha seedcake as an animal feed, the value of the seedcake could significantly increase the value of jatropha seeds. Another benefit to local economies is the production of an additional source of protein locally, where protein is often in short supply.

The D1 process for removing toxicity from jatropha seedcake has not been used on a commercial scale, and D1 is expected to build the first commercial demonstration facility in 2011. If this demonstration plant is successful and if feeding trials confirm the suitability of jatropha seedcake as an animal feed, then D1 intends to license the process and provide support to other jatropha producers for achieving certification. This demonstration and trial process might take several years. The scale required to make it commercially viable is expected to be 10–100 tons of jatropha seed processing per day. Regulatory approval will be needed, and procedures vary by country.

Oil Marketing

Only small-scale quantities of jatropha have been marketed globally, with very high prices being paid for oil for testing purposes. D1's jatropha oil has been marketed locally, which has the advantage of reducing transport costs and improving the operational activities of local businesses. No major off-take agreements have been developed for D1's oil because determining true market value has been difficult with such small quantities being traded. The lack of supply is caused partly by the limited availability of grain and partly by the scarcity of quality oil extraction facilities. Where grain is available, oil extractors are competing with groups purchasing grain for planting purposes.

Effect of Government Policy

Government policy can assist with the development of *Jatropha curcas* cultivation in a number of ways. Extension officers trained in farming practices for jatropha could help farmers understand jatropha, which could significantly improve the quality of jatropha plantings and the likelihood of project successes. Governments could help investors gain access and title to appropriate land for core plantations and demonstration farms and for implementation of processing facilities. According to company officials, government programs that could be beneficial include microfinancing for small farmers, reductions in import tariffs on farm machinery, and favorable taxation of jatropha oil. Most of the countries D1 is involved with already have government programs for rural development that could support development of jatropha. Governments also have taken inappropriate actions, such as sponsoring the planting of jatropha at the wrong time following delays in delivery of planting materials.

D1's experience has not been without challenges, but the company has developed knowledge that can support the development of jatropha as an energy crop and possibly as an animal feed. Incremental developments are expected each year. These include higher yields and increased oil content for jatropha seeds, better control of pests and diseases, and better understanding of agronomy and plant husbandry. Challenges still remain, and today jatropha is most viable in countries with low wages and high fuel costs. Improving its viability in other countries will require a reduction in the manual labor requirement per unit value of harvest. This goal can be accomplished by reducing the labor requirement per hectare, improving yields through agronomy research and breeding programs to introduce better-performing varieties, and improving the value of coproducts.

Diligent Tanzania Ltd.

Diligent is a five-year-old company located in Arusha, Tanzania. It was started by a Dutch investor in 2005 to produce jatropha oil for export and local use. Jatropha production is exclusively by smallholders who collect jatropha fruit from trees on their farms and shell and dry them to obtain seeds for sale to Diligent's collection agents. Seeds are transported from the collection agent's storage facilities to the Diligent factory in Arusha by hired trucks. The company owns crushing and storage facilities and offices in Arusha. The company does not produce biodiesel for sale but has a small unit to produce biodiesel for testing.

Farmers are registered, and Diligent's field staff visits and photographs each farm to ensure that production is sustainable from either existing jatropha trees or newly planted trees that do not displace existing trees or encroach on forests. This registration allows production to meet the sustainability criterion of the Netherlands and potentially allows production to qualify for carbon credits. New trees are planted by farmers using seeds provided by Diligent and supported by planting and growing advice from Diligent's field staff. The company had 5,000 registered farmers; 200 collection agents; and 28 factory, field, and administrative staff in mid-2009. The yield of clean oil was about 25 percent of the dry seed weight, and roughly 1,600 tons of seed were purchased from farmers to obtain 400 tons of oil. Farmers are paid 100 Tanzania shillings (T Sh) cash per kilogram (US$0.08) for their seeds.

The Vision

Diligent was one of the first companies to develop a vision of commercial, sustainable biofuel production based on jatropha. Diligent started its jatropha biofuel production with the objective of producing biofuels for local and export markets in a guaranteed sustainable way. The company's interest in producing biofuels was based on rising concerns over the effects of fossil fuel consumption on climate change, the growing scarcity of fossil fuels, and the economic and geopolitical risks associated with a high dependency on fossil fuels. Vegetable oil was identified as a form of biofuel that could serve as an alternative to fossil diesel fuel. The tropical plant jatropha was selected for biofuel production because it was promoted as an ideal crop that could contribute to the increasing demand for biofuels. The seeds contain nearly 40 percent oil, which is inedible and not used as a food crop. The plant can live on marginal soils and survive long periods of drought and thus does not require that the highest-quality farmland be used for energy production, nor does it require high inputs such as energy or fertilizers.

The Model

The Diligent model is to support farmers producing jatropha, with the agreement that Diligent will buy their seeds when the plants become productive. Diligent has developed a team of field officers who provide training to farmers and village heads; promote jatropha planting and distribute sowing materials; and provide technical support to farmers and secure contracts with new farmers, village heads, and rural communities. Diligent guarantees farmers a minimum price of T Sh 100 (US$0.08) per kilogram of dry seed and will pay higher prices if market conditions allow. The current network of outgrowers covers about 3,500 hectares of planted jatropha. Diligent has also established 200 collection centers to collect seeds harvested from existing plants in hedges and in the wild, established pilot-scale production facilities, and set up a laboratory to research jatropha biofuel. It is one of the largest producers of jatropha biofuel in eastern Africa.

Diligent has ambitious expansion plans and has a target of 50,000 hectares of jatropha planted by outgrowers by the end of 2012. Because farmers typically plant 0.5 to 1.0 hectare of jatropha hedges, pursuant to Diligent's scenario, about 50,000–100,000 farmers can eventually benefit from growing jatropha. The income is additional to other farm income, because the farmer can continue to use the largest part of his/her land for other crops. In addition, many others will be able to generate extra income by collecting and transporting the grain.

Farmers typically plant jatropha in hedges around their farms, and 1 hectare of hedge would contain about 2,150 plants spaced 30 centimeters apart. The hedgerows help protect against soil erosion and protect crops from animals. Plants will benefit from manure or irrigation, but this is not required. Jatropha roots much deeper than most crops and will benefit from any irrigation or fertilization that is applied to the land and not taken up by the main crop. Even without such inputs, jatropha will succeed, although yields may be less. Labor requirements in the initial years are very limited and restricted to planting, weeding (four times per year), and pruning (once or twice per year). At maturity, plants are expected to yield approximately 2 kilograms of seeds per year, meaning that farmers will obtain about 4,300 kilograms of seeds per hectare per year. Harvesters are assumed to pick about 60 kilograms of seeds per day, so for the yield of 1 hectare, about 29 days are required. Four-tenths of a hectare of jatropha is expected to yield a farmer T Sh 174,000, of which T Sh 49,500 are labor costs for harvesting, weeding, and pruning, at a daily wage of T Sh 1,500 per day.

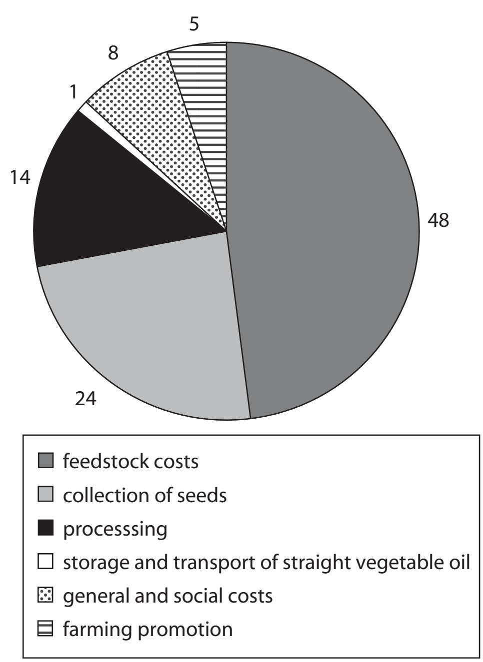
Production Costs of Oil

Diligent projects that oil production costs will be very high in the initial years and gradually decline to 1,280 T Sh (US$0.98) per liter from the eighth year onward. This estimate includes only direct costs and excludes interest, depreciation, amortization, and taxes. High initial costs in the early years reflect the farmer's promotion costs and overhead, which are very high in relation to the volumes of oil produced initially. As production volumes increase, feedstock and collection costs become the main factors in production costs. As illustrated in figure 5.3, Diligent incurs 78 percent of the costs involved with production before the seeds arrive at the factory gates (namely, farming promotion costs, feedstock costs, and collection and transport costs).

Markets and Prices for Jatropha Oil

Diligent currently sells jatropha-based straight vegetable oil (SVO) as its main product, and it expects to continue to do so. Jatropha SVO is currently a niche market product, purchased in particular by customers who value the product's social and ecological sustainability and who are willing to accept that biofuel is more expensive than fossil fuel. Over time, however, the volumes traded will increase, and customers will become

Figure 5.3 Diligent Tanzania Ltd. Production Cost Shares, Year 10



Source: Diligent Tanzania Ltd.

increasingly reluctant to pay more for jatropha oil than for diesel, given that they also need to invest in engine conversion to use SVO as a substitute for diesel.

Within Tanzania, Diligent considers large fleet owners (for example, safari companies) and users of large diesel generators as the most promising markets for jatropha oil. Furthermore, jatropha oil may be marketed as an alternative for kerosene to be used in oil lamps. Serving such markets first will avoid possible technical and logistical issues that could be encountered if SVO were to be marketed as an alternative transport fuel in retail markets. Financial projections assume that diesel prices remain around T Sh 1,650 (US$1.10) per liter. Correcting for the slightly lower calorific value of jatropha oil compared with diesel (39 megajoules per liter compared with 42 megajoules per liter), calculations show that Diligent must ensure an end-user price of its jatropha oil no higher than about T Sh 1,500 (US$1.00) per liter to serve the type of customers willing to use jatropha oil as an alternative for diesel. To achieve this as a commercial business, Diligent needs to be able to sell its jatropha oil free of additional taxes, in particular in the initial seven years of the business.

For international markets, Diligent expects a commodity market for jatropha oil to form in the near future, with most of the demand coming from biodiesel producers and the energy industry in Europe and the United States. In these markets, jatropha SVO will need to compete with other plant oils, such as soybean and palm oil, which are traded in large volumes on world markets. Given high transport costs for exporting relatively modest volumes of jatropha oil, as well as the volatile prices of vegetable oil on world markets, Diligent currently considers export markets as less interesting than Tanzanian markets.

Sustainability Safeguards

Diligent's business model ensures a high degree of social and ecological sustainability. Farmers produce jatropha seeds on their own land, with their own plants, and share significantly in the value chain. Their possibilities to produce food crops or engage in other farming activities remain the same, or even become better, because jatropha hedges protect soil against erosion, and the income from the seeds enables farmers to invest in fertilizers, pesticides, and other inputs. No forests are being cleared—nature is not being threatened—because Diligent promotes jatropha outgrowing only in existing agricultural areas. All these and other sustainability aspects were recently reviewed in a cooperation program between the Tanzanian and Dutch governments using Diligent's model as a case study. The project led to a video documentary and a report (RIVM 2008), both titled “Shinda Shinda. Option for Sustainable Bioenergy: A Jatropha Case Study.”

Currently, various certification schemes are being developed that will enable biofuel producers such as Diligent to demonstrate that their production methods are environmentally and socially sustainable. Such schemes include the following examples:

- Certification based on the “Cramer criteria” for sustainable biofuel production. This expected certification scheme, or its European successors, may even become obligatory for biofuel importers to the Netherlands or the European Union in future years.
- Voluntary certification schemes such as those now being elaborated under the leadership of the University of Lausanne (for biofuels in general), with specific jatropha indicators being prepared by the Jatropha Working Group under the leadership of Dutch BioX Group.
- Social sustainability schemes, such as the Fair Trade logo (that is, the Max Havelaar logo for the Netherlands).

For most of these schemes, Diligent’s model will meet many or all of the criteria. Diligent will, at the very minimum, ensure that it obtains the certifications required for access to Dutch and European Union markets. It will also seek to obtain other certificates that provide real added value in demonstrating sustainability or in enabling access to higher-yielding market segments.

Diligent seeks to market the carbon dioxide that is captured by the jatropha trees as “verified emission reductions” on the international market for carbon credits. Doing so obliges Diligent to prepare a baseline assessment of existing vegetation on the land of outgrowers before planting jatropha and to monitor how much carbon gets captured by plants above this baseline level. This requirement will also ensure that Diligent’s production does not lead to deforestation.

SEKAB BioEnergy Tanzania Ltd.

SEKAB is a Swedish biotechnology company that has planned large-scale projects in Tanzania and Mozambique to produce power and ethanol for the local market and exports of surplus ethanol to several markets in Europe. Its vision is to develop model projects in Africa to mitigate climate change and fossil energy shortages, contribute to development, and develop world-class sustainable agroenergy production practices. The company's core business has historically been the development of technology and processes for the production of cellulosic fuels, production of green chemicals, and diesel replacement fuel. It supports this business by a large-scale market and logistical ethanol system for northern European markets that handled approximately 400 million liters of ethanol in 2008. It is a leader in cellulosic ethanol production primarily from forest and sugarcane by-products and has operated a pilot cellulosic ethanol plant in Sweden since 2004 using technology based on enzymatic and acid hydrolysis. The company expects commercial production of cellulosic ethanol to begin in the next four to six years. SEKAB is also the largest European importer of sugarcane ethanol from Brazil and the largest producer of ethanol-based green chemicals, and it supplies 90 percent of the Swedish ethanol market for E85 (85 percent ethanol and 15 percent gasoline) for private vehicles in Sweden and ED95 (95 percent ethanol and 5 percent diesel) for municipal vehicles in Sweden with engines developed by Scania that can operate on ethanol. The demand for ethanol-powered municipal vehicles in Sweden and other countries is growing because of the reduced tailpipe emissions compared with fossil fuel engines. Higher compression ratios and ignition additives allow ethanol to be used as a replacement for diesel without loss of fuel efficiency compared with diesel.

SEKAB's demand for ethanol to supply the European market and its expertise in cellulosic ethanol led it to begin developing plans for sugarcane ethanol production and power generation in Tanzania. SEKAB made a proposal to the government to develop model projects in conjunction with the government of Tanzania, establish a national task force for capacity building, and develop the legal frameworks for coordinating future agroenergy investments in May 2006, and it signed a memorandum of understanding in June 2006. SEKAB BioEnergy Tanzania Ltd. (SEKAB BT) was formed in February 2007 to begin a long-term investment program to develop a bioethanol production cluster of approximately 200,000 hectares over a 15- to 20-year period in the Rufiji-Kilwa area, which is located 170 kilometers south of Dar es Salaam. A smaller stand-alone project was also to be developed north of Dar es Salaam on 20,000 hectares of the formerly government-owned Razaba farm in Bagamoyo district, which had been used for raising cattle but had been idle since 1992.

The cluster design was to develop a number of bioethanol factories in a limited area to reach a critical mass of production and create a center of excellence in Tanzania that would attract world-class expertise. The projects in the cluster would mutually support and strengthen each other as well as reinforce parallel investments in public sector development in the surrounding communities. Each factory was to entail approximately 30,000 hectares of sugarcane, employ 2,000–2,500 workers, and rely on a large number of outgrowers organized in block farms to facilitate coordination and maintain best production practices. Each factory was to require an investment of US$400 million to US$450 million. Subsurface drip-irrigated cane yields were projected to be greater than 120 tons per hectare to produce 10,000 liters of ethanol per hectare from sugarcane juice. An additional 5,000 liters of cellulosic ethanol would be produced per hectare once cellulosic ethanol was commercially viable. Each factory would produce 200 million to 250 million liters of ethanol per year and about 225 gigawatt-hours of electricity for the national grid—sufficient to supply 200,000 households. To secure international financing, the majority share of sugarcane production would come from company production, with the balance coming from outgrowers. Land for the company estate was to be leased from the Tanzania Investment Center. Production costs were estimated to be US$0.45–$0.50 per liter after the initial start-up period, and export costs to Rotterdam were estimated to be an additional US$0.07 per liter.

Government and community support for the SEKAB BT project has been consistently strong, even though the short-term expectations have not yet been met. The economic impact was expected to be substantial by providing significant local power production and employment in areas with few alternative job opportunities as well as bringing modern agricultural production methods to Tanzania. Poverty levels in the Rufiji district are among the highest in the country (SEI and others 2009), with only 5 percent of the population employed and outmigration of the youth high because of the lack of job opportunities.[2] Access to clean drinking water is very limited. Food insecurity is high because of frequent droughts, lack of irrigation, lack of fertilizer, and poor soils. Maize and rice yields are only two to three 50-kilogram bags per acre per year. The SEKAB BT proposal sought to improve food security by substantially increasing the region's income levels as well as focusing on village lands and improving farming methods developed in consultation with concerned villages, relevant government authorities, and other involved stakeholders. Communities in the Rufiji district are largely very positive toward the proposed biofuel investments by SEKAB BT and expect opportunities for sugarcane outgrower schemes, improved farming methods and inputs, and improved employment opportunities (SEI and others 2009). Communities expect improved infrastructure and better schools and access to electricity. However, they also have fears that the investment will bring unregulated land acquisitions by people moving into the area, pressure on the natural resources, and loss of access to areas used for livelihood activities.

An environmental impact assessment was prepared on the project in Bagamoyo district by the Swedish consulting company Orgut, along with an assessment of socioeconomic and environmental risk prepared by Stockholm Environmental Institute and the University of Dar es Salaam in 2009. The assessments led to concerns about the environmental impacts of the SEKAB BT investments and to debates, especially in Sweden, about the proposed investments. A study by the World Wide Fund for Nature Tanzania Programme Office, released in November 2008 (WWF Tanzania 2009), also raised questions about the biodiversity impact of the ethanol and power project on the Razaba farm in Bagamoyo district, because the farm is within the coastal forests area and full usage of the farm and further clearing could endanger endemic and rare species. The proximity of the site to Saadani National Park also creates the potential for wildlife conflicts.

The decline in world energy prices and consequent collapse of ethanol demand in Europe led to a restructuring of SEKAB, which led to majority control by the three-municipality-owned energy company in Sweden. The municipalities could not continue to invest in the project, and their share was bought by the minority owner and former management of the SEKAB group and became EcoEnergy. The new company, EcoEnergy, must seek other funding for the project, but the global economic downturn has made securing such funding difficult. Company officials continue to explore alternative financing and strategic partnership arrangements.

Lessons Learned

The companies studied in this chapter are pioneers in biofuel production in the African region, and they faced a number of challenges. One of the challenges faced by all of the companies was the importance and difficulty of reaching sufficient size to achieve economies of scale. Diligent has been relatively successful on a small scale by relying on outgrowers to produce jatropha, but the company has not been able to achieve the scale required to reduce costs and compete in the international biodiesel feedstock market. D1 attempted to reach large scale by planting large areas and contracting with outgrowers in Asia and Africa, but then the company found itself overextended and unable to raise additional capital to support its investments. SEKAB planned a cluster of investments to reach economies of scale in input supply, transport, and other services but has not been able to secure funding to establish the initial investments. SEKAB also encountered opposition to large-scale investments because of concerns over the environmental and social impacts. Scale is likely to remain a challenge because a large scale is required to reduce costs, but financing and implementing large projects are difficult, and concern over the impacts will likely emerge.

Financing large biofuel projects has become more difficult because of the decline in energy prices and the scarcity of capital for investments following the global financial crisis of 2008. Diligent is privately financed but will require additional capital if it is to expand its model in countries other than Tanzania. The long payback period for its investments (estimated at eight years) makes investor financing difficult to obtain even if the project appears profitable over the long term. D1 raised capital through a public stock offering that was well timed to capture investor interest in biofuels. Such an investment would probably not be as well received at this time because of the reduced investor confidence in biofuels and increased doubts about jatropha production. SEKAB BT began operations on capital provided by its parent company, and it has not yet been able to secure capital to begin implementing its investment program. Investor financing has also been a constraint to other projects in the region and will probably be a limiting factor to the rapid expansion of biofuels in the Africa region.

The degree of outgrowers' involvement in feedstock production is an important aspect of biofuel production, and a balance is required for ensuring local support for projects while meeting investor and financing requirements for assured supply and cost competitiveness. Outgrowers in Africa are often small, with limited access to credit and limited knowledge of biofuel feedstock production. This situation constrains the outgrowers' ability to make capital investments that increase yields and reduce costs. Technical assistance is required to support outgrowers, and such assistance adds to company production costs unless it is provided by the government. Investors are often reluctant to finance projects that have a high proportion of outgrower production because of greater uncertainty in supply and higher costs. However, the development effect of projects is often related to the degree of outgrowers' participation.

Government support for biofuel projects has generally been strong, but a lack of institutional capacity and delays in government decision making have created uncertainty for investors. SEKAB's proposal to develop a sugarcane ethanol industry in Tanzania was initially welcomed and supported in a memorandum of understanding signed with the government. However, delays in decision making and policy uncertainty have hampered the development of the project and added to management costs. Clearer policies on biofuels and consistent treatment of investors would reduce the time required to develop biofuel projects as well as the administrative costs.

The environmental and social impacts of biofuel projects are concerns that increase with the scale of the project. Diligent's model of buying jatropha seeds from widely dispersed outgrowers raises much less concern than SEKAB's model of large-scale concentrated production of ethanol. The environmental and social impacts of large-scale projects need to be fully understood, and programs need to be designed to mitigate the negative impacts if such projects are to be developed.

Second-generation technology may offer better opportunities for biofuel producers. Cellulosic ethanol production and better use of by-products such as jatropha seedcake could become available in the next decade and make biofuels more competitive with fossil fuels. However, both of these technologies are yet to be commercially proven. If these technologies develop and are economically viable, then financing for biofuel projects may become more readily available.

Managing price risk is a major challenge for start-up biofuel companies because of the long lag between project proposal, investment, and production. This delay makes hedging difficult and costly, and none of the companies studied anticipated or hedged against the decline in energy prices and therefore biofuel prices. Diligent was least affected because it targeted the local market for raw vegetable oils as a diesel substitute and targeted the international market for jatropha oil for testing, but it had not made substantial investments in production. D1 and SEKAB were more materially affected and found it difficult to raise capital to sustain or begin production.

Notes

1. D1 prefers to use the term *grain* rather than *seed*, which is more common in the industry. This section adopts the company's preferences.
2. This paragraph draws on SEI and others (2009).

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CHAPTER 6

Policies for Biofuels in Africa

The policy framework necessary for developing biofuels depends on the scope and scale of the industry. If crops that are already being produced and marketed are to be used as feedstocks for biofuels, then a biofuel policy may not be required, and the use of crops for biofuels can be treated as an additional demand for existing crops. However, if production of feedstocks is large scale and dedicated to biofuels, then policies are needed to protect the environment and the rights of current land users, who may have only informal rights. Policies to address other considerations, such as food security, research, and programs to support smallholder involvement, also may be appropriate. If biofuels are to be manufactured from feedstocks, then environmental policies may need to be strengthened to prevent damage from toxic waste and large volumes of by-products that may have little economic value. If biofuels are to be used as domestic transport fuels, rather than being exported, then the policy requirements increase substantially and include the need for biofuel standards; mandates on blending; and pricing, taxing, and tariff policies.

Many African countries are in the process of developing biofuel policies, but the process is often slow. Mozambique recently approved a biofuel policy and strategy, which culminated a process that lasted more than three years and included a bilateral agreement on technical cooperation with Brazil in September 2007, a national workshop in December 2007 to gather stakeholders to discuss the development of biofuels, and a study assessing the feasibility of biofuels that was completed in 2008. The ministries of energy and agriculture were the lead ministries involved in developing the policy and strategies, with support from other ministries and agencies. Donors and multilateral institutions and organizations supported the preparation of the policy and strategy with financial support and expertise. Research done by international consulting firms and organizations contributed to a better understanding of the potential benefits and problems of producing biofuels for domestic use and export (see box 6.1).

Box 6.1

Mozambique's Biofuel Policy and Strategy

Mozambique approved a biofuel policy in 2009 (Government 2009). The policy and strategy established the framework, principles, objectives, and targets for biofuels but left many of the specific details and regulations to be developed by designated bodies that would be created in a process to be carried out over the following five years.

The feasibility study that became the foundation of the policy and strategy received funding from the World Bank and the Italian embassy in Mozambique within the framework of an Italian cooperation program with the Ministry of Agriculture of Mozambique. Research on the economic effects of biofuels by the International Food Policy Research Institute in Washington also contributed to better understanding of the potential benefits of biofuels in Mozambique (Arndt and others 2008).

An important step in the development of the policy and strategy was land mapping undertaken by the government at a scale of 1:1,000,000 (capturing contiguous areas of more than 1,000 hectares). The government froze authorization of large-scale land requests from October 2007 to May 2008 while the initial land mapping was completed to identify land suitable for new large-scale projects for agriculture, livestock, and forestry. The mapping also identified land not considered available because it was already under use or designated for other uses, or was in ecologically sensitive areas. The mapping identified almost 7.0 million hectares of land deemed available for large-scale projects and 3.8 million hectares that were judged suitable for agriculture, livestock, and forestry based on soil suitability maps and rainfall data. The government has begun a second phase of mapping at a more detailed 1:250,000 scale in key provinces that have more investor interest (Locke 2009).

Box 6.1 *(continued)*

The institutional framework will include the creation of a National Program for Biofuel Development to give financial support to activities and projects that will promote the sector. An interministerial group will be created by the National Commission for Biofuels to supervise implementation of the biofuel policy and strategy. The national market for biofuels will be supported by the establishment of the renewable fuel norm, together with a biofuel purchasing program to buy certified ethanol and biodiesel for blending with imported fossil fuels. A price-fixing mechanism will be developed. In principle, the pricing of biofuels will be based on international market indicators, and tariffs on cogenerated electricity from bagasse will be established. Fiscal incentives will be provided to the sector in the form of discounts from the existing fuel tax at a level yet to be decided.

Implementation is to occur in three phases. The pilot phase will run from 2009 to 2015 and will include the initial buying of biofuels from national producers by the Biofuel Purchasing Program. The operational phase, from 2015 onward, assumes an expansion and consolidation of the industry, with the potential of increasing the blending targets. The expansion phase will occur no earlier than 2015, depending on the progress of the operational phase, and will involve development of separate and parallel distribution networks for fuel with higher percentages of ethanol (E75–E100) and pure biodiesel (B100).

Malawi does not have an explicit biofuel policy, but it has produced ethanol from molasses from its sugar industry continuously since 1982 and blended it with gasoline at up to 20 percent for domestic use. The government has mandated production, use, and pricing, and ethanol costs about half the cost of imported gasoline after adjusting for the lower energy content of ethanol. Neighboring Zambia does not have a biofuel policy and has not produced ethanol from molasses even though it has a large sugar industry and abundant supplies of low-cost molasses that could be used as feedstock. African countries can learn from the experience of Malawi and Zambia (box 6.2) as well as the Brazilian experience (see appendix A for the lessons from Brazil's experience) as they develop their own biofuel policies.

Policies for Biofuel Feedstock Production

Biofuels are a new source of demand for agricultural crops, and they can benefit farmers by expanding farmers' production alternatives and income-earning potential. When biofuels are produced from crops that farmers

Box 6.2

Malawi and Zambia: Neighboring Countries, Different Biofuel Policies

Malawi and Zambia are neighboring landlocked countries in southern Africa. Both depend on petroleum imports for transport fuels and have high import costs to bring fuel across neighboring countries. Both have large and profitable sugar industries producing sugar for the domestic market and export, and both produce large quantities of molasses as a by-product of sugar production.

Molasses has a low opportunity cost, and in Malawi, it is used to produce enough ethanol to provide a 10 percent blend with imported gasoline, which reduces import costs and saves foreign exchange. In Zambia, molasses is used to tar the roads on the sugar plantations. The cost of producing ethanol from molasses in Malawi was approximately US$0.20 per liter, and the inbound landed cost of gasoline was US$0.64 per liter in March 2009.[a] After adjusting for the lower energy efficiency of ethanol compared with gasoline, ethanol was still roughly half the cost of gasoline.

The difference between these two countries is that Zambia does not have a biofuel policy that allows ethanol to be sold as fuel and although Malawi does not have an explicit biofuel policy, the government has mandated the production and use of ethanol since 1982. Without such a policy or government mandate, the private sector in Zambia will not make the necessary investments to produce ethanol and develop the distribution system, because it cannot legally sell ethanol and is not willing to take the risk (Illovo Sugar 2009).

a. Malawi Energy Regulatory Authority, pers. comm., 2009.

already grow and market, then little policy intervention is required, and production decisions should be left to the farmers. The government should provide support through research, agricultural extension officers, and similar policies that are available for other cash crops. However, when new crops are being introduced for biofuels, they should require government approval to prevent the introduction of invasive species that can be harmful to the environment. Large-scale dedicated production of feedstocks for biofuels also raises important issues such as the impact on the environment, the rights of current users of land that will be used for biofuels, the impact on food security, policies to support smallholders, and investment incentives available to producers of biofuels. Existing policies on crops used for biofuels may also need to be changed if they establish high minimum prices that make feedstock production uncompetitive.

Strengthening Environmental Policies

Expanding crop production, whether for biofuels or other purposes, poses risks to the environment, including loss of biodiversity, pollution from fertilizers and pesticides used for biofuel crops, and additional stress on land and water resources. However, the environmental impacts of expanded crop production depend on what crops are produced, where they are produced, how the crops are produced and harvested, and how much is produced. Best practices in the production and harvesting of crops can greatly reduce the negative impacts on the environment, and policies should be formulated to ensure that farmers adhere to best practices. Sugarcane burning, for example, is one of the largest sources of air pollution from biofuel production, adding smoke, fine particles, and nitrogen gases to the atmosphere that cause acid rain and contribute to human health problems. In Brazil, the practice of burning is being replaced by mechanical harvesting, and that should become the standard in all countries.

Environmentally sensitive areas can be protected from development, and wildlife corridors can be left to allow animal migration between protected areas and wildlife sanctuaries. Other opportunities to improve the environment include restoring degraded areas with vegetation and sequestering carbon by planting crops, such as jatropha, that can tolerate conditions where food crops cannot be grown. Growing perennials such as sugarcane instead of annual crops can improve soil quality by increasing soil cover and organic carbon levels. In combination with no-tillage methods and reduced fertilizer and pesticide inputs, the negative impacts on biodiversity can be reduced (FAO 2008). Properly disposing of wastewater from biofuel plants by returning it to the field as fertilizer protects waterways from harmful contaminants and provides valuable fertilizer, which reduces the need for additional chemical fertilizers.

Strengthening Land-Use Policies

The opportunity to obtain large tracts of land on long-term leases is one of the most important factors attracting investors to Africa to produce biofuels. Sub-Saharan Africa has more than 1 billion hectares of land with potential for rain-fed crop production, but less than one-quarter of this land is currently being used for crops, according to the Food and Agriculture Organization (FAO) of the United Nations (FAO 2008).

Marginal and abandoned lands may be even more abundant, according to FAO. Although in many countries land may be abundant, it is not necessarily idle, and it may provide incomes to many people for subsistence farming and other livelihood activities, by providing areas for hunting and gathering, cutting building materials and fuel wood, and grazing livestock.

In addition to their productive value, lands are often important to the heritage of local people. Less than 10 percent of land in Africa is held under formal land tenure, and that is mainly urban land (Deininger 2003). Much of the land is held in "customary" land tenure systems, which are usually unwritten rules founded in tradition. Land is usually held by clans, families, or diverse groups and is accessed on the basis of group membership and social status and used through complex systems of multiple rights (Cotula 2007). Communal lands and common property resources, including grazing and indigenous lands, are a special case of customary tenure. Most African countries consider land to be "state land," and those who have cultivated such lands for generations have only precarious tenure rights and could lose those lands to investors or to powerful bureaucrats, with little or no compensation (World Bank 2007).

Land laws in many African countries may need to be strengthened to protect local people with insecure land rights based on customary tenancy. Land allocations for biofuels should be transparent, involve all stakeholders, and provide just compensation. Investors need to be given clear information on procedures, criteria for decision making, and conditionality, and decision making should be open to public scrutiny. Legal support should be given to local communities and those with land-use claims to help them negotiate with investors and protect their rights. Mechanisms should be developed to discourage purely speculative acquisitions of land and to develop closer ties between local communities and investors so that communities have an ongoing stake in the success of biofuel projects. These safeguards could possibly be created by granting equity in biofuel projects to local communities and existing land users. Investors should have a strong interest in the fair treatment of local land users to avoid the hostility of local populations, which can lead to myriad problems. Land leases of 50 years or 99 years, as are commonly available in Africa, are unsustainable unless some level of local satisfaction is achieved. Biofuel projects will need to have strong local community and political support to be sustainable. Without such support, land tenure arrangements can be revised, and security can become an ongoing problem.

Making Food Security More Than Food Production

Food security is a major concern of nearly all governments, and recent increases in food crop prices have led many African governments to restrict production of biofuel feedstocks in an effort to improve food security. However, such restrictions raise serious equity considerations because they limit the income opportunities of farmers, who are often among the poorest members of society. These restrictions also limit employment opportunities and wages in rural areas, where poverty is often pervasive, by limiting production of potentially profitable biofuel feedstocks. A better policy approach is to address food security directly through targeted social safety nets and investments in infrastructure, crop-breeding research, and other public goods that increase the efficiency of food production and lower costs. Maintaining low import tariffs on food can also allow food crops to be imported from neighboring countries when domestic production is reduced by drought or other factors.

Raising incomes of the poor is the most effective way to improve food security. Recent research on Mozambique has shown that increasing biofuel production based on either plantation sugarcane ethanol or outgrower jatropha biodiesel substantially enhanced economic growth and poverty reduction benefits from biofuels. Food crop prices did rise because of the competition for land and labor, but overall, welfare and food security broadly increased with enhanced purchasing power that resulted from economic growth and employment (Arndt and others 2008). A recent FAO study of bioenergy and food security in Tanzania (Maltsoglou and Khwaja 2010) also concluded that expanded biofuel production would not lead to lower food production or increase food insecurity. Under most alternative investment scenarios in biofuels considered, national GDP would rise and new employment opportunities would be created by biofuels. This outcome would lead to welfare gains throughout the income distribution and increased food security.

Directing Government Support to Agriculture

The largest cost component in the production of biofuels is the feedstock; thus, the competitiveness of the agricultural sector is critical to the cost of producing biofuels and the competitiveness of the industry. A number of African countries are among the world's lowest-cost producers of sugar, including Malawi, Swaziland, and Zambia, and should also be low-cost producers of ethanol and therefore able to develop successful biofuel industries. Policies to support sugarcane ethanol are similar to those to support agricultural production. Such policies include investment in public goods such as research and extension, maintenance of an enabling macroeconomic environment that does not discriminate against agriculture by imposing high export taxes or overvalued exchange rates, and policies that create a favorable business climate for the private sector.

Crops not commercially grown in the African region, such as jatropha, will require greater government support if they are to be produced competitively for biofuels by smallholders. Production practices are not well established for these crops, and farmers will require assistance to grow them. Investment incentives may be required for smallholders to encourage them to plant such crops on their farms because the crops will not produce significant yields until the third year following planting. Improved, high-yielding varieties will need to be developed that are tolerant to pests, disease, and drought. Planting materials will need to be produced and disseminated, along with adequate guidance on the appropriate planting procedures and husbandry practices. After planting, protective disease and pest control will be needed, and information on harvesting methods and postharvest handling will need to be provided. Ongoing research will be needed to address new problems that arise, such as new diseases.

Such support will stretch the abilities and budgets of many countries that are already doing crop research and extension on existing food and cash crops. Delivering these additional services and support will require cooperation between the private and public sectors to identify priorities, carry out the necessary research, and provide other services. An example of successful cooperation between the private and public sectors is found in the Tanzania Tea Research Institute (box 6.3), which is funded by a levy on tea sales. It could serve as a model for support to biofuel feedstock producers. A systematic research program is needed to evaluate the suitability of biofuel crops; evaluate their economic potential; and identify the production systems that can grow them efficiently and improve yields, disease resistance, and pest resistance.

Avoiding Constraints on Smallholder Involvement by Existing Policies

Existing policies are often a constraint on smallholder involvement because they may raise feedstock costs from smallholders to uncompetitive levels. For example, many African countries provide a high level of protection to their sugar industries, which gets reflected in high sugarcane prices. Because the cost of ethanol production is heavily dependent on the cost of the feedstock, producing ethanol competitively while paying outgrowers high prices for their sugarcane would be difficult. Efforts

Box 6.3

Tea Research Institute of Tanzania

Following marketing liberalizations, research responsibilities and facilities for Tanzania's major export crops were transferred from the government of Tanzania to autonomous research organizations representing each crop. Funding was by a statutory cess, levied on all production, and by grants from donors. A board of directors and an advisory panel directed the activities of each organization, which had the responsibility for maintaining cost-effective research and technology transfer. The Tea Research Institute of Tanzania emerged as the model. Until 1996, tea research was funded by the government through the Ministry of Agriculture and cooperatives. By the mid-1980s, the research program was in a state of collapse. The Tea Research Steering Committee, which was formed in 1988 to arrest the decline in research, recommended creation of an independent research organization.

The Tea Research Institute of Tanzania was established in July 1996 as a nonprofit organization. It was managed by a 10-member board with broad representation, including plantations, smallholders, and the government. As a nonstatutory body, the Tea Research Institute used merit and performance criteria rather than seniority to determine the salaries and promotion paths of its researchers. The institute's Technology Transfer Unit managed dissemination of research findings to plantations and small tea growers.

The research institute began operations in 1998 after taking over one government research station and one industry research station and signing a contract with Silsoe College of the United Kingdom. As recommended by the steering committee, the institute was funded by the industry. The institute received 1.5 percent of a 2.5 percent levy on the net sale value of made tea. Although smallholders contribute just one-tenth of the tea levy (because of their small share in total output), one-third of the institute's budget was earmarked for activities to benefit smallholders.

Source: Mitchell 2005.

for new ethanol producers to negotiate substantially lower prices would likely lead to protests from potential sugarcane growers and the cane growers association. Without smallholder involvement, the development effect of biofuel production is reduced, and political support is likely to be weakened.

Policies for the Manufacture of Biofuels

Manufacturing biofuels is an industrial activity that should be regulated by the ministry of industries or similar authority. Worker safety and health regulations along with labor regulations should be applied in accordance with existing laws. Environmental regulations may need to address the special characteristics of biofuel waste and by-products and should protect the environment from improper disposal of untreated waste. The ministry of the environment or similar agency should monitor and enforce environmental regulations as it does for other industries, with any additional laws and regulations necessary to protect the environment because of the unique nature of biofuel manufacturing.

Policies for the Domestic Sale of Biofuels

The policy framework required for the sale of biofuels as transport fuels is substantially more complex than the policies for production of biofuel feedstocks or the manufacture of biofuels for export or nontransport fuel uses. The sale of biofuels for transport fuel uses requires that standards and blend levels be established for biofuels to protect consumers from poor-quality biofuels or blends that can damage engines. It requires investment in additional storage and blending equipment by fuel distributors, which will most likely require investment incentives to offset those costs. Biofuel consumption mandates will most likely be required to encourage widespread participation of fuel distributors and to ensure that customers receive a consistent fuel mix. Pricing, taxing, and tariff policies for biofuels relative to fossil fuels will need to be established. Procedures are needed for monitoring, equipment for testing, and legal authority for enforcing the standards, requirements, and policies, and appropriate agencies must be assigned responsibility for those activities. The government and the private sector must work closely to ensure that standards, regulations, procedures, and policies can be implemented and are appropriate. Existing fuel distributors and retailers will need incentives to implement biofuel policies.

This complex policy framework may not be economically justified unless biofuel production costs are significantly lower than imported fuel costs and unless volumes of low-cost biofuel are large enough to provide a significant percentage of biofuel content in the blend that will result in savings to consumers and the government. Such conditions exist in some African countries with high fuel import costs and large quantities of low-cost feedstocks such as molasses. This is the case in Malawi (see box 6.2), which has a long history of producing ethanol from molasses and blending ethanol with imported gasoline.

Sale of biofuels for other domestic uses, besides blending with transport fuels, requires a less complex policy framework. Such uses could include the use of ethanol or straight vegetable oils for household uses such as cooking or lighting, and the use of straight vegetable oils in stationary power plants by heavy industry or rural communities. Those uses could be economically viable because of the high cost of domestic fuel transport and the low cost of feedstocks such as jatropha or croton oil in remote areas. Policy approval should be given to provide legal authority and to give investors the confidence to invest in production of biofuels for such activities.

Investment Incentives for Biofuels

Investment incentives apply to all aspects of biofuels and biofuel feedstock production and should be transparent and consistent with investment policies for similar activities. Incentives could include tax holidays and tariff exemption for imported equipment and supplies. Incentives should be explicitly stated, both to protect countries from politically powerful investors who can gain special advantages and to protect investors from unclear policies that increase the risk of investments.

A Biofuel Development Strategy

A prudent biofuel strategy would be to develop biofuels in phases. That approach would allow policy support, institutional capacity, and regulatory requirements to be developed as required for each phase rather than all at once, as has been attempted in most countries. The particular situation in each country could determine the progression from one phase to the next. During each phase, preparation for the next phase could begin with the benefit of experience gained in the previous phase. The risks of such a phased development strategy are less because implementing each phase could depend on the success of the previous phase. The phased approach would also allow countries to consider their comparative advantage of each phase. Some countries may have a comparative advantage in the production of feedstocks, but not in the manufacturing of biofuels, and the phased approach would allow them to evaluate each activity before developing policies.

The first phase could be the use of straight vegetable oils as a diesel fuel substitute in stationary power plants and specially modified vehicles. Fuel sales to the general public would be limited to prevent possible engine problems when such fuels are used in vehicles not specially adapted for them. The fuel would most likely be produced and consumed in remote areas where imported fuel is costly. It could be used by industries, such as mining, and other natural resources extractive industries; by rural communities to provide electricity to community centers, clinics, and schools; and in diesel engines to power farm machinery such as pumps, crop processing equipment, and small tractors. Straight vegetable oil is being used successfully in rural communities in Mali and several other countries in West Africa (Brew-Hammond and Crole-Rees 2004; Cotula, Dyer, and Vermeulen 2008). The rural development effects could be very substantial if such fuel allowed irrigation of food or cash crops. The oil could also be used for home cooking in place of fuel wood and would have health benefits by reducing indoor air pollution. Collection and crushing of oilseeds could be community or private sector based and could provide both income and power to rural communities. Institutional support would be required for training, assistance to purchase processing equipment, and research to improve feedstock varieties. Competition with local fuel supplies could be beneficial for all consumers by limiting fuel prices.

The second phase of biofuel development could be production of biofuels for export, to take advantage of the preferential access to the European Union (EU) and other markets that most African countries enjoy. This phase would have the advantage of providing income, employment, and a market for feedstocks without the need for the policy support and institutional capacity to regulate the consumption of biofuels. Production subsidies would not be required and should not be provided because many companies could export profitably. Production would be private sector and would most likely use production platforms such as the Brazilian model for producing ethanol from sugarcane or the large-scale production and processing of oilseeds for export as vegetable oils or biodiesel. The institutional support and policy requirements would be much larger than for the first phase but still much less than would be required to support consumption of biofuels. Land use, property rights, environmental impacts, and health and safety issues would need to be addressed. Research should be focused on improving feedstock varieties for smallholder production to provide widely shared benefits. The institutional capacity could be developed to monitor and regulate feedstock production, and the tax revenues would be available to support the industry. Because the sale of straight vegetable oil would be permitted in the first phase, it should also be permitted in the second phase—but only for commercial use and not for retail use. The private sector would need to accept responsibility for product quality and perform the necessary testing for the appropriateness for their application.

The third phase would require the greatest level of institutional capacity and support and would include production and sale of biofuels in the retail distribution network. Biofuel standards would need to be defined, monitored, and enforced. Regulations on handling, storage, transport, and distribution would need to be developed. Blending facilities must be constructed, and procedures and regulations developed. Pricing, taxing, and tariff policy must be agreed on. Targets and limits on blending levels of biofuels with fossil fuels must be established. This final phase could be economically justified in countries such as Zambia, where by-product molasses can be turned from a waste product into biofuel. However, this final phase involves considerable risk because it also is likely to require consumption mandates, price incentives, and tariff protection. That has been the case in all countries that have developed biofuels for domestic use, and it would almost certainly be required in most African countries. Without such policy support, the private sector may be unwilling to make the investments in production facilities and the distribution network to support biofuels.

Price incentives for biofuel consumption are often delivered by exempting biofuels from fuel taxes, and most African countries have high fuel taxes. In Malawi, for example, fuel taxes account for half the retail price, and ethanol is taxed at lower rates than gasoline. Brazil also has lower taxes on ethanol than gasohol in many states. Tax concessions are widely used in EU member states and in the United States. These concessions result in biofuels being sold without excise taxes in some countries and with reduced taxes in others. On average, the tax for ethanol and biodiesel is 50 percent lower than the rates for gasoline and diesel in EU member states (OECD 2008). Tax exemptions on biofuels increase the price that blenders can pay for fuel and raise the price to the producer. Exempting biofuels from fuel taxes results in decreased tax revenues, which will need to be made up from other sources. One way to exempt biofuels from taxes and to maintain tax revenue neutrality is to raise the tax rate on the blend fuel to offset the lower tax rate on biofuels.

Tariff protection is also required to prevent lower-cost imports from entering the country in response to the price incentives. The United

States introduced a specific tariff on ethanol imports in 1980 to prevent its excise tax exemption (introduced in 1978) from going to foreign producers, and it has maintained an import tariff at various levels since. The EU introduced an import tariff when it first promoted a biofuel program in 2003. Even Brazil, which is the lowest-cost biofuel producer in the world, has an import tariff on ethanol (FAO 2008). Such a tariff is often required to prevent lower-cost imports from entering in response to the price incentives.

The policy support increases significantly when biofuels are produced for retail distribution. The further risk exists that biofuels will be unprofitable during periods when crude oil prices are low and that supplies of biofuels may not be available during periods of drought. During such periods, the government would need to decide whether to import biofuels or to suspend the mandates. Periods of low profitability could also lead to pressure for government support, which political leaders may feel obligated to provide.

Development of the Policy Framework

If biofuels are to be produced for domestic use or export, the proper policy framework, regulatory structure, and fiscal regime must be established. One of the complexities of biofuel policies is the number of government ministries with policy responsibilities for different aspects of biofuel production and use. The ministry of energy has policy responsibilities for the fuel use of biofuels, the ministry of agriculture has responsibilities for agricultural feedstock production, and the ministry of industries has responsibilities for biofuel manufacture. Other ministries with important policy responsibilities related to biofuels would include environment, lands, standards, and finance.

The initial step in developing biofuel policy is to appoint the lead institutions and vest in them the power to coordinate disparate government agencies and formulate national policy. The ministry of energy is often chosen for this role, and the ministries of agriculture, environment, and natural resources must be closely involved to ensure sustainable production of biofuel feedstocks. A high-level task force should be formed to guide the work of the various ministries, agencies, and stakeholders. The business community, nongovernmental organizations, and the petroleum industry should be consulted and representatives included in the task force. A study of the potential of biofuel should be commissioned by a qualified consulting firm and used to launch a workshop to bring stakeholders together to discuss a biofuel industry. Such a study was done in Mozambique, and it provided a useful starting point for a program that resulted in the biofuel policy and strategy.

Following the workshop, if the decision is to continue to develop a biofuel policy, lead ministries should be assigned responsibilities in their respective areas. Capacity building will be necessary and could include study tours; training; hiring of new staff with the required skills; and hiring of consultants to prepare briefing papers or develop proposals for policies, regulations, and programs. The tasks of individual ministries could include the following:

- *Ministry of energy:* Establish regulations for the proper handling, storage, transport, blending, and distribution of biofuels. Evaluate alternative blends of biofuels for local use, and prepare to recommend blend limits.
- *Ministry of agriculture:* Evaluate alternative feedstocks for biofuel production, and identify suitable producing areas. Begin a research program to evaluate biofuel crops for local use and to improve yields and production characteristics of biofuel crops. Coordinate with other institutions conducting research on biofuel crops. Research alternative production systems and evaluate the effect on rural poverty.
- *Ministry of environment:* Establish environmental regulations for the proper treatment and disposal of biofuel waste and the proper production and harvesting of biofuel crops.
- *Ministry of lands:* Establish transparent rules for allocating land for biofuel production, review existing land laws and strengthen as needed to protect the rights of current land users, and ensure fair compensation for the loss of use of community lands.
- *Ministry of industry:* Adapt industry policies to deal with biofuel production as needed.
- *Ministry of finance:* Evaluate the economic effect of biofuel production and use, and develop an appropriate financial regime for taxes, pricing, and tariffs.
- *Bureau of standards:* Evaluate alternative standards for biofuels and identify standards appropriate for local conditions. Develop the capacity to monitor, test, and enforce biofuel standards.

Other ministries and agencies may also need to contribute to the development of a biofuel policy. Appropriate licensing along the entire biofuel value chain will be needed to protect consumers, workers, communities, and the environment. An economic evaluation unit should be established, with multidisciplinary skills to evaluate investor proposals for biofuel production and to ensure the viability of proposed projects prior to approval to consider land allocation.

The Role of Donors, Multilateral Institutions, Foreign Investors, and the Development Community

African countries often lack the capacity and resources to develop an effective biofuel policy. Donors and multilateral institutions can play an important role in providing financial support and policy expertise to assist countries in developing capacity and designing policy. Both played an important role in helping Mozambique develop its biofuel policy and strategy.

The wider development community can also play an important supporting role to countries as they consider biofuels. This support can include research by academics and research institutions to understand the potential benefits and risks of biofuel production, as well as input from diverse stakeholders that may be represented by nongovernmental organizations. Foreign investors can also contribute to the policy development process by sharing their experiences in other countries as well as dialogue on the likely effects of certain policy choices.

Summary and Conclusions

Biofuels can contribute to economic growth, provide employment opportunities in rural areas, and offer new cash crop production opportunities for farmers. However, investors are reluctant to begin biofuel production without clear policies, and most African countries do not have biofuel policies. The policy framework necessary for biofuels depends on the scope and scale of the industry. If crops that are already being produced and marketed are to be used as feedstocks for biofuels, then a biofuel policy may not be required, and the use of crops for biofuels can be treated as an additional demand for existing crops. However, if production of feedstocks is large scale and dedicated to biofuels, then policies are needed to protect the environment and the rights of current land users, who may have only informal rights. Policies to address other considerations, such as food security, research, and programs to support smallholder involvement, also may be appropriate. If biofuels are to be manufactured from feedstocks, then environmental policies may need to be strengthened to prevent damage from toxic waste and large volumes of by-products that may have little economic value. If biofuels are to be used as domestic transport fuels, rather than being exported, then the policy requirements increase substantially and include the need for biofuel standards; mandates on blending; and pricing, taxing, and tariff policies.

Developing the policy framework requires coordination across many ministries and agencies, because biofuel production spans the agriculture, manufacturing, and energy sectors and affects many others. The ministry of energy will usually take a lead role, with strong support from the ministries of agriculture and environment. A prudent strategy for developing a biofuel industry is to develop biofuels in phases, with the first phase being approval of the production and use of straight vegetable oils such as jatropha as fuel in stationary power plants and specially modified vehicles. This approach would be profitable in remote areas with high fuel import costs to supply heavy industry, such as mining, and to provide power to remote communities. Little policy support is needed, and the strategy would provide income to smallholders, produce power for local communities, and lower fuel costs to industries. The second phase could allow production and export of biofuels but not domestic consumption. That would allow the employment and income gains from exporting without the policy framework required for domestic consumption. A policy framework would be required for biofuel production and the protection of the environment and workers, but not for consumers, because retail sales would not be required. The final phase would allow biofuels to be sold in the retail distribution system. Although the potential benefits of such sales include savings on import costs, policy requirements are substantial, and all countries that have allowed domestic sales have also provided price supports, consumption mandates, and tariff protection.

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APPENDIX A

The Brazilian Experience

Brazil has been a global leader in biofuel production and use.[1] Although the experience is primarily related to ethanol, the lessons learned have application to African countries and others contemplating or producing biofuels.

Historical Developments

Ethanol from sugarcane has been used as fuel in Brazil since 1925, but a national policy to provide consistent policies toward ethanol production and use was introduced only in 1975. The program, called ProAlcool, was enacted by presidential decree in November 1975 in response to Brazil's increasing dependence on oil imports and the impact on the balance of payments. The basic instruments of that policy were the following:

- A mandate for blending anhydrous ethanol in all gasoline distributed in the country at the maximum level admissible by the existing fleet—initially 12 percent by volume, which was subsequently raised to 18 percent and then to the current blend of 20–25 percent.
- Stimulus for the development of cars using hydrous ethanol.
- Credit at favorable interest rates for investment in ethanol distilleries.

- Guarantees to consumers that the price of hydrous ethanol would not surpass a level that would stimulate the use of hydrous ethanol instead of gasoline.
- Guarantees to producers that the price received for ethanol would be indifferent to the price received for sugar. Until the end of the 1990s, the government determined the prices for gasohol (gasoline blended with alcohol), hydrous ethanol at the pump, sugar, and ethanol.
- Distribution of anhydrous and hydrous ethanol at the national level.
- A government-controlled system of ethanol sales and distribution.

The initial government interventions were mostly dismantled in the deregulations and price liberalization during 1989–99; however, the fundamentals of those policies still exist through blend mandates and relative price parity between ethanol and sugar. The former is still government controlled, but the latter is caused by market forces.

Prior to 1975, ethanol was produced only from molasses, and any surplus left after demand was met for domestic and industrial uses was added to gasoline as fuel. This situation meant a constantly changing proportion of ethanol mixed in gasoline and therefore unstable conditions for developing an automotive technology that could take advantage of ethanol blending. Instability of ethanol supply has recently been identified as a constraint to the development of an ethanol industry in El Salvador and India.

The demand for ethanol grew rapidly from 555 million liters in 1975 to 12–14 billion liters by the late 1980s because of mandates for anhydrous blending in gasoline and the development of technology for direct use of hydrous ethanol in light vehicles. The deregulation of the industry from 1989 to 1999 led to stagnation of ethanol demand and a shift toward sugar exports instead of ethanol production. The March 2003 introduction of "flexible fuel" cars that were capable of using any mixture of hydrous ethanol and gasohol (gasoline containing 20–25 percent anhydrous ethanol) led to increased ethanol demand, with an expected 22.5 billion liters projected for May 2009 to April 2010. The flex-fuel vehicles have allowed consumers to shift easily between fuels, and this ability has increased the price elasticity of demand for ethanol and gasohol.

The deregulation and liberalization of the industry since 1999 have led to a system whereby independent sugarcane farmers receive payments for sugarcane according to its sugar content and the value based on the end products—sugar and ethanol—sold in the domestic and export markets. This system rewards higher productivity and allows farmers to share the rewards, and the risks, of the value chain with sugarcane millers. The system has proved to be more effective than a minimum price guaranteed by the government, as is done in India. Prior to the ProAlcool program, sugar producers did not focus on ethanol, as is the case in many sugar-producing countries today. The key was the government decision to establish a price for ethanol at parity with sugar.

Environmental Effects of Producing Sugarcane

Policies to protect the environment have developed along with increased ethanol production.

Environmental Impacts of Vinasse

Vinasse is the main residue of ethanol production from sugarcane juice. It is the residual effluent of extracting ethanol from sugarcane juice, and most sugar and ethanol plants in Brazil produce 10–12 liters of vinasse for each liter of ethanol produced. It is very rich in potash and organic matter, with high content of magnesium, calcium, and sulfur and lower quantities of other minerals. It can be highly damaging as a pollutant because of its high chemical and biological demand for oxygen and its low pH. It can turn water environments uninhabitable and make underwater reservoirs unsuitable for consumption. Until the 1970s, all vinasse produced from ethanol in Brazil was deposited in "sacrifice areas," but the increasing volumes of vinasse led to the prohibition of its disposal in rivers and lakes and the eventual disposal by returning it to the cane fields, where the minerals and nutrients could replenish the soil and reduce the need for chemical fertilizers. Technology evolved to allow the use of vinasse in "ferti-irrigation" of sugarcane fields, in which it is mixed with water from the industrial process, ashes from boilers, and filter cake residue from filtering of cane juice. Technical alternatives are under development to reduce the volume of vinasse from 10–12 liters to 8–9 liters per liter of ethanol produced.

The composition of vinasse varies with the mix of sugar and ethanol produced. If only ethanol is produced from cane juice, the vinasse is the most diluted, with fewer nutrients in its composition. At the other extreme, ethanol produced from molasses has the most concentrated vinasse. Long-term application of vinasse has positive effects, resulting in higher pH, calcium, potash, and magnesium in soils. However, soils with lower silt content have the possibility of salinization, and the commonly applied threshold for vinasse application in Brazil is 300 cubic meters per hectare to avoid any risk of salinization. Brazilian regulations on the use of vinasse are contained in CETESB (Companhia Ambiental do Estado de São Paulo, or São Paulo State Environmental Regulatory Company) Regulation P4231.

Harvesting Methods and Cane Burning

Sugarcane harvesting can be done manually or mechanically, and cane can be harvested green or burned prior to harvesting. Manual harvesting is economically viable in Brazil because of the large supply of low-cost labor. The cane is usually burned prior to manual harvesting to remove leaves and straw and to rid the cane field of poisonous snakes. Burning is detrimental because it reduces biological controls by eliminating natural predators, reduces micro- and macrofauna, increases air pollution, risks fires in preservation areas, eliminates organic matter, increases absorption of minerals in the cane, and results in a loss of sucrose. The overall economic loss from burning cane is estimated at 8.2 percent of the cane's value. However, manual harvesting of unburned cane reduces worker productivity by 50–70 percent and increases the amount of minerals and vegetative impurities in the cane.

Mechanical harvesting can be done on green or burned cane, but mechanical harvesting of burned cane results in the worst of both methods because, in addition to the disadvantages of burning cane, mechanical harvesting cuts the cane into 0.3-meter pieces, which exposes more cane ends to contamination. Mechanical harvesting of green cane results in a cane field with higher soil moisture, more abundant organic matter, higher yields, greater ratoon (plant shoot) longevity, and reduced fertilizer and herbicide requirements. Soil compaction caused by intense field traffic can become a problem, and care must be taken to reduce this problem. Brazil has increased mechanical harvesting in the Centro-Sul (center-south) region to 55 percent of cane areas, with 41 percent green harvesting.

Brazilian regulations on sugarcane harvesting and burning began to phase out sugarcane burning over a 20-year period beginning in 2001 on areas that can be mechanically harvested, but they provide no specific regulation on sugarcane harvesting. Some states, such as São Paulo, also have specific legislation that requires the gradual phaseout of burning cane. And some states are reaching agreements with cane growers to phase out cane burning more quickly. Higher wages for labor as well as complaints from nearby city residents have accelerated the phasing out of cane burning.

Although no specific regulation exists regarding manual or mechanical harvesting, regulations cover labor conditions, including aspects such as occupational health and safety of rural workers. Such regulations should take into account the specific conditions of work in the cane fields to avoid overexposure of workers to strenuous and unhealthy conditions.

Water Intake and Discharge

Sugarcane is not irrigated in the main Centro-Sul producing area of Brazil, and water use in the industrial process of ethanol production has steadily decreased due to reuse. These conditions have allowed sugarcane production to be classified at risk-level 1—with no impact on water quality—by Embrapa (Empresa Brasileira de Pesquisa Agropecuária, or Brazilian Agriculture Research Corporation). The volume of water intake for industrial purposes has been reduced in the state of São Paulo, from 17 cubic meters per ton of cane during the 1970s to less than 2 cubic meters per ton of cane in 2004. Best practices indicate that water intake for industrial uses can be reduced to less than 0.7 cubic meter per ton of cane with better management of reused water.

Land Clearing

The European Union has approved sustainability criteria for biofuels used to meet its consumption mandate in its April 2009 Directive 2009/28/EC on the promotion of the use of energy from renewable sources (European Union 2009), and these criteria become more restrictive in the future. The directive emphasizes the importance of following good practices of biofuel production, including water and land use, effluent treatment, air emissions, and waste disposal. Clearing of land with native vegetation has become an important consideration in meeting sustainability criteria, and Brazil has had a land-use law since 1965. The federal law requires landowners to maintain areas of permanent preservation and legal reserves. Permanent preservation areas are lands that preserve hydrological resources, geological stability, biodiversity, genetic flow of fauna and flora, and soils. Legal reserves are areas that must be kept unused and cannot be used for agriculture. In practice, many farmers do not comply with legal reserves. Further legislation is being considered to zone sugarcane planting to certain areas.

Full-Cycle Energy Balance of Sugarcane

The full-cycle energy balance of ethanol produced from sugarcane was estimated by Macedo and others (2008) at 9.3, which represents the units of renewable energy generated for each unit of fossil energy used in production (excluding land use changes). The estimate was based on data for 44 mills located in the Centro-Sul region during the 2005/06 and 2006/07 crop seasons. If cogeneration of electricity from surplus bagasse was excluded, the ratio was 9.0.

Reductions in Vehicle Tailpipe Emissions

Brazil began a multiphase program in 1986 to reduce tailpipe emissions, especially in urban areas, by enacting the National Motor Vehicle Emissions Control Program. Among the objectives were the following:

- Reduce emissions of pollutant levels from motor vehicles.
- Promote technological development in automotive engineering, testing, and measuring of pollutants.
- Create programs of inspection and maintenance for vehicles in use.
- Promote population awareness regarding air pollution produced by motor vehicles.
- Determine methods to evaluate program results.
- Promote improvements of liquid fuels to reduce polluting emissions.

The program is credited with contributing to the significant emission reductions since the period prior to 1980, when gasoline contained no fixed blend of ethanol. Emissions from light-duty vehicles produced in Brazil in 2008 had reductions of at least 96 percent of carbon monoxide, hydrocarbons, nitrous oxide, and total aldehydes, compared with levels prior to 1980 for vehicles operating on gasohol (ethanol-gasoline blends) and for flex-fuel vehicles powered by ethanol. The emission reductions depended on both fuel utilization and vehicle technology as made evident by reductions in emissions in years when new technologies were implemented. The final phase of the program will come into force in January 2013, when emission limits for diesel-powered vehicles will be reduced, and in January 2014, when flex-fuel and gasohol-powered vehicles will have emission reductions.

The data on vehicle emissions show that the largest and most immediate gains in emission reductions from the introduction of ethanol blends in gasoline and pure ethanol occurred in older vehicles with carbureted engines. This segment of the vehicle fleet usually has higher emissions than engines equipped with fuel injection systems or more advanced equipment. These vehicles tolerate a wide range of blends of ethanol with gasoline and can accommodate blends as high as 20 percent ethanol, although automakers from EU Europe and Japan allow for 10 percent anhydrous ethanol blends in gasoline.

The specifications for ethanol in Brazil had to change in the late 1980s, when fuel injection systems were introduced in Brazil and the existing specification damaged the engines and the fuel tank and lines, but the revised specification has been used for almost 30 years and has proved effective. The Brazilian specification is easily achievable using existing distillation equipment and technologies and can be safely maintained at all distribution levels (producer, distributor, retailer, and end users).

Lessons from the Brazilian Experience

Based on the Brazilian experience of the past three decades, a number of lessons have been learned that can benefit African countries, including the following:

- Government policies must be consistent over time to reduce private sector uncertainty and to help build a strong public commitment to biofuels, which is necessary to overcome opposition from existing fuel suppliers and to gain the support of consumers.
- An initial blend mandate of 10 percent anhydrous ethanol with gasoline is recommended to contain blending costs, achieve emission reductions, and allow improvements in technology. If quantities of ethanol are insufficient, then the 10 percent blend mandate should be imposed only in certain areas.
- Environmental regulations should include stiff controls on the disposal of vinasse, limits on the disposal of industrial water to encourage water-conserving technologies, and controls on air emissions and the use of octane enhancers such as tetraethyl lead to improve the environment and support the use of renewable fuels.
- A specification for fuel ethanol that producers and distributors can follow is needed to guarantee quality to the consumer.
- Incentives to produce ethanol must be at least as good as the best alternative to encourage ethanol production. Initially, the government may need to guarantee this incentive, but over the longer term, the objective should be to have minimal government intervention and a market-driven system.
- Productivity gains in feedstock are necessary to increase production, reduce costs, and contribute to an economic development strategy.
- Technological cooperation between nations is important to sharing the benefits of improvements in production and marketing.

Note

1. Based on a report prepared by DATAGRO, a consulting firm in São Paulo, Brazil.

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APPENDIX B

Selected Data for African Countries

This appendix contains the most recent data available for African countries on population and income, food consumption and nutrition, land availability and use, and agricultural production and productivity. The data reflect some of the factors to consider in evaluating food security and resources potentially available for biofuels.

Table B.1 provides data on population levels and growth rates, population density, gross national income per capita, and growth rates for GDP per capita.

Table B.2 provides data on calories and protein consumption per capita per day, the share of the population undernourished, cereal consumption (tons per capita per year), and cereal import dependence. The level of calories and protein considered adequate for a healthy and active life depends on many factors, and information is available from the Food and Agriculture Organization of the United Nations, at http://www.fao.org/DOCREP/V7700T/v7700t06.htm.

Table B.3 provides data on agricultural land in total and per capita and the land in permanent crops (such as tree crops) and cereals.

Table B.4 provides indexes of agricultural and food production relative to the base period of 2000 = 100 and cereal yields; the coefficient of variation (standard deviation of yields divided by the mean from 1990 to 2007); and land irrigated.

Table B.1 Selected Data on Population, Population Density, and Income

Country	*Population (millions), 2007*	*Average annual population growth rate (percent), 2000–07*	*Population density (people per sq km), 2007*	*GNI per capita (US$), 2007*	*Average annual real GDP growth rate (percent), 2000–07*
Algeria	33.9	1.48	14.2	3,610	4.0
Angola	17.6	2.92	14.1	2,590	11.8
Benin	8.4	3.28	75.9	610	4.2
Botswana	1.9	1.26	3.3	6,100	5.2
Burkina Faso	14.7	3.11	54.0	430	5.2
Burundi	7.8	2.58	305.2	120	2.4
Cameroon	18.7	2.24	39.8	1,050	3.7
Cape Verde	0.5	1.65	122.0	2,680	5.6
Central African Republic	4.3	1.71	7.0	370	0.8
Chad	10.6	3.45	8.6	510	9.5
Comoros	0.8	2.15	337.7	690	2.1
Congo, Dem. Rep. of	62.5	2.89	27.5	140	3.3
Congo, Rep. of	3.6	2.20	10.4	1,510	4.2
Côte d'Ivoire	20.1	2.22	63.3	880	–0.2
Djibouti	0.8	2.01	35.9	1,070	3.0
Egypt, Arab Rep. of	80.1	1.88	80.4	1,500	4.6
Equatorial Guinea	0.8	2.80	22.9	9,710	22.4
Eritrea	4.8	3.87	47.9	270	0.1
Ethiopia	78.6	2.62	78.7	220	7.6
Gabon	1.4	2.07	5.5	6,450	1.7
Gambia, The	1.6	3.13	161.6	330	5.0
Ghana	22.9	2.27	100.5	600	5.2
Guinea	9.6	1.96	39.1	390	2.7
Guinea-Bissau	1.5	2.37	54.8	220	–0.1
Kenya	37.8	2.61	65.9	660	4.0
Lesotho	2.0	0.97	66.1	1,040	3.9
Liberia	3.6	3.93	37.7	150	3.3
Libya	6.2	2.02	3.5	9,010	3.7
Madagascar	18.6	2.84	32.0	340	3.6
Malawi	14.4	2.62	148.0	250	2.9
Mali	12.4	2.97	10.1	560	5.4
Mauritania	3.1	2.81	3.0	840	4.5
Mauritius	1.3	0.88	621.0	5,610	4.1
Morocco	31.2	1.18	69.2	2,290	4.6
Mozambique	21.9	2.32	27.2	340	7.5
Namibia	2.1	1.53	2.5	4,100	5.0
Niger	14.1	3.50	11.2	280	3.6

Table B.1 *(continued)*

Country	*Population (millions), 2007*	*Average annual population growth rate (percent), 2000–07*	*Population density (people per sq km), 2007*	*GNI per capita (US$), 2007*	*Average annual real GDP growth rate (percent), 2000–07*
Nigeria	147.7	2.46	162.5	970	6.1
Rwanda	9.5	2.99	383.2	330	6.9
São Tomé and Príncipe	0.2	1.72	164.6	920	7.0
Senegal	11.9	2.62	61.8	870	4.2
Seychelles	0.1	0.70	184.9	11,060	2.2
Sierra Leone	5.4	3.42	75.7	280	11.0
Somalia	8.7	3.01	13.9	—	—
South Africa	49.2	1.36	39.4	5,730	4.2
Sudan	40.4	2.12	17.0	910	7.5
Swaziland	1.2	1.01	66.9	2,550	3.5
Tanzania	41.3	2.69	46.6	400	6.5
Togo	6.3	2.69	115.8	370	2.0
Tunisia	10.1	0.98	65.8	3,210	4.9
Uganda	30.6	3.22	155.4	370	7.0
Zambia	12.3	2.35	16.6	740	5.0
Zimbabwe	12.4	0.08	32.2	—	–5.8

Source: World Bank, World Development Indicators database.
Note: GDP = gross domestic product; GNI = gross national income; sq km = square kilometer; — = not available.

Table B.2 Selected Data on Food Consumption and Nutrition

Country	*Food consumption per capita (Kcal per day), 2003*	*Protein consumption per capita (grams per day), 2003*	*Undernourished (percent), 2003–05*	*Cereal consumption (mt per capita), 2003*	*Cereal import dependence (percent), 2003*
Algeria	3,055	83	5	0.34	63.81
Angola	2,088	45	46	0.08	45.75
Benin	2,573	62	19	0.25	46.30
Botswana	2,196	65	26	0.10	80.41
Burkina Faso	2,515	72	10	0.26	2.91
Burundi	1,647	44	63	0.05	22.90
Cameroon	2,285	58	23	0.11	26.66
Cape Verde	3,215	78	15	0.18	96.58
Central African Republic	1,932	45	43	0.06	16.15
Chad	2,146	65	39	0.20	7.12
Comoros	1,760	43	52	0.09	70.55
Congo, Dem. Rep. of	1,605	24	76	0.03	22.01
Congo, Rep. of	2,182	44	22	0.07	91.44
Côte d'Ivoire	2,644	55	14	0.12	49.61
Djibouti	2,238	52	32	0.13	111.24
Egypt, Arab Rep. of	3,355	94	5	0.38	34.11
Equatorial Guinea	—	—	—	0.02	0.00
Eritrea	1,519	45	68	0.08	55.15
Ethiopia	1,858	53	46	0.16	5.54
Gabon	2,670	71	5	0.10	76.89
Gambia, The	2,288	53	30	0.19	50.45
Ghana	2,679	55	9	0.12	31.10
Guinea	2,446	51	17	0.32	15.13
Guinea-Bissau	2,050	39	32	0.15	20.38
Kenya	2,154	59	32	0.12	22.35
Lesotho	2,626	72	15	0.08	24.25
Liberia	1,929	30	40	0.12	47.42
Libya	3,336	78	5	0.42	91.73
Madagascar	2,056	46	37	0.24	7.78
Malawi	2,125	54	29	0.22	3.90

Table B.2 *(continued)*

Country	*Food consumption per capita (Kcal per day), 2003*	*Protein consumption per capita (grams per day), 2003*	*Undernourished (percent), 2003–05*	*Cereal consumption (mt per capita), 2003*	*Cereal import dependence (percent), 2003*
Mali	2,236	63	11	0.33	6.43
Mauritania	2,786	8	8	0.18	68.96
Mauritius	2,970	79	6	0.21	109.24
Morocco	3,098	84	5	0.27	72.28
Mozambique	2,081	39	38	0.10	36.16
Namibia	2,290	64	19	0.09	37.63
Niger	2,169	56	29	0.29	7.14
Nigeria	2,713	61	9	0.21	11.65
Rwanda	2,070	47	40	0.05	24.61
São Tomé and Príncipe	2,467	50	5	0.10	81.06
Senegal	2,374	60	26	0.19	70.17
Seychelles	2,484	81	9	0.24	100.09
Sierra Leone	1,943	44	47	0.19	14.67
Somalia	—	—	—	0.06	64.24
South Africa	2,962	77	5	0.26	26.50
Sudan	2,260	70	21	0.22	16.61
Swaziland	2,342	59	18	0.18	88.03
Tanzania	1,959	47	35	0.16	12.89
Togo	2,357	53	37	0.16	14.95
Tunisia	3,247	89	5	0.50	61.48
Uganda	2,360	57	15	0.10	16.53
Zambia	1,974	49	45	0.13	3.93
Zimbabwe	2,003	44	40	0.14	29.81

Sources: FAOSTAT; http://www.fao.org/DOCREP/V7700T/v7700t06.htm.
Note: Kcal = kilocalories; mt = metric tons; — = not available.

Table B.3 Selected Data on Agricultural Land and Use, 2007

Country	*Agricultural area (1,000 ha)*	*Agricultural area per capita (ha)*	*Arable land (1,000 ha)*	*Permanent crops (1,000 ha)*	*Cereal harvested area (1,000 ha)*
Algeria	41,252	1.2	7,469	921	2,972
Angola	57,590	3.3	3,300	290	1,491
Benin	3,520	0.4	2,700	270	902
Botswana	25,852	13.7	250	2	86
Burkina Faso	11,260	0.8	5,200	60	3,330
Burundi	2,295	0.3	995	350	223
Cameroon	9,160	0.5	5,960	1,200	1,123
Cape Verde	78	0.2	50	3	28
Central African Republic	5,205	1.2	1,925	80	205
Chad	49,330	4.6	4,300	30	2,584
Comoros	150	0.2	80	55	16
Congo, Dem. Rep. of	22,650	0.4	6,700	950	1,976
Congo, Rep. of	10,545	3.0	495	50	27
Côte d'Ivoire	20,200	1.0	2,800	4,200	780
Djibouti	1,701	2.0	1	—	—
Egypt, Arab Rep. of	3,538	0.0	3,018	520	2,850
Equatorial Guinea	47	0.1	33	3	—
Eritrea	7,542	1.6	640	2	390
Ethiopia	35,077	0.4	14,038	1,039	8,511
Gabon	5,160	3.6	325	170	21
Gambia, The	813	0.5	348	6	188
Ghana	14,850	0.6	4,100	2,400	1,395
Guinea	13,570	1.4	2,200	670	1,810
Guinea-Bissau	1,630	1.1	300	250	137
Kenya	27,000	0.7	5,200	500	2,037
Lesotho	2,304	1.1	300	4	231
Liberia	2,600	0.7	385	215	160
Libya	15,550	2.5	1,750	300	343
Madagascar	40,843	2.2	2,950	600	1,637
Malawi	4,970	0.3	3,000	120	1,394
Mali	39,619	3.2	4,850	130	3,529
Mauritania	39,712	12.7	450	12	229
Mauritius	101	0.1	90	4	—
Morocco	29,960	1.0	8,065	895	4,853
Mozambique	48,800	2.2	4,450	350	1,877
Namibia	38,805	18.6	800	5	285
Niger	43,515	3.1	14,720	15	9,052
Nigeria	78,500	0.5	36,500	3,000	19,410

Table B.3 *(continued)*

Country	*Agricultural area (1,000 ha)*	*Agricultural area per capita (ha)*	*Arable land (1,000 ha)*	*Permanent crops (1,000 ha)*	*Cereal harvested area (1,000 ha)*
Rwanda	1,925	0.2	1,200	275	332
São Tomé and Príncipe	57	0.4	9	47	1
Senegal	8,637	0.7	2,985	52	1,069
Seychelles	6	0.1	1	5	—
Sierra Leone	3,180	0.6	900	80	890
Somalia	44,027	5.0	1,000	27	470
South Africa	99,378	2.0	14,500	950	3,415
Sudan	136,773	3.4	19,321	225	11,657
Swaziland	1,342	1.2	178	14	49
Tanzania	34,200	0.8	9,000	1,200	4,987
Togo	3,630	0.6	2,460	170	782
Tunisia	9,826	1.0	2,757	2,174	1,411
Uganda	12,812	0.4	5,500	2,200	1,725
Zambia	25,589	2.1	5,260	29	997
Zimbabwe	15,450	1.2	3,230	120	1,928

Sources: Food and Agriculture Organization of the United Nations; FAOSTAT.
Note: ha = hectares; — = not available.

Table B.4 Selected Data on Agricultural Productivity and Food Production, 2003

Country	*Agricultural production index per capita*	*Food production index per capita*	*Cereal yields (mt/ha)*	*CV for cereal yields*	*Area under irrigation (ha 1,000)*
Algeria	122	122	1.39	26.6	570
Angola	122	124	0.49	26.5	80
Benin	81	86	1.29	11.0	12
Botswana	102	102	0.46	60.7	2
Burkina Faso	99	99	1.12	15.1	25
Burundi	78	79	1.31	3.8	21
Cameroon	93	97	1.37	19.6	26
Cape Verde	100	100	0.11	67.4	3
Central African Republic	89	93	1.11	9.6	1
Chad	82	86	0.76	22.8	30
Comoros	88	88	1.31	1.2	—
Congo, Dem. Rep. of	78	78	0.77	1.7	11
Congo, Rep. of	104	104	0.78	6.9	2
Côte d'Ivoire	94	101	1.59	30.3	73
Djibouti	134	134	1.67	3.5	1
Egypt, Arab Rep. of	101	102	7.56	11.3	3,530
Equatorial Guinea	—	—	—	—	—
Eritrea	78	78	0.45	49.3	21
Ethiopia	113	113	1.39	14.7	290
Gabon	91	91	1.66	10.0	7
Gambia, The	54	53	0.80	10.8	2
Ghana	106	106	1.33	9.0	31
Guinea	107	109	1.44	1.8	95
Guinea-Bissau	93	93	1.35	16.2	25
Kenya	112	113	1.79	10.1	103
Lesotho	83	82	0.55	30.7	3
Liberia	95	100	1.45	15.2	3
Libya	88	88	0.62	8.7	470
Madagascar	98	99	2.51	10.7	1,086
Malawi	117	118	2.47	29.5	56
Mali	103	118	1.10	16.6	236
Mauritania	93	93	0.77	16.7	45
Mauritius	94	95	9.45	29.3	21
Morocco	110	110	0.52	44.1	1,484
Mozambique	97	84	0.77	32.3	118
Namibia	92	91	0.42	29.1	8
Niger	113	114	0.42	16.9	74
Nigeria	100	100	1.40	9.4	293

Table B.4 *(continued)*

Country	*Agricultural production index per capita*	*Food production index per capita*	*Cereal yields (mt/ha)*	*CV for cereal yields*	*Area under irrigation (ha 1,000)*
Rwanda	100	100	1.09	15.0	9
São Tomé and Príncipe	102	102	2.31	5.6	10
Senegal	61	61	0.72	16.4	120
Seychelles	84	84	—	—	0
Sierra Leone	139	141	1.01	8.5	30
Somalia	83	83	0.42	25.3	200
South Africa	101	102	2.79	24.4	1,498
Sudan	107	107	0.65	17.7	1,863
Swaziland	101	103	0.56	23.8	50
Tanzania	110	110	1.25	21.9	184
Togo	87	99	1.12	17.0	7
Tunisia	108	109	1.43	20.3	418
Uganda	84	84	1.53	8.3	9
Zambia	102	101	1.54	21.5	156
Zimbabwe	68	80	0.65	39.0	174

Source: Author's calculations based on FAOSTAT data.
Note: CV = coefficient of variation; ha = hectares; mt = metric tons; — = not available.

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ECO-AUDIT
Environmental Benefits Statement

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Biofuels offer a new economic opportunity for sub-Saharan Africa. Energy prices are expected to remain high for an extended period of time because of the increasing demand in prospering and populous countries such as China and India and the depletion of easily accessible supplies of crude oil. High energy prices and concern over global climate change have sparked a renewed interest in biofuels as an alternative to fossil fuels.

Africa is uniquely positioned to produce biofuels and biofuel crops for both domestic use and export. The region has abundant natural resources and preferential access to protected markets with higher-than-world-market prices. The rapid growth in demand for transport fuels in Africa and high fuel prices create domestic markets for biofuels. The European Union and the United States have approved legislation that requires large increases in the consumption of biofuels over at least the next decade. Imports are expected to be needed to meet these mandates, thus opening the door to African and other developing countries that can produce biofuels or feedstocks for biofuels competitively.

Expanding the global production of crops for biofuels will affect the entire rural sector in Africa as resources are shifted away from traditional crops and the prices of all agricultural commodities rise. Smallholders can also participate in producing biofuel crops. To promote the sustainability and significant contribution of this enterprise, *Biofuels in Africa* provides guidance in formulating suitable policy regimes, which are based on protecting the rights of current land users, developing revenue-sharing schemes with local communities, safeguarding the environment and biodiversity, expanding institutional capacity, formulating new regulations and procedures, and emulating best practices from experienced countries.

Now that African countries are trying to significantly increase their energy supply systems, biofuels are an attractive option using both dedicated crops and agricultural waste. This book provides guidance for them to develop a suitable policy regime for a significant contribution by biofuels.

—Professor Ogunlade R. Davidson, *Minister of Energy and Water Resources, Sierra Leone*

Biofuels in Africa is a sorely needed resource for our understanding of the problems of expanding biofuels production in Africa. A high point of the book is a description of the projects that were started in several countries. A very useful book!

—Professor José Goldemberg, *University of São Paulo, Brazil*

As Africa most likely will play the same role for global biofuels as the Middle East does for oil, this comprehensive book on African biofuels should be compulsory reading for anyone interested in either African development or biofuels. The book captures the essence of long-term drivers and opportunities as well as the complex challenges for investors and society of this huge emerging industry.

—Per Carstedt, *Executive Chairman, EcoEnergy Africa*

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