

Potential for Biofuels for Transport in Developing Countries

October 2005



JOINT UNDP / WORLD BANK
ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

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Energy Sector Management Assistance Programme (ESMAP)

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First printing October 2005

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Photographs on the front cover: Flex-fuel vehicle and a filling station in Brasilia, 2005, Todd Johnson; sugarcane field in São Paulo, 2004, courtesy of Carlos Goldgrub, Reflexo.

CONTENTS

Acknowledgments	vii
Abbreviations and Acronyms	ix
Units of Measure	xiii
Currency Equivalents	xv
Glossary of Terms	xvii
Executive Summary	1
1. Background	13
Description of Biofuels.....	14
Ethanol.....	15
Biodiesel.....	16
Uses.....	16
A Brief Summary of Current Advantages and Disadvantages.....	17
Ethanol.....	20
Biodiesel.....	21
Future Potential.....	21
2. International Experience	23
Brazil.....	23
United States.....	31
Ethanol.....	32
Biodiesel.....	36
European Union.....	37
Australia.....	42
Canada.....	43
China.....	44
Colombia.....	45
India.....	45
Thailand.....	47
3. Resource Costs of Biofuels	49
Agricultural and Trade Policies.....	50
Feedstock Costs.....	53
Processing Costs.....	57
Ethanol.....	57
Biodiesel.....	58

Co-Product Sales and Use.....	59
Overall Cost	60
Retail Prices and Tax Considerations	62
Environmental Impact of Biofuel Production.....	71
Other Economic Impacts of Biofuel Production.....	72
4. Impact on Emissions and Vehicle Performance.....	77
Emissions of Harmful Pollutants	77
Fuel Economy	81
Impact on Engines and Other Vehicle Components	83
Lifecycle Analysis of Greenhouse Gas Emissions.....	87
5. Considerations for Developing Countries.....	91
Commercial Viability of Biofuel Industry	91
Relation to world oil price	92
Agricultural Trade liberalization	95
Land-locked countries	95
Surplus feedstock.....	96
Non-crop feedstock.....	96
Biofuel mandate.....	97
Rural Development	97
Enabling environment.....	98
Impact of policy	98
Implications for biofuel programs	99
Job Creation	100
Accounting for Poorly Priced Externalities	102
Energy Diversification	104
Economic Analysis of Biofuel Programs.....	106
Future Technologies.....	111
6. Conclusions	113
Annex 1. Process Description	121
Ethanol.....	121
Biodiesel	123
Annex 2. Sugar and Ethanol Industry in Brazil	125
Field Burning	125
Water Use and Effluents	126
Pest Control.....	127
Crop Disease Control.....	127
Weed Control.....	128

Employment Generation	128
Annex 3. Labor Intensity of Different Crops	133
References	135

Tables

Table 2.1 Average Monthly Earnings for All Jobs, R\$ in 2003	31
Table 3.1 Biofuel Cost in 2002 in US\$ per Liter.....	61
Table 3.2 Gasoline-Ethanol Blend Price Structure in Brazil in June 2005 Price for 1,000 liters. 64	
Table 3.3 Hydrous Ethanol Price Structure in São Paulo, Brazil, in June 2005 Price per 1,000 liters	65
Table 3.4 EU Taxation Policy for Ethanol	67
Table 4.1 Change in Lifecycle Greenhouse Gas Emissions per Kilometer Traveled by Replacing Gasoline with Ethanol in Conventional Spark Ignition Vehicles	89
Table 4.2 Change in Lifecycle Greenhouse Gas Emissions per Kilometer Traveled by Replacing Diesel with Biodiesel in Conventional Compression Ignition Vehicles.....	89
Table 5.1 World Sugarcane Production in 2004–2005.....	95
Table A2.1 Legislation Requiring Phase-out of Sugarcane Field Burning in Brazil Percentage of Land Where Burning Is Phased Out	126
Table A2.2 Number of Workers in the Sugarcane Sector	129
Table A2.3 Breakdown of Formal Sector Workers by Education, 2002.....	131
Table A2.4 Mean Income and Years of Education in Agriculture, 2003	132
Table A3.1 Average Labor Use in Person Days per Hectare in Indochinese Countries	133
Table A3.2 Resource Use Efficiency in Vegetables Versus Rice Cultivation	134

Figures

Figure 1 Economic Analysis of Biofuel Production and Marketing	6
Figure 1.2 Historical Prices of Gasoline and Diesel (real prices in 2 nd quarter 2005 US\$).....	19
Figure 2.3 Share of Ethanol in Gasoline/Ethanol Market in Brazil.....	30
Figure 2.4 Historical Market Share of Hydrous-Ethanol-Fueled Cars in Brazil	30
Figure 2.5 U.S. Ethanol Production and Gasoline Consumption	35
Figure 5.1 Recent International Prices of Crude Oil, Gasoline, and Diesel	93
Figure 5.2 Historical Crude Oil Price (2004 US\$).....	93
Figure 5.3 World Raw Sugar and Gasoline Prices (real prices in 1 st quarter 2005 US\$).....	106
Figure 5.4 Financial and Economic Analysis of a Domestic Biofuel Program.....	109

Acknowledgments

This report was prepared in response to increasing requests to the Energy Sector Management Assistance Programme (ESMAP), a joint program of the United Nations Development Programme (UNDP) and the World Bank, to help developing countries assess the potential of biofuels in the near to medium term. ESMAP commissioned the Air Quality Thematic Group of the World Bank to review global experience with biofuels as transportation fuels and assess potential for their production and use. The Air Quality Thematic Group is supported by the Environment, Transport, Urban, and Energy and Mining Sector Boards and consists of specialists from these sectors. The financial assistance of the Government of the Netherlands through ESMAP under the Bank Netherlands Partnership Program is gratefully acknowledged.

This report was prepared by Masami Kojima of the Oil, Gas, Mining, and Chemicals Department, and Todd Johnson of the Finance, Private Sector, and Infrastructure Department of the Latin America and the Caribbean Region. The comments of World Bank peer reviewers—Robert Bacon (Oil, Gas, Mining, and Chemicals Department), Derek Byerlee (Rural Development and Environment Department, Africa), Donald Larson (Development Research Group), Stephen Mink (Rural Development and Natural Resource Sector Department, East Asia and the Pacific), Robert Schneider (Environment and Social Sustainable Development Department, Latin America and the Caribbean), and Robert Townsend (Rural Development and Environment Department, Africa)—as well as those from other World Bank specialists are gratefully acknowledged.

The authors also thank the following individuals who provided valuable written comments:

- Reid Detchon, Executive Director, Energy Future Coalition, United States
- William A. Ward, Director, Center for International Trade, Clemson University
- Uwe R. Fritsche, Coordinator, Energy and Climate Division, Oeko-Institut, Germany
- Tomas Kåberger, Associate Professor, International Institute for Industrial Environmental Economics, Lund University, Sweden
- Isaías de Carvalho Macedo, State University of Campinas, São Paulo, Brazil
- Plinio Mário Nastari, President, Datagro Ltda., São Paulo, Brazil
- Alfred Szwarc, Director, Technology and Sustainable Development, São Paulo, Brazil
- Suani Teixeira Coelho, São Paulo State Environment Agency, Brazil

Editorial support was provided by Paula Whitacre of Full Circle Communications, the cover was designed by Samantha Constant (consultant), and the publication and distribution of the report was coordinated by Marjorie K. Araya of ESMAP.

Abbreviations and Acronyms

ACEA	Association des Constructeurs Européens d'Automobiles
ADM	Archer Daniels Midland
AFTA	Association for Fair Trade in Alcohol
ANFAVEA	Associação Nacional dos Fabricantes de Veículos Automotores (National Association for Automotive Vehicle Manufacture, Brazil)
ANP	(Brazilian) National Petroleum Agency
AQIRP	Air Quality Improvement Research Program
ASTM	American Society of Testing and Materials
CAP	Common Agricultural Policy (of the European Union)
CARB	California Air Resources Board
CDM	Clean Development Mechanism
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CER	Certified emission reduction
CNG	Compressed natural gas
CO	Carbon monoxide
CO ₂	Carbon dioxide
CPI	Consumer price index
DDGS	Distiller's dried grains with solubles
EBB	European Biodiesel Board
EEB	European Environmental Bureau
EGR	Exhaust gas recirculation
EMA	(U.S.) Engine Manufacturers Association
EPAct	(U.S.) Energy Policy Act (of 1992)
ESMAP	Energy Sector Management Assistance Programme
ETBE	Ethyl tertiary-butyl ether
EU	European Union
EUA	European Union allowances
EWG	Environmental Working Group
FAME	Fatty acid methyl ester

FAPRI	Food and Agricultural Policy Research Institute
FIE	Fuel injection equipment
GDP	Gross Domestic Product
GHG	Greenhouse gas (gas that contributes to global warming effects)
HHI	Herfindahl-Hirschman Index (a measure of market concentration)
IAA	Instituto do Açúcar e do Alcool (Brazilian Institute of Sugar and Alcohol)
IEA	International Energy Agency
IMF	International Monetary Fund
JAMA	Japan Automobile Manufacturers Association
LPG	Liquefied petroleum gas
MON	Motor octane number
MTBE	Methyl tertiary-butyl ether (an oxygenate)
N ₂ O	Nitrous oxide (a powerful greenhouse gas)
NOVEM	Nederlandse Organisatie voor Energie en Milieu (Netherlands Agency for Energy and Environment)
NO _x	Oxides of nitrogen
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of Petroleum Exporting Countries
PM	Particulate matter
R&D	Research and development
RFA	Renewable Fuels Association
RFG	Reformulated gasoline
RME	Rapeseed methyl ester
RON	Research octane number
RVP	Reid vapor pressure
UBA	Umweltbundesamtes (German Federal Environmental Agency)
UFOP	Union zur Förderung von Oel- und Proteinpflanzen (Union for the Promotion of Oil and Protein Plants)
UN	United Nations
UNDP	United Nations Development Programme
UNICA	São Paulo Sugarcane Agroindustry Union
USDA	U.S. Department of Agriculture
U.S. DOE	U.S. Department of Energy
U.S. EIA	U.S. Energy Information Administration

U.S. EPA U.S. Environmental Protection Agency
U.S. GAO U.S. General Accounting Office
VAT Value added tax
VEETC Volumetric ethanol excise tax credit
VOC Volatile organic compound

Units of Measure

A\$	Australian dollars
°C	Degrees Celsius
C\$	Canadian dollars
cSt	Centi-Stoke (unit of kinematic viscosity)
€	Euros
g	Grams
g/km	Grams per kilometer
kg	Kilograms
km	Kilometers
kPa	Kilopascals (a unit of pressure)
m ³	Cubic meters (1 m ³ is 1,000 liters)
MJ	Mega-joules (10 ⁶ joules)
pH	A measure of acidity. A pH higher than 7 is basic, and a pH lower than 7 is acidic.
ppm	Parts per million. 10,000 ppm is 1 percent, 1,000 ppm is 0.1 percent, and so on.
psi	Pounds per square inch (a unit of pressure)
R\$	Brazilian Real
ton	Short ton, 2,000 pounds or 908 kg
tonne	Metric tonne, 1,000 kg
US gallon	3.7854 liters
vol%	Percent by volume
wt%	Percent by weight
£	British pounds

Currency Equivalents

Brazilian Real to US\$ Exchange Rate US\$1.00 =

<i>Date</i>	<i>Rate</i>	<i>Date</i>	<i>Rate</i>	<i>Date</i>	<i>Rate</i>
September 2005	2.32	November 2004	2.80	January 2004	2.85
August 2005	2.36	October 2004	2.85	2003	3.08
July 2005	2.37	September 2004	2.90	2002	2.91
June 2005	2.42	August 2004	3.01	2001	2.35
May 2005	2.47	July 2004	3.05	2000	1.83
April 2005	2.60	June 2004	3.13	1999	1.81
March 2005	2.70	May 2004	3.07	1998	1.16
February 2005	2.61	April 2004	2.90	1997	1.08
January 2005	2.70	March 2004	2.94	1996	1.00
December 2004	2.73	February 2004	2.93	1995	0.91

Glossary of Terms

Anhydrous ethanol	Ethanol with sufficient water removed to make it suitable for blending with gasoline.
Aromatics	Hydrocarbons that contain one or more benzene rings in their molecular structure. Aromatics have valuable anti-knock (high-octane) characteristics.
B5	A diesel-biodiesel blend containing 5 percent biodiesel.
Benzene	An aromatic hydrocarbon with a single six-carbon ring and no alkyl branches. Benzene is a carcinogen.
Blending octane number	The effective octane number of a gasoline component when it is blended into gasoline.
Blendstock	A component combined with other materials to produce a finished refined product.
Cetane number	An empirical measure of a diesel fuel's ignition quality that indicates the readiness of the fuel to ignite spontaneously under the temperature and pressure conditions in the engine's combustion chamber. Adding cetane improvement additives can increase the cetane number.
Diluent	Something that dilutes. Ethanol, for example, contains no benzene, no sulfur, no aromatics, and no olefins. Adding ethanol thus "dilutes" all other components having benzene, sulfur, aromatics, and olefins.
E10	An ethanol-gasoline blend containing 10 percent anhydrous ethanol.
Flash point	The lowest temperature (under certain conditions) at which a combustible liquid will give off sufficient vapor to form a flammable mixture with air. It denotes the volatility of the product.
Higher heating value	The amount of heat released per unit mass or unit volume of a substance when the substance is completely burned, including the heat of condensation of water vapor to liquid water.
Hydrocarbons	Organic compounds composed of carbon and hydrogen.
Hydrous ethanol	Ethanol with about 95 percent purity, the balance being water. It is not suitable for blending with gasoline.
Lower heating value	The amount of heat released per unit mass or unit volume of a substance when the substance is completely burned, excluding the heat of condensation of water vapor to liquid water. The lower heating value is the relevant parameter when fuels are used in automotive engines.

Motor octane number (MON)	The octane number of a fuel, determined when vehicles are operated at high speed or under highway driving conditions.
Octane number	A measure of resistance to self-ignition (knocking) of a gasoline when mixed with air in an engine cylinder. The higher the octane number, the higher the anti-knock quality of the gasoline. In the United States, the word <i>octane</i> , as used at filling stations, refers to an average of MON and RON; it is also called the <i>anti-knock index</i> . Because MON is usually lower than RON, averaging the two results in a lower number, typically by 4 or 5. For example, “87 octane” in the United States corresponds to 91 or 92 RON.
Olefins	A class of hydrocarbons that have one double-bond in their carbon structure.
OPEC basket price	Between January 1, 1987, and June 15, 2005, the Organization of Petroleum Exporting Countries’ (OPEC’s) basket price was an average of the prices for Saudi Arabia’s Arab Light, the United Arab Emirates’ Dubai, Nigeria’s Bonny Light, Algeria’s Saharan Blend, Indonesia’s Minas, Venezuela’s Tia Juana Light, and Mexico’s Isthmus. The first six countries are OPEC members. Effective June 16, 2005, OPEC changed the composition of the basket and the way the price is calculated. The new basket comprises the following 11 crude streams: Saharan Blend (Algeria), Minas (Indonesia), Iran Heavy (Islamic Republic of Iran), Basra Light (Iraq), Kuwait Export (Kuwait), Es Sider (Libya), Bonny Light (Nigeria), Qatar Marine (Qatar), Arab Light (Saudi Arabia), Murban (United Arab Emirates), and BCF 17 (Venezuela).
Oxygenates	Organic compounds containing oxygen. Specifically for the petroleum industry, oxygenates typically refer to alcohols and ethers used to boost octane or to facilitate fuel combustion in the combustion chamber, thereby reducing the amount of products of incomplete combustion such as carbon monoxide.
Ozone	A colorless gas, it is an allotropic form of oxygen in which the molecule is O ₃ .
Polyaromatic hydrocarbons	Aromatic compounds with more than one six-membered ring. Polyaromatic hydrocarbons are carcinogens.
Reid vapor pressure (RVP)	A standardized measure of a fuel’s volatility at a specified set of conditions, with a higher value indicating a more volatile fuel. RVP is usually measured in psia (pounds per square inch absolute) or kPa (thousand pascals).
Research octane number (RON)	The octane number of a fuel, determined when vehicles are operated at low speed or under city driving conditions.

Splash blending Blending of ethanol into gasoline or biodiesel into petroleum diesel at terminals

Vinasse The residue liquid from the distillation of ethanol, rich in potassium and organic matter.

Executive Summary

1 Liquid biofuels made from biomass are attracting increasing interest worldwide. Industrial countries see biofuels as a way of reducing greenhouse gas (GHG) emissions from the transport sector and diversifying energy sources. Developing countries see biofuels as a way to stimulate rural development, create jobs, and save foreign exchange. Both groups view biofuels as a means of increasing energy security. These concerns, taken together and highlighted by recent surges in the world oil price, have prompted a wide range of countries to consider biofuels programs. Canada, Colombia, the European Union (EU), India, Thailand, and the United States have adopted new targets, some mandatory, for increasing the contribution of biofuels to their transport fuel supplies. In Brazil, after a period of a decline in ethanol consumption, flex-fuel vehicles—capable of running on varying percentages of ethanol—are revitalizing the ethanol market.

2 This report responds to increasing requests from developing countries to help assess the feasibility of domestic production of biofuels for transport. The scope of the analysis is the short to medium term. As such, the report considers primarily commercially available or near-commercial technologies that could be adopted in developing countries in the next 5 to 10 years. Given the focus on transport applications, the report does not look at potential small-scale options for biofuels in rural communities (such as for diesel generators or agricultural machinery), where cost of biofuel production would be higher, but where the delivered costs of fossil fuels are also high. The report also does not discuss biogas, or solid biomass (such as combustion of solid biomass to generate electricity), except where its use occurs as part of liquid fuel production. The report reviews global experience with large-scale biofuel programs, focusing on ethanol and biodiesel as transportation fuels, and assesses the socio-economic considerations for establishing such programs in developing countries.

3 Ethanol and plant-oil-based biodiesel are the two primary biofuels consumed in the transport sector. Bioethanol has a much longer commercial history and larger market than biodiesel. The world's largest biofuel market is Brazil, where ethanol is made from sugarcane. Between 1975 and 2004, the ethanol program in Brazil displaced about 230 billion liters of gasoline. The second largest market for ethanol is the United States, where most ethanol is produced from maize. The sizes of the Brazilian and U.S. fuel ethanol markets today are nearly comparable, but ethanol constitutes only about 3 percent of the gasoline-ethanol market in the United States compared to more than 40 percent in Brazil. Although growing rapidly, the global biodiesel market is an order of magnitude smaller in size, with the European Union as the world's largest producer, making biodiesel primarily from rapeseed. Soybeans are the primary feedstock for biodiesel in the United States.

4 Ethanol from sugarcane grown in the Center-South region of Brazil is by far the cheapest biofuel today. The financial cost of ethanol production in Brazil is estimated to be in the range of US\$0.23–0.29 per liter at the exchange rate prevailing in mid-2005 (R\$2.40 = US\$1.00), with the range largely reflecting the difference in sugar production costs in different regions. Depending on the impact of substituting gasoline with ethanol on vehicle fuel economy, these are equivalent to gasoline prices when crude oil is between US\$35 and \$50 per barrel.¹ For comparison, during the first eight months of 2005, the OPEC (Organization of Petroleum Exporting Countries) basket price averaged \$49 per barrel.² The costs of ethanol production in other countries, or using other feedstocks, are significantly higher than from sugarcane in Brazil. Biodiesel production costs are considerably greater, at least US\$0.50 per liter (or US\$79 per barrel of biodiesel) and, in many cases, higher.

5 Developing country interest in biofuels is motivated by a number of factors:

- *Diversification of energy sources and lower exposure to the price volatility in the international oil market.* Countries that are net importers of crude oil, or gasoline and diesel fuel, may be able to enhance their energy security through the substitution of gasoline and diesel fuel by domestically produced biofuels. Similarly, countries that have high delivered costs of petroleum (for example, land-locked countries) may be able to reduce their overall transport fuel expenditures. The extent of energy diversification possible from biofuels will depend on the demand for transport fuels relative to energy used in other sectors and the supply potential of biofuels.
- *Rural development.* Biofuels hold the promise of contributing to rural development through agricultural growth and creating jobs in feedstock production, biofuel manufacture, and in the transport and distribution of feedstock and products. Feedstock accounts for more than half the cost of biofuels production.
- *Reduction in harmful pollutants from vehicle exhaust.* Where vehicles are important contributors to poor urban air quality, and in certain applications (such as marine uses) to water quality, biofuels may be environmentally preferable to petroleum-based fuels. In a recent move toward ultralow sulfur fuels, biofuels have the added advantage of being sulfur-free. Ethanol has the greatest air-quality benefits where vehicle fleets are old, as is often the case in developing countries. It helps to reduce the exhaust emissions of carbon monoxide (CO) and hydrocarbons, especially in cold climate. Ethanol has a high blending octane number, and for this reason it has been used in a few countries in eliminating

¹ The impact of substituting gasoline with ethanol on vehicle fuel economy varies from vehicle to vehicle and application to application. In this report, a reduction in fuel economy of 20–30 percent is taken as representative of study findings. See the section on fuel economy in chapter 4 for more detail.

² In discussing “the world price of oil,” it is important to note that crude oil qualities vary considerably, resulting in marked price differences from crude to crude. In the main text, this report specifies the crude or basket of crude oils when quoting oil prices.

gasoline lead (a powerful toxin that boosts gasoline octane). A comprehensive analysis by the U.S. Environmental Protection Agency (U.S. EPA) reported that the use of a diesel mixture containing 20 percent biodiesel reduced particulate, hydrocarbon, and CO emissions by 10, 21, and 11 percent, respectively, but increased the emissions of oxides of nitrogen (NO_x), an ozone precursor, by 2 percent. Biodiesel also lowered air toxic emissions (U.S. EPA 2002).

- *Net reductions in lifecycle GHG emissions.* The prospect of bilateral or multilateral aid transfers for climate change mitigation is generating significant interest in biofuels in developing countries. Developing countries do not currently have binding GHG reduction targets under the Kyoto Protocol and are typically more concerned with potential climate change impacts than with reducing their own GHG emissions. Under the Clean Development Mechanism (CDM), however, developing countries can sell carbon credits to countries with reduction commitments. Depending on the feedstock and the conditions under which it is produced, biofuels have significant potential to reduce GHGs in the transport sector. With carbon prices at US\$3–20 per metric tonne of carbon dioxide (CO₂)-equivalent,³ biofuels could earn between US\$0.005–0.03 per liter on the carbon market.

6 On the other side of the ledger, developing countries are also concerned with the potential social and economic costs of biofuel programs. These include

- The economics of biofuels and the historical need for significant and ongoing government subsidies to the industry
- The capture of biofuel program subsidies by large-scale farms and agribusiness
- Fiscal and equity impacts of reducing government revenues from progressive taxation of gasoline while subsidizing the ethanol industry
- Implications for agriculture and agricultural trade policy
- Environmental damages associated with feedstock production and biofuel manufacture, such as water and air pollution and excess land degradation.

7 The greatest barrier to the widespread development of the biofuel industry is economics. It is therefore worth reviewing the factors that have contributed to the success of the Brazilian bioethanol industry. Feedstock costs account for 58 to 65 percent of the cost of ethanol production in Brazil. As such, the commercial viability of ethanol is critically dependent on the cost of cane production. Brazil is the lowest-cost producer of sugarcane in the world. The Center-South region of Brazil, which accounts for 85 percent of the country's cane production, is virtually unmatched in its productivity and low production costs. One potential challenge of cane cultivation is its large water requirements.

³ In 2005, EU allowances were traded in the EU Emissions Trading Scheme for as much as €30 per ton. It is important to understand that the EU Emissions Trading Scheme is different from the market for certified or verified emission reductions under the Kyoto Protocol. The high prices seen in the EU Emissions Trading Scheme in 2005 are for immediate delivery. The prices rose because of short-term demand and supply factors, including the cold winter in Europe and the lack of supply for 2005–2007. It is expected that the prices will come down and stabilize over time with more experience and additional supply.

Nearly all cane fields in the Center-South of Brazil are rain-fed. This gives a marked advantage to Brazil and other regions with adequate rainfall compared to other cane growers relying on irrigation, such as Australia and India. High productivity in Brazil has also benefited from decades of research and commercial cultivation. For example, cane growers in Brazil use more than 500 commercial cane varieties that are resistant to many of the 40-odd crop diseases found in the country.

8 Most distilleries in Brazil belong to sugar mill/distillery complexes, capable of swinging between 60 percent sugar / 40 percent ethanol to 40 percent sugar / 60 percent ethanol. This capability enables complex owners to take advantage of fluctuations in the relative prices of sugar and ethanol, as well as to benefit from the much higher price that can be fetched by converting molasses into ethanol.⁴ Flex-fuel vehicles, widely marketed in Brazil beginning in 2003, are capable of running on any mixture of hydrous ethanol and a gasoline-anhydrous ethanol blend (pure gasoline is not sold in Brazil, and at present the blend contains 25 percent anhydrous ethanol),⁵ and have further increased the attractiveness of building hybrid sugar/ethanol complexes. The average mill/distillery deals with about 15 sugarcane varieties, and many of the plant and agricultural operations (harvest times, equipment maintenance, distillery efficiency optimization) are highly sophisticated and computerized. These optimization methods are made possible by a high level of managerial skills, research and development technical capability, and the existence of economies of scale for sugarcane and ethanol production in Brazil. Because most plants are hybrid mill/distillery complexes, there is no opposition to ethanol production from sugar producers and vice versa in Brazil. And because there is significant scope for expanding cane production, sugar and ethanol do not have to compete for land.

9 The net-of-tax price of ethanol more than halved in Brazil between 1980 and 2001. The advances that contributed to cost reduction include development of new sugarcane varieties, more efficient use of bagasse (residue obtained after crushing cane) for electricity generation, an increase in fermentation efficiency, optimization of agricultural and industrial process operations, and new cane harvesting and transportation systems. Between 1975 and 2000 in the state of São Paulo—the largest and lowest-cost ethanol producer in the country—the sugarcane yield per hectare increased 33 percent, cane’s sugar content 8 percent, ethanol yield from sugar 14 percent, and fermentation productivity 130 percent.

10 A critical question for replication of Brazil’s experience in other developing countries is at what point on Brazil’s historical cost “learning curve” they will be able to enter the ethanol market. While it is unlikely that they will be able to start at production costs of US\$0.25 per liter—approximately where Brazil is today—some countries hope to move quickly down the cost curve. Certain aspects of Brazil’s ethanol industry are more easily transferable than others. Engineering design and plant construction can be

⁴ Sucrose is typically converted into 83 percent sugar and 17 percent molasses. Molasses fetches between 10 percent and 35 percent of the price of sugar. Conversion of molasses into ethanol enables the producer to realize the near-equivalent of the price of sugar for molasses.

⁵ Flex-fuel vehicles outside of Brazil operate on any mixture of pure gasoline and a gasoline-ethanol blend typically containing up to 85 percent ethanol.

imported—although other developing countries will not be able to take advantage of domestic ethanol plant equipment manufacturers as in Brazil, and would be expected to pay more for plant construction, at least initially. Entrepreneurial and managerial skills, and a cadre of technical people capable of developing new commercial cane varieties, for example, will take time to develop.

11 Where biofuels are entirely commercially viable, government involvement can be limited to regulating the industry to ensure a level-playing field, consumer protection, and compliance with environmental, healthy, safety, and technical standards. Under all circumstances, governments should improve the investment climate wherever possible by establishing a clear, stable, and transparent legal and fiscal framework accompanied by efficient administration.

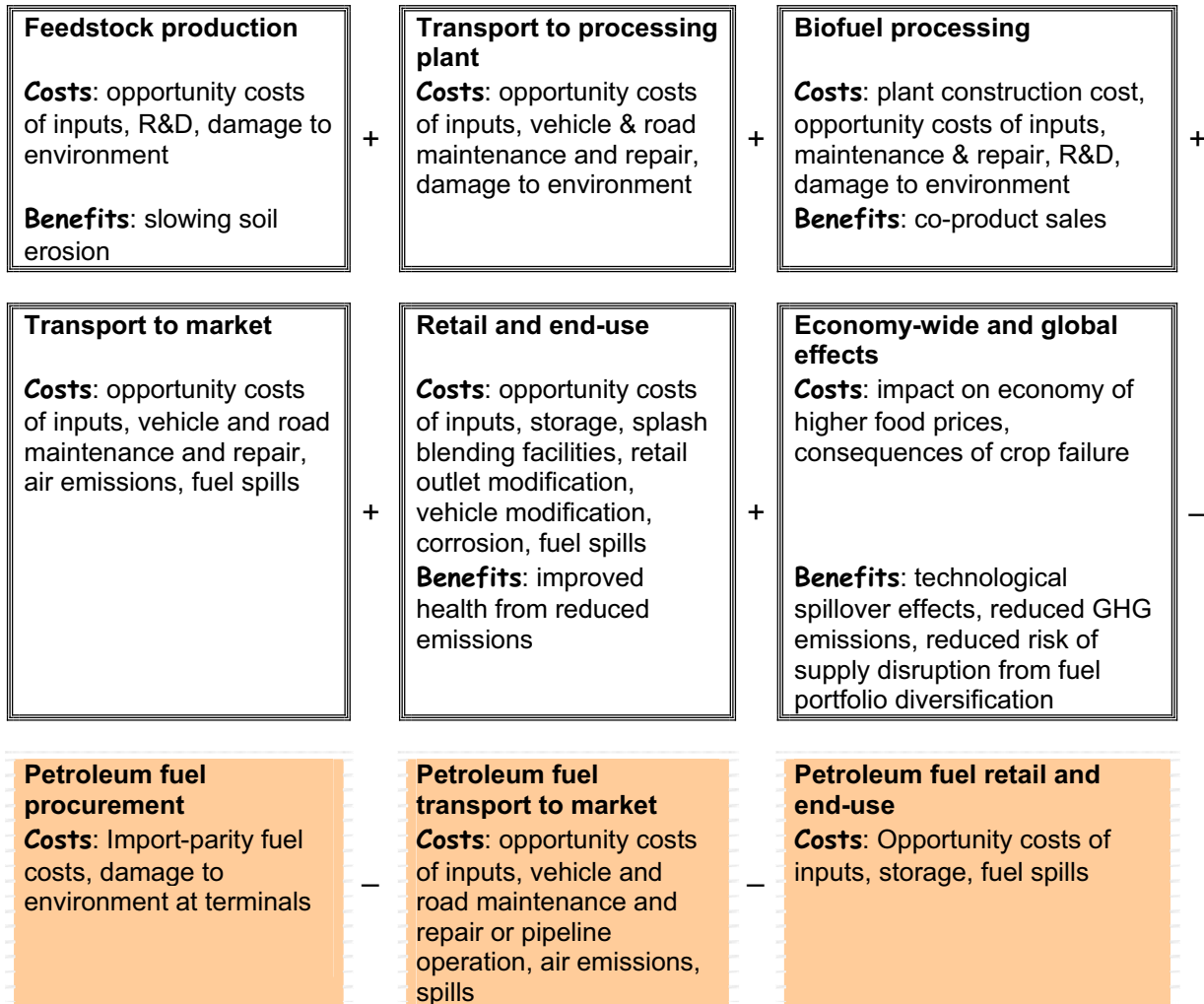
12 Because no country has been able to launch a domestic biofuels industry without active government support beyond its normal regulatory role, it is important to carry out a proper economic analysis to weigh upfront the social costs and benefits of biofuels and to decide when, where, and how to embark on a biofuel program. Economic analysis can also be a valuable tool in reshaping planned or existing programs to maximize their efficiency and their net benefits to society. The economics of biofuel production are site- and situation-specific, and each country will produce different results. Steps involved in economic analysis for a country importing petroleum products are illustrated in Figure 1. A more complex case in which crude oil is imported and refined domestically is given in Figure 5.4 and discussed in chapter 5. Where benefits do not appear in the figures, it is either because there are no net benefits going from the base case to the biofuel case, or because benefits cannot be reasonably counted and valued.

13 Assessing the costs of biofuel programs begins with estimating the *opportunity* costs of land, water, fertilizers and other agrochemicals, electricity and diesel for irrigation and powering farm equipment, labor, seeds, and machinery used in feedstock production. Opportunity costs, rather than the prices paid, should be used to ensure that the costs of subsidized inputs and alternative uses of resources are properly reflected. Research and development (R&D) can foster innovation and reduce biofuel production costs. The opportunity cost of labor should be considered at every stage in the supply chain.

14 Damage to the environment can occur throughout the supply chain for both biofuels production/distribution and petroleum fuel importation/distribution. On the positive side, certain feedstock plants can contribute nutrients to the soil and help stem soil erosion, with some plants, like *Jatropha*, able to grow on marginal land with limited rainfall.

15 At the retail and end-use level, splash blending facilities for ethanol may have to be built, vehicle modifications may be needed, and, in the case of hydrous ethanol, purpose-built vehicles will need to be purchased. On the benefit side, lower emissions of harmful exhaust will have a positive impact on public health. The impact of using biofuels on tailpipe emissions varies from pollutant to pollutant and is dependent on the vehicle technology, individual vehicle tuning, and the driving cycle. Because biofuels are more biodegradable than petroleum fuels, their discharge into water bodies will be more benign.

Figure 1 Economic Analysis of Biofuel Production and Marketing



16 From these costs and benefits should be subtracted the corresponding costs (and benefits, if they exist and can be valued) of the baseline alternative of importing petroleum products. Finally, economy-wide and global effects of switching to biofuels should be considered. If food prices rise because of crop substitution, then the economy-wide impact of food price increases should be taken into account. Poor harvests could push up the price of feedstocks and possibly necessitate unplanned import of biofuel, petroleum fuel, or both. On the benefit side, R&D can lead to technological spillovers in other sectors, the economy may benefit from lower exposure to fuel supply disruptions from fuel source diversification, and overall GHG emissions will fall in most cases.

17 The economic analysis should account for changing costs and benefits through time and should model the risks and uncertainties in the underlying variables. Key assumptions affecting the economic analysis of biofuels include future commodity prices (especially the price of crude oil), the pace of technological change, the rate of decline in production costs, future demand for transport fuels, and macroeconomic variables such as future gross domestic product (GDP). The economic analysis should also detail the

distribution of the impacts upon different parts of society by switching to biofuels. Income improvements for otherwise unemployed or underemployed workers will be counted as net benefits in the cost-benefit analysis. The economic analysis implicitly accounts for creating jobs for the unemployed and underemployed by costing those laborers at a low opportunity cost, thus decreasing the overall cost and increasing the net benefits from the program. The distribution analysis will list the numbers and types of jobs gained and lost, the wages for those jobs, and the change in overall income of all the parties affected. Methods for calculating employment and other distributional implications are discussed in chapter 5.

18 Oil prices have the largest effect on the economics of biofuel production. If world oil prices remain high for a prolonged period of time, biofuel programs have a better chance of becoming financially viable without sustained government support in a larger number of countries. Sustained prices above \$50 per barrel are predicted by a number of analysts over the next few years. However, if oil prices fall to US\$35 per barrel in the next five years, as some analysts forecast (IMF 2005, Oil and Gas Journal 2005), this would pose a challenge to the financial viability of biofuel production without government support in many areas of the world.

19 There are several important considerations in assessing the likelihood of commercial viability of a biofuel program over the long run. A list is provided below for ethanol as an illustration:

- *Do climatic conditions favor sugarcane production?* Is there plentiful rainfall, or a good irrigation system that is sustainable without large subsidies, either directly or through subsidized electricity or diesel fuel (for water pumping), or good agricultural water resource management? Is soil fertility adequate for cane production? A region facing perennial water shortages for agriculture would not be a good candidate for an ethanol program.
- *Is there good road and communications infrastructure?* Fertile land with good rainfall must be accessible in order to minimize the costs of moving cane to processing plants and ethanol to consumption centers. There are economies of scale for biofuel production, requiring infrastructure for transport and distribution. Communication infrastructure is also essential to keep informed about weather and market conditions.
- *Is there good agricultural research and extension,* or a high probability of strengthening it? Brazilian experience underlines the benefits of developing new cane varieties to stay ahead of cane diseases and pests, identifying the right variety for each microclimate, disseminating knowledge through agricultural extension services, and ensuring that farmers implement them.
- *Are farmers provided with adequate primary education?* Especially in low-income countries, farmer education is often lacking. Farmers need to be able to absorb and apply advice provided by extension services, so as to be able to respond to new technical, marketing, organizational, and financial opportunities.
- *Is there a functioning credit market?* Farmers need access to credit in order to implement the advice of extension service officers on soil improvement, select and plant the right cane varieties, and adopt adequate pest, weed, and disease

- control methods. Such measures are needed to improve cane yield to make ethanol production economic. A functioning capital market is needed for the construction of distilleries.
- *Is there a cadre of managers that can be called upon to manage the industry?* Managerial skills, including technical management, are needed across the supply chain, from optimizing seed selection and harvest timing to processing plant operations.
 - *Is the sugar industry organized to foster cooperation across the supply chain for ethanol production?* Conflicts between sugar and ethanol producers, or between cane growers and distilleries, have slowed down the growth of the ethanol industry in some countries.
 - *Is there a mechanism for capturing poorly priced externalities?* In some cases, the commercial viability of ethanol will depend on charging for externalities such as urban air pollution and GHG emission reductions that are not financially accounted for.

20 There is wide experience with sugarcane cultivation around the world: close to 100 countries are growing sugarcane. However, no other country has been able to match Brazil's sugarcane cost structure. In mid-2005, sugar production costs in the three lowest-cost countries were estimated to be \$145/tonne in Brazil (at R\$2.40 = US\$1.00), \$185/tonne in Australia, and \$195/tonne in Thailand. About one-quarter of the total worldwide sugar production is at \$200–250/tonne, above which the cost jumps to \$400/tonne and higher; these high-cost sugars in turn account for about one-half of the total world sugar production (Macedo 2005). It is estimated that ethanol as an automotive fuel is economic in Australia in the long run only if world oil prices remain at 2005 levels (Biofuels Taskforce 2005). In other countries, this breakeven point will likely be higher.

21 Given these cost figures, it is likely that subsidies—indirect, direct, or both—would be needed to launch and maintain a biofuels industry in most developing countries. If sustained government support is needed, additional issues would need to be carefully considered. Historical experience shows that, once granted and the biofuel industry has been launched, subsidies are difficult to withdraw. Every country with a biofuel program has provided subsidies to the industry, and none of them has yet removed the subsidies entirely. Brazil is the only country to have achieved a commercially competitive ethanol industry, and this was preceded by more than 20 years of government support. Even today, Brazil continues to maintain a significant tax differential between gasoline and hydrous ethanol. The forgone tax revenue in the state of São Paulo (which accounts for more than one-half of the total hydrous ethanol consumption in the country) is about US\$0.6 billion in 2005, taking the tax difference of US\$0.30 per liter⁶ and assuming annual consumption of about 2 billion liters.

22 Tax exemptions, administered pricing, and restrictive trade policies have all been used to assist biofuel manufacturers. Such indirect means of support tend to be adopted and maintained more readily than direct government assistance provided as a line

⁶ See paragraph 3.56 for detail.

item in the annual budget. This is in part because it is easier to transfer public resources to private agents if an actual exchange of money is not involved. One universal instrument for supporting biofuels has been the use of tax expenditures—when the government collects less tax than from other goods with similar characteristics—which can take the form of tax exemptions, allowances, credits, deferrals, or relief. There are both equity concerns and practical difficulties for using tax exemptions to support biofuels in developing countries. Gasoline taxes are often a significant source of tax revenue in developing countries and are also progressive in that gasoline consumption is greatest among high-income groups. The provision of tax exemptions to ethanol results in a loss of tax revenue from gasoline, revenue that could have been used for other social programs. Once enacted, tax expenditures usually come under little scrutiny and are rarely repealed. While the use of tax expenditures has been a political reality in assisting biofuel industries around the world, it is preferable, from a good governance perspective, to have public support for biofuels subject to normal budgetary scrutiny so that public expenditures on biofuels are weighed against other social priorities. Diesel fuel, in contrast, is either taxed at very low levels or is subsidized in many developing countries. In these circumstances, tax exemptions cannot be used to support biodiesel and alternative means of support would need to be found.

23 Where biofuels are not commercially viable on their own, a case for government interventions must be made. This report considers several possible justifications for government interventions in biofuel manufacture: rural development, accounting for poorly priced externalities, and energy diversification. Foreign exchange savings remains a frequently cited benefit of domestic biofuel programs. However, foreign exchange benefits are much less important today as more countries maintain flexible exchange rates. If a country is pursuing a market-based approach to setting the exchange rate and the official rate reflects real economic values, then there would be no need to distinguish between local currency and foreign exchange costs or benefits of biofuel programs. In economies with under- or overvalued exchange rates, the addition of second- and third-best policy distortions (via import substitution, for example) has seldom proven a lasting solution to problems better handled through good macroeconomic management including market-oriented exchange rates.

24 *Rural development.* Certain interventions are nearly universally regarded as being beneficial to rural development: strengthening property rights, removing barriers to trade both within the domestic market and with foreign markets, investment in rural education and health, agricultural research and extension, rural water supply, the provision of electricity, and transport infrastructure. Biofuel programs need to be integrated within a broader context of investment in rural infrastructure and human capital formation. The extent to which biofuel programs can contribute to rural development is dependent on the characteristics of the industry (scale, modernity, integration) and, ultimately, whether it is able to become financially viable without direct government financial support. The successful Brazilian ethanol model is based on modern and mechanized agricultural production, with many small-scale cane producers (but still large by developing country standards), large but not monopolistic mill/distillery complexes that generate electricity for themselves and for sale to the grid, and with a nationwide ethanol supply system well

integrated with urban and industrial development. Low-income countries will need to assess whether the basic underlying conditions for a successful biofuel program exist or could be developed in the near term, including infrastructure and essential public services. If public funds are needed to support the industry, the question becomes whether government resources will be diverted from other programs, and the corresponding impact on rural incomes and growth.

25 *Unaccounted externalities.* Accounting for poorly priced externalities arising from GHG emissions is likely to deliver US\$0.01–0.03 per liter based on the current estimates of carbon prices of US\$10–15 for the foreseeable future. For air pollution from urban transport, efficient fuel taxation requires that polluting goods be taxed more, and not that less-polluting alternatives be subsidized. In order to support biofuels through differentiated taxation to reflect the cost of urban air pollution, there must be fuel taxes reflecting this externality in place initially. However, taxes are typically low on diesel in developing countries even though diesel emissions are damaging to public health. By contrast, gasoline often carries a high tax rate, but the tax difference that can be justified may not be much more than US\$0.02 per liter.⁷ These figures are much smaller than the tax exemptions currently given to ethanol, for example A\$0.38 (US\$0.28) per liter in Australia, the second lowest-cost producer of sugarcane. Marine applications of biodiesel hold promise, especially where environmental standards for marine vehicles are being tightened, but the high cost of biodiesel manufacture is likely to limit the large-scale commercial application for the foreseeable future. Biofuel production is not without environmental cost. The environmental costs of biofuel manufacture can include water and air pollution and soil depletion associated with feedstock production and biofuel processing.

26 *Energy diversification.* Promoting biofuels for energy diversification can make sense if large government subsidies are not required. The benefits of diversification can also be greatly enhanced if trade of biofuels is liberalized. What is important for energy diversification through biofuels is that there be alternative, reliable, and inexpensive sources of fuels from suppliers that are not traditional oil producers. Pursuing a policy of self-sufficiency in fuel production, regardless of the cost, will not necessarily deliver energy diversification benefits. Although increasing the number of potential fuel suppliers can help against supply disruptions, diversifying into biofuels is unlikely to mitigate oil price volatility in a liberalized trade regime. Biofuel and petroleum fuel prices will equilibrate in a free trade regime on the international market and biofuels will be price takers as long as biofuel production remains a small fraction of the total petroleum fuel production. Barriers to biofuel trade or non-market-based biofuel pricing may de-link biofuel and petroleum product prices to some extent. Restrictions on world trade are damaging, however, and government interventions in commodity pricing typically offer at best short-term solutions to price volatility and introduce new distortions to the economy.

27 Because the feedstock currently used for commercial biofuel production is agricultural crops, no discussion of biofuel programs is complete without addressing global distortions in agricultural products, especially the domestic subsidies and trade barriers in

⁷ See paragraph 3.66 for detail.

high-income countries. Agricultural commodity markets are distorted at both the national and international level, characterized by significant government support for domestic producers in a number of high-income countries, high import tariffs, quantitative restrictions on imports, export subsidies, and preferential trade agreements extended to some countries. These distortions, as well as their removal, can have potentially large effects on the biofuel industry.

28 Liberalization of agricultural trade and removal of domestic subsidies and protection, especially in industrial countries, would induce significant price increases for many agricultural commodities. Among currently used feedstocks for biofuel manufacture are sugarcane, maize, and soybeans. The world sugar market is one of the most distorted. Complete trade liberalization, which would dramatically reduce the production of sugar in a number of countries, is forecast to raise the world price of sugar by about 30–40 percent according to most estimates. This in turn would raise the cost of ethanol production until supply expansion responds to the much higher world sugar price. The impact on the price of maize would be smaller, and that on soybeans very small.

29 Removing barriers to biofuel trade would be helpful for a number of reasons. First, the most efficient biofuel producers could expand their market share beyond their borders. Second, the political pressure to maintain large implicit and explicit subsidies in favor of biofuels in any given country could lessen or even disappear if, in addition to or instead of domestic producers, imported biofuels benefited from these subsidies. Both effects would provide a stimulus to increase efficiency and close inefficient manufacturers. Growth of the most efficient biofuel manufacturers in turn would strengthen the industry and contribute to energy source diversification worldwide.

30 In assessing biofuel programs from around the world, it is important to recognize that, to a large measure, they have been driven by agribusiness and farm interests. In the United States and the European Union, the biofuel industry is closely linked to government support of domestic farmers, which costs tens of billions of dollars annually. In Australia, financial hardships faced by sugar growers are the primary driver, and the government has recently changed the biofuel support policy to make ethanol imports more expensive. The National Alcohol Program established in Brazil in the 1970s was clearly related to the sugar industry's overcapacity, in addition to energy security concerns. India's sugar surplus and growing supplies of molasses were important drivers behind its ethanol program: the sugar industry, burdened with overcapacity, lobbied the government for several years to adopt a bioethanol program.

31 In the near term, ethanol from sugarcane is likely to offer the best chance of commercial viability. Other feedstocks for producing ethanol increase the cost of production markedly and are unlikely to be financially viable without government support. Experience in Australia in 2002–2003 with ethanol-gasoline blends containing 20–30 percent ethanol suggests that it may be wise to limit the amount of anhydrous ethanol in gasoline to 10 percent or less when launching an ethanol program. Biodiesel remains expensive even against the backdrop of rising world oil prices, thus raising similar concerns over financial viability in the near term.

32 In the medium term, biofuel production costs will come down and other feedstocks may become attractive, expanding feedstock options and enabling countries not suited for growing sugarcane to enter into biofuel production. Particularly interesting over the medium term is the potential for cost reduction in biodiesel manufacture from plants not requiring much rainfall and nutrients, such as *Jatropha*. An added benefit of the cultivation of such plants could be to reclaim land and provide other environmental benefits such as carbon storage. The processing technology for producing biodiesel is presently oil extraction followed by transesterification, both well-proven processes with limited scope for significant cost reduction. For this production pathway, the greatest potential cost reduction lies in producing, harvesting, and transporting feedstock to processing plants.

33 In the long run, one of the areas with the greatest promise to become commercially viable is manufacture of ethanol from cellulose: forest products, wood wastes, crop residues, and energy crops such as switch grass. Their widespread availability, abundance, low cost, and significant lifecycle GHG emission reductions make them suitable and attractive for biofuel production. There may be breakthroughs in other alternative technologies, such as conversion of biomass to synthetic gas followed by liquid fuel production. At the same time, the world oil price as well as the price of carbon may rise appreciably, altering the comparative economics of biofuel manufacturing greatly in their favor.

1

Background

1.1 There has been growing worldwide interest in biofuels as renewable sources of energy to substitute for petroleum-derived products. Unlike crude oil, feedstocks for biofuels—plants for ethanol and biodiesel and animal fats for biodiesel—are more uniformly dispersed, being available in every country, albeit in varying quantities and at different costs. Concerns over having to rely on a limited number of countries for crude oil supply and these countries’ enormous market power also make biofuels attractive as a means of enhancing security of energy supply.

1.2 The bulk of current and future uses of biofuels target the transport sector whereby biofuels substitute for gasoline and diesel, either wholly or partially by blending into the petroleum products. Because the contribution of the transport sector to greenhouse gas (GHG) emissions will grow in the coming decades, substitution of gasoline and diesel with biofuels has the added advantage of addressing global climate change. In industrial countries, the amount of feedstocks available at reasonable prices that can be used for biofuel production using technologies that are commercially available today is relatively small compared to petroleum imports. Biofuels can thus have a limited impact on security of energy supply and on GHG emissions from the transport sector. Developing countries will similarly need to assess to what extent biofuels can diversify their own energy supplies. The situation will change if biofuels from agricultural residues, energy crops, wastes (forestry, mill, municipal), and other feedstocks become commercially viable.

1.3 Ethanol is the most commonly used biofuel to substitute for gasoline, and biodiesel to substitute for diesel. Both ethanol and biodiesel contain oxygen and lower exhaust emissions of a number of harmful pollutants. The production and use of ethanol is much more extensive than that of biodiesel at the present time, largely due to the lower cost of production of ethanol from biomass.

1.4 This report responds to increasing requests from developing countries to help assess the potential of biofuels for transport in the near to medium term. It defines biofuels as *liquid* fuels produced from biomass; it excludes treatment of solid biomass as a source of energy. With a time horizon covering the next 5 to 10 years, this report focuses on ethanol and biodiesel based on currently commercially available or near-commercial technologies and discusses their potential as alternative transportation fuels. The report does not discuss in any detail potential future technological breakthroughs and

associated cost reductions, as the timing and the magnitude of cost reduction are both uncertain. Chapter 1 gives background information. Chapter 2 reviews international experience with biofuels to date. Chapter 3 examines resource costs of biofuels, beginning with a description of the processes for fuel production, then covering feedstock costs, processing costs, co-product sales and use, and overall costs. Because of the significant role played by tax exemptions in all biofuel programs to date, the chapter also reviews fiscal measures in some detail. The chapter concludes with environmental impacts of biofuel production and other economic impacts. Chapter 4 focuses on the impact of biofuels on vehicle exhaust emissions, vehicle performance, and lifecycle GHG emissions. Chapter 5 looks at the range of considerations for developing countries in deciding whether to encourage or mandate the use of biofuels in their transport sector. They include agricultural and macroeconomic policies, social and infrastructure spending, global trade policies, retail gasoline and diesel prices, and effects of world oil prices. It also outlines a methodology for an economic analysis of domestic biofuel programs. Chapter 6 draws conclusions.

Description of Biofuels

1.5 Ethanol and biodiesel are commercially produced mostly from agricultural crops. The two most widely used crops for ethanol production are sugarcane and maize.⁸ Biodiesel is currently made mainly from rapeseed and soybeans. There is also limited use of waste grease: conversion of spent cooking oils. One of the best-known examples is “McDiesel” in Graz, Austria, nicknamed after the McDonald’s restaurants from which frying oils are collected. Agricultural crop markets greatly influence the production costs of biofuels through feedstock prices. Because crop prices and world crude prices are not correlated, biofuels can be attractive in times of low crop prices and high oil prices, but can be uncompetitive when the reverse is true.

1.6 In 2003, 13 countries used ethanol as a fuel component (Berg 2004). Brazil is the world market leader in ethanol production, followed by the United States. The largest manufacturer and consumer of biodiesel is the European Union (EU). In terms of volume, the global production of biodiesel is an order of magnitude smaller than that of ethanol, but is growing rapidly.

1.7 Biofuels are often designated by the amount of the biofuel contained in conventional petroleum products. Letters “E” and “B” are used for ethanol-containing and biodiesel-containing fuels, respectively. For example, the term E85 is used to designate a mixture of 85 percent ethanol and 15 percent gasoline. Gasohol is a gasoline blend containing at least 10 percent ethanol. Similarly, B100 represents pure biodiesel, B5 a blend containing 5 percent pure biodiesel and 95 percent petroleum diesel, and so on. This convention is not used in the case of ethanol-diesel blends, discussed below.

1.8 Although neat (that is, pure) ethanol and biodiesel have been used, the most likely applications of these biofuels are for blending into gasoline and diesel. Gasoline blends containing up to 10 percent ethanol, and diesel blends containing similar

⁸ Throughout this report, internationally accepted terminology maize is used in the place of corn, which is the term used in the United States. “Corn syrup” is therefore written as “maize syrup,” “corn gluten meal” as “maize gluten meal,” and so on.

percentages of biodiesel, will likely be biofuel use of choice for the foreseeable future. For this reason, this report pays special attention to blends with low biofuel contents.

1.9 The lower heating values⁹ of various fuels are 36 mega-joules (MJ) per liter for diesel, 34 for kerosene, 32 for gasoline, 21 for anhydrous ethanol, 20 for hydrous ethanol, and 33–36 for biodiesel. When prices are quoted on a unit volume basis, it is important to bear in mind that, owing to differences in the energy content and the resulting fuel economy, a liter of petroleum fuel is not necessarily equivalent to a liter of biofuel. More than a liter of biofuel is typically needed to travel the same distance as that corresponding to a liter of petroleum fuel. The impact on fuel consumption of using biofuels is discussed in more detail in chapter 4.

Ethanol

1.10 Ethanol is manufactured from microbial conversion of biomass materials through fermentation. Ethanol contains 35 percent oxygen. The production process consists of conversion of biomass to fermentable sugars, fermentation of sugars to ethanol, and the separation and purification of the ethanol. Fermentation initially produces ethanol containing a substantial amount of water. Distillation removes the majority of water to yield about 95 percent purity ethanol, the balance being water. This mixture is called hydrous ethanol. If the remaining water is removed in a further process, the ethanol is called anhydrous ethanol and is suitable for blending into gasoline. Ethanol is “denatured” prior to leaving the plant to make it unfit for human consumption by addition of a small amount of products such as gasoline.

1.11 Traditional fermentation processes rely on yeasts that convert six-carbon sugars, such as glucose, to ethanol. Sugar feedstocks that contain six-carbon sugars are therefore the easiest to convert to ethanol. According to a 2003 survey, about 61 percent of world ethanol production is from sugar crops: sugar beet, sugarcane, or molasses. Brazil’s fuel ethanol program is based on sugarcane, which is the lowest-cost path. Sugar beet is used in Europe, although this makes the feedstock cost several times higher than the sugarcane in the Center-South region of Brazil (Berg 2004). Other feedstocks rich in sugars such as sweet sorghum and various fruits are typically too expensive to use for fuel ethanol production.

1.12 Starch consists of long chains of glucose molecules and is an alternative feedstock option. Starchy feedstocks include maize, wheat, potato, sweet potato, and cassava. They require hydrolysis, a reaction of starch with water, to break down the starch into fermentable sugars in a process called saccharification and this adds to the cost of ethanol production.

1.13 Feedstock costs are a major component to overall biofuel production costs. In Brazil, feedstock accounts for as much as two-thirds of the total cost of ethanol production. Both sugar and starchy materials are consumed as human food and are thus potentially more expensive than a third alternative: cellulosic materials. Cellulosic

⁹ Heating values can be expressed as higher (which include the heat of condensation of water vapor to liquid water) and lower (which excludes the heat of condensation of water vapor) heating values. Because the heat of condensation of water vapor is not used to drive vehicles, the lower heating values are quoted.

materials, such as wood and fibrous plants, can be the cheapest feedstock option on account of being abundant and outside the human food chain. The technologies available today for breaking down cellulosic materials into sugar, however, are still expensive, and the cost of harvesting and transporting cellulosic feedstocks to ethanol plants can also be high.

1.14 Agricultural crops are collected and sent to ethanol production facilities. The co-products include bagasse (the residual woody fiber of the cane obtained from crushing cane), which can be used for heat and power generation in the case of sugarcane; distiller's dried grains sold as an animal feed supplement from maize in dry mill processing plants; and high-fructose maize syrup, dextrose, glucose syrup, vitamins, food and feed additives, maize gluten meal, maize gluten feed, maize germ meal, and maize oil in wet mill processing plants. In all cases, commercial carbon dioxide (CO₂) can be captured for sale, but the process is costly and therefore not widespread at present.

Biodiesel

1.15 Biodiesel fuels are oxygenated organic compounds—methyl or ethyl esters—derived from a variety of renewable sources such as vegetable oil, animal fat, and cooking oil. The oxygen contained in biodiesel makes it unstable and requires stabilization to avoid storage problems. Rapeseed methyl ester (RME) diesel, derived from rapeseed oil, is the most common biodiesel fuel available in Europe. In the United States, biodiesel from soybean oil, called soy methyl ester diesel, is the most common biodiesel. Collectively, these fuels are referred to as fatty acid methyl esters (FAME).

1.16 Biodiesel fuels are produced by first crushing seeds to extract oils followed by a catalytic process called transesterification in which oils (triglycerides) are reacted with an alcohol (methanol or ethanol) into alkyl esters. Methanol derived from a fossil fuel is the alcohol used, but Brazil is experimenting with sugarcane-derived ethanol, making the feedstocks entirely renewable. It should be noted that, because biodiesel marketed today is made with methanol, all the emissions and health tests as well as fuel specifications have been for methyl, not ethyl, esters. Glycerine (also called glycerol) and water are by-products of the reaction and need to be removed along with traces of the alcohol, unreacted triglycerides and catalyst. Co-products that can be sold include animal feed and glycerine. Glycerine is used in pharmaceuticals, cosmetics, toothpaste, paints, and other commercial products. Aside from oxidation stability concerns, biodiesel does not require special handling.

Uses

1.17 The most prevalent use of biofuels is as transportation fuels. Ethanol is used primarily in spark-ignition engine vehicles. The amount of ethanol ranges from 100 percent to 5 percent or lower, blended with gasoline. The ethanol added to gasoline needs to be free of water, or else a phase separation can occur between gasoline and water-ethanol. This is the reason anhydrous ethanol is used in a gasoline-ethanol blend. Anhydrous ethanol is transported separately to terminals to minimize contact with water and typically blended into gasoline just before loading into trucks by splash blending, a process that requires no special equipment or temperature control. In Brazil all gasoline contained 25 percent

ethanol in 2005. Elsewhere, gasoline containing 5 to 10 percent ethanol is the most common blend. Gasoline containing 85 percent ethanol is also used but to a much lesser extent.

1.18 Hydrous ethanol is used neat, that is, without addition of gasoline, in vehicles designed specifically for use with ethanol. Because hydrous ethanol does not require purifying ethanol completely to remove the residual water, it is cheaper to manufacture than anhydrous ethanol. Brazil has the largest market for vehicles running on hydrous ethanol. Aside from vehicles manufactured to run on hydrous ethanol, flex-fuel vehicles in Brazil run on any mixture of a gasoline-ethanol blend and hydrous ethanol.¹⁰

1.19 Another application of ethanol is as a feedstock to make ethers, most commonly ethyl tertiary-butyl ether (ETBE), an oxygenate with high blending octane used in gasoline. ETBE contains 44 percent ethanol. Ethanol from sugar beet in France is used primarily in the form of ETBE in gasoline.

1.20 Ethanol can also be blended into diesel. The blends are referred to as “e-diesel.” E-diesel contains up to 15 percent ethanol by volume and an emulsifier, and is a micro-emulsion. As with gasoline-ethanol blends, e-diesel is prepared by splash blending.

1.21 Biodiesel is used either neat (100 percent purity) or blended with diesel, typically ranging in quantity from 2 to 20 percent. Diesel containing up to 5 percent biodiesel is gaining popularity, and is accepted by auto manufacturers.

A Brief Summary of Current Advantages and Disadvantages

1.22 Advantages and disadvantages of biofuels relative to liquid or gaseous fuels from fossil fuels can be categorized broadly into the following areas: physical properties of the fuels, performance in vehicles including tailpipe emissions of pollutants harmful to public health, lifecycle¹¹ GHG emissions, production costs, and economy-wide impacts of biofuel production. Production costs are discussed in detail in chapter 3. Performance in vehicles and lifecycle GHG emissions are treated in chapter 4. Three often-cited economy-wide benefits of biofuel production are job creation in rural areas, foreign exchange savings, and enhancing security of energy supply. This section gives a brief summary.

1.23 As liquid fuels, biofuels require relatively little modification to storage, distribution, and refueling infrastructure. This offers a significant advantage over other alternative fuels such as compressed natural gas (CNG), liquefied petroleum gas (LPG), electricity, and hydrogen. Because of ethanol’s miscibility with water, ethanol handling

¹⁰ In other countries, flex-fuel vehicles run on any mixture of gasoline and E85 or some other gasoline/anhydrous ethanol mixture.

¹¹ GHG emissions need to be analyzed on a lifecycle basis. In the case of petroleum products, the so-called well-to-wheel analysis calculates total GHG emissions from an oil well during oil exploration and production, transportation to a refinery, refining process, storage, distribution, retailing, fueling a vehicle, and finally evaporative and tailpipe emissions from the vehicle. In the case of biofuels, field-to-wheel lifecycle GHG emissions include consideration of the carbon storage of different land-use types; emissions from energy generation needed for irrigation; use of fertilizers and insecticides; planting and harvesting of crops; transportation to a biofuel plant; processing at the plant; transportation, storage, distribution, retailing, and fueling a vehicle; and evaporative and tailpipe emissions.

requires more care, but the extra steps are minor compared to the large changes required for handling gaseous fuels. Equally important, the vehicle modifications needed to operate on biofuels are also minimal, if any. Existing vehicles fueled by gasoline or diesel can run on E10 or B5 with essentially no modification.

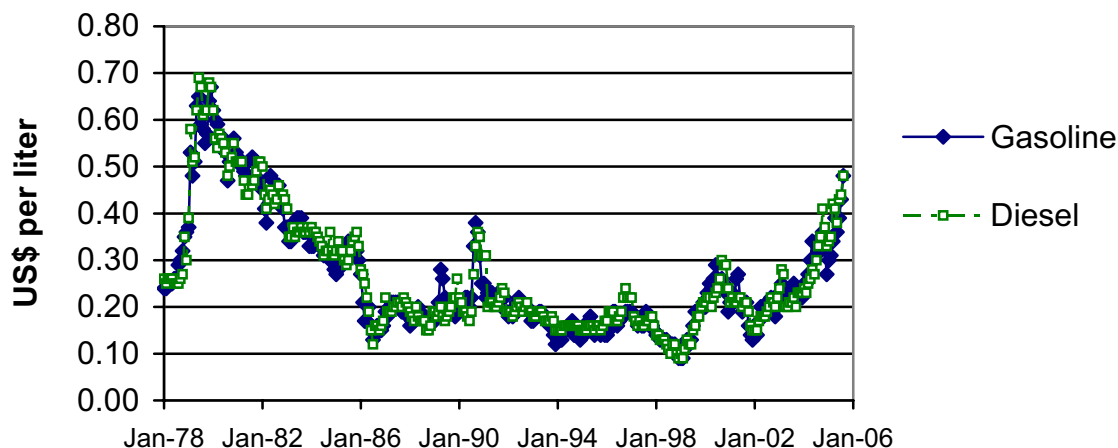
1.24 Both ethanol and biodiesel have less energy content than petroleum fuels on a unit volume basis. Ethanol has about one-third less energy than gasoline, and biodiesel up to 10 percent less. The distance that can be traveled per unit volume of fuel depends on a number of factors, not just on the fuel's energy content, and is not directly proportional to it, but the lower energy content can result in lower fuel economy (shorter distance traveled per liter). Because of ethanol's high octane rating, dedicated ethanol-fueled vehicles can run on engines with a higher compression ratio,¹² partially offsetting the lower energy content.

1.25 A potentially significant advantage of biofuels is a reduction in lifecycle GHG emissions in the transport sector. Worldwide, the contribution of the transport sector to GHG emissions grows unabated, constituting more than one-fifth of total GHG emissions (OECD 2001). In theory, biofuels enable large GHG emissions savings, especially if the conversion of cellulosic materials to ethanol can be carried out on a commercial scale. Ethanol from sugarcane in Brazil already provides large GHG emissions savings. Future progress in reducing the cost of production and expanding the feedstock base may enable significant expansion of the use in the transport sector of biofuels with low lifecycle GHG emissions.

1.26 The greatest barrier to large-scale commercialization of biofuels is their relatively high cost of production. Because they are used primarily to replace gasoline or diesel, world petroleum product prices drive commercial viability of biofuels to a large extent. Net-of-tax historical gasoline and diesel prices, expressed in second quarter 2005 US dollars, are shown in Figure 1.2. During the period examined, prices ranged from a low of 9 US cents per liter to a high of 68 US cents per liter, averaging 26 US cents per liter (all in second quarter 2005 US dollars). Because of the generally lower fuel economy of biofuels on a volume basis, biofuel prices on a per liter basis would have to be lower than petroleum fuel prices to deliver the same number of kilometers driven as the gasoline and diesel that the biofuels have displaced. As discussed in paragraph 3.18, the international prices of plant-based oils, from which biodiesel is made, can be as high as 45–55 US cents per liter, almost twice the historical average price of diesel. To date, the only biofuel that could be competitive with petroleum fuels without financial support over a wide range of oil prices is ethanol from sugarcane grown in the Center-South region of Brazil.

¹² The higher the compression ratio of the engine, the higher the engine efficiency.

**Figure 1.2 Historical Prices of Gasoline and Diesel
(real prices in 2nd quarter 2005 US\$)**



Notes: Regular unleaded gasoline and diesel with 0.2 percent sulfur, Northwest Europe monthly spot prices, barges, free on board.

Source: Energy Intelligence 2005, US gross domestic product deflator from the IMF's *International Financial Statistics Online*

1.27 Import substitution by means of displacing imported crude oil or refined oil products with domestically produced biofuels, thereby saving foreign exchange, is cited as an important benefit. The countries promoting biofuel development run the gamut from major exporters with undervalued currencies and large trade surpluses to countries with overvalued currencies struggling to meet their foreign exchange needs for basic imports (Frankel 2004). The latter tend to be the main focus of the import substitution argument, while the former tend to promote biofuel development in pursuit of employment or other objectives. The economic analysis of biofuel programs (chapter 5) deals with both categories by adjusting for the degree of under- or over-evaluation in comparing traded with non-traded goods in the accounts.¹³ These currency adjustments can have both positive (biofuels' main competitors, gasoline and diesel, will be more expensive, if the local currency is overvalued) and negative (imported machinery for fuel production will also be more expensive after adjusting for overvaluation) effects on the domestic biofuels industry.

1.28 Job creation in rural areas, where the poor tend to be concentrated, is also cited as an attractive benefit of biofuel production. This becomes a policy issue when government subsidies (implicit or explicit) or other support measures are required for

¹³ Facing comparable issues in the industrial sector during the 1950s and 1960s, Little and Mirrlees introduced the "trade policy approach to cost-benefit analysis" in 1968 (and revised in 1974, see Little and Mirrlees 1974). Their approach was incorporated into World Bank practice via Squire and van der Tak (1975/1992). Around the same time, the major bilateral and multilateral development agencies adopted similar methods. Ensuing applications provide today's biofuel programs with a rich base of experience for analyzing first-best and second-best policy options (chapter 3) raised by import substitution and related policies.

biofuel production. From the point of view of government policy formulation, job creation can be part of a policy package to reduce gross income inequality and alleviate poverty. A relevant question is whether the government policy interventions, including subsidies, in biofuel programs are contributing to job creation or poverty alleviation and how cost-effective these expenditures are compared to other government intervention measures, such as investments in infrastructure, regulatory reform to promote new businesses and investments, and targeted anti-poverty measures. Another relevant question is whether the subsidy is an investment in an economically sustainable job, or whether the job will require the subsidy for a very long time. The answers to these questions are closely tied to the economic competitiveness of the biofuel products.

1.29 Enhancing security of supply is a universal concern, especially given the highly concentrated market power of oil producers. An important question here is the extent to which biofuels can physically displace petroleum products. In Brazil, ethanol has displaced a significant portion of gasoline, more than 50 percent in the latter half of the 1980s. The ability of other countries to substitute petroleum products through domestic biofuel production will be determined by the availability of suitable land for feedstock production—such as the amount of land with adequate fertility and rainfall, and also the necessary infrastructure to access the land—and, in the case where biofuels are not financially viable compared to petroleum products, whether the government considers it worthwhile to provide adequate subsidies. World feedstock supply and commercial viability of fuels from cellulosic materials are important for a significant increase in security of supply.

1.30 In addition to these features that are common to both ethanol and biodiesel, the advantages and disadvantages of different biofuels are discussed below.

Ethanol

1.31 Ethanol is a good enhancer of fuel octane in a blend with gasoline. Ethanol has a blending research octane number (RON) of about 112–120 and a blending motor octane number (MON) of 95–106. (Blending octane numbers depend on the properties of the base gasoline.) Some countries have used ethanol as an octane booster in phasing out lead—a toxic octane enhancer traditionally used in gasoline until health concerns prompted its ban in a growing number of countries around the world—from gasoline.

1.32 Ethanol contains no sulfur, benzene, other aromatics, or olefins. All these components can worsen air quality and adversely affect public health. The addition of ethanol to gasoline has a positive volume dilution effect: these potentially harmful gasoline components are diluted.

1.33 The use of ethanol in the United States in the 1990s was motivated in part by the fact that the presence of oxygen in gasoline-fueled cars can reduce hydrocarbon and carbon monoxide (CO) emissions, an important consideration especially in winter when these emissions were higher. This generally holds for old-technology vehicles with no oxygen sensors. The hydrocarbon and CO benefits when used in modern gasoline vehicles are much smaller, if any.

1.34 Pure ethanol has low volatility, but when ethanol is blended into gasoline, it increases the volatility of the resulting blend markedly. The volatility increase is the highest at an ethanol content in the vicinity of 5 percent. The increase in volatility from ethanol addition declines slowly with increasing ethanol content. This is one shortcoming of low-level ethanol blends, especially in regions where evaporative emissions of gasoline are undesirable (for example, where ambient ozone is a problem).

1.35 Ethanol is not transported by a nondedicated pipeline because trace water in a pipeline will contaminate the ethanol and require expensive separation of water from ethanol. The need to avoid contamination with water is one reason ethanol is blended into gasoline at terminals by splash blending prior to loading trucks going to filling stations. This makes long-distance transport of ethanol, such as from the maize-growing U.S. Midwest to California, very expensive, since pipelines, which offer the cheapest mode of shipping fuels long-distance, cannot be used and ethanol is instead trucked. There is no pipeline transport of ethanol in the United States. In Brazil, three pipelines owned by Petrobras are used to transport ethanol (Banco Pactual 2002).

1.36 E-diesel can significantly lower diesel particulate emissions. The main barriers to commercializing e-diesel include its low flashpoint and concerns expressed by engine manufacturers about safety, liability, and materials and component compatibility. Engine manufacturers as a result will not currently warrantee their engines for use with e-diesel. These issues are discussed in more detail in chapter 4.

Biodiesel

1.37 Biodiesel typically has high cetane (an empirical measure of a diesel fuel's ignition quality that indicates the readiness of the fuel to ignite spontaneously) and essentially no sulfur. The addition of biodiesel to conventional diesel can lower particulate, CO, and hydrocarbon emissions. Biodiesel fuels are biodegradable, making them especially suitable for marine or farm applications. Biodiesel has better lubricity than petroleum diesel, making it suitable for blending into low and ultralow sulfur diesel, which lack lubricity. The higher viscosity range of biodiesel helps to reduce barrel/plunger leakage and increase injector efficiency in engines.

1.38 Biodiesel seems to increase exhaust emissions of oxides of nitrogen (NO_x). Biodiesel fuels have shown poor oxidation stability. When they are used at low ambient temperatures, filters may plug, and the fuel in the tank may thicken to the point where it will not flow sufficiently for proper engine operation. Biodiesel is an excellent medium for microbial growth. Because water accelerates microbial growth and is more prevalent in biodiesel than in petroleum diesel, care must be taken to remove water from fuel tanks.

Future Potential

1.39 The greatest long-term future potential for large-scale application of biofuels appears to be in the manufacture of ethanol from cellulosic materials on account of their widespread availability, abundance, low feedstock cost, and significant lifecycle GHG emission reductions that can be attained. Examples of cellulosic feedstock include forest products, wood wastes, crop residues such as maize stover (stalks, leaves, and husks left in the fields after harvesting maize), and energy crops such as switch grass.

The most promising pathway lies in enzymatic hydrolysis of cellulosic feedstock (which converts cellulose and hemicellulose into sugars), an area in which advances have been made in recent years.

1.40 The feedstock cost can be a significant component of the overall production cost. One way of lowering the feedstock cost is to identify feedstocks that have no attractive alternative uses. One low-cost scenario could be one in which the feedstock grows on land on which no other biomass would grow. In developing countries, biomass is valued for its use as timber, fodder, or fuel, and hence it is unlikely that the biomass would have no alternative value. The cost of producing and transporting biomass, even without alternative values—especially if the biomass is grown on marginal land—can also be significant and would need to be taken into account

1.41 The production of biodiesel from non-food crops, such as *Jatropha*, growing on low-grade land without fertilizers, pesticides, and irrigation also holds promise. Biodiesel can use waste vegetable oil, but alternative uses (edible and inedible tallow and lard) compete with its use as biodiesel, making large-scale conversion of waste vegetable oil to biodiesel relatively expensive.

1.42 Another application of biofuel is small-scale production and use of unmodified plant oil (so-called straight vegetable oil) rather than biodiesel in rural areas. This would avoid reacting the oil with methanol. These unmodified plant oils can be blended into diesel or used alone. This report does not cover unmodified plant oils in any detail because their use as a diesel replacement or extender has so far been limited. These oils are touched upon briefly in chapter 5.

2

International Experience

2.1 Ethanol is widely used in Brazil as a transportation fuel, and the United States, the world's second largest consumer of fuel ethanol, passed legislation in 2005 to expand the use of renewable fuels, such as ethanol and diesel, to a minimum of 4 billion gallons (15 billion liters) by 2006 and 7.5 billion gallons (28 billion liters) by 2012. Brazil and the United States account for 80 percent of world ethanol demand. The European Union (EU) is pursuing large-scale expansion of biofuel use in the transport sector. This policy will also affect the EU accession countries. Australia, China, Colombia, India, and Thailand are all embarking on national biofuel programs to varying degrees.

2.2 This chapter reviews international experience to date. Countries with significant consumption of biofuels are treated in detail first: ethanol programs in Brazil and the United States, and biodiesel in the European Union. This is followed by a brief description of countries where governments have announced strong commitments to biofuel programs in the coming years. Several countries in Africa manufacture fuel ethanol from biomass, but their cases are less well documented and are not discussed in this report.

Brazil

2.3 Brazil is the world's largest producer and exporter of sugar, and is also the largest producer and consumer of fuel ethanol from sugarcane as a transportation fuel. Between 1975 and 2004, the ethanol program in Brazil substituted about 230 billion liters of gasoline (Nastari 2005a). The Center-South region of Brazil is the lowest-cost sugarcane-producing area in the world. This region accounts for 85 percent of Brazil's sugarcane and ethanol production (Macedo 2005). The state of São Paulo is the largest and the lowest-cost ethanol producer in the country. One-half of the sugarcane output in Brazil has been made into ethanol in recent years. In the 2004–2005 season, Brazil produced one-quarter of the total world sugarcane output. About 5.4 million hectares are used for sugarcane production, and Brazil produced close to 12.5 billion liters of anhydrous and hydrous ethanol in 2004. As of December 2004, there were 320 Brazilian plants processing sugarcane (Nastari 2005a).

2.4 The bioethanol industry in Brazil is an undisputed world leader. Ethanol from sugarcane in Brazil is arguably the first renewable fuel to be cost-competitive with a petroleum fuel for transport. This achievement builds upon 70 years of history. Blending of 5 percent anhydrous ethanol in gasoline was first authorized in 1931, and mandated in 1938.

The percentage of ethanol blended into gasoline was increased to 22 percent in 1993, and adjusted on several occasions subsequently. Since the National Alcohol Program, Proálcool, was launched in 1975, the ethanol industry has addressed and overcome a number of challenges and difficulties. Today, the domestic content of equipment for sugar and ethanol production and combined heat and power generation is nearly 100 percent. Many advances have been made in agrosience to control pest, disease, and weed infestations. Effluents and wastes, previously sources of serious environmental contamination, are now recycled to a considerable extent for ferti-irritation, aiding to minimize environmental damage.

2.5 As of December 2004, there were 303 plants producing ethanol, 100 in the North-Northeast and 203 in the Center-South. Of the 303 plants, 82 were autonomous distilleries producing only ethanol, and 221 were sugar mill/distillery complexes, which take advantage of the synergy between sugar and ethanol. Mill/distillery complexes are capable of shifting the production mix from 60/40 to 40/60 sugar/ethanol (Nastari 2005a). This enables the producer to extract the maximal value from cane, while improving the quality of sugar. This is because sucrose from sugarcane typically yields 17 percent molasses and 83 percent sugar. Molasses earns only about 10 to 35 percent of the price of sugar. Converting molasses to ethanol, the price of which tends to be close to parity with that of sugar, enables the producer to earn the sugar-equivalent price for molasses. This reduces the disincentive to extract molasses from sugar, thereby improving sugar quality. The flexibility to shift production also enables a price-hedging strategy whereby the producer can make more of the product commanding a higher market price.

2.6 Having bagasse as a by-product is one significant advantage of sugarcane-based ethanol production: bagasse can be used as a fuel for combined heat and power generation. Use of bagasse for this purpose, as well as the efficiency of the generation process, increased when commercial sale of surplus electricity to the power grid became possible in 1997. Today, mills and distilleries are nearly entirely self-sufficient in energy supply and a few sell surplus electricity.

2.7 Sugarcane accounts for 58 to 65 percent of the total cost of ethanol production (Nastari 2005a). This makes efficient and low-cost production of sugarcane essential. Considerable efforts have been devoted to fighting diseases and pests. Protection against crop diseases is achieved primarily through use of cane varieties genetically resistant to the main crop diseases, an approach that has been found to be the only economically viable disease control option. There are more than 500 commercial varieties of cane, of which 20 varieties are used in 80 percent of the cane area. Diversification of varieties is an essential component of the pest and disease control strategy. Resistance to disease control or occurrence of new diseases is one of the main factors for replacing a commercial variety. Highly damaging epidemics have been controlled by fast replacement of varieties. Pesticides and biological control methods (such as releasing parasitoids for sugarcane beetles and a certain fungus for spittlebugs) are employed to combat pests. Weeds are controlled by combined use of mechanical, cultural (crop rotation, crop plant spacing variation, use of green covers), and chemical (use of herbicides) methods. These and other aspects of the sugar and ethanol industry are discussed further in annex 2.

2.8 Growing sugarcane is water-intensive. High yields require a suitable humidity level to be maintained throughout the growing period. In the state of São Paulo, which has more than one-half of the total land area for sugarcane cultivation in the country, virtually all cane is rain-fed and does not use irrigation. Productivity can be increased further through irrigation, but cost-benefit analysis suggests that irrigation in São Paulo is not cost-effective at this point in time. Not using irrigation has a number of environmental benefits. It does not deplete water resources, and at the same time substantially reduces soil loss and leaching out of nutrients and agrochemical residues.

2.9 In the past, direct discharge of vinasse (the residue liquid from the distillation of ethanol, rich in potassium and organic matter) to water streams was a cause of significant environmental damage. For each liter of ethanol, 10 to 15 liters of vinasse are produced. Vinasse began to be recycled to the cane fields in 1978 when the first legislation governing the disposal of vinasse was passed. The current practice is full recycling of vinasse and industrial wastewaters for ferti-irrigation. The application of vinasse is optimized for specific topographic, soil, and environmental conditions. Filtercake, another waste stream, is also recycled as a fertilizer. Nutrient recycling in turn has reduced application of fertilizers.

2.10 There are large regional differences in Brazil. The Center-South region exhibits high productivity and low cost. The North-Northeast region, in contrast, is characterized by low yields and much higher overall costs. More labor is used, sometimes as much as three times more labor, in the North-Northeast region. The wages are correspondingly much lower, as discussed later. In the past decade, the area harvested has been increasing in the Center-South region and falling in the North-Northeast region.

2.11 Cassava is another feedstock for ethanol production. Unlike sugar, which requires much water and fertile soil, cassava grows under a variety of soil and climatic conditions. Cassava tends to be grown in small farms using labor-intensive methods, but can be readily mechanized for commercial large-scale production. Because it has a less clearly defined harvest period, it creates a reasonably constant demand for labor throughout the year. In Brazil, cassava has been grown historically as a subsistence crop on small plots of marginal lands by resource-poor farmers (Saint 1982). It is more complicated and expensive to process than sugar, because the starch from cassava must first be turned into sugar before fermentation.

2.12 Efforts at cassava-based ethanol production have not fared well in Brazil. Cassava does not have the equivalent of bagasse that can be used for power generation. Without such a by-product, an external energy source had to be used. In the only cassava-based ethanol project, the fuel used for power generation was wood. Having to rely on an external source of energy increased the cost of energy relative to ethanol manufacture from sugarcane. Developing large-scale farming of cassava proved to be difficult because the pests and diseases plagued the crop. Cassava is usually harvested manually, making it very labor-intensive and time-consuming. For all these reasons, a cassava-based ethanol industry has not developed, and there is no commercial production using cassava today (Nastari 2005a).

2.13 Because Brazil was the first country to embark on bioethanol production on a large scale, it was also the first country to face—and address—a number of challenges. The historical evolution of the sugarcane and ethanol industry in Brazil offers many valuable lessons for other countries considering ethanol production, and it is worth reviewing their history for this reason. The implications of these lessons are discussed further in chapter 5.

2.14 The first oil crisis of 1973–1974, which quadrupled the price of crude oil, prompted Proálcool to be established by Decree 76593 of November 14, 1975. At the time Brazil was importing four-fifths of its oil. The objective of Proálcool was to use ethanol as a fuel substitute for gasoline and to increase ethanol production for industrial use. The guidelines for Proálcool were defined by a number of instruments enacted by the Instituto do Açúcar e do Alcool (IAA, Institute of Sugar and Alcohol), a government agency that was part of the Ministry of Industrial Development and Commerce.

2.15 In the 1970s, an estimated 200–250 plantation families controlled two-thirds of cane production and all of the processing. By 1979, 104 ethanol distilleries were in operation. This rapid expansion was a direct result of extremely attractive incentives in the form of credits provided for distillery construction, effectively offering a government subsidy of as much as 75 percent for these projects, to the point where overcapacity became a concern. The principal beneficiaries of the credit programs were the large producers. There was also rapid expansion of cane areas. For example, total areas under cane cultivation in São Paulo increased by 31 percent between 1978 and 1979. Much of this increase occurred as a result of larger plantations buying up surrounding land belonging to small farmers who were primarily food producers. Existing incentives for food production were not competitive with those of Proálcool, and many chose to sell out and move. According to reports, some farmers were forced off their land by legal or economic pressure, or by direct physical intimidation (Saint 1982).

2.16 With the second oil crisis of 1979, the government expanded Proálcool to promote the use of hydrous ethanol as an automotive fuel. The government gave tax incentives for the purchase of cars fueled by hydrous ethanol and subsidized ethanol prices. One fiscal goal set was to ensure that the retail price of hydrous ethanol was at most 65 percent of the retail price of gasoline, making ethanol cheaper than gasoline even after accounting for hydrous ethanol's lower fuel economy. Despite serious fiscal problems that arose in the 1980s, the price difference was not reduced from 35 percent to 25 percent until January 1989 (Szmrecsányi and Moreira 1992).

2.17 During the first 10 years of Proálcool, ethanol production increased at an annual rate of 35 percent (Szmrecsányi and Moreira 1992). Between 1983 and 1988, cars fueled by hydrous ethanol were more than 90 percent of total auto sales. The highest penetration of ethanol in the fuel market for spark-ignition engines occurred in 1988 when ethanol made up 57 percent of the total fuel consumed (Nastari 2001). By 1990, more than 5 million ethanol-fueled vehicles were in circulation, and represented an estimated 50 percent of the fleet (de Hollanda and Poole 2001). The amount of sugarcane harvested area doubled between 1975 and the mid-1980s (Bolling and Suarez 2001). In fact, enough cane was planted to supply virtually the whole world sugar market had all cane be refined into sugar (Hannah 2000).

2.18 In launching Proálcool, the government made ethanol-fueled vehicles mandatory in its official fleet. The government also set the price of ethanol at a fixed percentage of regular gasoline so that switching to ethanol resulted in fuel cost savings. In the beginning, existing gasoline engines were retrofitted to run on ethanol. The engine compression ratio was increased to take advantage of ethanol's high octane. Conversion involved addressing technical problems encountered initially, such as corrosion of car components caused by water in ethanol and difficulties in warming up the engine on cold days (de Hollanda and Poole 2001).

2.19 Aside from fiscal implications, Proálcool was not without other problems, especially during the first decade. Concerns with the negative consequences of the program included the exacerbation of historical labor problems, water contamination by vinasse, air pollution from the burning of field residues, and competition with other food and agricultural products. The volume of vinasse produced in Brazil in 1979 was approximately the same as the amount of sewage waste generated by 145 million people, more than Brazil's total population at the time (Saint 1982). In the mountainous areas of northeastern Brazil, the pumping cost and the cost of land to store vinasse were prohibitive, and it was therefore released into rivers, resulting in enormous fish kills at every harvest. Before cane was cut, the fields were set on fire to eliminate the voluminous amount of biomass. When this was done, huge clouds of black smoke blanketed the areas. With respect to labor problems, the land tenure law in Brazil was weak, giving little protection to smallholder farmers. Smallholder farmers and landlords frequently clashed over land rights and landlords often recruited the help of the police, resulting in human rights violations as alluded to earlier. In this context, Proálcool in the 1970s and 1980s, which made sugarcane production attractive on account of large government subsidies, exacerbated the land tenure conflict. Some landlords took their land in hand or made false demarcation claims in order to plant sugarcane. Resistance by smallholder farmers sometimes took the form of trespassing and pulling down the sugarcane.

2.20 In 1988, the world sugar price rose considerably, and, at the same time, the government freed the sugar export market. As a result, sugarcane growers diverted crops to the export market, and a severe shortage of ethanol occurred in the second quarter of 1989. This shortage resulted in a loss of consumer confidence in the security of ethanol supply and discredited Proálcool. In response, the government authorized ethanol imports, and Brazil became the world's largest importer of ethanol. Between 1989 and 1996, Brazil imported on average 0.6 billion liters of ethanol annually (AFTA 2000).

2.21 The government originally intended the incentives and subsidies offered in Proálcool to be temporary. However, the collapse of the international oil price in 1986 required continuing financial support for the continuation of Proálcool. This imposed a considerable fiscal drain on successive governments, but the withdrawal of subsidies to help ease the burden on the treasury would have had a significant impact on the industry, so incentives and subsidies were extended. As oil prices fell in the late 1980s, the government reduced the subsidies, resulting in declining production of alcohol. By the end of the 1990s, the sales of ethanol-fueled cars amounted to less than 1 percent of total annual auto sales because fuel manufacturers could not assure hydrous-ethanol consumers security of supply. In 1997, the government again made the use of ethanol

vehicles mandatory in the federal government and in vehicles sold with tax exemptions, mainly taxis.

2.22 In addition to price guarantees and price subsidies, public loans and state-guaranteed private bank loans were provided to processors and growers. However, loan repayments became a problem. By 1986, the government was sufficiently concerned about the arrears in loan repayments that it established an interdepartmental commission to investigate the status of repayment and to propose refinancing measures. Agreements on debt rescheduling were reached in 1987 and 1988. In 1989, the debt was estimated at US\$1.5 billion (1999 U.S. dollars). A second interdepartmental commission, set up in February 1991, found the debt to stand at US\$2.8 billion (1999 U.S. dollars) and rescheduled the debt repayment again. In 1997, the total debt to Banco do Brasil alone amounted to US\$2.5 billion. One calculation estimates that the average subsidy due to unpaid debt in 1999–2000 was US\$0.049 per liter (AFTA 2000).

2.23 The sale of hydrous ethanol declined from a peak of 11 million cubic meters (m³) in 1989 to 5.1 million m³ in 2000, and continued to decline until 2004. Low oil prices and the government's policy to maintain a strong Real made ethanol uncompetitive with respect to gasoline. During the 1990s, sugar price controls were eliminated and the government's setting of producer prices for sugarcane was abandoned in 1999. IAA was officially abolished in March 1990. Anhydrous ethanol was deregulated in May 1997. Hydrous ethanol producers won a reprieve and continued to enjoy a guaranteed price of US\$0.37 per liter. This led to overproduction relative to demand, which was falling. Gasoline prices were liberalized in 1998. Price liberalization for hydrous ethanol was postponed twice and was finally effected in February 1999. Ex-distillery prices fell from US\$0.15 per liter in February to US\$0.08 per liter by mid-May. To combat falling prices, 181 alcohol producers formed a cartel in May 1999 that would sell all of their outputs under an exclusivity agreement for the next three years in order to control supply. The firms dominated 85 percent of the national production of ethanol (Correa 2001). Following this agreement, the price of anhydrous ethanol doubled in eight months and that of hydrous ethanol nearly tripled compared to a 50 percent increase in the prices of petroleum products during the same period (AFTA 2000). The cartel was investigated by the Brazilian antitrust authority and the investigators recommended that the exclusivity agreement not be accepted.

2.24 The export sugar market has a strong impact on ethanol supply, leading to ethanol shortages in times of high world sugar prices. As recently as January 2001, Brazil imported ethanol, in this specific instance from the United States (Automotive Environment Analyst 2001). The concern over diversion of sugarcane to the sugar export market at the expense of ethanol production prompted a government proposal in mid-2002 to impose a tax on sugar exports whenever ethanol stocks appeared insufficient to meet demand. To avoid such an export tax, producers agreed to produce an additional 1.5 billion liters of ethanol in 2003–2004 and not to exceed a maximum selling price to alcohol distributors. There has not been a supply shortage in recent years. Brazil exported 2.4 billion liters in 2004, rising from 610 million liters in 2003 and 780 million liters in 2002. Top destinations for Brazilian ethanol in 2004 were the United States, India,

Republic of Korea, Japan, Sweden, and the Netherlands (Foley 2003, Dow Jones Energy Service 2004, RFA 2005a, OsterDowJones Commodity Wire 2005).

2.25 At the heart of the fuel ethanol program in Brazil is mandatory blending of ethanol with gasoline. The actual percentage is determined by an interministerial committee made up of representatives of the Ministry of Agriculture, Ministry of Finance, Ministry of Mines and Energy, and Ministry of Industrial Development and Commerce. The blending rate has varied between 20 and 26 percent in recent years. The blending ratio tends to be increased when ethanol prices are low and decreased when ethanol prices are high. The government also bans the use of diesel-powered cars (retail prices of diesel are markedly lower than those of E25, making diesel otherwise very attractive as an automotive fuel), operates an Alcohol Storage Program to support producers holding alcohol stocks, and imposes an import duty on ethanol (except for the intra-zone trade of ethanol with Brazil's Mercosur partners)—21.5 percent as of late 2003—to protect domestic ethanol producers (USDA 2003). The government also offers a large tax break in favor of hydrous ethanol over the gasoline/anhydrous ethanol blend, similar to the federal ethanol tax exemption granted in the United States, as discussed in chapter 3.

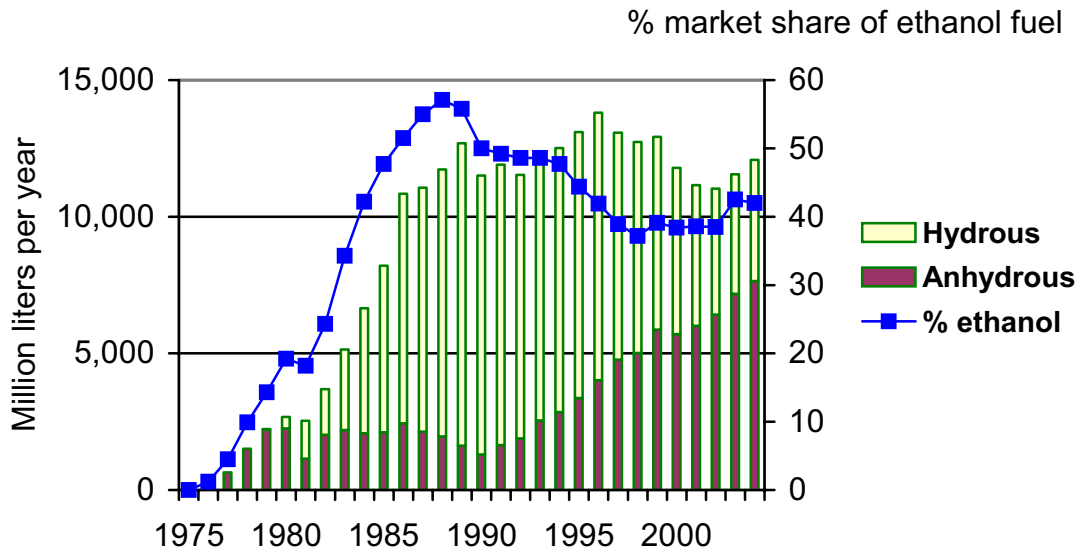
2.26 There are more than 300 ethanol distributors compared to a handful of refineries. The much larger number of tax revenue collection points for ethanol has created enforcement problems for the government in terms of tax collection, black market sales of ethanol, and fuel adulteration. Concern over tax evasion has led the state of São Paulo in 2004 to halve its value-added tax (VAT) for ethanol, as explained in chapter 3. The National Petroleum Agency (ANP) reported in 2002 that some distributors were also adulterating ethanol with chlorinated tap water in order to take advantage of the lower tax rate on ethanol. This not only causes tax-evasion problems, but also raises chlorine contamination and environmental issues (Hart's Diesel Fuel News 2002).

2.27 The historical consumption of anhydrous and hydrous ethanol in Brazil and their market share as a percentage of the automotive fuel for spark-ignition vehicles (normally fueled by gasoline) is shown in Figure 2.3. The market share of vehicles fueled by hydrous ethanol (including flex-fuel vehicles) sold in the new passenger car segment of the automotive market is shown in Figure 2.4. The rapid penetration of flex-fuel vehicles—capable of running both on a gasoline-ethanol blend and hydrous ethanol—in the last couple of years is evident.

2.28 Although there were questions about the quality of new jobs created in the ethanol industry during the first 10 years of Proálcool, sugarcane workers in São Paulo in the late 1990s were receiving, on average, wages that were 80 percent higher than those of workers holding other agricultural jobs. Their incomes were also higher than 50 percent of those in the service sector and 40 percent of those in industry. As a result of the high wages, there has been a steady rise in agricultural mechanization for sugarcane production. In the North-Northeast region, wages are much lower. Special legislation required that 1 percent of the net sugarcane price and two percent of the net ethanol price be channeled into medical, dental, pharmaceutical, sanitary, and educational services for sugarcane workers (Moreira and Goldemberg 1999). A survey of jobs in the formal and informal sectors was conducted in 2003, and key income statistics are given in Table 2.1. There is a large regional difference in the earnings of sugarcane workers. The differences are much smaller

in the sugar and ethanol industry. Sugarcane workers fare better than those in agriculture as a whole, earning about 15 percent more.

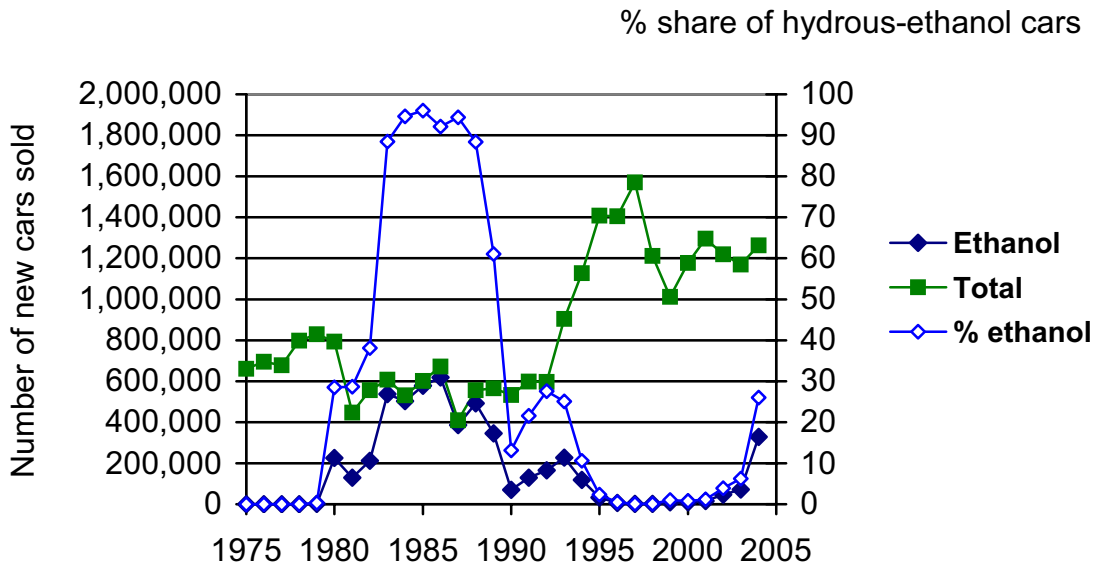
Figure 2.3 Share of Ethanol in Gasoline/Ethanol Market in Brazil



Note: Data from different sources—measured at the point of distribution or that of production—are not consistent, in part on account of widespread fuel adulteration and illegal sale of ethanol evading taxes. The data for ethanol presented here represent ethanol production at the mills and distilleries.

Sources: Ethanol data from Nastari 2005a and gasoline data from Ministério das Minas e Energia / Ministério da Infra-estrutura.

Figure 2.4 Historical Market Share of Hydrous-Ethanol-Fueled Cars in Brazil



Source: ANFAVEA 2005

Table 2.1 Average Monthly Earnings for All Jobs, R\$ in 2003

<i>Sector</i>	<i>Brazil</i>	<i>N-NE</i>	<i>C-S</i>	<i>São Paulo</i>
Sugarcane agriculture	447	283	679	797
Sugar industry	821	708	866	882
Ethanol	850	766	855	1,099
Agriculture	390	—	—	—
Food and beverages	575	—	—	—
Chemicals	1,075	—	—	—
All sectors	692	—	—	—

— Not available

N-NE North-Northeast, C-S Center-South

Source: Macedo 2005

2.29 Technological innovations have enabled a nearly three-fold increase in the yield of ethanol produced from sugarcane in Brazil since 1975. About 2,000 liters of ethanol were produced per hectare of sugarcane in 1975. By 1999, the yield had increased to 5,000 liters, and to 5,900 liters of hydrous ethanol by 2004, or averaging an annual increase of 3.8 percent over this period (Nastari 2005b). The amount of harvesting area in the Center-South region, where area expansion is occurring, increased from 2.8 million hectares in 1993 to 4.2 million hectares in 2003. Very little of this increase was from expansion into new, previously unused land; most was from crop substitution and turning pasture land into sugarcane fields. Between 1975 and 2000 in the state of São Paulo—which accounts for more than 60 percent of the total cane production in the country—the sugarcane yield per hectare increased 33 percent, cane’s sugar content 8 percent, ethanol yield from sugar 14 percent, and fermentation productivity 130 percent (Macedo 2005).

2.30 The trend in ethanol as a transportation fuel in Brazil has moved away from vehicles powered only by hydrous ethanol to flex-fuel vehicles. The flex-fuel technology originated from research conducted in the United States, Europe, and Japan at the end of the 1980s as a solution to the problem of lack of a distribution and supply infrastructure for alcohol use, limiting applications of methanol and ethanol. Flex-fuel vehicles have sensors that check the alcohol content in a gasoline blend and automatically adjust engine operation. In August 2002, the government of Brazil reclassified flex-fuel vehicles so that they would receive the same tax breaks as vehicles fueled by hydrous ethanol. In 2003, General Motors, Volkswagen, and Fiat launched flex-fuel versions of their popular models (AWKnowledge 2003) and Ford did so in 2004 (Laydner 2004). The ethanol market in 2004 saw a sharp increase in the purchase of flex-fuel vehicles, and the trend is continuing in 2005.

United States

2.31 The United States has the second-largest fuel ethanol market in the world. About 90 percent of ethanol is produced from maize (U.S. GAO 2002). The United States is the world’s largest producer and exporter of maize. The United States also has a biodiesel market derived from soybean oil, although it is much smaller than the fuel ethanol market.

Ethanol

2.32 U.S. ethanol consumption rose from 660 million liters in 1980 to 2.9 billion liters in 1990 and to 5.6 billion liters in 2000 (DiPardo 2000, Kapell 2003, U.S. GAO 2002). In 2004, the U.S. ethanol industry set an annual production record of 12.9 billion liters, more than double that produced in 2000. Eleven percent of U.S. maize production and more than 11 percent of grain sorghum production were processed into ethanol in 2004 (RFA 2005a).

2.33 There are two types of mills in the United States. Wet mills have larger production capacities, are more capital intensive, and produce ethanol along with a number of other products such as maize oil, maize syrup, and animal feed. Dry mills produce ethanol as the primary product and a high-protein animal feed, known as distiller's dried grains, as a co-product. During the 1990s, low, stable ethanol prices led wet mills to shift production towards higher margin markets such as high-fructose maize syrup (the competition from high-fructose maize syrup is in turn possible due to the very high sugar prices in the United States relative to world market prices). Annual capacities of new mills increased to the 20–30 million-gallon (75–115 million-liter) range. During the late 1990s and into 2000, capacity of new dry mills reached 40 million gallons (150 million liters) of ethanol per year, and in 2005, plants in excess of 60 million gallons (230 million liters) are planned to take advantage of economies of scale. Dry-mill plants reach economies of scale at about 30–40 million gallons (115–150 million liters) per year, wet-mill plants at about 100 million gallons (380 million liters) (U.S. GAO 2002). Almost all new plants are dry mills. In 2004, dry mill facilities accounted for 75 percent of U.S. ethanol production, and wet mills 25 percent (RFA 2005a). Increasing mill size has attracted public attention to higher air emissions, odors, and organic discharges in water. New larger size mills are adding emission control systems and switching to alternative operations that lower emissions.

2.34 The number of ethanol facilities in the United States peaked in 1984 at 163. However, by the end of 1985, despite the low price of maize, the number of operating ethanol plants had fallen to 74 due to low international oil prices. As of February 2004, there were 72 ethanol plants in 19 states with a combined plant capacity of nearly three billion gallons (11 billion liters). Out of the 72 plants, 32 were farmer-owned, representing 40 percent of U.S. production capacity (RFA 2004). This trend is changing with the boom in the ethanol industry. The need for large capital has shifted production from farm cooperatives to large corporations: corporate producers are expanding their capacity, companies not traditionally focused on agriculture are entering the ethanol industry, and developers are constructing new facilities with annual production capacities of at least 300 million to 420 million liters in contrast to the 40 million to 150 million liters typical of farmer-owned facilities (Chadbourne & Parke LLP 2004). By August 2005, the number of plants had increased to 86 and combined plant capacity to 14.9 billion liters (RFA 2005b). Although market prospects look very good in the long run, excess capacity led to a large fall in ethanol prices in 2005, leading industry analysts to predict a number of small, uneconomic producers to exit the industry. Among those with the greatest potential to exit are the 14 plants that are individually owned or owned by companies with multiple

businesses. A consolidation among the 47 farmer-owned or multi-owner plants, seeking economies of scale, is also believed to be likely (Platts Oilgram News 2005).

2.35 As in Brazil, mandates and tax incentives have been the two main drivers for the growth of the fuel ethanol industry in the United States. The 1990 Clean Air Act Amendments mandated the wintertime use of oxygenated fuels in 39 non-attainment areas for CO and year-round use of oxygenates in nine severe ozone non-attainment areas in 1995.¹⁴ These measures provided a boost to the maize-ethanol industry. The two principal oxygenated fuels used to meet the oxygenate mandate were ethanol and methyl tertiary-butyl ether (MTBE), with ethanol used primarily in the maize-growing Midwest and MTBE elsewhere. In 1999, concerns about groundwater contamination with MTBE led several states to pass bans on future use of MTBE. As of August 2005, 25 states had passed legislation banning the use of MTBE in gasoline (Platts Oilgram Price Report 2005). These decisions to ban MTBE will provide significant market expansion opportunities for ethanol producers.

2.36 Against this background, the 2005 Energy Bill, signed into law in August 2005, contained a Renewable Fuels Standard requiring that a minimum of 7.5 billion gallons (28 billion liters) of renewable fuels be used annually by 2012. Every liter of ethanol derived from non-grain sources (such as cellulose or waste) is counted as 2.5 liters of grain-based ethanol toward this requirement. The bill also eliminated the oxygenate mandate for reformulated gasoline, which means that MTBE does not have to be replaced by ethanol. Earlier, the Energy Information Administration (EIA) of the U.S. Department of Energy carried out a study analyzing the near- and mid-term potential price and supply effects of the Fuels Security Act of 2005, which was similar in content to the 2005 Energy Bill. The average price increase as a result of adopting the Fuels Security Act of 2005 between 2006 and 2025 was calculated to be 0.8 US cents per gallon (0.2 US cents per liter). The ethanol content in gasoline would rise and peak at 5 percent in 2012, after which it would fall because of increasing use of cellulosic bioethanol, which receives extra credit (U.S. EIA 2005a).

2.37 Turning to tax incentives, the Energy Tax Act of 1978 defined gasohol as a blend of gasoline with at least 10 percent alcohol by volume, excluding alcohol made from petroleum, natural gas, or coal. A federal excise tax exemption on gasohol in the amount of US\$0.04 per gallon (US\$0.01 per liter) of gasohol, or equivalent to US\$0.40 per gallon (US\$0.11 per liter) of ethanol, was granted. This reduced the cost of ethanol to about the wholesale price of gasoline. The tax exemption is a credit that fuel blenders receive for using ethanol in gasoline. Marketing of commercial alcohol-blended fuels began in 1979. Federal excise tax exemption was supplemented by state tax incentives to ethanol producers. By 1980, 25 states had exempted ethanol from all or part of their gasoline excise taxes (U.S. National Alcohol Fuels Commission 1981). In 1980,

¹⁴ The addition of oxygen to gasoline could reduce CO and hydrocarbon emissions in old technology vehicles if the engine is tuned with a low air-to-fuel ratio. Gasoline vehicles manufactured in the United States since the early 1990s are equipped with oxygen sensors which automatically adjust the fuel injection rate to achieve an optimal air-to-fuel ratio, and the environmental benefit of adding oxygenates to gasoline for these vehicles is very small.

Congress enacted a series of tax benefits to ethanol producers and blenders, including insured loans for small ethanol producers, an import tariff on foreign-produced ethanol, and extension of the ethanol-gasoline blend tax credit. Ethanol production increased in just one year from 10 million gallons (38 million liters) in 1979 to 175 million gallons (660 million liters) in 1980 (RFA 1999).

2.38 The ethanol tax exemption was increased to US\$0.50 per gallon (US\$0.13 per liter) of ethanol in 1983 and to US\$0.60 per gallon (US\$0.16 per liter) in 1984. The excise tax exemption was lowered to US\$0.54 per gallon (US\$0.14 per liter) in 1990, and in 1997 it was extended through 2007 but with a gradual reduction to US\$0.51 per gallon (US\$0.13 per liter) in 2005. The poor maize crop and the doubling of maize prices in 1995–1996 led some states to pass additional subsidies to keep the ethanol industry solvent. To remain economically viable as a gasoline-blending component in the United States, ethanol from maize has relied heavily on federal and state tax exemptions. In fiscal 2000, the partial exemption from the excise tax for ethanol amounted to US\$800 million and the income tax credits for ethanol US\$15 million (U.S. GAO 2000).

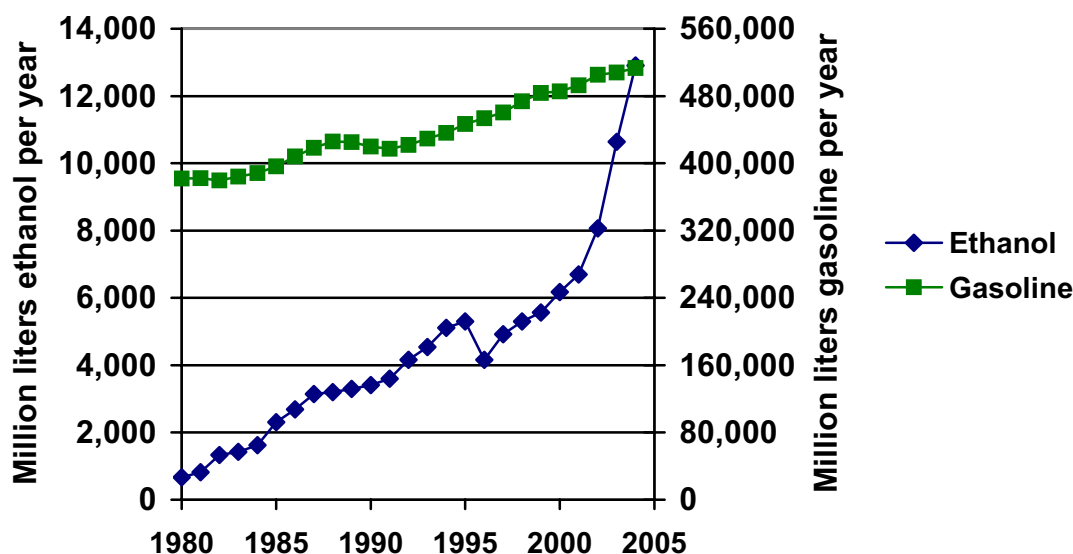
2.39 The Energy Policy Act (EPAAct) of 1992 provided for two additional gasoline blends, 7.7 percent and 5.7 percent ethanol. It also required specified car fleets to begin purchasing alternative fuel vehicles, provided tax deductions for the purchase or conversion of vehicles fueled by alternative fuels and the installation of equipment to dispense alternative fuels, and defined ethanol blends with at least 85 percent ethanol as alternative transportation fuels. Beginning with the model year 1999, many cars in the United States were manufactured to be able to run on E85 fuel without modification. According to the National Ethanol Vehicle Coalition, there are about 4 million flex-fuel vehicles capable of using E85 and 400 public and private E85 fueling sites. Nearly all fuel ethanol in the United States is consumed as E10, a 10 percent blend with gasoline.

2.40 Beginning in January 2005, the Volumetric Ethanol Excise Tax Credit (VEETC) in the American Jobs Creation Act has extended the ethanol tax incentive through December 31, 2010, at a rate of US\$0.51 per gallon. VEETC changed the tax structure by allowing this tax credit on *all* ethanol blended with gasoline, diesel, and ethyl tertiary-butyl ether (ETBE). The earlier restrictions on the percentages of ethanol that could be blended into gasoline (5.7, 7.7, and 10 percent) were removed.

2.41 In addition to the tax benefits given directly to ethanol producers, it is worth mentioning that the maize sector is the largest single recipient of the U.S. government agricultural subsidy, amounting to US\$37.4 billion between 1995 and 2003 (EWG 2004). One-tenth of the maize crop is used for ethanol production. Large agricultural corporations, which are also involved in ethanol production, benefit disproportionately from the maize and ethanol subsidies. In addition, the Commodity Credit Corporation BioEnergy Program under the U.S. Department of Agriculture (USDA) provided US\$150 million in fiscal 2001 as incentive payments to producers of ethanol, biodiesel, and other bio-based fuels. The majority of these payments go to large agribusiness corporations (Slivinski 2001) such as Archer Daniels Midland (ADM), which controlled 41 percent of total ethanol production capacity in 2002 (U.S. GAO 2002).

2.42 An analysis of ethanol production, consumption, and production capacity issued in February 2002 by the U.S. General Accounting Office (GAO) showed that between 1994 and 2000, production capacity consistently exceeded consumption and production demand. The average capacity utilization rate was about 84 percent during this period (U.S. GAO 2002). Ethanol production is plotted against gasoline consumption for 1980–2004 in Figure 2.5.

Figure 2.5 U.S. Ethanol Production and Gasoline Consumption



Sources: U.S. EIA 2004 and 2005b, RFA 2005a.

2.43 Industry structure has a large impact on the level of competition among producers and on end-user prices. A 2002 GAO analysis pointed out that the U.S. ethanol industry was highly concentrated. One measure of market concentration is the so-called Herfindahl-Hirshman Index (HHI). The higher the HHI, the higher the market concentration: fewer the number of firms competing with each other, and potentially the easier it is for the few firms to collude or lobby politically for special concessions and treatment at the expense of consumers or the economy or both. According to the guidelines of the Federal Trade Commission and the U.S. Department of Justice, an HHI greater than 1,800 is considered highly concentrated. The HHI for the U.S. ethanol industry as of January 2002 was 1,866. The industry consisted of one dominant (controlling 41 percent of the total production capacity) and many smaller or fringe suppliers. The market share in 2002 of the top four firms was 58 percent and of the top eight firms 71 percent. Further, some large producers may have partnered with smaller producers or farm co-operatives to market the smaller producers' ethanol. If so, the calculated HHI underestimates the actual market concentration (U.S. GAO 2002).

2.44 HHI is one measure by which the potential competitiveness of an industry is gauged. A number of other factors affect the industry's competitiveness, such as the availability of substitute products, the cost of initial investment, and product homogeneity.

The initial capital costs of dry mills would not be prohibitive, but incumbent firms have a cost advantage over new entrants because expansion costs are substantially smaller than new plant construction costs. There is no product quality variation in ethanol, enabling consumers to source from the least-cost supplier and thereby enhancing competition. The U.S. GAO did not draw firm conclusions about the impact of the industry structure on competition and price levels, but noted that the high HHI is a potential cause for concern.

2.45 One environmental concern is the higher volatility permitted for ethanol-gasoline blends, resulting in higher evaporative emissions of hydrocarbons that are ozone precursors. Because of higher volatility of gasoline-ethanol blends, conventional gasoline with a Reid vapor pressure (RVP) ceiling of 62 kilopascals (kPa) is allowed a 6.9 kPa waiver if it contains 10 volume percent ethanol. In addition, reformulated gasoline containing 10 volume percent ethanol sold in the Chicago and Milwaukee areas receives a 2.1 kPa allowance in meeting the applicable volatile organic compound (VOC) performance standard. The reason for granting these RVP waivers, despite their potentially adverse impact on ambient air quality, is that, without the waivers, the cost of producing gasoline-ethanol blends would increase—because manufacturing gasoline with lower volatility is more costly—and even a greater tax exemption would be needed to make ethanol competitive with gasoline.

Biodiesel

2.46 The dedicated annual production capacity for biodiesel in the United States was estimated to be about 570 million liters in 2004, 24-fold smaller than the ethanol production capacity (National Biodiesel Board 2004). As of 2002, 80 percent of biodiesel was derived from soybeans, 19 percent from yellow grease, and the remaining 1 percent from other feedstocks, according to the National Biodiesel Board (U.S. EPA 2002). In January 1999, only a few fleets were using biodiesel. By September 2001, the number had increased to more than 100.

2.47 Military vehicles and fleets belonging to government agencies, state governments, and the U.S. Department of Energy (U.S. DOE) make up the expanding biodiesel market on account of the recognition of biodiesel as an alternative fuel under the EPAct of 1992. Effective November 1998, Congress approved B20 as an alternative fuel under the EPAct. The U.S. DOE issued a final ruling for the EPAct requirements for biodiesel in January 2001. Fleets that fall under this category can buy 450 gallons (1,700 liters) of pure biodiesel and use it in new or existing diesel vehicles in a blend containing at least 20 percent biodiesel to satisfy up to 50 percent of their annual alternative fuel vehicle acquisition requirements.

2.48 Unlike ethanol, there have been no mandates or universal tax exemptions specifically designed for biodiesel, although this changed in January 2005 (see below). In 2002, Minnesota enacted the first statewide law in the United States requiring that the state's diesel fuel comprise 2 percent biodiesel. In September 2005, Minnesota implemented a mandate requiring diesel for on-road use to contain 2 percent biodiesel. Diesel used by off-road vehicles, railways, and power stations are exempt.

2.49 To offset the high cost of biodiesel production, the American Jobs Creation Act of 2004, signed into law in October 2004, provides a federal excise tax credit for biodiesel: a one-cent credit for each percentage point in a fuel blend made from agricultural products and a 0.5-cent credit for each percentage point of biodiesel made from recycled oils. The tax credit for biodiesel from soybean oil and other agricultural products is US\$1.00 per gallon of biodiesel, or US\$0.26 per liter. The tax incentive took effect in January 2005 and will last for two years.

2.50 As with maize, soybeans receive considerable subsidies from the federal government. Between 1995 and 2003, soybean subsidies amounted to US\$12 billion (EWG 2004). The amount of land on which soybeans were planted increased on average by more than one million acres annually between 1997 and 2001 (USDA 2002a) despite historic low prices, in part on account of higher margins enabled by subsidies. The Farm Security and Rural Investment Act of 2002 (the so-called 2002 Farm Bill) provided for three primary government payments, and soybeans and maize are eligible for all three: marketing loans, direct payments, and counter-cyclical payments whereby farmers are paid when crop prices are below the target price set for each crop. For soybeans, the bill established a loan rate of US\$5.00 per bushel (the farmer can borrow today against a future crop with the loan amount equal to the loan rate times the amount of crop produced), a direct payment of US\$0.44 per bushel, and a target price of US\$5.80 per bushel.

2.51 One consumer concern in deciding whether or not to start using a new product is quality control. The growth of the biodiesel market in Germany is in part attributed to the establishment and enforcement of biodiesel quality standards. In December 2001, the American Society of Testing and Materials (ASTM) issued a specification (D 6751) for biodiesel fuel. The National Biodiesel Board has established the National Biodiesel Accreditation Commission to develop and implement a voluntary program for the accreditation of producers and marketers of biodiesel. The Commission has developed “BQ-9000, Quality Management System Requirements for the Biodiesel Industry” for use in the accreditation process.

2.52 In a development that perhaps signals the future market potential of biodiesel, Volkswagen and grain processor ADM announced in January 2004 that they had formed a research venture to develop and use biodiesel fuels for the automotive industry. The agreement was the first between one of the world’s leading automotive manufacturers and a global agribusiness company to develop renewable automotive fuels. ADM is the largest U.S. producer of maize-based ethanol and the largest U.S. processor of soybeans (Automotive Environment Analyst 2004).

European Union

2.53 The European Union is the world leader in the production and consumption of biodiesel. A total of 1.9 million metric tonnes (about 2.2 billion liters) of biodiesel was produced in the European Union in 2004. The top three producers were Germany (1.04 million tonnes), France (0.35 million tonnes), and Italy (0.32 million tonnes), accounting for 88 percent of the total production (EBB 2005). The production capacity increased by a factor of four to a total of 2 million tonnes a year between 1996 and 2002 (Bockey 2003),

and increased by another 10 percent to 2.2 million tonnes in 2004 (EBB 2005). By 2003, production capacity in Germany far outstripped demand (UFOP 2002). Biodiesel use varies from country to country. Germany and Austria have had a concerted effort to promote B100. In contrast, biodiesel is used almost exclusively in B5 in France. In Italy, half of the biodiesel production is used as heating oil, the remainder blended in B5 with petroleum diesel (Australian Government Department of the Environment and Heritage 2003). In early 2004, Germany began allowing oil companies to blend up to 5 percent biodiesel in conventional diesel, opening up a new market for biodiesel and increasing demand.

2.54 Two factors have contributed to the European Union's becoming the world leader in biodiesel production. One is the reform of the Common Agricultural Policy (CAP), a supranational and domestically oriented farm policy for EU member countries, adopted in 1992 and implemented in 1993–1994. The 1992 reform addressed agricultural surpluses through supply control in the form of a mandatory, paid, “set-aside” program. In addition to price support, per-hectare payments are made to producers based on the average historical yield in tonnes per hectare. Producers of grains, oilseeds, and protein crops are eligible for direct payments if they remove a specified percentage of their area from production. Producers also receive a separate set-aside payment for the areas removed. The area of subsidized oilseed production is limited by the terms of the 1994 U.S.-EU Blair House Agreement, and oil seed producers (barring small producers) are required to set aside a minimum of 10 percent of their land to qualify for payments. Because non-food crops are permitted on set-aside land, this policy has encouraged oilseed production for biodiesel manufacture on set-aside land. The Blair House Agreement limits output from oilseeds planted on set-aside land for industrial purposes to 1 million tonnes of soybean meal equivalent a year.

2.55 The second factor is high fuel taxes, which have enabled indirect subsidies for biofuel production through partial or full exemption of the fuel excise tax. Taxes normally constitute 50 percent or more of the retail price of diesel in EU member states. In February 1994, the European Parliament adopted a 90 percent tax exemption for biodiesel. Germany, the largest biodiesel market, has excluded biofuels from taxation altogether (Schöpe and Britschkat 2002). In addition, some governments have implemented the European Community “Scrivener” Directive, which recommends a certain level of tax relief for investment in liquid biofuel plants. According to the European Commission, without this relief, the cost of biofuel production was two to three times that of petroleum fuels as of the early 2000s (Commission of the European Communities undated).

2.56 To win the acceptance and confidence of consumers and vehicle manufacturers, much attention has been paid to quality control. German authorities issued a provisional specification for fatty acid methyl ester (FAME) under DIN 51606. In 2003, DIN 51606 was replaced by EN 14214 of Europe's Committee for Standardization (CEN) upon its publication. The European specifications have more stringent limits for sulfur and water, as well as a test for oxidation stability that is absent from the current ASTM specification in the United States.

2.57 The German biodiesel industry has worked closely with the automotive industry from the beginning. This was essential for persuading the auto industry to issue the same warranties for biodiesel use. Making DIN 51606 for plant-oil methyl ester mandatory

in 1994 was an important step. The Union for the Promotion of Oil and Protein Plants (UFOP) has played a critical role in disseminating information and educating the public about biodiesel (Australian Government Department of the Environment and Heritage 2003). As of June 2002, biodiesel was available at 1,500 filling stations in Germany (Bockey 2003). The average distance between the filling stations selling biodiesel was about 30 kilometers (km), although with substantial regional variation. About 40 percent of biodiesel is sold through filling stations and 60 percent to fleet operators (UFOP 2002).

2.58 Some government agencies have shown less enthusiasm for biodiesel. Notably, the German Federal Environmental Agency (UBA) issued a report in 2001 that concluded that from an environmental point of view, the use of rapeseed methyl ester (RME) in diesel engines had no distinct advantages over the use of modern diesel fuel made from mineral oil, nor did the use of RME make sense with respect to the national economy because it required substantial implicit and explicit subsidies. As for the benefits of using biodiesel to reduce contribution to global warming, the report stated that other measures to reduce GHG emissions—such as energy efficiency in buildings—could achieve substantially larger reductions at lower costs (Hart's Diesel Fuel News 2001).

2.59 In contrast, there has been little fuel ethanol production in the European Union. Ethanol in Europe is produced from sugar beets and wheat, both of which are much more expensive than sugarcane-derived ethanol. In 2003, bioethanol production reached 370 million liters. The corresponding figure in EU-25 in 2003 was 570 million liters. Both France and Spain have established fuel ethanol industries where ethanol is not used directly but is transformed into ETBE. In 2003, the largest consumers were Spain at 200 million liters, Sweden at 180 million, and France at 100 million. Sweden uses ethanol in both E5 and E85. Poland was closely behind, producing and consuming 80 million liters of bioethanol. The German parliament has exempted all biofuels for heating and transport purposes from the mineral oil tax. The tax exemption for ethanol, amounting to €0.655 per liter, is substantially larger than those in the Americas and is among the highest in the world (Corre 2004). In contrast, the French Assemblée Générale in 2003 voted to reduce the tax relief from €0.502 to €0.38 per liter (Automotive Environment Analyst 2003a). Among the three largest consumers, Spain and Sweden grant a 100 percent exemption from gasoline tax to ethanol today, and France 63 and 65 percent exemption (Corre 2004).

2.60 In 2003, the European Union issued a directive requiring member states to set national indicative targets for the purpose of ensuring that a minimum proportion of biofuels and other renewable fuels be placed on their markets. A reference target value for end-2005 is 2 percent, calculated on the basis of energy content, of all gasoline and diesel for transportation purposes, and 5.75 percent by end-2010 (EU 2003). In an earlier proposal put forward by the Commission of the European Communities in 2001, the three main objectives were stated to be:

- Increasing the security of supply of transport fuel
- Reducing CO₂ emissions
- Contributing to rural development and maintenance of employment in the rural community.

The proposal considered biofuels to offer in theory little, if any, local air pollution emission advantage over gasoline and diesel in the future, given rapid tightening of fuel quality and exhaust emission standards in the European Union in the coming years (Commission of the European Communities 2001a).

2.61 The proposal and the final directive stated that biofuels cost upwards of €0.30 per liter more than conventional fuel based on the world oil price of €30 per barrel, and that it would take an oil price of about €70 per barrel to make biofuels break even with conventional petroleum-derived diesel and gasoline. If production of biofuels were restricted to 10 percent of agricultural land (set-aside land), 8 percent would be considered the maximum road gasoline and diesel substitution achievable through biomass.

2.62 The proposal saw biofuels as an option to be exploited in the short to medium term. At the time of the proposal writing, biofuels made up less than 0.5 percent of diesel and gasoline consumption. Substitution above 5 percent was said to require more than €5 billion annually.

2.63 Three policies were considered for overcoming the higher cost of biofuels:

- *Supporting the non-food agriculture sector* The scope offered by this approach was considered extremely limited, given that the existing agreement with the United States would limit support for rapeseed, soybean, and sunflower production, likely public opposition to further agricultural subsidies, and the Berlin ceilings on the budget.
- *Tax differentiation in favor of biofuels* Tax incentives were considered an effective means of promoting the development of biofuels.
- *Specifying a certain amount of biofuel in transport fuels sold* A requirement for a certain minimum percentage of biofuel in all transport fuels sold throughout the European Union was considered the simplest step for large-scale expansion of the biofuel market. Because costs are shared by all, this would carry only a modest incremental cost. As a first step, a minimum biofuel share of 2 percent was considered reasonable. This would require no modification of existing vehicles. That said, this approach does not recognize the fact that some parts of the European Union would favor more biodiesel and other parts more bioethanol. In addition, many of the already existing biofuel programs were based on pure or mixed biofuels in captive fleets. In light of these observations, the Commission recommended that, as a first step, there be a general overall commitment by member states to ensure that a certain percentage, increasing over time, of the transportation fuels sold in their territories be biofuel. In the second phase, substitution above 5 percent was considered to require blending of biofuels in each type of fuel marketed.

2.64 The European Environmental Bureau (EEB), the largest environmental citizens' organization in Europe, strongly objected to this directive and to the fiscal measures to support the directive (discussed below) on the following grounds:

- The transport sector is growing at an annual rate of 2 percent, so that the maximum achievable substitution of 8 percent is offset in less than four years. Only those technologies and options that have the potential to provide significant

environmental benefits should be promoted. The Commission should examine the opportunities for reducing the volume of transport much more.

- Increasing vehicle fuel efficiency offers more carbon dioxide (CO₂) savings at lower costs than biofuels. The use of biofuels is among the highest cost options for CO₂ emission reduction. Estimates of CO₂ savings in the proposal for substituting petroleum fuels with biofuels also appear to be too optimistic.
- Other biomass use of agricultural land is much more promising, such as short rotation coppice for the generation of heat and electricity.
- The Commission's proposal focuses on biofuels that are produced from intensively farmed annual crops. When biofuel crops are intensively cultivated on set-aside land, they will provide less habitats for animals, push aside other plants when cultivated in monocultures, and decrease the variation in the landscape. They also require high use of fertilizers and pesticides. All these factors tend to worsen ecosystem health and reduce biodiversity. A less energy intensive agriculture would, in the long run, save more energy than intensive agriculture for marginal CO₂ gains through production of biofuels.

EEB concluded by rejecting the promotion of biofuels derived from conventional agricultural crops (Jonk 2002).

2.65 In order to support the target biofuel consumption levels, a proposal for a directive was issued in 2001, defining fiscal incentives for biofuels. It allows member states to apply a reduced rate of excise duty when biofuels are used to displace transportation or heating fuels. When used as a motor fuel, the reduction in the level of taxation, which comprises all indirect taxes excluding VAT, cannot be higher than 50 percent, except when used by public passenger transport, including taxis, and by public authority-operated vehicles. In the case of pure biofuels used in public transport, even a 100 percent exemption may be permitted (Commission of the European Communities 2001b).

2.66 While these tax exemptions may provide additional incentives in some countries, in those countries where much higher excise duty reductions have historically been implemented, such as Germany, concerns have been raised as to whether biodiesel can remain competitive at a 50 percent tax rate compared to petroleum diesel.

2.67 Directorate-General Energy and Transport at the European Commission estimated in early 2005 that the European Union appeared set to achieve 1.4 percent substitution of all transportation fuels with biofuels in 2005. This is more than double the 0.6 percent in 2003 but falls short of the target of 2 percent. The Czech Republic, France, Germany, Poland, Portugal, Spain, and Sweden were among countries set to significantly increase their output. In order to meet the EU target of 5.75 percent by 2010 from domestic sources, some 9 percent of total EU land would need to be given over to rapeseed and other feedstock crops, according to the Directorate-General. Germany was looking to Eastern Europe for biodiesel supplies (Agra Europe 2005a). In July 2005, the European Commission initiated legal action against 16 member states for failing to establish a biofuel usage target for 2005 or for setting a national target at below the 2 percent level mandated in the Biofuel Directive. Because targets are non-binding, legal

action can be taken against failure to set the appropriate indicative targets, but not against failure to meet them once they have been set (Agra Europe 2005b).

Australia

2.68 Following an election commitment made in 2001 to increase biofuel production from 40 million to 350 million liters a year—the latter corresponding to approximately 2 percent of the current fuel market—by 2010, there have been a number of studies to examine the costs and benefits of ethanol and biodiesel. In September 2002, the Federal Government announced that an excise on ethanol used in gasoline would be at the same rate already applying to gasoline, A\$0.38143 per liter. At the same time, a production subsidy of the same amount, A\$0.38143 per liter, would be paid to domestic producers of the ethanol blended into gasoline (Anderson 2002). Significantly, this change raises the cost of importing ethanol and provides protection to domestic producers.

2.69 Australia is one of the lowest-cost producers of sugar, second only to Brazil. The sugar industry in 2000 identified a cane-based ethanol market as a means of overcoming a significant financial hardship confronting the industry at the time. Calls for assistance heightened in 2002 following a return to low international prices of sugar. In March 2004, the government extended the subsidy for ethanol producers to June 30, 2011 (Berg 2004).

2.70 The government in 2003 set a ceiling of 10 percent on the content of ethanol in gasoline. This decision followed vehicle-testing results that showed that E20 might cause engine problems in some older vehicles. There was a loss of consumer confidence in 2002–2003 following reports of the distribution of high-concentration (20–30 percent) ethanol blends around Sydney and widely publicized allegations of vehicle damage (Biofuels Taskforce 2005). The Department of the Environment and Heritage Studies commissioned studies to examine the impact of using E20. A durability study, released in May 2004, found that deterioration in the regulated tailpipe emissions at 80,000 km were markedly higher for E20 compared to gasoline. Greater wear was observed for engines run on E20 at 80,000 km, but not enough to result in a notable loss of combustion performance. Engine deposit levels were also higher when E20 was used; this could lead to longer-term durability issues. As of early 2005, E10 was still being used in a trial stage in Australia. The government requires labeling of ethanol levels at the pump (Australian Government Department of Environment and Heritage 2005, Orbital Engine Company 2004, Herald Sun 2005).

2.71 Perhaps more than in any other country, the ethanol program in Australia has stirred public controversy, caused partly by blending of more than 10 percent ethanol into gasoline in the early days of the program. Signs that read “No Ethanol” began to appear at filling stations in 2003 after problems were reported with vehicles fueled with blends containing up to 20 percent ethanol. Some car makers threatened to void warranties if new cars used ethanol blends. The ethanol program has also divided Australia’s farmers. The Livestock Feed Grain Users Group, which represents chicken, pork, dairy, and beef producers, opposes the support the government provides to the ethanol industry via start-up grants and a A\$0.38 fuel excise rebate, and has spoken up against mandatory blending of ethanol, fearing feed grain shortages that would result from an ethanol mandate (Australian

Financial Review 2005). These events have led to politicizing the ethanol program more than in other countries.

2.72 In May 2005, a prime ministerial taskforce was set up to review the target of increasing annual biofuels use to 350 million liters; the impacts on automotive operations from using ethanol-gasoline blends; the health and environmental benefits of supplementing petroleum fuels with biofuel blends; and the bases for which decisions have been made to support ethanol and other biofuel production in North America, Europe, and elsewhere. The final report of the taskforce concluded that, in the absence of long-term government assistance, Australian ethanol would be competitive with conventional gasoline if oil prices remained above US\$47 a barrel at a long-run exchange rate of A\$0.65 to US\$1.00 (or US\$56 per barrel at the 2005 exchange rate of A\$0.77). The taskforce identified a number of barriers to a viable biofuels market in Australia. These included continuing lack of consumer confidence in ethanol (identified as a “fundamental problem for the ethanol industry”), fuel economy reduction associated with ethanol blending of gasoline and the absence of a price discount in favor of ethanol-gasoline blends to reflect the fuel economy difference, and significant commercial risks associated with market entry in the face of low demand for ethanol. To address these barriers, the taskforce recommended not labeling blends containing up to 5 percent ethanol, providing accurate technical information to consumers, increasing the level of compliance with fuel quality standards through inspection, and conducting comprehensive scientific research under Australian conditions to quantify the environmental and health benefits of using biofuels (Biofuels Taskforce 2005).

Canada

2.73 The Canadian government’s Climate Change Plan sets a target that 35 percent of gasoline be an E10 blend by 2010. This will require the 2004 equivalent of upward of 1.3 billion liters of ethanol a year, against an estimated 245 million liters produced in 2004. Feedstocks are maize, wheat, and forestry products. To date, three provinces—Manitoba, Ontario, and Saskatchewan—have introduced regulations requiring ethanol addition to gasoline.

2.74 The federal government offers an excise tax exemption of C\$0.10 per liter of ethanol used in ethanol-blended gasoline. The portion of the tax corresponding to the exemption is returned to the ethanol producer. Ethanol producers also benefit from provincial fuel tax exemptions in six provinces, ranging from C\$0.09 per liter in Alberta to C\$0.25 per liter in Manitoba. These incentives mean that, if the wholesale price of ethanol is C\$0.45 per liter, the producer can get C\$0.80 in Manitoba (C\$0.45 + C\$0.10 + C\$0.25) (Rilett 2003).

2.75 The federal government launched the Ethanol Expansion Program (EEP) in August 2003 as part of its plan to reduce GHG emissions. In the first round of funding, seven plants were awarded a total of C\$78 million in February 2004 (Renewable Fuels News 2005b). In July 2005, the government announced that it would spend another C\$46 million to help build five ethanol plants. The new plants will boost Canada’s ethanol production to about 1.4 billion liters per year by 2007 (Oil Daily 2005).

2.76 In December 2004, the government announced that its vehicle fleet became the first in the world to be fueled by ethanol made from cellulose on an ongoing basis, at an annual rate of approximately 100,000 liters. The ethanol is supplied by Iogen, which has been producing cellulose ethanol for commercial use at its demonstration plant since April 2004 and has received financial assistance from the government and others (Renewable Fuel News 2004b). Iogen plans to build a 50-million-gallon-per-year (190 million liters) cellulosic ethanol plant in the near future (Time Magazine 2005).

2.77 Fuel ethanol production has historically been concentrated in southeast Ontario. This could change on account of incentives and mandates in other provinces. Saskatchewan's Ethanol Fuel Act of May 2002 requires 2.5 percent ethanol to be added to gasoline by July 2004 and 7.5 percent by April 2005. It also requires distributors to purchase 30 percent of ethanol from plants with production capacities smaller than 10 million liters per year. Manitoba's Biofuels Act requires that 85 percent of gasoline sold in the province contain 10 percent ethanol by September 2005. A subsidy and tax exemption are given but only for ethanol produced and consumed in Manitoba (Klein and others undated). As of January 1, 2007, gasoline sold in Ontario must contain an average of 5 percent ethanol. This requirement can be met by the actual blending of ethanol or through the trading of renewable fuel credits (Canada Business News 2004).

China

2.78 Although the use of fuel ethanol is limited in China today, the government has embarked on a large program to increase its consumption. China launched a pilot ethanol program in five cities in central and northeastern region in June 2002: Zhengzhou, Luoyang, and Nanyang in Henan province in central China, and Harbin and Zhaodong in Heilongjiang province in northeast China. From June 8, 2002, all motor vehicles carrying a license plate starting with "Yu A" in Zhengzhou, the capital of Henan, have been ordered by the municipal government to use ethanol-based fuels. Motorcycles, military vehicles, and vehicles in transit from outside the city are exempted from this requirement (People's Daily 2002). In 2004, China expanded its trial use of fuel ethanol to seven additional provinces: Jilin, Liaoning, Anhui, and parts of the provinces of Hubei, Shandong, Hebei, and Jiangsu (People's Daily 2004). Jilin is home to the world's largest ethanol plant, the Jilin Tianhe Ethanol Distillery (Berg 2004).

2.79 The government recognizes that ethanol will not be cost-competitive with respect to gasoline initially. Lu Tianxiong, director and senior engineer at Beijing Memsep Technologies Co. Ltd., said in 2001 that while China had a surplus of maize and was looking for ways to improve farmers' income, at 1,000 yuan (US\$120) per tonne, the price of maize in China was too high for its widespread use as ethanol feedstock. But production costs could decline with increasing scale and market uptake in the coming years (Planet Ark 2001).

2.80 The push for ethanol is motivated by concerns about depleting oil and gas reserves in China and, until recently, a growing stockpile of surplus wheat and maize, both of which can be used for ethanol production. In Henan, the most populous province in China, the stockpile of grain totaled 35 million tonnes in 2002, mostly wheat (People's Daily 2002). China is the world's second largest maize producer, after the United States.

Much of China's maize is grown in the northeast provinces and in the North China Plain. China increased maize production by almost 50 percent in the 1990s in response to high domestic support prices (USDA 2000). In the past few years, however, China has rapidly drawn down stocks of grain to only seasonal carry-over needs. China has historically been a net importer of wheat and exporter of maize. Maize production has benefited from border protection, but protection is expected to decline under the World Trade Organization accession agreements. By 2006 or 2007, China is anticipated to become a net importer of maize, making China a net importer of both maize and wheat in the coming decade (OECD 2004, FAPRI 2005, USDA 2005a).

Colombia

2.81 In September 2001, the government approved a law requiring cities in Colombia with populations exceeding 500,000 to add 10 percent ethanol to gasoline beginning in 2006. According to the Ministry of Agriculture, an additional 150,000 hectares will need to be cultivated for producing sugarcane as a feedstock for ethanol, against the present area under cane for sugar production of about 200,000 hectares. Another 230,000 hectares under cane are used for panela (unrefined sugar) production. Meeting domestic demand in 2006 will require construction of nine new ethanol plants. To that end, the government will exempt ethanol completely from the tax on gasoline (Berg 2004).

2.82 Construction of the country's first ethanol plant began in December 2004. In the same month, Congress approved a bill that permitted blending 10 percent ethanol in gasoline starting in September 2005 (subsequently delayed to November) and another that promoted the production, consumption, and commercialization of biofuels. These measures are intended to address the concerns raised by the forecast that Colombia's self-sufficiency in hydrocarbons will cease in 2009. The biofuel bill provides for a 10-year grace period from paying income taxes on crops and a tax exemption on biodiesel (Business News America 2004, Portafolio 2005).

2.83 Start-up of ethanol plants appears to be on schedule. The first ethanol plants will be run by the companies Incauca (US\$18 million for daily capacity of 300,000 liters) and Providencia (US\$13 million for daily capacity of 250,000 liters) in September, followed by sugarcane mills Mayaguez (US\$18 million for daily capacity of 150,000 liters), Manuelita (US\$14 million), and Risaralda (US\$13 million for daily capacity of 75,000 liters) in December. The total investment by the mills in ethanol production amounts to US\$75 million (Portafolio 2005).

India

2.84 Effective January 2003, India mandated the blending of at least 5 percent ethanol in the gasoline sold in nine states and four Union Territories to reduce the country's dependence on imported oil, help the sugar industry, and benefit the environment. The nine states included key sugar producers: the western state of Maharashtra and the northern state of Uttar Pradesh. The rest of the country was to be covered later. This mandate was estimated to require 320 million liters of ethanol (Economic Times 2002). The proportion of ethanol in the blend was to be increased to 10 percent at a later date.

2.85 To date, ethanol program implementation has been slow, in part because of ethanol shortages. Against an annual requirement of 363 million liters of ethanol during fiscal 2003–2004, only 196 million liters were available (Hindustan Times 2004). It is worth noting that India has no comparative advantage in sugarcane production, which is water-intensive, and in fact faces a serious agricultural water shortage. This raises questions about the long-term sustainability of ethanol manufacture from sugarcane in the country. India's sugar surplus and growing supplies of molasses were important drivers behind the ethanol program. The sugar industry, burdened with overcapacity, lobbied the government for several years to adopt a bioethanol program.

2.86 To promote the use of ethanol-blended fuel, an excise duty concession of Rs 0.75 per liter for ethanol-blended petrol was announced in the Union Budget 2002–2003, corresponding to Rs 15 (about US\$0.31) per liter of ethanol. Implementation was delayed until February 2003 because of opposition from the chemical industry. During the first half of 2003, there were reports that the diversion of molasses for ethanol production had raised the price of molasses from Rs 1,000 per tonne to Rs 1,500–1,600 per tonne (Economic Times 2003).

2.87 Pricing became an issue. In June 2003, the Ministry of Petroleum and Natural Gas announced that it would appoint a Tariff Commission to set an appropriate price for ethanol sourced from sugar mills. Pricing is further complicated by differences in excise duty and sales tax across states, and by substantial differences in the profitability of potable ethanol against fuel ethanol in several states, resulting in a deficit of about 150 million liters given the current geographical distribution of fuel ethanol production (Berg 2004). The tax benefits were withdrawn on June 30, 2004 (Hindustan Times 2004).

2.88 Droughts affected cane harvests in 2004 and production fell by 5 percent (Reuters News 2005a), forcing India to import significant quantities of ethanol from Brazil. Amidst mounting ethanol imports, the government issued a new ruling in October 2004 that stopped mandatory blending of ethanol in gasoline. The ruling instead stipulated that fuel ethanol should be procured only if it is economical. More specifically, gasoline blended with 5 percent ethanol is to be supplied in the identified areas if (1) the price of ethanol offered for blending into gasoline is comparable to that offered by the indigenous ethanol industry for alternative uses, (2) the delivery price of indigenous fuel ethanol at a particular location is comparable to the import-parity price of gasoline at that location, and (3) there is adequate supply of ethanol (Hindustan Times 2004).

2.89 In August 2005, the government decided to revive the ethanol program, requiring E5 in nine states and four federally administered territories from October. The Indian Sugar Mills Association assured the government of adequate supply of sugarcane residue for making ethanol (Press Trust of India 2005). Centralization of pricing of ethanol and distribution policy is to boost fuel ethanol supply in India. The dispute on pricing of ethanol between the oil marketing companies and ethanol suppliers was resolved by agreeing to centralization of ethanol pricing and distribution policy. The price of ethanol to oil marketing companies was set at Rs 18.75 (US\$0.43) per liter (Financial Express 2005).

2.90 As for biodiesel, the Government of India also announced in September 2003 that it planned to stipulate up to 20 percent biodiesel blended in conventional diesel fuel by 2011–2012. The first tender for procurement of biodiesel, manufactured from *Jatropha* and *Karanja* plants, for the purpose of a first pilot project at Rewari took place at the end of 2003. However, only two parties submitted tenders and the bid prices were Rs 70 per liter against the retail diesel price in the neighborhood of Rs 20–25 per liter inclusive of taxes. The Ministry of Petroleum and Natural Gas decided to reduce the size of the pilot project and at the same time seek import duty exemption for the biodiesel used in the pilot (The Hindu 2003).

2.91 In early 2005, Gujarat became the first state to put biodiesel to commercial use. Gujarat State Road Transport Corporation, a state-owned transport utility, began commercial service of buses that run on a diesel blend containing 5 percent biodiesel from *Jatropha* (Renewable Fuel News 2005b). There are plans for constructing biofuel plants and some firms have set targets for planting *Jatropha*. In October 2005, Minister for Petroleum and Natural Gas Mani Shankar Aiyar announced that, beginning January 1, 2006, the public sector oil marketing companies will be purchasing biodiesel, using oil from *Jatropha* and *Pongamia* plants, at Rs 25 (US\$0.57) per liter. Initially, B5 will be marketed during trial runs, and the percentage of biodiesel blended will be increased in stages to 20 (The Hindu 2005).

Thailand

2.92 Thailand has annual surpluses of 2 million to 4 million tonnes of cassava and hundreds of thousands of tonnes of molasses, both suitable for conversion to ethanol. Thailand is also one of the world's largest exporters of sugar and ranks among the world's lowest-cost producers. The Thai government has launched a national program to convert surplus farm products into biofuels. As of late 2005, the government maintained a pricing policy that ensured that the retail price of gasohol would consistently be 1.5 baht (\$0.037) per liter lower than that of gasoline by reducing the excise tax and the oil fund levy on gasohol. Given that gasohol contains 10 percent ethanol, this difference amounts to \$0.37 per liter of ethanol. The sale of gasohol increased nearly an order of magnitude between January and mid-October in 2005 (Thai News Service 2005d).

2.93 The Thai government approved a package of tax incentives in 2000 to encourage more production of ethanol for fuel use. The package gives ethanol manufacturers an eight-year corporate tax holiday and allows them to import ethanol plant machinery without paying duties (Carbohydrate Economy 2000). For the following five years, income tax is 50 percent of the normal level. The package also exempts ethanol in gasoline from excise tax. Ethanol is to be used as E10, and can replace MTBE that is being imported. In late 2001, eight private companies were granted licenses by the Ministry of Industry to build ethanol production plants (Berg 2004). The first commercial fuel-grade ethanol plant, producing 25,000 liters a day, has been running since October 2003 in the province of Ayutthaya (Oxy-Fuel News 2004). There are two ethanol manufacturing plants operating today, both using molasses as feedstock (Dow Jones Commodity Service 2004). By early 2005, about 700 filling stations were reportedly selling gasoline blended with ethanol, 30 percent of which were in Bangkok (Thai News Service 2005a). Two additional

plants, with daily capacities of 130,000 liters and 500,000 liters, were under construction as of mid-2005. The two new plants would use cassava as the feedstock (Thai News Service 2005b).

2.94 Thailand was seriously affected by droughts in 2004 and raw sugar production fell 26 percent from the previous year (Reuters News 2005a). From the point of view of cane producers, the ethanol program lost its attractiveness in the face of falling supply of sugar on the domestic market and rising world sugar prices. The tight supply is expected to continue into 2005–2006. This illustrates the impact of weather variability on biofuel supply. The price of ethanol to oil marketing companies was fixed at 15 baht (US\$0.37) per liter in a three-month contract through September 2005 (Thai News Service 2005b). In negotiation with the government at the expiration of the contract, ethanol producers asked for an upward price adjustment to 17–18 baht (US\$0.41–0.44) per liter, but with the negotiated price becoming a reference rather than a fixed price to the buyers (Thai News Service 2005c). The two existing ethanol plants were facing a cost squeeze due to the doubling of the price of molasses to about 4,000 baht a tonne since the beginning of 2005. Based on the price of molasses, the cost-recovery price of ethanol was 19 baht (US\$0.46) a liter, resulting in a shortage of gasohol supply (Bangkok Post 2005).

3

Resource Costs of Biofuels

3.1 The greatest hurdle facing the biofuel industry is its high cost of production compared to conventional fuels. It is therefore important to understand the production cost build-up, where there is scope for large cost reduction, and the likely chances of such reductions. The biofuel production costs are functions of the feedstock cost (which depends on crop prices where crops are used), capital recovery cost for ethanol or biodiesel plants, processing costs, storage and transportation costs, and revenues from the sales of co-products.

3.2 The feedstock costs are currently closely linked to prices in agricultural commodity markets. These markets in turn are distorted at both the national and international level, characterized by significant government support for domestic producers in a number of high-income countries, high import tariffs, quantitative restrictions on imports, export subsidies, and preferential trade agreements extended to some countries. These distortions as well as their removal have potentially large effects on the biofuel industry. Important features of distortions in agricultural commodity markets are described first as background for interpreting the cost figures that follow.

3.3 This chapter discusses the different cost components—feedstock costs, processing costs that include investment costs, co-product use or sales—followed by overall costs, all net of tax. A description of the processes for ethanol and biodiesel production is given separately in annex 1. Because of the heavy reliance of all biofuel programs on tax concessions, the chapter then deals with fiscal considerations. It closes with environmental impacts of biofuel production as well as other economic impacts.

3.4 In discussing costs, it is worth bearing in mind that the exchange rates in some countries have fluctuated significantly in recent years. By converting prices to U.S. dollars, both domestic price changes and exchange rate changes are reflected. The recent weakening of the U.S. dollar has also meant that the oil price increase is smaller in countries that have strengthened against the U.S. dollar, such as Europe and Japan. The impact of the U.S. dollar-Brazilian real exchange rate is sufficiently important that the historical rates are given under “Currency Equivalents” at the beginning of this report to enable proper interpretation.

Agricultural and Trade Policies

3.5 The European Union (EU), the United States, and most other high-income regions of the world have agricultural policies that strongly protect domestic farmers. Australia is a notable exception. Developing countries to varying degrees also offer protection to farmers (although an equally common pattern has been to impose taxes or restrictions on farmers in favor of industry or of urban consumers). These policies have enabled countries with no comparative advantage in the production of a particular crop to begin and expand production. In some cases these policies have even enabled high-cost producers to export at the expense of much lower-cost producers. Growing concerns about mounting government support and the international pressure to liberalize domestic markets have led producers and governments alike to look for alternative markets for these crops. Biofuels are seen as one such alternative market. These policies have also affected both world crop prices, including crops that are used as feedstocks for biofuels, and their price volatility. It is useful to review the history and the current status of agricultural and trade policies so that biofuel industries in high-income countries can be understood in context.

3.6 Domestic support for farmers may boost production above market equilibrium, depress world prices, worsen the volatility of world prices, and reduce the scope for competition from imports. In 2003, estimates of producer support in countries belonging to the Organisation for Economic Co-operation and Development (OECD) were 32 percent of domestic market production value and 46 percent of production valued at world market prices. The share of developing countries' agricultural exports to industrial countries in fact fell from 25.8 percent in 1980–1981 to 22.9 percent in 2000–2001 (World Bank 2004a and 2004b, Beghin and Aksoy 2003). The majority of this support was provided through market price support, which is the most trade-distorting type of protection. Progress in reforms has been particularly slow in sugar. OECD support to sugar producers amounts to US\$6.4 billion, about the same as entire developing country exports, with the European Union, Japan, and the United States among the worst offenders.

3.7 The farm subsidies in the United States provide an interesting illustration. Since the New Deal era of the 1930s, farm subsidies were designed to support reasonable prices for farm products by paying farmers for not overproducing crops. But the 1996 Freedom to Farm Law introduced a simpler subsidy program and provided fixed, but declining, payments to eligible farmers through 2002, regardless of market prices or production volume: producers are paid for every bushel of subsidized crops by the government. This law separated federal income support from planting decisions and market prices. If the market price of the crop fell, subsidy payments increased to make up the difference. With no check on production and a guaranteed price for their products, farmers produced as much as they could, irrespective of demand. Between 1996 and 2000, oversupply halved the price that food manufacturers paid for grain. Between 1995 and 2002, about US\$90 billion of U.S. tax was spent to boost the incomes of farmers producing crops including rice, soybeans, sugar, wheat, and, above all, maize, and to a much lesser extent of livestock farmers. Between 1995 and 2003, US\$37.4 billion was paid to maize growers alone (EWG 2004).

3.8 High support prices through price intervention and high external tariffs in the European Union have provided strong incentives to invest in domestic agriculture, resulting in significant productivity increases. The European Union turned from being a net importer of wheat and sugar in the 1960s to a net exporter of wheat and sugar by the 1990s. Because the support was tied to production and exports, the EU outlays on agriculture rose rapidly. The outlays grew from €3 billion in 1975 to a peak of €41 billion in 1996, excluding government spending on agriculture by individual member countries. Agriculture at one point accounted for as much as 70 percent of the EU budget. In 2000, agriculture made up 51 percent of the budget. Grains, oilseeds, and protein crops in turn account for almost half of the EU agricultural expenditures (USDA 2002b). In order to lower production, grain and oilseed producers must set aside 10 percent of arable land to be eligible for direct payments, but production of crops for non-food purposes, such as biofuel production, is permitted on set-aside land.

3.9 Developing countries generally have low levels of domestic support, in part on account of budget constraints, but use tariffs to protect domestic production. Average import tariffs in agriculture and food range from 11 to 34 percent in developing regions and 17 percent in industrial countries. South Asia has the highest average tariff, 34 percent, followed by sub-Saharan Africa. Latin America and the Caribbean have the lowest average tariff, 11 percent. The share of developing countries' exports in world agricultural trade stagnated at about 35 percent between 1980–1981 and 2000–2001, with the share of trade among developing countries increasing but that between developing and industrial countries declining. By way of comparison, average tariffs on manufactured goods range from 4 to 24 percent in developing countries and only 2 percent in industrial countries. The share of developing countries' exports in manufacturing during the same period grew from 19 percent to 33 percent (World Bank 2004a). These statistics show the much higher protection given to domestic agriculture compared to the manufacturing sector, and the large adverse impact of such protection on farmers in developing countries. Reductions in the highly protected regimes of industrial countries will offer large gains for developing countries, but lowering high barriers in South-South trade in agriculture and food will also be helpful.

3.10 Because government interventions in the production of sugar, an important feedstock for ethanol manufacture, are common, it is worth reviewing historical and recent trends. Among large producers of sugar—Australia, Brazil, China, Cuba, European Union, India, Mexico, Thailand, and the United States—nearly all intervene in the sugar trade in ways that affect international prices with the exception of Australia, Brazil, and Cuba. Preferential trade arrangements have shaped some small economies. For example, sugarcane production—destined for the United States and the European Union—occupies nearly half of the arable land in St. Kitts and Nevis. The consensus of industry analysts is that market interventions lower world prices significantly while increasing price volatility. Developing country governments have attempted to protect domestic sugar industries, resulting in higher consumer prices in countries such as Chad and Ukraine, and by giving input subsidies in others such as China and India. Even if input subsidies are given to all farmers, sugar growers may benefit disproportionately. Taking India as an example, sugar production requires more water, power, fertilizer, and credit than other crops, and the

subsidies given for these inputs favor sugar over other crops. A number of countries have also historically subsidized sugar exports. These protection measures can cost an enormous amount. For example, before reforms commenced, policy interventions were costing Brazil an estimated US\$2.5 billion annually. A study conducted in the mid-1990s indicated that continuing the existing policies in India could cost the economy about US\$2 billion a year by 2004 (Larson and Borrell 2001).

3.11 Despite liberalization efforts, about 80 percent of world sugar trade remains at subsidized or protected prices. Only Australia, Brazil, and Cuba—accounting for 25 percent of world production and 70 percent of world trade in the 2004–2005 season—have sugar sectors that produce and operate at world market price levels. The rest rely on production subsidies, export subsidies, or preferential access to protected markets. In India, sugar prices are about 50 percent higher than world market prices on account of minimums established by the central government and higher prices advised by state governments. In Mexico, pricing and production liberalization in 1995 was accompanied by a doubling of tariffs on raw sugar and a 74 percent increase in tariffs on refined sugar, resulting in a 60 percent increase in domestic sugar prices. Thailand maintains high domestic sugar prices by means of quotas and import tariffs, although costs of production are among the lowest in the world. China’s import restrictions keep domestic sugar prices nearly as high as those in the United States (Mitchell 2005a).

3.12 Although there are substantial variations in effects across commodities and countries, liberalizing agricultural trade by reducing barriers and subsidies would benefit developing countries considerably because, on the whole, they have a strong comparative advantage in agriculture. Studies suggest that trade distortions seem more important and prominent in most markets than domestic distortions. Trade distortions are more widespread and large in absolute terms. They block trade flows directly (for example, sugar tariff rate quotas), distort markets with inefficient production, and tend to induce larger price effects than domestic programs. Trade distortions also underpin many domestic policies, many of which would not be feasible or fiscally sustainable without trade barriers. As such, trade opening disciplines domestic policies (Beghin and Aksoy 2003).

3.13 Agricultural trade liberalization would induce significant price increases for most commodities. Not all countries would benefit. Some would be harmed by the loss of preferential trade agreements and higher prices paid by domestic consumers. Consumers in highly protected markets, on the other hand, would benefit enormously from trade liberalization because of lower prices and greater product choice. In general, enhanced trade and integration with the world economy are important for agricultural growth, rural development, and poverty reduction. Although agriculture represents a relatively small share of world output, studies suggest that a disproportionate portion of the gains from future trade reforms would come from removal of barriers in agriculture (Beghin and Aksoy 2003, World Bank 2004a).

3.14 The impact of agricultural market liberalization and removal of subsidies and production will differ between domestic and world prices. For example, complete liberalization of sugar markets would raise world prices by about 40 percent, raise prices in Brazil, but lower prices by 65 percent in Japan, 40 percent in Western Europe, and 25 percent in the United States (Mitchell 2005a). One model simulated the impact of

multilateral reform assuming supply elasticity in Brazil of 2.0—that is, if the price of sugar increases by 10 percent, Brazil, which accounted for one-half of the world’s sugar trade in the 2004–2005 season, would increase supply by 20 percent. The results still provided a global price increase of 30 percent. The model did not take into consideration an increase in demand for sugarcane from new fuel ethanol markets, and assumed instead that demand increase would be limited to the sugar sector. Based on these results, it appears reasonable to conclude that prices would rise by 30–40 percent. The price increase would occur as a result of a combination of time required for suppliers to adjust, the reduction in supply from high-cost producers such as those in the Caribbean, and the increased demand from the highly protected OECD markets (Mitchell 2005b). The price increases might be short-lived because of Brazil’s potential to expand production, but the supply-demand imbalance would be exacerbated if demand for ethanol were to increase in parallel. In the short term, some of the additional sugar supply on the world market might even come from a reduction in ethanol production in Brazil, as seen previously in times of high sugar prices. With growing use of flex-fuel vehicles, the adverse effect of lower ethanol production in Brazil will not be as detrimental as in the past. The impact of trade liberalization on the ethanol market will be moderated. Liberalization of maize markets would raise world prices slightly and probably lower prices in the United States. These observations should be borne in mind when evaluating feedstock options for biofuels. The rest of the chapter considers financial (that is, not accounting for the impact of direct and indirect subsidies), and not economic, costs.

Feedstock Costs

3.15 The suitability of any potential feedstock for biofuel production depends on

- Its physical and chemical characteristics and how well they satisfy the criteria for production, yield, and purity
- Competition for the feedstock by other users and markets (which affects its price)
- The consistency and reliability of supply
- The quantity available within a reasonable distance of a biofuel production facility (to minimize the transportation cost).

3.16 Sugar, maize, wheat, rapeseed, and soybeans are in the human food chain or used as animal feeds. As such, their prices depend on supply and demand on the food or animal feed market, making these feedstocks both relatively expensive and their prices highly variable. Because crop and crude oil prices do not necessarily move together—although transportation costs do increase with increasing crude price and, in the 1970s and 1980s, fertilizer prices moved with energy prices, both pushing up crop prices—in times of high crop and low crude oil prices, biofuels become uncompetitive. When crop prices are high, farmers have a much greater incentive to sell crops at the high crop price on the domestic or international market than to sell them at discounted prices to biofuel producers. This phenomenon has in the past led to periodic shortages of ethanol in Brazil, damaging the fuel ethanol market and the reputation of the industry.

3.17 Around 2001, the gross feedstock cost per liter of ethanol was about US\$0.23–0.24 for U.S. maize, US\$0.08 for Brazilian sugarcane (Berg and Licht undated), €0.20–0.32 for EU sugar beet, and €0.22–0.34 for EU wheat (Enguíanos and others 2002). In Brazil, the cost of the feedstock for ethanol in mid-2005 fell within the range of US\$0.13 to US\$0.18 per liter (Nastari 2005a). Maize in 1995 reached US\$5 per bushel in the United States, making the feedstock cost alone equivalent to US\$0.50 per liter in the most efficient plant, pricing maize-derived ethanol out of the market even with government tax exemptions. The U.S. Farm Security and Rural Investment Act of 2002 guaranteed a floor price of US\$2.60 per bushel of maize in 2002 and 2003, and US\$2.63 a bushel in 2004–2007 for the purpose of calculating the counter-cyclical payments to maize growers (see chapter 2). As a rule of thumb, a bushel of maize produces about 2.6 to 2.8 gallons of ethanol. Maize prices in central Illinois in the United States averaged US\$1.92 per bushel in the 2001–2002 marketing year, US\$2.35 in 2002–2003, and an estimated US\$2.60 in 2003–2004. At 2.7 gallons per bushel, these would correspond to a gross feedstock cost of US\$0.19, 0.23, and 0.25 per liter of ethanol, respectively. High gross feedstock costs make commercial use or revenues from sales of co-products crucial to make bioethanol competitive.

3.18 Rapeseed and soybeans are the two most commonly used feedstocks for biodiesel today. Rapeseed has a higher oil content than soybeans. They both have alternative markets as cooking oil and food, pushing up their prices. Rapeseed produces about 435 liters of biodiesel per acre, but high-yield rapeseed can produce as much as 550 liters. Soybeans produce about 160 liters per acre. Other feedstocks for biodiesel include sunflower oil, palm oil, linseed, olive oils, cottonseed oil, and coconut oil, all of which have alternative markets. Sunflowers can produce 280 liters of biodiesel per acre, palm oil as much as 975 liters. These oils can fetch US\$400–500 per tonne, or US\$0.45–0.55 per liter. Each liter of oil in turn produces approximately a liter of biodiesel. In other words, the gross feedstock cost for biodiesel from these oils can be approximately US\$0.50 per liter. This is one of the factors that make biodiesel from plant oils expensive. In fact, before adding operating and capital recovery expenses for the transesterification plant, normal market prices of most plant oils are higher than the market price of diesel fuel even as of mid-2005. For example, the soybean oil prices were US\$550 per tonne in August 2005, and expected to rise to US\$580 per tonne by mid-2006, corresponding to US\$0.58 and US\$0.61 per liter of biodiesel in gross feedstock cost, respectively (Reuters News 2005b). As for waste oils and greases, large, high-paying markets often already exist for rendered products such as edible and inedible tallows, lards, and various grades of grease. As such, large-scale conversion of these feedstocks to biodiesel is likely to require additional incentives for biodiesel production.

3.19 One way of lowering the feedstock cost for a given crop is to increase yield per acre with little additional cost. This can be achieved through moving to more fertile areas (potentially displacing other crops); use of genetically modified seeds; and optimal application of fertilizers, pesticides, and herbicides. In areas with little use of fertilizers, pesticides, and herbicides, this could mean their greater application, but the push in most high-income countries is to reduce these inputs and hence costs without lowering yields. In Brazil, the sugarcane yield increased from an average of 63 tonnes per hectare in 1990–

1991 to 66 tonnes per hectare in 2002–2003 (Schmitz and others 2002). In the Center-South region of Brazil today, the annual yield is 82.4 tonnes of sugarcane per *harvested* hectare, and assuming five harvests between replanting, this translates to an overall annual yield of 68.7 tonnes of sugarcane per hectare. Similarly U.S. maize yield increased from 86 bushels per acre in 1975 to 142 bushels per acre in 2003 (University of Illinois Extension 2005). The yield reached a historic high of 160 bushes per acre in 2004 but fell to 140 in 2005 (USDA 2005b). Genetically engineered crop varieties are relatively new and can dramatically increase yields. They are not without controversy; there are concerns about long-term effects of genetically modified crops in general and whether cross-pollination can be prevented.

3.20 With respect to ethanol production, the greatest promise for the future lies in lowering the processing cost of cellulosic biomass resources. Those that could in principle lower the feedstock cost include

- Agricultural residues such as sugarcane trash (crushed stalks, leaves and stem tips), maize stover (stalks, leaves, cobs, and husks), wheat straw, and rice straw
- Forest materials such as forest thinnings and slash
- Wood mill residues
- Energy crops such as switchgrass or fast-growing trees
- Urban waste such as waste paper, urban wood waste, tree trimmings, and grass clippings.

However, these materials must be collected, processed, and transported to conversion facilities, which requires truck drivers and collection and receiving personnel. It should be noted that some agricultural residues should be returned to the soil to maintain fertility and build up soil carbon levels.

3.21 Although the cellulosic materials listed above are not in the human food chain or used as animal feed, there are competing markets. For example, some of the wheat straw in the Northwest in the United States is exported to Japan as livestock feed, so that the price paid to wheat farmers must match the export price. Similarly, urban wood waste can be used to make particle wood and other construction-related materials. An alternative to collecting and delivering rice straw to an ethanol plant is to burn it, or if burning is banned, to plow the rice straw into the soil; farmers would need an incentive to collect and transport rice straw. Municipal waste paper can be recycled, and can command a higher price when remanufactured into paper products. Wood mill residues are often burned to generate electricity and heat used on site or sold to others. Fast-growing trees present another feedstock option, but the pulp and paper market may pay more than what ethanol producers would or could bear. Grass crops make sense if there are no higher value uses for the land.

3.22 The focus on research and development (R&D) for cellulosic ethanol is corn stover in the United States and sugarcane trash in Brazil. The volume of available corn stover is very large—roughly equivalent to corn grain, the largest crop in the United States—and it is already there, largely unused, requiring little additional investment or resources to produce it. Corn stover can be dried and used as fodder. Similarly, sugarcane

trash is currently unused and burned in the field for the most part. Low-cost conversion of these materials to ethanol would increase the cost-competitiveness of corn- and sugarcane-derived ethanol. Commercially viable ethanol production will likely require that the ethanol plant be located within tens of kilometers of the source of biomass. This may present a challenge for biomass collected solely to make cellulosic ethanol: a sufficient quantity of feedstock at a low enough cost is needed within a certain radius of a processing plant to make production economically viable. For corn stover and sugarcane trash, collection and transportation may be easier because the infrastructure for transportation and processing already exists.

3.23 For developing countries, biomass that can grow on marginal land with little input and rainfall, such as *Jatropha* or honge nuts, may provide an attractive alternative as a feedstock for biodiesel. High-yield varieties of *Jatropha* have been found in Mexico and Mali. Wild *Jatropha* grows in many countries and in fact thrives on infertile soil. A good nut crop may be obtained with little effort after two to five years, depending on soil quality and rainfall. The nut kernels contain about 60 percent oil, which can be extracted and processed into biodiesel. As with ethanol, transportation costs limit how far potential feedstocks can be transported. Biomass growing on marginal land with little input does not automatically translate into low feedstock costs. A paper examining the economics of *Jatropha* plantations in India reports that the gross cost of the feedstock alone could be equivalent to US\$0.37 per liter of biodiesel from *Jatropha* seeds (Francis and others 2005).

3.24 There is no large-scale plantation of *Jatropha* for biodiesel manufacture today. There are questions that need to be addressed to assess economic viability of *Jatropha*-derived biodiesel, including

- Oil yield per hectare (or crop yield and oil content of the seeds), which depends on climatic and soil conditions
- Stability of the harvested seed and oil, which will determine the optimal size of the processing plant and storage space, and the plant utilization rate, which will affect the economics of plant construction
- Amount of labor needed to grow, harvest, and transport the plant seeds to the processing plant
- Environmental impact of extensive monoculture.

Site-specific questions include whether there is adequate infrastructure (to accommodate laborers and for transporting seeds and oil) to support biofuel production, the distance from and road infrastructure to energy consumption centers, and, where harvesting may require migrant laborers, whether the areas surrounding *Jatropha* plantations can absorb the seasonal laborers.

3.25 Lastly, it is important to note that all forms of biomass have alternative uses, and especially in marginal areas, they are often highly valued for fuel and animal feed. Also, infrastructure and other services tend to be poor in marginal areas, which can raise the transport and other expenses incurred getting the fuel to the market and limit the economic scale of production.

Processing Costs

3.26 There are two principal cost components for any industrial processing. One is the capital cost (including debt service) for the construction of the plant, and the other is plant operation (which includes the feedstock costs discussed in the preceding section) and maintenance. The plant construction cost depends on the technology used to produce the biofuel and also the extent to which air and water emissions are controlled.

Ethanol

3.27 One estimate of the processing cost for manufacturing ethanol from sugarcane in Brazil is US\$0.04 per liter of ethanol, not including capital cost recovery and feedstock cost (Laydner 2004); of this amount, 70 percent is the variable cost, with the balance as fixed cost. This is markedly lower than the corresponding costs in the United States or Europe. In Brazil, a new mill/distillery complex with a nameplate capacity of 2.16 million tonnes of sugarcane per year costs about US\$60 million (as of mid-2005). Assuming a tonne of sugarcane produces 80 liters of ethanol and half of the capacity is used for ethanol production, this plant can produce 86 million liters of ethanol a year operating at full capacity (Nastari 2005a). An opportunity cost for capital of 8–10 percent and a lifecycle of 20 years for the plant adds US\$0.04 per liter to the cost of production at full plant utilization. In practice, plants do not run at full capacity. Taking the nation-wide average utilization rate of 86.5 percent in 2004 (Nastari 2005a), capital cost recovery increases to US\$0.05 per liter.

3.28 The U.S. ethanol yield per bushel of maize has been steadily increasing, from less than 2.4 US gallons per bushel in the 1970s to 2.6–2.8 US gallons per bushel by the mid-2000s, depending on maize's starch content and the process efficiency. The main operational cost components are utility (energy and water), chemical, and labor. A 2002 publication (Novozymes and BBI International 2002) documents the following cost reductions between the 1970s to 2000 in the United States:

- Utility costs declined from about US\$0.22 per gallon (US\$0.06 per liter) to US\$0.14 per gallon (US\$0.04 per liter) of ethanol produced, due largely to improved yields and increases in plant size.
- Labor costs declined six-fold, from US\$0.24 per gallon (US\$0.06 per liter) to US\$0.04 per gallon (US\$0.01 per liter), as a result of computer automation and increasing plant size.
- Chemical costs increased, leveling off at about US\$0.09 per gallon (US\$0.024 per liter).

More recent publications (R.W. Beck, Inc. 2004a and 2004b) give utility costs ranging from US\$0.12 to 0.22 per gallon of ethanol produced (US\$0.03 to 0.06 per liter) depending on the products produced, equipment efficiency, use of internal electrical power generation, and regional energy costs; chemical costs ranging from US\$0.06 to 0.14 per gallon (US\$0.02 to 0.04 per liter); and labor costs from US\$0.04 to 0.11 per gallon (US\$0.01 to 0.03 per liter). Since 1987, these operating costs have fallen more than 15 percent. Typical operating costs in 2004 were US\$0.53 per gallon (US\$0.14 per

liter) of ethanol produced at plants with an annual capacity smaller than 30 million gallons (114 million liters) and US\$0.41 per gallon (US\$0.11 per liter) at larger plants.

3.29 The average U.S. dry mill size increased eight-fold from the 1970s to 2000, contributing to the halving of the capital cost on the basis of the annual volume of ethanol produced, from US\$2.50 per gallon (US\$0.66 per liter) of ethanol produced per year to US\$1.30 per annual gallon (US\$0.34 per liter) (Novozymes and BBI International 2002). Standardized design of dry mill facilities has reduced the capital cost. Some plants today are reported to cost about US\$1.10–1.25 per annual gallon of ethanol produced (US\$0.29–0.33 per annual liter). Additional equipment to generate steam and electricity on site will add approximately 15–20 percent to the installed costs (R.W. Beck 2004b).

3.30 One barrier to commercialization of cellulosic ethanol has been the high overall cost of enzymes, used to convert cellulose to sugar. Recent advances have lowered the cost of enzyme from about US\$5.00 per gallon (US\$1.32 per liter) of ethanol produced to US\$0.10–0.20 per gallon (2.6 to 5.3 US cents per liter) in laboratory trials for conversion of maize stover to ethanol. This cost reduction, if the process can be scaled up, would reduce the cost of ethanol production from maize stover further to about US\$2.00 per gallon.

3.31 The National Renewable Energy Laboratory has identified biorefineries—facilities that integrate biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass—as the most promising route to the creation of a new domestic bio-based industry. Economies of scale are particularly important for biorefineries producing ethanol from cellulose. Construction of a commercial-size biorefinery has been estimated to cost about US\$200–250 million (Greer 2005). The National Renewable Energy Laboratory estimated earlier that a biorefinery with an annual capacity of 70 million gallons (260 million liters) would cost about US\$200 million (NREL 2002).

3.32 Ethanol from wheat in Europe carries a combined operating, maintenance, and capital recovery cost of about €0.28 per liter and from sugar beet about €0.22 per liter. (Enguítanos and others 2002). These costs are comparable to feedstock costs, so that feedstock and operating costs contribute about equally to the total production cost.

Biodiesel

3.33 The technology for extracting oil from plant seeds has remained the same for the last decade or two. Transesterification of oil with alcohol is a relatively simple process, but offers little scope for efficiency improvement. As a result, processing costs are not envisaged to fall markedly in the coming years.

3.34 A study by the International Energy Agency (IEA) gives the transesterification cost of US\$0.20 per liter of biodiesel in small scale plants and US\$0.05 per liter in large scale plants (Fulton and Howes 2004). The U.S. Energy Information Administration (U.S. EIA) estimates the operating expenses for transesterification to be about US\$0.31 per gallon (US\$0.08 per liter) in 2002 U.S. dollars. Energy costs added another \$0.16–0.18 per gallon (US\$0.04–0.05 per liter) (Radich 2004). A German study gives €0.18 per liter of biodiesel as typical processing costs when the transesterification plant is not in close proximity of an oil mill, and €0.15 per liter when oil extraction and

transesterification occur at the same site. Of these, the cost of transesterification is €0.06–0.09 per liter (Schöpe and Britschkat 2002). Examples of U.S. estimates of processing costs (including oil extraction but excluding feedstock costs) range from US\$0.15 per liter of biodiesel plus US\$0.09 per liter for overhead, or a total of US\$0.24 per liter, to US\$0.08–0.16 per liter in total (Coltrain 2002). A German study of a biodiesel plant based on *Jatropha* in India estimated the oil extraction cost to be US\$0.019 per liter of biodiesel and transesterification cost to be US\$0.12 per liter (Francis and others 2005).

Co-Product Sales and Use

3.35 Co-product sales are crucial in the biofuels industry. However, rapid expansion of biofuel production can flood the market with co-products, exerting downward pressure on their prices. This has been observed with both distiller's dried grains with solubles (DDGS)—a high-protein animal feed—and glycerine.

3.36 In the United States, DDGS prices declined from the mid-US\$120s per short ton in 1993 to US\$80 per ton in 2003, reducing the contribution of DDGS to total revenues earned from ethanol production from nearly 25 percent to a range between 15 and 20 percent. DDGS prices appear to have stabilized over the past five years because they are nearing the value of maize on a unit weight basis, which serves as a floor to DDGS prices (Kapell 2003). DDGS prices in the first half of 2005 were US\$70–80 per ton (Morris and others 2005). By September 2005, DDGS prices had fallen further to less than US\$70 per ton (Renewable Fuel News 2005c).

3.37 Ethanol from wheat also produces DDGS as a by-product. The income from the by-product sale in the European Union can generate €0.11–0.14 per liter of ethanol according to one estimate. The contribution of the sale of by-products in ethanol production from sugar beet is negligible (Enguidanos and others 2002).

3.38 An important by-product of biodiesel manufacture is glycerine. The market for glycerine has been quite volatile in the past. Glycerine markets in most countries are likely to become saturated if biodiesel production grows significantly. Glycerine can fetch the equivalent of US\$0.05–0.10 per liter of biodiesel at present, but if there is oversupply, the biodiesel producer may earn significantly less from glycerine sale. A 2004 U.S. EIA study estimated that the sale of glycerine would generate US\$0.15 per gallon (US\$0.04 per liter) of biodiesel in 2004–2013 (Radich 2004).

3.39 Residual biomass can be burned to generate steam or power, which can lower or eliminate external energy purchases by the processing facility. In some cases, excess power can be sold to the grid, a situation that is often inhibited by inflexible power purchase regulations. The use of bagasse to fuel sugar mill and distillery complexes in Brazil, including the ability to sell excess power to the grid, has significantly improved the economics of both sugar and ethanol production.

3.40 If ethanol production from cellulosic materials can be commercialized, one co-product is lignin. Lignin, depending on the quality, can be processed into specialty products such as plasticizers, extractives, electrically conductive polymers, or phenolic-resins, which can be used as glues or binders in the production of plywood and fiberboard.

Overall Cost

3.41 The technologies to produce ethanol from sugarcane and grains and biodiesel from oil seeds are mature with cost structures that are fairly well understood. Incremental improvement is continuing, but major technical breakthroughs under current processes are not expected. Thus, future costs are likely to be similar to the costs of production observed today.

3.42 The cost of ethanol production in Brazil at the exchange rate prevailing in mid-2005 (R\$2.40 = US\$1.00) is in the neighborhood of US\$0.25 per liter. Much lower figures have been reported in the past. For example, the U.S. Department of Agriculture (USDA) reported in 2003 that some analysts believed that the costs of producing ethanol in the Center-South region of Brazil was about US\$0.15 per liter (USDA 2003). The rise in the cost of ethanol production is primarily as a result of depreciation of the U.S. dollar against the Real, and does not mean that the ethanol industry in Brazil has become less competitive. It should be noted that the recent rise in the world price of gasoline is also in part due to depreciation of the U.S. dollar against other major currencies. The cost of ethanol production in the Center-South of Brazil is estimated to be US\$0.23 per liter, and 10–25 percent higher in the North-Northeast. When different fuel economies are taken into account, the range for the estimated cost of ethanol production—US\$0.23–0.29 per liter—widens to US\$0.29–0.41 per liter of gasoline equivalent.

3.43 In the United States, the combined (financial) cost of dry mill plant operation/maintenance and feedstock purchase fell steadily from 1996—when the price of maize was very high—to about US\$1.10 per gallon (US\$0.19 per liter) in 1999, but has since been rising and was about US\$1.50 per gallon (US\$0.40 per liter) in 2004. The capital investment cost adds another U.S. cent or two per liter. This is considerably higher than the cost of production in Brazil. Higher costs come from having to convert starch into sugar first, higher gross feedstock cost, and the need to purchase power (in contrast to the energy self-sufficiency of most distilleries in Brazil thanks to the use of bagasse, a by-product). The higher gross costs are partially offset by by-product sales, amounting to an estimated 24 percent of the total revenue in 2004 (R.W. Beck, Inc. 2004b). For any given plant size, production costs decrease with increasing capacity utilization. Capacity utilization in the United States has remained near 85 percent over the past decade (Kapell 2003). Increasing capacity utilization would help to lower the cost of production further, but as of 2005 the opposite situation persisted—excess capacity was driving down ethanol prices, leading industry analysts to predict that small producers lacking economies of scale might exit the industry (Platts Oilgram News 2005).

3.44 In the European Union, according to one estimate, ethanol production costs range from €0.36 to €0.48 per liter if the feedstock is wheat, and from €0.42 to 0.54 per liter if the feedstock is sugar beet (Enguíanos and others 2002). These cost figures are considerably higher than ethanol production in Brazil or the United States. The production costs in the EU candidate countries are comparably high. A 2003 EU report quotes ethanol production costs of €0.36 per liter in Bulgaria, €0.56–0.57 in the Baltics, and €0.60 per liter in Poland (Kovalov and others 2003).

3.45 In Germany the cost of biodiesel production from rapeseed is about €0.50–0.64 per liter (Schöpe and Britschkat 2002). In the EU candidate countries, the cost of biodiesel production is about €0.41–0.42 per liter in the Baltics, €0.65 in Hungary, €0.75 in Poland, and €0.70 in the Slovak Republic (Kovalov and others 2003).

3.46 A 2004 U.S. EIA study estimated production costs of biodiesel from soybeans in 2004–2013. Because there is currently excess production capacity in the biodiesel industry, no additional capital investments were assumed to be necessary. Excluding capital, biodiesel production costs averaged US\$0.68 per liter in 2002 US dollars during this period. If capital expenditures were added, the average cost would rise to US\$0.72 per liter, assuming full plant utilization (Radich 2004). Another study estimated the cost of production of biodiesel from soybean oil to be US\$0.48–0.73 per liter, corresponding to soy oil prices of US\$330–550 per tonne (Coltrain 2002).

3.47 A study of a biodiesel plant based on *Jatropha* in India yielded a biodiesel cost of US\$0.40 per liter if by-product sale credits of US\$0.08 per liter of biodiesel for glycerine and US\$0.05 per liter for animal seed cake can be assumed. If by-product prices fall markedly as a result of oversupply, then the ex-factory price of biodiesel could be as high as US\$0.53 per liter (Francis and others 2005).

3.48 A review of biofuel production costs in 2002 gave the estimates for various biofuels shown in Table 3.1 (AEA Technology 2003). The cost of ethanol production varies from the low of US\$0.19 per liter in Brazil to the high of US\$0.51 per liter from beet sugar in the European Union. The cost of ethanol production from maize in the United States in this study is even lower than the optimistic projections given by the U.S. ethanol industry. The cost of biodiesel production is much higher, and without dramatic cost reductions in the foreseeable future, the price of crude will need to increase further from the level in mid-2005 before biodiesel can compete with petroleum diesel.

Table 3.1 Biofuel Cost in 2002 in US\$ per Liter

<i>Fuel</i>	<i>Feedstock</i>	<i>Location</i>	<i>Cost</i>
Biodiesel	Oil seeds	US	0.50
	Oil seeds	EU	0.62
Ethanol	Sugarcane	Brazil	0.19
	Maize	US	0.23
	Wheat	EU	0.45
	Sugar beet	EU	0.51
	Straw - acid hydrolysis	EU	0.62
	Wood - acid hydrolysis	US	0.32

Note: Original costs in Pound Sterling converted to US\$ using the average exchange rate for calendar 2002.

Source: AEA Technology 2003

3.49 There has been considerable interest in conversion of cellulosic materials to ethanol. However, the advances in scientific work have not been as rapid as initially anticipated. The U.S. Department of Energy (DOE) has revised its targets several times, and even the most recent estimate does not envisage achieving the current cost of ethanol production in Brazil for another four decades. In 2003, the Office of the Biomass Program set the target of 2010 for cutting the cost of production of ethanol from maize stover to US\$1.32 per gallon (US\$0.35 per liter) (U.S. DOE 2003). In 2004, the cost of ethanol production based on a conceptual design (so-called State of Technology cost) was calculated to be US\$2.50 per gallon (US\$0.66 per liter). The two indicative targets set at that point were a Biomass Program target of US\$1.87 per gallon (US\$0.49 per liter) by 2010 and a market target of US\$1.09 per gallon (US\$0.29 per liter) by 2020. A production cost of US\$0.80 per gallon (US\$0.21 per liter) by 2030 at the gate of advanced integrated biorefineries was also suggested (Schell 2004). The Biomass Program target has been modified further. As of mid-2005, it was US\$1.75 per gallon (US\$0.46 per liter) by 2010–2012, and 2040–2050 was considered more realistic for achieving cost reduction to US\$0.80 per gallon (Kaempf 2005, Ferrell 2005). It is worth noting that the long-term target of US\$0.80 per gallon is only slightly below the cost of ethanol production in the Center-South of Brazil today.

Retail Prices and Tax Considerations

3.50 Tax¹⁵ considerations have been essential for creating a market for biofuels because biofuels have almost always been more expensive, and sometimes markedly so, to produce than petroleum fuels, which usually bear substantial taxes and are an important source of government revenue. The most common form of fiscal assistance is excise duty reduction or elimination. Other measures include giving low-interest loans and tax holidays to firms engaged in biofuel production, levying lower corporate taxes on ethanol producers, outright subsidies, and tax reductions on vehicles specifically manufactured to run on biofuels (as with cars powered by hydrous ethanol in Brazil). Differential fuel taxation in turn creates opportunities for tax evasion, as will be seen in the case of Brazil below. Tax exemptions, allowances, credits, deferrals, and relief are known as tax expenditures. Tax considerations in biofuel production are also inevitably linked to agricultural subsidies, and these are discussed at the end of this section.

3.51 Governments have taken two different approaches to fiscal incentives. One is to provide fiscal assistance to make the retail prices of biofuels no higher on average than those of petroleum fuels. The tax credits given to ethanol in the United States have had this effect. The other is to make biofuels cheaper than pure petroleum fuels to encourage their uptake and continuing use. The government of Brazil has followed this approach with respect to hydrous ethanol in its ethanol program, as has the government of Germany with respect to biodiesel. When introducing a new fuel that the public is not familiar with, offering price incentives to consumers is one way of drawing consumers away from conventional fuels and ensuring a steady expansion of the biofuel market, but a

¹⁵ Tax here is defined broadly to include taxes, levies, fees, and contributions collected by the government as part of general revenues.

“permanent” tax reduction (which is what is observed worldwide for biofuels) raises serious questions about the long-term viability of the industry.

3.52 In rare occasions, such as with biodiesel in the United States until 2005, a biofuel is not given a favorable tax treatment (although there are significant upstream subsidies for U.S. soybeans), making it much more expensive than petroleum fuels. Biodiesel still had a market presence, even if limited, in the United States prior to 2005 because of the conscious decisions by the federal and state government agencies to run their fleets on biodiesel despite the higher fuel cost, and because of mandates and incentives for alternative fuels. In theory, in the presence of quantitative restrictions—that is, if a fuel is mandated in some fashion, as in the case of ethanol in Brazil, certain provinces in China, some states and Union Territories in India, and now in the United States under the Renewable Fuels Standard—special tax considerations need not be given, since users have no choice but to use the fuel, however expensive. The government may still decide not to let the fuel price rise markedly. Aside from winning consumer acceptance, the government may have concerns about the impact of higher fuel prices on the economy or on the poor. Because the direct and indirect expenditures on gasoline usually constitute only a very small fraction of the total expenditures by the poor in developing countries, the impact of higher gasoline prices as a result of blending ethanol into gasoline is unlikely to have a serious adverse impact on the poor. However, as will be discussed, the loss of gasoline tax revenues resulting from tax exemptions may have fiscal impacts in developing countries that could affect the poor.

3.53 Three largest biofuel markets in the world—ethanol in Brazil and the United States, and biodiesel in Germany—provide useful illustrations of the extent of fiscal incentives given to establish these markets. All of them use tax expenditures as one policy component. Unlike direct expenditures, tax expenditures are usually not included in annual budget reviews and, once enacted, are seldom subjected to the same level of fiscal analysis carried out on direct expenditures. While lesser attention given to tax expenditures may help biofuel producers, the need to evaluate all expenditures from the point of view of cost-effectiveness and national priorities remains.

3.54 In Brazil, the gasoline/anhydrous ethanol blend carries much higher taxes than hydrous ethanol. There are more than 300 ethanol producers, making ethanol taxation more problematic than gasoline taxation where there are only three refiners (Petrobras, Repsol, and Ipiranga). To minimize tax evasion, the government has taken all taxes off anhydrous ethanol and transferred them to gasoline so that there are only three points of tax collection for gasoline, namely the three refiners. The tax structure for the gasoline-ethanol blend in June 2005 is shown in Table 3.2. The total “tax” amounted to about US\$0.42 per liter of the blend.

3.55 Hydrous ethanol carries a much lower tax than gasoline. The price structure varies from state to state. The structure in the state of São Paulo as of June 2005 is shown in Table 3.3. São Paulo is selected for illustration purposes because it accounts for more than one-half of total hydrous ethanol consumption in the country (ANP 2005). The government’s policy has always been to make the retail price of hydrous ethanol markedly lower than that of gasoline-ethanol blends through differential taxation.

Table 3.2 Gasoline-Ethanol Blend Price Structure in Brazil in June 2005
Price for 1,000 liters

<i>Item</i>	<i>R\$</i>	<i>US\$</i>
Gasoline commodity price	890	366
CIDE	280	115
PIS/PASEP & COFINS	261	107
ICMS Refinaria	477	196
ICMS substituição Tributaria	331	136
Ex-refinery price	2,239	921
Commodity price of anhydrous ethanol	657	270
Freight cost for anhydrous ethanol	20	8
Anhydrous ethanol output price	677	278
Gasoline freight cost	2	1
Distributor's cost for E25 acquisition	1,850	761
Distribution margin	70	29
Delivery freight	10	4
CPMF	7	3
Distributor's price	1,937	797
Retail margin	210	86
CPMF	8	3
Retail price	2,155	887
Total tax	1,027	423

Blend composition 75% gasoline/25% anhydrous ethanol

CIDE (Contribuição de Intervenção no Domínio Econômico) contribution for intervention in economic domain

PIS/PASEP & COFINS (Programa de Integração Social e o Programa de Formação do Patrimônio do Servidor Público e a Contribuição para o Financiamento da Seguridade Social) program for social integration, program for patrimony of public service, and contribution for financing social security

ICMS (Imposto sobre Circulação de Mercadorias e Serviços) tax on circulation of merchandises and services; ICMS Refinaria refinery ICMS; ICMS substituição Tributaria ICMS substituting tax authority

CPMF (Contribuição Provisória sobre Movimentação Financeira) provisory

contribution on financial movement, 0.38%

Source: Laydner 2005

Table 3.3 Hydrous Ethanol Price Structure in São Paulo, Brazil, in June 2005
Price per 1,000 liters

<i>Item</i>	<i>R\$</i>		<i>US\$</i>	
	<i>Actual price</i>		<i>Hypothetical</i>	
Ethanol commodity price	575	237	832	342
PIS/PASEP & COFINS	21	9	30	12
ICMS Refinaria	81	33	118	48
Ex-distillery ethanol price	677	279	980	403
Freight cost	30	12	30	12
Distributor's acquisition cost	707	291	1,010	415
Distribution margin	50	21	50	21
Delivery freight cost	10	4	10	4
CPMF	3	1	4	2
PIS/COFINS	66	27	90	37
ICMS substituição Tributaria	34	14	49	20
Price charged by distributor	870	358	1,214	499
Retail margin	150	62	150	62
CPMF	4	2	5	2
Retail price	1,024	421	1,369	563
Total tax	209	86	297	122

Hypothetical assumes that the commodity price of hydrous ethanol is the same as that of the gasoline/anhydrous ethanol price.

CIDE (Contribuição de Intervenção no Domínio Econômico) contribution for intervention in economic domain

PIS/PASEP & COFINS (Programa de Integração Social e o Programa de Formação do Patrimônio do Servidor Público e a Contribuição para o Financiamento da Seguridade Social) program for social integration, program for patrimony of public service, and contribution for financing social security

ICMS (Imposto sobre Circulação de Mercadorias e Serviços) tax on circulation of merchandises and services

CPMF (Contribuição Provisória sobre Movimentação Financeira) provisory contribution on financial movement, 0.38%

Source: Laydner 2005

3.56 In order to illustrate the difference in tax revenue between hydrous ethanol and E25, Table 3.3 also applies the tax structure for hydrous ethanol to E25 in the last two columns. The tax computed in this way should be compared to the actually tax levied on E25, shown in Table 3.2. In the columns labeled "Hypothetical" in Table 3.3, the same commodity price as that of E25 is used as the starting commodity price (more specifically, the sum of 75 percent of R\$890 and 25 percent of R\$657, or R\$832 per kiloliter). The total tax imposed on R\$832 per kiloliter of hydrous ethanol is calculated to be US\$0.12 per liter, compared to US\$0.42 per liter levied on E25 with the same commodity price. This suggests

that hydrous ethanol enjoys a tax advantage of US\$0.30 per liter, much greater than the U.S. federal tax exemption of US\$0.13 per liter granted to ethanol.

3.57 Two problems facing the government with respect to fuel ethanol are tax evasion and sales on the black market. According to one estimate, about 39 percent of alcohol is sold through the black market, escaping taxes (Banco Pacual 2002). An illustration of tax evasion is given for the state of São Paulo. Until 2004, hydrous ethanol produced in São Paulo and sold to a distributor in São Paulo was taxed at a value added tax (VAT) rate of 25 percent, while that produced in São Paulo and sold to a distributor in other states was levied a VAT of 12 percent. This resulted in significant tax evasion: small distributors would buy hydrous ethanol from a distillery in São Paulo allegedly for sale in another state, only to sell it in São Paulo and profit the VAT tax difference of 13 percent. Given the distribution margin is in the neighborhood of 5 percent, this provided a very attractive means of increasing the profit several-fold. In response, the government reduced the VAT on the ethanol produced and sold in São Paulo to 12 percent. This illustrates that differential taxation involving a large number of sellers creates opportunities for tax evasion, reducing government revenue.

3.58 In the United States, the federal ethanol tax exemption has played a crucial role in promoting and maintaining the fuel ethanol industry. The current exemption of US\$0.51 per gallon (US\$0.13 per liter) is legislated by law to remain in force until the end of 2010. The U.S. Treasury figures show that the revenue loss from the partial exemption from the excise tax for ethanol between fiscal 1980 and fiscal 2000 is estimated to amount to US\$11 billion, adjusted to 2000 US dollars (U.S. GAO 2000). An analysis conducted by U.S. EIA to assess the fiscal impact of the 2005 Energy Bill (more precisely, an earlier version called the Fuels Security Act of 2005; see chapter 2) assumed that the federal tax credit of \$0.51 per gallon of ethanol blended into gasoline would continue to the end of 2025. The net change in tax revenue was computed as US\$11.4 billion in 2006–2010 and US\$37.8 billion in 2011–2025 (U.S. EIA 2005a). Sixteen states offer incentives including direct subsidies and tax breaks. The state of Minnesota, considered to embody a “model” ethanol policy by ethanol producers, provides a US\$0.20 subsidy for every gallon (US\$0.053 per liter) of ethanol produced in the state, subject to an annual ceiling of US\$30 million. The state Agriculture Department also provides low-cost financing for ethanol plant construction and for helping farmers buy ethanol cooperative shares (Mazza 2001). Unlike Brazil where ethanol at times has been and is currently cost-competitive relative to gasoline without tax credits, the U.S. fuel ethanol industry may not survive a withdrawal of federal and state tax credits and subsidies in the absence of a mandate to use ethanol.

3.59 While Brazilian ethanol prices are driven primarily by the world sugar market, U.S. ethanol prices have been highly correlated with wholesale gasoline prices. Historically, the price of ethanol has been on average higher than that of gasoline by slightly more than US\$0.55 per gallon, or US\$0.15 per liter. Depending on supply and demand, the price of ethanol has been above or below the historic average (the price of gasoline plus US\$0.55 per gallon) by up to US\$0.20 per gallon (US\$0.05 per liter) (Kapell 2003). This suggests that suppliers charge as much as what the market, set by gasoline pricing, will bear, capturing all of the federal tax credit and not passing it on to consumers

to make ethanol more attractive than alternatives. Because of excess ethanol plant capacity, this situation changed in 2005. Instead of trading at a premium of US\$0.51 per gallon over unleaded gasoline, the federal excise tax credit for blending it in motor fuels, ethanol was selling US\$0.40 per gallon below unleaded gasoline in the first several months of 2005 (Platts Oilgram News 2005).

3.60 In 2001, USDA launched a US\$300 million biofuels effort that provides payment to renewable fuels plants that increase the amount of fuels produced from the preceding year, to a maximum of US\$7.5 million each year. Some new ethanol plants could receive this maximum amount. For biodiesel plants, each gallon of increased production is worth about US\$1.25. This program was extended in the 2002 Farm Bill through 2008.

3.61 The German federal government has exempted pure and blended biofuels, used for heating and in transport, entirely from the mineral oil tax until 2009. The mineral tax is €0.47 (US\$0.57) per liter for diesel and €0.655 (US\$0.79) per liter for gasoline (British Embassy Berlin 2002). Unlike France and Italy, there are no quantitative limits on biofuels that can be produced and benefit from tax exemption (Bockey 2003). The tax exemption of €0.47 per liter for biodiesel is considerably greater than the reduction granted by the U.K. government to biodiesel of £0.20 (US\$0.37) per liter. As a result of this large tax exemption, the price of biodiesel is about €0.09 (US\$0.11) per liter lower than that of petroleum diesel (Schöpe and Britschkat 2002). Table 3.4 lists the current tax policy of some EU member countries for ethanol used in gasoline.

Table 3.4 EU Taxation Policy for Ethanol

<i>Country</i>	<i>Gasoline tax €/liter</i>	<i>Exemption €/liter</i>	<i>Percent exemption</i>
France	0.59	0.37/0.38	63/64
Germany	0.655	0.655	100
Spain	0.42	0.42	100
Sweden	0.52	0.52	100
UK	0.68	0.29	43

Source: Corre 2004

3.62 In Australia, a biofuels taskforce appointed by the Prime Minister estimated that, on current policy settings, government assistance to the biofuels industry could cost the budget in forgone excise A\$118 million annual in 2009–2010, falling to A\$44 million annually by 2015–2016, assuming the target annual ethanol consumption of 350 million liters is reached. Costs to the economy of the policy settings, driven by the biofuels excise advantage, were estimated at around A\$90 million annually in 2009–2010, falling to \$72 million annually (in 2004–2005 dollars) to 2015 and beyond (Biofuels Taskforce 2005).

3.63 Tax exemptions on fuels blended into gasoline raise questions about equity. A high rate of excise tax on gasoline in developing countries is progressive for the most part because gasoline is not used by the very poor. This is one way for the government to

tax the better-off and use the revenue for social services targeting the poor, such as primary health care, provision of safe water and sanitation, and primary education. This consideration is especially important in low-income developing countries: a recent World Bank analysis shows that taxes on petroleum products are a critical source of government revenue for these countries. The reason is that taxing fuel is one of the easiest ways to collect revenue (Bacon 2001). A switch to biofuels accompanied by a tax reduction or exemption reduces this important source of government revenue.

3.64 Where excise taxes on fuels are markedly lowered or eliminated, the question is who are the direct recipients of the forgone taxes. If taxes are lowered to make the biofuel cheaper than the petroleum fuel it has displaced, then transport fuel purchasers are among the beneficiaries. In developing countries, gasoline taxation is progressive because the poor do not own cars. When the price of ethanol is made lower than that of gasoline on account of a significantly lower tax on ethanol, the main beneficiaries are high-income families who own cars. The poor benefit to the extent that they make use of public transport vehicles that run on gasoline-ethanol. The worst case scenario from the point of view of equity and poverty alleviation would be if the taxes that were previously spent on social programs for the poor go to large agribusinesses. There are indeed indications that large, not small, farmers and agribusiness corporations benefit disproportionately from these tax credits. For example, one complaint against ethanol in the United States is that federal tax incentives are in effect a form of “corporate welfare,” benefiting global agricultural corporations such as ADM, the world’s largest grain processor, and Cargill (Mazza 2001). A detailed study of Proálcool in Brazil by two Brazilian academics in 1988 expressed similar concerns: while gasoline taxation was based on the principle of making the rich pay for the poor by using the tax revenue to subsidize the so-called social fuels (diesel and kerosene), the fiscal framework for ethanol passed the forgone tax revenue to “sugar barons” (Ashford 1989).

3.65 *Total* exemption of biodiesel from fuel excise duty, as in Germany, raises a number of questions. Taxes on transport fuels typically seek to satisfy multiple objectives (Gwilliam and others 2001) including

- Raising government revenue for general (non-transport) expenditure purposes
- Efficient allocation of resources to and within the transport sector
- Financing road provision and maintenance
- Reducing congestion
- Reducing environmental externalities of road transport
- Redistributing income.

A vehicle running on pure biodiesel would still contribute to road damage, congestion, and environmental externalities (since exhaust emissions are not eliminated). In particular, because road damage is broadly proportional to the fourth power of axle weight and heavy-duty vehicles use exclusively diesel, biodiesel would be expected to contribute significantly to road damage. Ethanol, on the other hand, typically substitutes gasoline, which in turn is used in light- and medium-duty vehicles. As such, much less road damage would be expected to be caused by ethanol in comparison. The need to raise government revenue for general expenditure purposes applies to all fuels irrespective of

their origin. There is therefore little rationale from a public economics standpoint to exempt biofuels completely from excise duties.

3.66 There may be an argument for differentiated tax between petroleum and biofuels because biofuels generally reduce emissions of pollutants harmful to public health, the greatest externality of vehicular air pollution. The cost to society of health damage depends on the toxicity of the pollutant, its ambient level, the number of people exposed, and the duration of exposure. Heavily polluting vehicles used in long-distance transport cause much less damage than those used in intra-city transport, because long-distance vehicles travel outside cities much of the time. The economic ideal would be a system of direct taxation on emissions and exposure, but such an approach is technically a long way off for vehicles in use. Fuel tax has good incentive properties for reducing the amount of vehicle kilometers traveled and encouraging the use of fuel-efficient vehicles, but fails to reflect the location or the time of emissions. Nevertheless, fuel tax may be considered as one of the instruments for capturing health-related externalities, in which case a policy question is the size of the tax. Fuel tax should be less than the marginal damage cost—optimal tax would be at the level of the abatement cost. There are not many marginal cost estimates, but one study used 1993 data to examine the environmental costs of various fuels in six developing country cities. It found that marginal costs of environmental damage from automotive diesel averaged about US\$0.32 per liter and gasoline \$0.075 per liter (Lvovsky and others 2000). Because not all transportation fuels are used in densely populated cities, the damage costs averaged across all fuel use would be lower. If these damage estimates are halved (which is a big “if”) to arrive at order-of-magnitude estimates of national averages, damage costs become US\$0.16 per liter of diesel and US\$0.04 per liter for gasoline. If, as another simplification, biofuels are assumed to halve environmental damage, this would give a maximum fuel tax difference of US\$0.08 per liter between petroleum diesel and biodiesel, and US\$0.02 per liter between gasoline and ethanol.

3.67 Significant financial incentives in the form of tax exemption may be justified to assist infant industries. Governments have given fiscal incentives to enable a new product or technology to win consumer acceptance, iron out initial problems, and gain sufficient market share to capture economies of scale. The government funding of research and development (R&D) for alternative fuels and pilot-scale testing certainly falls under this category. Under an infant industry argument, it is reasonable for governments to assist the biofuel industry, provided that costs are expected to decline to market-competitive levels within a reasonable period of time, of the order of several years.

3.68 Government interventions may also be necessary if there is a clear market failure—for instance, where benefits are not priced in the market or where it is difficult or impossible to charge users, such as with public goods. The returns accruing to individual investors constructing sewage systems, waterworks, schools, roads, ports, bridges, and railways would be much smaller than the benefits accruing to society as a whole, and for this reason governments step in to take on these projects. A classic example is given by roads. Short of making every road a toll road, private investors will not build roads because it is difficult to recover the cost of road construction fully. Road construction is considered a public good: the benefits are enjoyed by the public at large, and the most practical way of

spreading the cost is to use public funds. There is no comparable market failure of this magnitude in the case of transportation fuels.

3.69 One concern regarding significant fiscal incentives is that investment decisions can be driven by financial incentives and perceived future regulatory requirements, rather than by market forces. This may in part explain the large oversupply of biodiesel production capacity in Germany (UFOP 2002) and the recent surge in the United States of construction of new ethanol production facilities, resulting in capacity in excess of what could be reasonably be expected to be needed to meet any regulatory mandated usage (Kapell 2003).

3.70 In a study investigating international costs of biodiesel and bioethanol for the U.K. Department of Transport, AEA Technology found that, even after taking transportation costs into account, the cheapest option for ethanol in the United Kingdom in both 2002 and 2020 would be to import it from Brazil. Biodiesel was significantly more expensive under all circumstances, but the cheapest option was to import biodiesel from the United States (AEA Technology 2003). At the moment, heavy protection of domestic agriculture prevents the most efficient allocation of resources. For example, with respect to ethanol exports to the United States, the only duty-free program is the Caribbean Basin Initiative, which has a ceiling of 7 percent of the total amount of U.S. ethanol. Even Brazil, the lowest-cost producer of ethanol, imposes a high import duty on ethanol. The European Union imposes an import tariff of as much as €0.193 per liter of ethanol (Kapell 2003).

3.71 Even if these import tariffs are eliminated, a broader question would be to what extent governments' interest in biofuels would be maintained if the biofuel industry does little to "support" domestic agriculture as a result of allowing free imports. One of the arguments put forward to maintain fiscal incentives is that farmers are heavily subsidized in any event, and this is one way of using subsidies "productively." If free imports were allowed and end up displacing domestically produced biofuels, it is entirely possible that governments would withdraw fuel excise tax reductions and exemptions, making biofuels potentially uneconomic.

3.72 Because the feedstocks currently used for the commercial production of biofuels are all agricultural crops, no discussion of biofuel tax considerations is complete without addressing large farm subsidies in industrial countries. Some aspects have already been discussed at the beginning of this chapter. While the government of Brazil has historically intervened in the sugar market through production quotas, production subsidies, export control, and the management of export terminals, the government no longer directly supports or subsidizes the production of sugar. By 1999, the government ceased setting producer prices for sugarcane. In contrast, the amounts of public funds used to support maize, wheat, and rapeseed in industrial countries run into billions of dollars every year, supported by complex farm policies. As a result, agriculture sector considerations drive the biofuel industry and government biofuel policies to a considerable extent. Market prices and biofuel production in turn are dependent largely on government subsidies and policies.

3.73 The support given to maize growers in the United States—US\$37.4 billion between 1995 and 2003—lowered the production cost of ethanol somewhat, but the overall impact was not large. Subsidies are also given to oil producers. For comparison on an equal footing, significant tax incentives given to the exploration and production of oil and gas in the United States are reviewed below. These are comparable to farm subsidies in that both are financial assistance to the producers of feedstocks for transportation fuels (crude oil for gasoline and diesel, maize for ethanol, and soybeans for biodiesel). The incentives given to oil and gas producers include

- Percentage depletion deductions on limited quantities of domestic output allowed to independent oil and gas producers amounting to US\$27 billion between fiscal 1980 and fiscal 2000 (during this period, major integrated oil producers were not allowed to claim the percentage depletion allowance)
- Deductions from gross income allowed to independent oil and gas producers for intangible drilling and developments, amounting to US\$20 billion between fiscal 1980 and fiscal 2000
- Revenue loss estimates for the nonconventional fuel production credit, amounting to US\$8 billion between fiscal 1980 and fiscal 2000
- Exemption from the passive income limitations, amounting to US\$1 billion between fiscal 1988 and fiscal 2000
- Credit for enhanced oil recovery costs, amounting to US\$1 billion between fiscal 1994 and fiscal 2000.

The above estimates are from the figures provided by the U.S. Treasury Department and are adjusted to 2000 US dollars using a fiscal year gross domestic product deflator. The estimates are not additive because of the nature of assumptions used. In fiscal 2000, tax expenditure estimates for the above categories of tax credits and exemption for domestic oil and producers were US\$275 million, -US\$15 million, US\$960 million, US\$25 million, and US\$260 million, respectively (U.S. GAO 2000). Although these figures are not additive, if the total is taken to be around US\$1.5 billion, this translates to about US\$0.50 per barrel of domestic oil produced, or US\$0.003 per liter. Because the incentives are given to both oil and gas producers, the actual portion going to oil production would be lower.

Environmental Impact of Biofuel Production

3.74 Historically, the choice of biofuel crops has often been restricted to intensively cultivated crops. The economics of biofuel production improve with decreasing cost per unit yield, and intensified use of genetically engineered crops, irrigation, and fertilizer, pesticide, and herbicide application is intended to increase yields and lower costs. In the worst case, lands are cleared to make way for sugar cultivation; rapeseed and other crops are planted on set-aside land (as in Europe); and maize is planted in regions that require considerable irrigation, resulting in nutrient losses, contamination of ground and surface waters, eutrophication, and a fall in biodiversity (as pesticides and other toxins kill invertebrates in the soil, interrupting the food chain for birds and other animals). Fertilizer and herbicide run off into streams and waste water from the production process are some of

the environmental concerns. That is to say, production of renewable energy can give rise to serious environmental harm. These environmental externalities should ideally be compared with those resulting from the production and combustion of petroleum gasoline and diesel to assess their relative damages.

3.75 In the United States, with increasing scale of production, air emissions, odors during drying of distiller's dried grains, and wastewater discharges from the plants have become a serious concern (for example, from plants producing 110,000 to 150,000 m³ of ethanol per year). Some small municipal systems cannot handle the large wastewater discharge from high-capacity production plants. High oxides of nitrogen (NO_x) emissions from boilers are addressed by installing low NO_x burner systems. Volatile organic compound (VOC) emissions of concern include acetic acid and acetaldehyde. One way of dealing with VOC emissions from DDGS dryers is to install wet scrubber systems, although this can shift organic compounds from the gas stream to the wastewater stream, which would increase wastewater discharges even more. One solution is installing thermo oxidizer and heat recovery boiler systems that remove particulate matter (PM), VOC, and odors from DDGS dryers. The issue of increased chemical oxygen demand build-up in the process waste streams can be addressed by installing anaerobic digester systems (Novozymes and BBI International 2002).

3.76 In Brazil, two major environmental problems encountered in the past were the improper disposal of untreated vinasse and field burning prior to the harvesting of sugarcane. One liter of ethanol produces approximately 10 to 15 liters of vinasse, a hot corrosive pollutant with a very low pH and an extremely high mineral content. In the mountainous areas of northeastern Brazil, the pumping cost and the cost of land to store vinasse were prohibitive, and they were therefore released into rivers, resulting in an enormous fish kill at every harvest. Today, vinasse and wastewaters are recycled and used for ferti-irrigation. Before cane is cut, the fields are set on fire to eliminate the voluminous amount of biomass. When this is done, huge clouds of black smoke blankets the areas. Both the state of São Paulo and the federal government have passed legislation setting a time table for gradually phasing out the burning of sugarcane fields (see annex 2). At present only São Paulo is enforcing the time table. Twenty percent of sugarcane fields no longer burn the cane trash before harvesting (Macedo 2005).

Other Economic Impacts of Biofuel Production

3.77 One positive outcome of biofuel production that is often cited is rural job creation. Brazil's sugarcane, sugar, and ethanol industries employed 680,000 people in 2003 (Macedo 2005). The Renewable Fuels Association reports that the U.S. ethanol industry in 2004 supported the creation of more than 147,000 jobs in all sectors of the economy (RFA 2005a). A report submitted in August 2005 by a biofuels taskforce set up by the Australian prime minister stated that meeting the target of 350 million liters of ethanol by 2010 could create some 648 additional direct and indirect jobs regionally, although these would not be net gains to employment nationally (Biofuels Taskforce 2005).

3.78 Since all biofuel projects to date have required subsidies, a question is whether government resources spent on biofuel programs are being used more on increasing the rate of return on capital (biofuel plants) and land or on labor costs and benefits. If, as is claimed in the United States and earlier in Brazil, a sizable fraction of government expenditures are increasing the rate of return on capital or land, then the cost-effectiveness of the subsidies for job creation will be low. A related question is how the biofuel program compares to other government-sponsored job creation programs.

3.79 Employment generation is a powerful tool for alleviating poverty and reducing gross income inequality. For these broader goals, a relevant policy question is what alternative means there are to achieve the same goals. If there are policy distortions that discourage job creation and new investments (such as extremely rigid labor or investment laws), inadequate investment in the creation and maintenance of social overhead capital (roads, bridges, railroads) or human capital (education, training), policy reform or increased investment in these areas may have greater employment and social benefits. These considerations can be factored into the economic analysis (see chapter 5) through the economic costing of labor, which compares the wages in the biofuel program to the wages forgone in the alternative use. That analysis can be extended to explore policy or institutional issues leading to differences between the financial wage and the opportunity cost of labor, and to identify parallel interventions to help improve the lot of the affected workers.

3.80 Imports of crude oil or oil products can require a significant amount of foreign exchange. This was one of the main drivers for Proálcool in Brazil. The fuel import bills rose from one-tenth of Brazil's total imports in 1970 to more than one-half a decade later. The merits of saving foreign exchange are argued on the grounds that foreign exchange is scarce—the demand for foreign goods and services exceeds the supply of foreign currency needed to pay for them (that is, the earnings from exports of goods and services and any net foreign loans and grants). Such an imbalance arises when the domestic prices of foreign goods are under-valued relative to domestic resources. As a result, the relative prices of foreign and domestic resources do not reflect their respective scarcities. Under these circumstances, the real value of foreign exchange would be different from that indicated by the official exchange rate. In those countries with under-valued exchange rates, the opposite relationship between domestic and foreign prices would hold, and a correction for exchange rate distortion would increase the value of local goods compared to traded goods. Economists have long recommended that the first policy response should be to correct distortions in the foreign exchange policy, not to promote import substitution or export subsidization while leaving this underlying cause largely untouched. Subsidization of exports or discouraging imports can represent second- or third-best policy responses, if not accompanied by exchange rate policy reform (a first-best response) and can introduce additional distortions into the economy that reduce efficiency further and exacerbate the problems faced by local producers and consumers.

3.81 In examining the net flow of foreign exchange in economies with over- or undervalued exchange rates, it is important to account for capital goods that are imported for biofuel production as well as a loss of foreign exchange earnings from reduced exports of goods that biofuel production replaced (for example, sugar that used to be exported and

is now used for ethanol production). In addition, it is important to account for the indirect effects upon the demand and supply of foreign exchange that occurs as biofuel production is implemented (for example, increased imports of fertilizer that might be required by biofuel crops compared to the crops they replace). If the analysis of the country's national parameters indicates that the country pursues a market-based approach to setting the exchange rate and that the official rate fairly represents real economic values, then there would be no need to make a strong distinction between local currency and foreign exchange costs or benefits of biofuel programs.

3.82 Another potential benefit cited in replacing petroleum fuels with biofuels is lower exposure to the volatility in the world oil market. In a liberalized market, biofuel prices will track petroleum fuel prices as long as biofuels represent a fraction of the total petroleum fuel consumption. Where there are barriers to free trade of biofuels (which is the current situation) or where the government controls biofuel pricing, biofuel and petroleum fuel prices may be de-linked to an extent, but these restrictions introduce problems of their own. Further, where there is non-market allocation of biofuels and consequently biofuel prices do not track petroleum fuel prices, biofuel prices are subject to volatility of agricultural output and crop prices. As chapter 5 shows, the volatility of world raw sugar prices has not been any smaller than that of gasoline prices in recent decades. In assessing this category of benefits and costs, the economic analysis should be conducted over a range of years using actual and forecast data and should take advantage of risk and uncertainty and related modeling techniques.

3.83 Because commercial feedstocks for biofuels are crops at present, large expansion of biofuel production could put upward pressure on food or animal feed prices. In a liberalized market, crop substitution should not normally lead to higher prices, since most foods and feeds are tradable and prices are set by world prices. In a liberalized regime, food or feed prices will rise in response to crop substitution only if the scale of substitution is so significant as to reduce the world supply of the substituted crop. With incomplete liberalization, however, where agricultural or other policy interventions continue to make it difficult for farmers or consumers to adjust, international prices will not necessarily play such a buffering role in the local economy (for example, where overvalued exchange rates and foreign exchange shortages impede importation of additional food or animal feed). Any pass-through effects of the biofuel program upon these other segments of society should be captured in the economic analysis of the program.

3.84 Brazil is endowed with a huge land mass that is agriculturally productive and has plentiful rainfall. Despite this abundance of land and water, the subsidies and other incentives given for sugar production for fuel ethanol in the 1970s and 1980s were sufficiently attractive that land use was diverted to ethanol production, replacing food crops. For example, the 362,000 new hectares of cane added in São Paulo between 1974 and 1979 occurred largely at the expense of food production. The greatest impact was on maize and rice, which declined in area by 35 percent (Saint 1982). The result was higher food prices, affecting especially the poor. To the extent that crop substitution occurs, the net value to the economy is reduced by the loss of value added on the crop being substituted. In the United States, the growth of the fuel ethanol industry has increased aggregate demand for maize. A study by Northwestern University estimated that, in 1997,

the U.S. fuel ethanol industry increased the price of maize by US\$0.45 per bushel, boosting net farm income by US\$4.5 billion (Evans 1997).

4

Impact on Emissions and Vehicle Performance

4.1 The majority of biofuels are used as road transportation fuels. The impact of biofuels on exhaust (and in the case of ethanol, evaporative) emissions and lifecycle GHG emissions has attracted much attention in recent years. There is greater agreement on the impact on tailpipe exhaust emissions than on lifecycle GHG emissions. This chapter summarizes the findings.

Emissions of Harmful Pollutants

4.2 Road transport is a growing contributor to urban air pollution in many developing country cities. The costs of air pollution include reduced visibility and damage to vegetation and buildings, but by far the greatest cost is the increased incidence of illness and premature death that result from human exposure to elevated levels of harmful pollutants. Using damage to human health as the primary indicator of the seriousness of air pollution, the most important urban air pollutants to control in developing countries are lead, fine particulate matter, and, in some cities, ozone. Fine particulate matter is the pollutant of most concern in developing countries today on the basis of exposure, toxicity, and ambient concentrations. Ambient concentrations of fine particulate matter are often several times higher in developing country cities than those in industrial countries. In a growing number of cities, ambient concentrations of ground-level ozone are also rising.

4.3 Two major contributors in transport to fine particulate air pollution are diesel vehicles and two-stroke engine gasoline vehicles. In two-stroke engines, the primary problem is the lubricant that passes through the engine that is emitted unburned as a result of “scavenging”; the two parameters that affect the levels of particulate emissions are the quality and quantity of the lubricant added (Kojima and others 2002). As such, the quality of the fuel being used is of secondary importance. For diesel-fueled vehicles in use, high particulate emissions are caused by higher fuel injection rates to compensate for underpowered engines or overloading, dirty injectors, and injection nozzle tip wear. Proper engine tuning can reduce particulate emissions markedly. Technical solutions that can reduce particulate emissions, some significantly, include electronic fuel injection, oxidation catalysts, and particulate filters. Advanced exhaust control devices require ultralow sulfur diesel fuel. Among fuel options to reduce particulate emissions, switching to a gaseous fuel would be most effective.

4.4 Against this background, the impact of using biofuels depends upon how they are used. Biofuels are sulfur-free and burn more easily because of the presence of oxygen. When used neat, ethanol is a clean fuel (aside from increased acetaldehyde emissions). More typical use of biofuels will be as low blends. In these applications, biofuels act as diluents. Ethanol has an added advantage of having a high blending octane number, thereby reducing the need for other high-octane blending components, many of which can have adverse environmental effects.

4.5 Ethanol can be effective for cutting carbon monoxide (CO) emissions in winter in old technology vehicles. It is for this reason that the Clean Air Act Amendments of 1990 in the United States required OxyFuel, which is gasoline with an oxygen content of 2.7 percent by weight (wt%)—corresponding to 15 percent by volume (vol%) methyl tertiary-butyl ether (MTBE) or 7.3 vol% ethanol—in CO nonattainment areas during the winter months, when CO emissions are high. At the same time, ethanol can lower emissions of hydrocarbons, which are ozone-precursors, in old technology vehicles. The 1990 Clean Air Act Amendments also required reformulated gasoline, which must contain 2 wt% oxygen throughout the year, in the areas that have the most serious problems with ozone pollution. This oxygen requirement corresponds to 11 vol% MTBE or 5.4 vol% ethanol. The oxygenate requirement was repealed in the 2005 Energy Bill.

4.6 Changing the fuel-to-oxygen ratio through the use of oxygenates such as ethanol will not automatically have a positive effect unless vehicle tuning is known. The emission reductions occur primarily if the vehicle is tuned “rich” (that is, the air-to-fuel ratio is set low). If the vehicle air-to-fuel ratio is reasonably adjusted, oxygenates can raise oxides of nitrogen (NO_x) emissions, and can also cause “lean misfire” (fuel does not combust adequately because the oxygen-to-fuel ratio is too high), raising hydrocarbon emissions. In summer, ethanol addition to gasoline can also produce higher emissions of NO_x, an ozone precursor.

4.7 The dilution effect on sulfur, olefins, benzene, and total aromatics in gasoline with increasing ethanol content is almost universally positive. Benzene is a carcinogen. Aromatics with two or more alkyl groups and olefins are strong ozone precursors. Non-benzene aromatics can also “dealkylate” (lose alkyl groups) during combustion to appear as benzene in the exhaust gas. Sulfur reduces the conversion efficiency of catalytic converters as well as contributes to ambient concentrations of oxides of sulfur (SO_x), acid rain, and the formation of sulfate-based particulate matter.

4.8 The high blending octane number of ethanol offers additional advantages when used as a blending component. A number of high-octane gasoline components are harmful or can have adverse effects on the environment and public health. Lead is a classic example. Used historically as an octane enhancer, its use has been banned in a growing number of countries on account of the damage it causes to human health, especially to the intellectual development of children. When lead is taken out of gasoline, alternative sources of octane must be found. Olefins and aromatics are high in octane and their quantities can be increased, but these hydrocarbons are not without problems. Some are carcinogenic, others are strong ozone-precursors. Ethanol in contrast is a benign octane enhancer. In August 2005, Venezuela began importing ethanol from Brazil as part of the effort to eliminate lead from gasoline. The Venezuelan state oil company announced that ethanol

would initially be blended into gasoline at 8 percent in the eastern part of the country (Gazeta Mercantil 2005).

4.9 The Auto/Oil Air Quality Improvement Research Program (AQIRP), a cooperative research program conducted by three U.S. auto manufacturers and 14 petroleum companies at a cost of US\$40 million between 1989 and 1995, examined the impact of E85 on exhaust emissions. Compared to conventional gasoline, the impact of using E85 on hydrocarbon and CO emissions was not statistically significant except that compared to California reformulated gasoline, hydrocarbon emissions increased. The impact on NO_x emissions was statistically significant and was lower by up to 50 percent, contrary to the findings in other studies. Toxic emissions increased as much as two- to three-fold, primarily due to an increase in aldehyde emissions (Auto/Oil AQIRP 1997).

4.10 The U.K. government commissioned a study (Reading and others 2002) to investigate the potential impact of E10 on tailpipe emissions. The study tested five vehicles—designed to meet emission standards ranging from Euro II to Euro IV—fueled by pure gasoline as well as E10. The findings showed lower CO (two out of five vehicles) and lower particulate emissions (two out of five) for E10, while NO_x emissions were not markedly influenced. It should be noted that particulate emissions were very low for both fuels, in the vicinity of 0.005 grams per kilometer (g/km) in most cases. Reproducibility was about ±20 percent for CO and NO_x, so that differences smaller than 20 percent could not be identified. Reproducibility for particulate matter was ±35 percent, so that only very large differences could be deemed statistically significant. For some, but not all, vehicles tested, acetaldehyde emissions were significantly increased with E10. Summarizing the results that were found to be statistically significant, the study found that E10 reduced CO emissions by 21 percent, particulate emissions by 46 percent, 1,3-butadiene emissions by 28 percent, and methane emissions by 14 percent, and increased acetaldehyde emissions by 510 percent.

4.11 The Australian government commissioned a study to investigate long-term use of E20 (Orbital Engine Company 2004). This is one of few studies that assessed durability of the existing vehicle fleet through mileage accumulation and measured exhaust emissions at 6,400 km, 40,000 km and 80,000 km, amongst others. The mileage accumulation cycle was designed to test the durability of exhaust emissions control devices. As expected, emissions of pollutants increased with increasing mileage accumulated in all cases, but this effect was much greater when E20 was used. Of the 30 measurements made at 80,000 km of the regulated pollutants (CO, hydrocarbons, and NO_x), deterioration with mileage was greater for E20 in all but four measurements. This deterioration was attributed to thermal deactivation of the catalytic converter caused by the increase in the exhaust temperature when combusting E20. There was no discernable difference between the two fuels in the increase in air toxic emissions with increasing mileage. The exception was formaldehyde and acetaldehyde, which increased significantly for E20 with mileage.

4.12 Pure ethanol has low volatility, having a Reid vapor pressure (RVP) measurement of 15–17 kilopascals (kPa) against gasoline's 50–100 kPa. However, ethanol has a very high *blending* RVP of 118–144 kPa. When gasoline is commingled with an ethanol-gasoline blend, such as when filling a tank, the RVP of the commingled fuel

increases significantly. Higher volatility in turn leads to higher evaporative emissions, including emissions of harmful hydrocarbons (such as benzene) and ozone precursors (such as light olefins). The latter would be a concern in cities with high ambient concentrations of ozone. The RVP of a gasoline-ethanol blend reaches a maximum at an ethanol concentration in the neighborhood of 5 percent by volume. Above 5 percent, the RVP falls, but very slowly.

4.13 Maintaining the same blend volatility as prior to ethanol addition would require making gasoline with lower volatility to compensate for the high blending volatility of ethanol, and this carries an incremental cost. Further, the lower the RVP of the base gasoline, the greater the increase in RVP when ethanol is added. These facts have led the U.S. Environmental Protection Agency (U.S. EPA) to give an RVP “waiver” of 6.9 kPa for conventional gasoline—that is, gasoline containing ethanol can have an RVP that is 6.9 kPa higher than pure gasoline. The RVP waiver is not granted for reformulated gasoline. The waiver in turn may have adverse effects on air quality.

4.14 In a handful of developing countries or cities contemplating adopting the stringent emission standards being implemented in industrial countries, consideration may need to be given to the requirement for precise control of the air-to-fuel ratio. To meet this requirement, there is a tendency to minimize the range of oxygen content in gasoline. The World-wide Fuel Charter, issued by vehicle manufacturers around the world, limits the amount of oxygen in all gasoline to 2.7 wt%, corresponding to 7.7 vol% of ethanol, in all categories of gasoline and states that ethers are preferred to alcohols where oxygenates are used. Where up to 10 percent ethanol is permitted by pre-existing regulations, labeling at the pump is recommended. The charter cites the emission tests conducted by the California Air Resources Board (CARB) on fourteen 1990–1995 model year vehicles using two gasolines, one with 10 percent ethanol and the other with 11 percent MTBE. Ethanol decreased toxic emissions by 2 percent and CO by 10 percent, but increased NO_x by 14 percent, total hydrocarbons by 10 percent, and ozone-forming potential by 9 percent. A separate report to CARB estimated a substantial increase in evaporative emissions due to fuel system permeation with ethanol-blends (ACEA and others 2002). The European Union (EU) gasoline fuel specifications for 2000, 2005, and 2009 (EU Directive 2003/17/EC) are more stringent and limit ethanol to 5 percent. There are, however, many developing countries that are not at the stage of adopting these emission and fuel standards any time soon, for which this would not be a serious concern.

4.15 Turning to biodiesel, one of the most comprehensive analyses conducted to date is a review commissioned by the U.S. EPA that examined available data systematically (U.S. EPA 2002). The vehicle fleet for which data were available and used in the review did not contain engines equipped with exhaust gas recirculation (EGR) or advanced exhaust control devices such as NO_x adsorbers and particulate filters. Nearly all data were collected on 1997 or earlier U.S. model year engines, the majority of them heavy-duty engines. Most studies used in the review tested either B100 or B20.

4.16 Nearly 80 percent of the biodiesel blends in the database were plant-based, predominantly made from soybeans, but some were made from rapeseed and three from canola oil. There was significant variation in natural cetane (that is, unmodified with cetane additives) among biodiesel fuels, with plant-based biodiesel having lower cetane than

animal-based biodiesel. Of 29 pure biodiesel fuels, 7 had natural cetane below 50, all plant-based. The review found that effects of biodiesel on emissions depended on the type of biodiesel and the type of petroleum diesel to which the biodiesel was added. With one minor exception, the engine model year did not seem to influence the emission effects of biodiesel much.

4.17 In the final tabulation of the results, the EPA analysis reported that, on average, the use of B20 based on soybean-derived biodiesel increased NO_x emissions by 2 percent and reduced particulate, hydrocarbon, and CO emissions by 10, 21, and 11 percent, respectively. Biodiesel also lowered aggregated toxics emissions. Soybean-based biodiesel increased NO_x emission more than rapeseed-based biodiesel, while animal-fat-based biodiesel had a significantly less impact on NO_x emissions. The benefit of reducing CO emissions was the greatest for animal-based biodiesel, less for rapeseed-based and least for soybean-based biodiesel. Particulate emission reductions were greater for animal-based than plant-based biodiesel. Purely from the point of view of emissions, animal-based biodiesel appeared to do better than plant-based biodiesel.

4.18 In the United States, biodiesel has overcome one important barrier to its commercialization: undergoing Tier 1 and Tier 2 emission and health effects testing, a time-consuming and expensive process, required by the U.S. EPA. In May 2000, biodiesel became the first alternative fuel in the United States to have completed Tier 1 and Tier 2 health effects testing under the Clean Air Act. Tier 2 test results on biodiesel indicated no biologically significant short-term effects on the animals studied other than minor effects on lung tissue at high exposure levels. Tier 1 and Tier 2 testing is needed to satisfy EPA registration and health testing requirements. EPA registrations are in effect licenses to introduce fuels and fuel additives on the market. Tier 1 testing consists of a literature search on the health effects of emissions, and emissions characterization and measurement of hydrocarbon exhaust species. Tier 2 testing includes short-term toxicology testing consisting of 90-day subchronic inhalation exposures (designed to determine a concentration-response relationship for potential toxic effects in rats resulting from continuous or repeated inhalation exposure to emissions over a period of 90 days), exposing animals to real-time emissions, evaluating general organ and systemic toxicities, and determining potential dose-response relationships and levels below which there are no observed adverse effects for carcinogenicity, mutagenicity, developmental and fertility effects, pulmonary effects, and neurotoxic effects.

Fuel Economy

4.19 Fuel consumption is the amount of fuel consumed per unit distance. This is what is directly measured in emissions laboratories. Its inverse, distance traveled per unit fuel, is fuel economy. Fuel consumption and economy depend on fuel properties including energy content, vehicle technology, driving patterns, and the state of vehicle repair. Differences in fuel consumption affect the effective price of fuel when sold on a volume basis. If 10 percent more biofuel is needed to travel the same distance, the price of the biofuel needs to be, everything else being equal, 91 percent (1 divided by 1.1) of that of the corresponding petroleum fuel per liter for the consumer to be financially indifferent.

4.20 Ethanol has lower energy content than gasoline, about one-third lower. However, the higher hydrogen-to-carbon ratio of ethanol, resulting in larger gas volume produced, and the higher heat of vaporization of ethanol, resulting in cooler air and hence more mass of air drawn into cylinders, increase engine efficiency. The combined effect is that the fuel economy penalty of adding ethanol to gasoline may be smaller than what the energy content alone would suggest, as will be discussed below.

4.21 For meaningful and statistically significant results, large fleet tests are needed. Unfortunately, such tests would be difficult and expensive to design, and have not been carried out. This section summarizes the results of available study findings. In each case, the change in fuel economy given corresponds to the use of 100 percent ethanol. This scaled-up number is not intended to give the change in fuel economy as a result of running the same vehicle on pure ethanol, but is shown to indicate the price difference that would be needed for financial neutrality.

4.22 One of the most extensive studies examining the impact of adding ethanol to gasoline on fuel consumption was one undertaken by the Auto/Oil AQIRP. One program component tested twenty 1989 model year vehicles in an emissions laboratory to measure the impact of adding oxygenates to gasoline. The test program was carefully designed to ensure maximum statistical significance. Each test was repeated at least twice. The study found that E10 (there were four blends of E10 and the actual ethanol amount varied from 9.6 to 9.7 percent) increased fuel consumption, but the presence of oxygen partially compensated for the lower energy content of the gasoline-ethanol blend. Because all the vehicles were equipped with feedback control of the air-to-fuel ratio, it was not entirely clear why the presence of oxygen should lower fuel consumption. One explanation proposed was that the oxygen in ethanol lowered fuel consumption only when the vehicle was operating in the open-loop mode (when the feedback control is ignored). On average, addition of ethanol to gasoline reduced fuel economy by 2.6 percent, corresponding to a fuel economy reduction of 27 percent compared to pure gasoline when the results are extrapolated to 100 percent ethanol (Hochhauser and others 1993).

4.23 The U.K. government study mentioned above (Reading and others 2002) also measured fuel consumption. Fuel economy actually increased by 2.7 percent. In this study, E10 had higher octane numbers, research octane number/motor octane number (RON/MON) of 100/88 against the base gasoline RON/MON of 96.6/86.4. The authors offered the higher octane as one possible and partial explanation of the higher fuel economy of E10. Two vehicles with the highest fuel economy gains were fitted with knock sensors, which gave them the ability to change the ignition timing and reduce fuel consumption over the test cycle.

4.24 An Australian study found that E10 increased fuel consumption by 2.6 percent when it was measured in an emissions laboratory (Apace Research Ltd. 1998). This finding corresponds to an increase in fuel consumption of 26 percent for 100 percent ethanol. A pilot study sponsored by the American Coalition of Ethanol tested three 2005 model year cars. Rather than measuring emissions in a vehicle emissions laboratory and performing a carbon balance, this study installed a data logger in each vehicle. The logger monitored various parameters including fuel consumption, vehicle speed and acceleration, calculated load, and air flow rate on three 100-mile trips. E10, E20, and E30 were

compared to pure gasoline. The three vehicles averaged reductions in fuel economy of 1.5, 2.2, and 5.1 percent for the three fuels, respectively. When scaled up to 100 percent ethanol, these correspond to fuel economy reductions of 15, 11, and 17 percent, respectively. An examination of a database provided by the U.S. Department of Energy for the fuel economy of 2006 model year flex-fuel vehicles shows that, on average, use of E85 results in a fuel economy reduction of about 26 percent, or equivalent to 30 percent when extrapolated to 100 percent ethanol (U.S. DOE 2005).

4.25 The U.S. Energy Information Administration (U.S. EIA), in its analysis of the impact of substituting gasoline with ethanol in low-ethanol blends, uses a fuel economy reduction of about 30 percent (U.S. EIA 2005a). On balance, it appears that the price of ethanol will need to be less than 70 to 80 percent of that of gasoline for consumers to be indifferent between the two fuels.

4.26 Diesel contains a lower heating value of about 36 mega-joules (MJ) per liter. The biodiesel fuels reviewed by U.S. EPA (U.S. EPA 2002) average 33 MJ per liter, or 9 percent less. There was a difference in fuel energy content between animal-based and plant-based biodiesel. The former contained 11 percent less, the latter 8 percent less energy on a unit volume basis than petroleum diesel. The impact on fuel economy of using biodiesel was a decrease of 0.9 to 2.1 percent for B20 and 4.6 to 10.6 percent for B100.

Impact on Engines and Other Vehicle Components

4.27 The standard engine tests for RON and MON are not entirely applicable to ethanol. The RON of pure ethanol ranges between 102 and 113, and MON between 89 and 96. When blended into gasoline, ethanol has a very high blending RON of about 112–120 and a blending MON of 95–106. Because the difference between RON and MON is larger for ethanol than for most other gasoline components, it is possible for a gasoline-ethanol blend to have a lower MON. MON is more indicative of anti-knock characteristics of an engine under highway driving conditions. At high speeds or under heavy load conditions, some engines may suffer more readily from knocking using a gasoline-ethanol blend for this reason.

4.28 Volatility of gasoline affects vehicle performance. If the volatility is too low, resulting problems include poor cold start and warm-up performance, poor cold-weather drivability, unequal fuel distribution to cylinders in carbureted vehicles, and higher deposits in crankcases, spark plugs, and combustion chambers. If the volatility is high, there will be greater evaporative emissions, drivability problems from vapor lock formation, and a possible fuel economy penalty. Because gasoline consists of hundreds of hydrocarbon components, gasoline volatility can be adjusted according to seasonal requirements. Volatility adjustments are more difficult with gasoline containing ethanol.

4.29 Ethanol-gasoline blends do not behave the same as pure gasoline. Because it is more difficult to start an engine on ethanol than on gasoline due to its lower volatility, starting a vehicle fueled by a blend with high ethanol content at a very low ambient temperature can be problematic. Other concerns about low-temperature fuel characteristics of blends include the blend's increased viscosity that could impede fuel flow and a possible phase separation in the vehicle fuel system on account of reduced solubility.

4.30 At ambient temperatures, some studies have suggested that gasoline and ethanol-gasoline blends behave similarly in terms of drivability. One study examining the performance of E10 in 108 vehicles from model years 1974 to 1981 found that occurrence of problems with starting, stalls, rough idle, hesitation, and loss of power was statistically higher than with vehicles running on pure gasoline (Prakash 1998). The World-wide Fuel Charter cites that the use of ethanol is “well documented” to cause an offset in drivability performance (ACEA and others 2002).

4.31 Ethanol attacks certain rubber and plastic materials. Neat ethanol cannot be used in unmodified car engines. If there is contamination of ethanol with water, then a gasoline-ethanol blend can separate into two phases, one hydrocarbon and the other aquatic containing water and ethanol. Because water and ethanol have higher densities than gasoline, the aquatic phase will settle at the bottom of the fuel tank. Most vehicles draw fuel from the bottom of the fuel tank, so that once the phase separation occurs, the vehicle will not run. The amount of water that can be tolerated without inducing phase separation depends on temperature, the amount of ethanol, and the amount of aromatics, but typically varies between 0.3 and 0.5 percent (Prakash 1998).

4.32 The study commissioned by the government of Australia, comparing gasoline with E20, also assessed the durability performance of fuel systems and engines (Orbital Engine Company 2004). An earlier study immersing vehicle components in gasoline and E20 for 2,000 hours found evidence of metal corrosion, heavy tarnishing of some brass fuel system components, and changes in the appearance of some polymeric materials after immersion in E20 (Orbital Engine Company 2003). The durability study did not find marked differences in the performance of fuel pumps, filters, pressure regulators, and injectors between the two fuels. Greater levels of wear were observed for engines running on E20. Excessive wear of the parts identified could compromise the combustion system and lead to poor engine operation and higher fuel consumption as well as higher engine-out emissions, but the levels of wear observed in the test program were not large enough to result in a notable loss of combustion performance. Greater deposition in engine parts was also observed with E20. These deposits could lead to poor sealing of the combustion chamber, affecting engine performance and emissions.

4.33 These findings seem to argue for limiting the ethanol content to 10 percent when first launching a fuel ethanol program. Associação Nacional dos Fabricantes de Veículos Automotores (ANFAVEA, National Association for Automotive Vehicle Manufacture, Brazil) provides a list of vehicles modifications that may have to be made when switching from gasoline to a gasoline-ethanol blend (Joseph 2005). No modifications are necessary when the ethanol content is 5 percent or less. Between 5 and 10 percent, the carburetor may have to be modified, but no other modifications should be necessary. Between 10 and 25 percent, a large number of changes may be required.

4.34 Biodiesel has a higher viscosity range than petroleum diesel, reducing barrel/plunger leakage and increasing injector efficiency. Biodiesel also has better lubricity, reducing the need for lubricity additives in some fuels. However, the use of biodiesel primarily as a lubricity additive is unlikely to be cost-effective, given that there are much cheaper chemical fuel lubricity agents available. For example, the U.S. EPA estimates that the cost of chemical lubricity additives is 0.2 US cents per gallon, or about 0.05 cents per

liter (U.S. EIA 2001). If 2 percent biodiesel is blended into diesel to achieve comparable lubricity at the same cost, the incremental cost of biodiesel would need to be limited to 2.5 US cents per liter of biodiesel (0.05 US cents at 2 percent or 0.05 divided by 0.02), about an order of magnitude smaller than the incremental production cost of biodiesel.

4.35 The net impact of using pure biodiesel is estimated to be a loss in maximum power output of 5 to 7 percent (EMA 2003). As the U.S. EPA study above suggests, there is likely to be a fuel economy penalty associated with the use of biodiesel.

4.36 Biodiesel is an effective solvent. The solvent effect may cause deposits accumulated on tank walls and pipes from previous diesel fuel use to be released, and the release of deposits in turn can clog filters initially, especially with blends containing a high fraction of biodiesel. Therefore, precautions should be taken to replace filters until the deposit build-up is eliminated. The solvent effect can also soften and degrade certain types of elastomers and natural rubber compounds over time. Using blends with high percentages of biodiesel can affect fuel system components, primarily fuel hoses and fuel pump seats that contain elastomer compounds incompatible with biodiesel. Biodiesel has the disadvantage of degrading rubber gaskets and hoses in older vehicles (for example, U.S. model years prior to 1992) but not in newer vehicles (Wikipedia 2005).

4.37 Depending on the feedstock, some fatty acid methyl esters (FAME), when used as B100, can have kinematic viscosities that are much higher than the upper limits of petroleum diesel specifications. Flash-point, boiling-point, or cloud-point temperatures may also be higher than the petroleum diesel specifications. Fuel systems on many direct-injection diesel engines are optimized for the expected range of physical properties of petroleum diesel. The different physical properties of biodiesel fuels could affect fuel atomization and penetration into the combustion system of the engine. There is some evidence in the literature of increased fuel penetration for biodiesel fuels with subsequent increased surface impingement of injected fuel and increased lubricating oil dilution with fuel. Depending on the additive package used within the engine lubricant and the interval between lubricating oil changes, this could cause anti-oxidant depletion and polymerization which would increase lubricating oil viscosity, or could simply reduce lubricating viscosity in direct proportion to dilution with fuel. There have also been reports of reductions in the base number of lubricant, promoting the acidification of the lubricating oil. Some engine manufacturers have recommended halving oil-change intervals when biodiesel fuels are used. While indirect-injection diesel vehicles have demonstrated much less sensitivity to the differences in the physical properties of biodiesel and petroleum diesel fuels, few, if any, indirect-injection diesel engines are in production for automotive use today (McDonald 2004).

4.38 In Germany, involving auto manufacturers closely from the early days of biodiesel development has helped to win the approval of the vehicle manufacturing industry for rapeseed methyl ester (RME). The Volkswagen group—Volkswagen AG, Skoda, Audi, and Seat—has adapted all passenger car models from 1995 for use with biodiesel. However, Volkswagen AG points out that all the technical data have been collected exclusively with RME, and that the problem-free use of biodiesel made from other vegetable oils must be demonstrated first (Bockey 2003).

4.39 In May 1998, a consortium of diesel fuel injection equipment (FIE) manufacturers issued a position statement concluding that blends greater than B5 can cause reduced product service life and injection equipment failures. They disclaimed responsibility for failures attributable to operating their products with fuels for which the products were not designed (FIE Manufacturers 1998). The February 2003 technical statement by the U.S. Engine Manufacturers Association (EMA) maintained that blends up to a maximum of B5 should not cause engine or fuel system problems, provided that the biodiesel used in the blend meets the requirements of ASTM D6751, DIN 51606, or EN 14214. For blends exceeding B5, EMA asked that engine manufacturers be consulted regarding the implications of using such fuel. The engine performance problems that can potentially be caused by the use of neat biodiesel and higher percentage diesel blends mentioned by EMA are filter plugging, injector coking, piston ring sticking and breaking, elastomer seal swelling and hardening/cracking, and severe engine lubricant degradation. The amount of information on elastomer compatibility with biodiesel and the effect of neat biodiesel and biodiesel blends on engine durability was considered too limited to draw conclusions. EMA suggested that the condition of seals, hoses, gaskets, and wire coatings be monitored regularly.

4.40 Against this background, the National Renewable Energy Laboratory in 2004 conducted a nationwide sampling of pure biodiesel blendstock used for blending with diesel fuel and found that 4 out of 27 samples, or 15 percent, did not meet ASTM D6751 standards for biodiesel. The survey also found that only one sample met the requirement for EN14214 oxidation stability test which requires a six-hour induction time. The survey results reinforced the views of automakers and engine makers who rank biodiesel instability and uncertain quality at the top of their list of concerns with biodiesel (Renewable Fuel News 2004a).

4.41 The World-wide Fuel Charter limits the amount of biodiesel in diesel to 5 percent in the first three categories, and to none in the fourth (most stringent) category. Where biodiesel is blended into diesel, labeling at the pump is recommended. The limit is motivated by present concerns about the effects of biodiesel on fuel viscosity and loss of fluidicity at low temperatures, corrosion, and the compatibility of biodiesel with seals and fuel system materials (ACEA and others 2002). Internal sealing problems have arisen in connection with biodiesel.

4.42 Some auto manufacturers have warned that if the engine is not run for a prolonged period, biodiesel can polymerize, with a risk of the resulting resinous material blocking injector ports. In response, anti-oxidants for biodiesel are being developed. For example, Bayer Chemicals has developed the Baynox Biodiesel Stabilise, a liquid that is added to the base biodiesel. The product is claimed to prevent oxidation of the fuel's inherent fatty acids into corrosive volatile acids. It is also said to inhibit the formation of undesirable insoluble polymers in the fuel. According to Bayer, the noncorrosive, nonhazardous stabilizer meets the requirements of DIN EN 14214 requiring biodiesel to be "oxidation stable," especially after delivery in bulk to forecourts (Automotive Environment Analyst 2003b).

4.43 A blend of diesel and ethanol has been used in diesel-engine vehicles. However, Cummins, one of the world's largest diesel engine manufacturers, stated in 2002 that it views a diesel-ethanol blend "an extreme fire hazard and under certain circumstances an explosive hazard." Cummins also reported that tests on a blend containing 10 percent ethanol resulted in a 9 percent fuel penalty on a volume basis (Hart's European Fuels News 2002).

4.44 Earlier, vehicle and diesel manufacturers raised concerns over potential problems associated with the use of diesel-ethanol blends related to fire safety, fuel systems, materials incompatibility, and health. Manufacturers pointed out that the minimum flash point required is 52°C. E-diesel typically has a flash point of only about 13°C, and may go as low as 10°C. They also cautioned that e-diesel fuels must contain a proprietary additive to keep the ethanol and diesel components in a uniform emulsion. If the emulsion becomes unstable, the components will stratify, creating a potentially explosive environment inside the fuel storage tank (Oxy-Fuel News 2001). General Motors said it was concerned about flammability in fuel tanks, describing it as a major issue. Other concerns include corrosion, solubility at low temperatures, water tolerance, and elastomer compatibility and lubricity, the latter being crucial to the proper functioning of fuel pumps normally lubricated by diesel (Automotive Environment Analyst 2000).

4.45 These concerns are reflected in the World-wide Fuel Charter, which does not allow any alcohol, including ethanol, in diesel. The charter cites "serious safety concerns," potential damage to vehicle parts, and lower fuel economy. The charter concludes that until safety, performance, and health concerns are addressed, auto manufacturers do not support adding ethanol to any category of diesel fuel (ACEA and others 2002).

Lifecycle Analysis of Greenhouse Gas Emissions

4.46 One rationale cited for promoting biofuels, in Europe and among potential "carbon traders," is that switching from petroleum fuels to biofuels can reduce lifecycle greenhouse gas (GHG) emissions considerably. A number of reports have been issued, calculating changes in GHG emissions relative to conventional gasoline and diesel fuels. There is considerable variation in the results due to different assumptions made as well as the level of detail of the analysis. In some cases, different assumptions have even led to a reversal of sign.

4.47 Macedo and others (2004) studied net energy consumption and GHG emissions for ethanol from sugarcane. Two scenarios were considered, the first taking average consumption of energy and materials in the ethanol industry, and the second assuming the best practice in the sector resulting in minimal emissions. While stating that a direct comparison between ethanol, gasohol, and gasoline engines in Brazil is not possible, the study assumed that there was no change in fuel economy when blending anhydrous ethanol into gasoline (as with E25 in Brazil) on the grounds that the 1:1 equivalence was "widely accepted today." For hydrous ethanol, the study assumed that 1 liter of hydrous ethanol was equivalent to 0.7 liters of gasoline. Net GHG emission savings ranged from 87 percent to 96 percent, depending on the scenario and the type of ethanol.

4.48 Perhaps the most publicized debate around lifecycle GHG analysis has been in the United States concerning the energy needed to grow, harvest, transport, and distill maize into ethanol. Assumptions about how to attribute energy consumption between ethanol and its by-products about fertilizer, pesticide, and herbicide consumption and irrigation have a significant impact on the net energy balance. A 2002 U.S. Department of Agriculture (USDA) study concluded that maize-ethanol yielded 34 percent more energy than it took to produce (Shapouri and others 2002). In a 2004 USDA study, using data from 2001 and averaging across dry and wet mills, this percentage increased to 67 percent (Shapouri and others 2004). In contrast, Pimental (Pimental 2003) and Pimental and Patzek (Pimental and Patzek 2005) claimed that each liter of ethanol required 29 percent more fossil energy to make than it eventually produced. The Argonne National Laboratory countered that maize-ethanol reduced fossil fuel energy consumption by 26 percent and cellulosic biomass-based ethanol by 90 percent. They attributed the differences in the net energy gain or loss computed by different researchers to differences in the assumptions about energy use for maize farming, nitrogen fertilizer production, and ethanol production, as well as about energy credits for by-products (Wang 2005).

4.49 What this debate highlights is the critical importance of what happens to baseline energy consumption figures when maize, sugar, and other crop production is increased to expand the use of biofuels. The most fertile soils with plentiful rainfall are presumably used first. As less fertile and drier areas are used for biofuel crop production, the demand for artificial fertilizers and irrigation will increase, changing the energy balance. In the case of maize, crop yields can be increased by using modern maize hybrids, but they demand more nitrogen fertilizer and pesticide.

4.50 Changes in GHG emissions per vehicle kilometer traveled as a result of displacing gasoline with ethanol are shown in Table 4.1, taken from recent studies for which these figures are available. The figures are not directly comparable because the studies differed in the level of detail. Ethanol from maize is the least favorable from the point of view of reducing GHG emissions, with some studies reporting an increase in overall emissions. The largest gain in GHG emission reduction has been found to be achieved by using sugarcane in Brazil or cellulose or wood waste as the feedstock.

4.51 Percentage changes in lifecycle GHG emissions as a result of displacing diesel with biodiesel, calculated by various groups, are shown in Table 4.2. As before, the figures are not strictly comparable because they differ in the level of detail as well as the assumptions made. It is worth noting that one of the most detailed studies, by Delucchi (2003), shows a marked increase in lifecycle emissions when soybeans are used as the feedstock.¹⁶ The other two studies on soybean-based biodiesel show a decrease. As expected, using waste cooking oil gives significant GHG savings.

¹⁶ The analyses by Mark Delucchi (2003) includes materials lifecycle in addition to fuel lifecycle, and takes into account the global warming potential of CO₂, methane, nitrous oxide (N₂O), NO_x, VOCs, SO_x, PM, and CO.

Table 4.1 Change in Lifecycle Greenhouse Gas Emissions per Kilometer Traveled by Replacing Gasoline with Ethanol in Conventional Spark Ignition Vehicles

<i>Feedstock</i>	<i>Location</i>	<i>C h a n g e</i>		<i>Source</i>
Wheat	UK	-47%		Armstrong and others 2002
Sugar beet	North France	-35% ^a	-56% ^b	Armstrong and others 2002
Maize, E90	USA, 2015	10%		Delucchi 2003
Maize, E10	USA	-1%		Wang and others 1999
Maize, E85	USA	-14% ^c	-19% ^c	Wang and others 1999
Cellulose, E85	USA, 2005	-68% ^c	-102% ^c	Wang and others 1999
Molasses, E85	Australia	-51% ^d	-24% ^d	Beer and others 2001
Woodwaste, E85	Australia	-81%		Beer and others 2001
Molasses, E10	Australia	1% ^d	3% ^d	Beer and others 2001
Sugar, hydrous ethanol	Brazil	-87% ^e	-95% ^e	Macedo and others 2004
Sugar, anhydrous ethanol	Brazil	-91% ^e	-96% ^e	Macedo and others 2004

Note: Percentage changes are for neat ethanol unless indicated otherwise.

^a Average

^b Best case

^c A range given in the study report

^d Different assumptions about credits for by-product

^e The first uses average values of energy and material consumption, the second represents best practice

Table 4.2 Change in Lifecycle Greenhouse Gas Emissions per Kilometer Traveled by Replacing Diesel with Biodiesel in Conventional Compression Ignition Vehicles

<i>Feedstock</i>	<i>Location</i>	<i>Change</i>	<i>Source</i>
Rapeseed	Germany	-21%	Armstrong and others 2002
Rapeseed ^a	Netherlands	-38%	Novem 2003
Soybeans ^a	Netherlands	-53%	Novem 2003
Soybeans ^a	USA	-78%	Sheehan and others 1998
Soybeans, 2015	USA	173%	Delucchi 2003
Tallow	Australia	-55%	Beer and others 2001
Waste cooking oil	Australia	-92%	Beer and others 2001
Canola	Australia	-54%	Beer and others 2001
Soybean	Australia	-65%	Beer and others 2001

^a Only CO₂ emissions are considered.

4.52 Strictly from the point of view of reducing GHG emissions, biofuels are currently quite expensive relative to other mitigation measures, according to analyses from many parts of the world. In the European Union, for example, an analysis of several studies shows that, based on domestic production from wheat and sugar beets, fuel ethanol saves

GHG emissions at a minimum cost of €200 per tonne of CO₂ under the best-case scenario, against the benchmark abatement cost in the neighborhood of €30 per tonne (Henke and others 2003). Another study points out that using biomass as a fuel to produce steam and electricity or combined heat and power is much more cost-effective than conversion to liquid fuel, giving as much as 200 gigajoules per hectare of land compared to 30–60 in the best of scenarios for biodiesel or ethanol (Armstrong and others 2002). In Brazil, a 1999 paper estimated the cost of carbon emission abatement from ethanol to be about US\$44 per tonne of CO₂ (Moreira and Goldemberg 1999). This can be compared to Clean Development Mechanism (CDM) carbon market prices of less than US\$10 per tonne of CO₂, and an expected maximum price of US\$15–20 per tonne of CO₂ over the coming decade.

5

Considerations for Developing Countries

5.1 As shown in chapter 2, with the exception of Brazil, large-scale experience with biofuels to date has occurred predominantly in industrial countries. Brazil's fuel ethanol industry is mature, low cost, well established, and can expand significantly in the future in response to rising demand. A crucial question is how replicable Brazil's experience is in other countries, both in terms of sugarcane-production costs and the other attributes that make Brazil an efficient producer of both sugar and ethanol. This chapter reviews the issues for developing country governments to consider in assessing potential costs and benefits of biofuel programs and draws lessons, where applicable, from countries that have had biofuel programs for a number of years.

5.2 The chapter first considers whether a biofuel industry can be commercially viable without government support. It then considers whether there are justifications for government interventions where the industry cannot stand on its own. Potential justifications include rural development, poorly priced externalities, and energy diversification. Included in the discussion are factors and policies that affect the viability, as well as benefits and costs, of biofuel programs, which include domestic agricultural policies in the country contemplating biofuel production and in other countries, agricultural trade policies, factors that enable farmers to respond to higher demand, and some aspects of macroeconomic policies. The chapter concludes with an outline of how to conduct an economic analysis of a domestic biofuel program.

Commercial Viability of Biofuel Industry

5.3 The first determinant of the economics of biofuels is how their production costs compare to market-based prices of gasoline and diesel. There are several considerations. First, for countries wishing to start a domestic biofuel industry, the question usually boils down to comparing import- or export-parity fuel prices with domestic biofuel manufacturing costs. Second, trade liberalization may have a large impact on traded feedstocks' world prices, and this will have a bearing on the economics of biofuels. Third, in land-locked countries, prices of imported petroleum fuels may be markedly higher than free-on-board international prices, potentially giving a price advantage to domestic biofuels. Fourth, there may be niche markets for biofuels where there is surplus feedstock, or where non-crop feedstock can be grown, harvested, and collected cheaply. Lastly, if biofuels are mandated in some countries and trade barriers are removed, then the lowest-cost producers

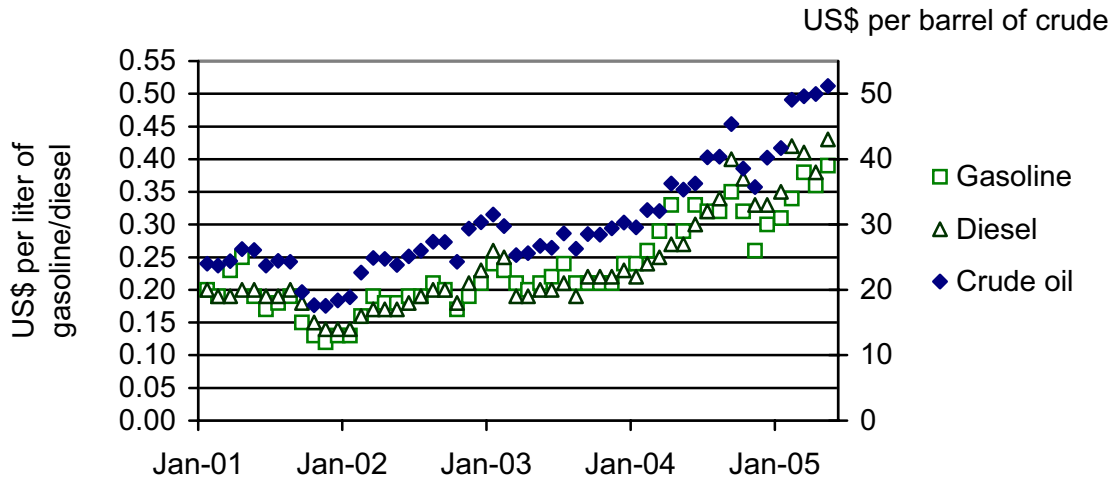
can export biofuels to the countries with mandates even if production costs are higher than international petroleum fuel prices.

Relation to world oil price

5.4 The current cost of biodiesel production appears to suggest that the price of crude oil will have to rise further above the levels observed in 2005 and remain at these levels for a prolonged period of time for biodiesel to be competitive. Commercial viability can be achieved at lower world oil prices for bioethanol. The cost of ethanol production from a new plant in Brazil was estimated in chapter 3 to be in the neighborhood of US\$0.23–0.29 per liter (at R\$2.40 = US\$1.00), corresponding to US\$0.29–0.41 per liter of gasoline equivalent, assuming a reduction in fuel economy of about 20–30 percent. This cost estimate is a function of the U.S. dollar–Brazilian Real exchange rate and, as recently as early 2003, the cost of ethanol production in Brazil was about US\$0.15 per liter on account of the much weaker Real relative to the dollar. A comparison of prices in Figure 5.1 shows that the price of gasoline is US\$0.29 per liter when the OPEC basket price is about US\$35 per barrel, and reaches US\$0.40 per liter when the OPEC basket price is above US\$50 per barrel. Brazilian analysts report that the world oil price would need to remain above US\$30 per barrel for Brazil’s ethanol program to be commercially viable (Lèbre La Rovere 2004), and more competitive than gasoline at or above US\$35 per barrel (Rodriguez 2005). Australia is the second lowest-cost sugar producer, with costs about 30 percent higher than in Brazil. A study undertaken for the government in 2005 concluded that West Texas Intermediate crude will need to be above US\$42–47 per barrel at an exchange rate of A\$0.65 per US\$1.00 for new ethanol producers to be viable beyond 2015 without government assistance (Biofuels Taskforce 2005). At the exchange rate prevailing during the first eight months of 2005, this would correspond to US\$50–56 per barrel, against the average spot price for West Texas Intermediate during the same period of \$54 per barrel.

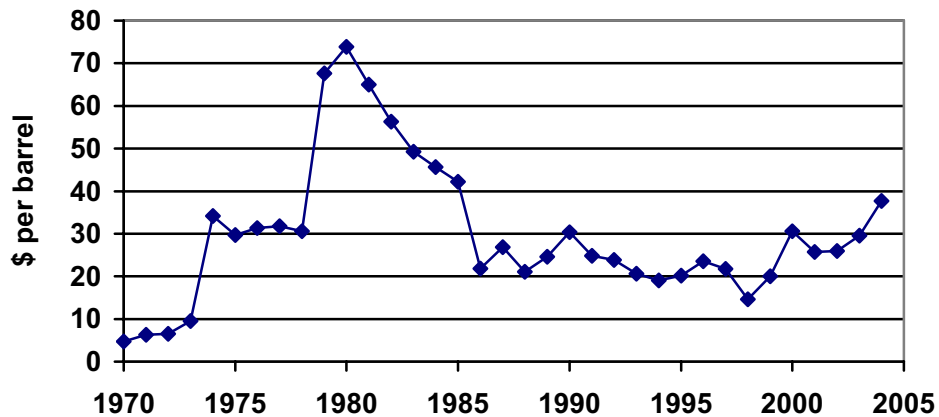
5.5 Figure 5.2 shows that the world oil price surpassed US\$35 per barrel in real terms between 1974 and 1985, and then again only in 2004. It is difficult to forecast future prices of any commodity, and oil is no exception. At a North American energy and power conference in June 2005, two-thirds of the energy executives and institutional investors surveyed said that they expected oil prices to fall back to US\$35 per barrel in five years, while the remaining one-third stated that they believed the world oil price would rise to \$100 per barrel in the same timeframe (Oil and Gas Journal 2005). The first scenario would make biofuels uneconomic in nearly all cases in the near to medium term with the exception of the Center-South of Brazil, whereas the second scenario would open up opportunities for biofuel markets around the world. The first scenario would mean a biofuel program requiring sustained government support, and this has important, long-term ramifications for a national budget. Periods of high crude oil price prompted the launch and expansion of Proálcool, but the sharp decline in the price of oil in the mid-1980s undermined the viability of the ethanol program. As mentioned in chapter 2, the government of Brazil initially intended subsidies to be temporary. However, it was politically difficult to reverse the process of biofuel production in times of collapsing world oil prices, and the government ended up adopting job and industry protection measures with implicit and explicit subsidies in the latter half of the 1980s.

Figure 5.1 Recent International Prices of Crude Oil, Gasoline, and Diesel



Notes: Regular unleaded gasoline and diesel with 0.2 percent sulfur, Northwest Europe monthly averaged prices, barges, free on board; OPEC basket, spot price monthly average
 Source: Energy Intelligence 2005

Figure 5.2 Historical Crude Oil Price (2004 US\$)



Note: World Bank crude price average. Dubai until 1978, average of Dubai and Brent until 1981, average of Dubai, Brent, and West Texas Intermediate thereafter.
 Source: World Bank. Prices adjusted by the annual U.S. gross domestic product deflator from the IMF's *International Financial Statistics Online*

5.6 Because the cheapest path to biofuel production today is ethanol from sugarcane and other pathways are markedly more expensive, it is worth reviewing the factors that have contributed to the low cost of ethanol production in the Center-South region of Brazil. This region of Brazil did not achieve low production costs overnight. A surrogate for the cost of production is the price paid to ethanol producers in Brazil. In 2001 U.S. dollars, it was more than US\$0.60 per liter in 1980. It fell to US\$0.50 by 1983, and after remaining near US\$0.50 for a couple of years, it more than halved between 1985 and 1999. The price per liter reached an all-time low of less than \$0.20 in 1999 before rising to US\$0.30 in 2001 (Goldemberg and others 2004). The price paid to producers of hydrous

ethanol in June 2005 was US\$0.24 per liter. A critical question is to what extent other developing countries will be able to benefit from the Brazilian experience, at what point on Brazil's historical cost "learning curve" they will be able to enter the ethanol market, and, to the extent that none are likely to be able to start an ethanol industry at US\$0.25 per liter, how quickly they will be able to move down the cost curve. Certain aspects of Brazil's ethanol industry are more easily transferable than others. Engineering design and plant construction can be imported—although other developing countries will not be able to take advantage of domestic ethanol plant equipment manufacturers as in Brazil and will consequently have to pay more for plant construction, at least initially. Entrepreneurial and managerial skills, and a cadre of technical people capable of developing new commercial cane varieties, will take more time to develop.

5.7 Table 5.1 shows the leading 13 sugarcane producing countries in the 2004–2005 crop season, listed in order of decreasing cane production. These countries accounted for 78 percent of global sugarcane production and 80 percent of the world's harvested areas. The prices paid to cane growers varies markedly: about US\$10–12 per tonne of cane in Brazil, US\$14 in Thailand, US\$18 in India, and US\$25–30 in the United States. To date, none of the countries listed have been able to achieve the same low cost of production as the Center-South region of Brazil. More than one-half of the total world sugar production occurs in areas where the cost of production is close to three times that in Brazil, in part because some countries that are actually not suited for sugarcane cultivation are growing cane because of the protection provided to the domestic sugar market or for their sugar exports.

5.8 The Center-South region of Brazil is endowed with plentiful land, rainfall, and other favorable climatic and soil conditions. There are other regions that have not yet established large-scale sugarcane industries and that possess comparably favorable climatic and soil characteristics; Zambia is one example. But having favorable natural endowments alone is not sufficient. The Center-South of Brazil has good infrastructure (which Zambia currently lacks), a functioning capital market, and a sugar industry structure that enables cooperation among various players along the supply chain to achieve high efficiency and low cost. The industry has developed more than 500 commercial varieties of sugarcane to match different microclimates and conditions. The average mill/distillery deals with about 15 varieties. Computer programs are used as a matter of routine to optimize agricultural and plant operation. In agriculture, computer programs are used to determine when to harvest so as to maximize the sucrose content and to optimize the distribution of cane varieties on the basis of available soil types, distance to the cane processing plant, and other considerations. Maintenance during the harvesting season and harvest teams are scheduled using computer programs. In cane processing, automation is aimed at increasing extraction, fermentation, and distillation efficiency, and each process uses computer-aided operational controls. These optimization methods are made possible by a high level of managerial skills, research and development technical capability, and the existence of economies of scale for sugarcane and ethanol production Brazil. Because most plants are hybrid mill/distillery complexes, there is no opposition to ethanol production from sugar producers and vice versa. And because there is significant scope for expanding cane production, sugar and ethanol do not have to compete for land.

Table 5.1 World Sugarcane Production in 2004–2005

<i>Country</i>	<i>Harvested area '000 ha</i>	<i>Cane yield t/ha</i>	<i>Production '000 tonnes</i>	<i>Net export '000 t sugar</i>
Brazil	5,350	70	373,000	18,100
India	3,900	62	240,000	-1,780
China	1,410	64	90,750	-1,150 ¹
Thailand	1,020	59	60,000	4,800
Pakistan	945	50	47,038	214 ¹
Mexico	610	75	45,500	-9
Australia	408	94	38,250	4,154
Colombia	396	82	32,350	1,215
Cuba	792	34	27,000	1,250
Philippines	381	67	25,478	200
United States	363	69	25,141	-1,305 ¹
Indonesia	340	72	24,600	-1,350
South Africa	325	62	20,250	994
World	20,410	66	1,346,000	

Harvested area in thousand hectares (ha), sugarcane yield in tonnes (t) per hectare, sugarcane production in thousand tonnes, net export in thousand tonnes of sugar.

¹Countries in which both beet sugar and cane sugar are produced.

Source: FAPRI 2005

Agricultural Trade liberalization

5.9 Liberalization of the world sugar trade could raise the production cost of ethanol markedly. As discussed in chapter 3, if the world sugar market were to be completely liberalized, world sugar prices would likely rise by about 30–40 percent in the short run, and cane prices would rise in parallel. This would raise the opportunity cost of cane in Brazil to the current cane production cost in Australia. The price increase would be induced by both an increase in demand in markets where sugar prices are currently kept artificially high by protectionist measures, and a fall in supply as a result of high-cost producers exiting the industry. While supply from low-cost producers will be expanded, most notably in Brazil, in the short term, supply of ethanol is likely to fall as mills/distilleries produce the higher-priced product. Medium-term supply elasticities are expected to be higher, bringing the market back to equilibrium. Liberalization of maize and soybean trade is expected to have a much smaller effect.

Land-locked countries

5.10 In fuel-importing land-locked countries with poor infrastructure and high transportation costs, prices of gasoline and diesel may be markedly higher than the international prices. If it is possible to transport biofuels to consumption centers at relatively low costs (if, for example, crop and biofuel production can be located close to consumption centers), then biofuels may be competitive with imported petroleum fuels. If,

on the other hand, transportation costs within the country are also very high and biofuel production cannot be located close to consumption centers, then biofuels may not be competitive. Very high transportation costs to the country would add considerably to the cost of constructing and maintaining biofuel plants if materials and equipment need to be imported.

5.11 Cases of very high import costs do not usually occur in isolation and tend to be negatively correlated with levels of economic and infrastructure development. If the cost of transporting fuels is very high for a given country, the cost of exporting goods is likely to be equally high. This would suggest little trade and a generally low level of economic development. To what extent biofuel manufacture can be successfully carried out under these circumstances is not clear.

Surplus feedstock

5.12 If there is surplus feedstock for biofuel production—such as surplus molasses to make ethanol—the feedstock price may be very low. As chapter 2 shows, the ability to convert molasses to ethanol strengthens sugar economics. The question here would be how much molasses would be available at a low price within a certain radius of a potential ethanol plant to achieve adequate scale economies in ethanol manufacture. A large and steady surplus of other feedstocks, in contrast, may suggest an inherent problem in the market such as overcapacity or a policy distortion that makes it difficult to shut down surplus capacity and inefficient operators. If so, the surplus feedstock for biofuel production could disappear if these underlying market distortions are resolved. Still, it is possible that there is a surplus without serious underlying problems. The size of the biofuel industry in these cases would be limited, but a niche market could exist for one or two biofuels producers.

Non-crop feedstock

5.13 There is a great deal of interest in converting non-crop plants to biofuels. If these plants can grow on marginal land with little rainfall, that would make them even more attractive, provided that the cost of harvesting, transporting, and converting them to biofuels can be kept reasonably low. As discussed in chapter 3, commercially viable production of ethanol from cellulose is unlikely for the foreseeable future. There are too few data to assess the economics of biodiesel manufacture from *Jatropha*, but it may not be as favorable as at first glance; the cost of feedstock is relatively high despite *Jatropha* not having an alternative commercial market. Whether large cost reductions are possible and how quickly costs will come down with experience remains to be seen. If *Jatropha* plantations improve soil quality, soil improvement may create demand for switching from *Jatropha* to food production. It is also worth remembering that all forms of biomass have alternative uses and they tend to be highly valued as animal feed or fuel, especially in marginal areas. Infrastructure is usually poor in marginal areas, adding significantly to the cost of transporting biomass or the biofuel (if the biomass is converted to biofuel at the site of collection) to consumption centers. These factors may limit the commercial viability of potentially cheaper feedstocks.

Biofuel mandate

5.14 Some countries are passing biofuel mandates, either for the entire country or in certain regions. If free biofuel trade is allowed, or if compliance requires some biofuel imports, then the question is who can supply the importing country with the lowest-cost biofuel. In the case of mandates, biofuels do not have to be competitive with petroleum fuels. World biofuel trade has remained limited to date, on account of the near-universal policy of protecting domestic biofuel manufacturers. This can and should change in the future through increasing liberalization of trade driven by trade negotiations, and in some parts of the world growing interest in reducing greenhouse gas (GHG) emissions by substituting a fraction of transportation fuels with biofuels. One large market where this may happen is Japan. There are no plans in Japan to start significant domestic bioethanol production, but Japan is seriously interested in biofuels as part of its plan to meet the targets set forth in the Kyoto Protocol. There were earlier indications that Japan might start blending ethanol in gasoline, but more recently the strategy has shifted to blending ethyl tertiary-butyl ether (ETBE). In 2004, Japan was the fourth largest market for Brazilian ethanol (AWKnowledge 2005a). With respect to trade flows to the United States, which has now mandated biofuel use in the 2005 Energy Bill, ethanol presently flows from the Caribbean under the Free Trade Area of the Americas. This ethanol includes raw ethanol from Brazil (which does not enjoy duty-free access to the United States) and, in the past, wine alcohol from the European Union that had been exported to the Caribbean.

5.15 For biofuel programs that are not commercially viable without government support, the next question is whether there are sound economic justifications for government interventions. Possible justifications include rural development, poorly priced externalities, and energy diversification.

Rural Development

5.16 One argument for promoting biofuel manufacture is that it strengthens the agricultural sector by creating demand. Agriculture plays a significant role in the economy of many developing countries. Although declining over the years, agriculture in low-income countries still provides almost 70 percent of total employment and produces close to 25 percent of the gross domestic product (GDP) on average. In middle-income countries, agriculture accounts for one-quarter of employment, although its share of GDP is on average below 10 percent (World Bank 2004a). In Africa, agriculture employs 70 percent of the labor force. Yet agriculture in Africa remains undercapitalized and uncompetitive (World Bank 2000). If agriculture can be made more efficient and competitive, it could spur economic growth, providing much needed jobs and income in rural areas where a disproportionate share of the poor live.

5.17 Many developing countries have adopted growth-reducing agricultural and agrarian policies that have been very difficult to reform (Binswanger and Deininger 1997). Institutional failures and poor policies, for example, have characterized the weak performance of agriculture in Africa (World Bank 2000). There are also other conditions, not necessarily linked to policy failure, that have made it difficult for the agricultural sector to perform. Against this background, what needs to be asked is whether creating

demand by itself will unlock agricultural potential and enable sector growth, and what impact biofuel programs would have on agriculture in developing countries.

Enabling environment

5.18 In considering to what extent domestic manufacture of biofuels is likely to help agriculture, it is useful to take a step back and ask what the priority is for the government to develop agriculture in developing countries. In particular, is the main constraint a lack of demand for farmers' products, or is it a poor enabling environment? There is a great deal of research on agriculture in Africa and poor countries in other regions (World Bank 2000). The most frequently cited priority is improving the enabling environment, and in particular the following aspects:

- *Infrastructure* Roads are necessary to transport products to markets. Good communications infrastructure enables efficient marketing. Where rainfall is inadequate, irrigation systems are needed, including possibly dams.
- *Research and extension services* Good research testing different seed varieties under the local conditions and identifying those with higher yields or with greater resistance to diseases and pests, matching different local conditions, has been instrumental in raising the productivity of the sugarcane sector in Brazil. Once research findings are available, high-quality extension services offering advice on how to cultivate crops and disseminating new seed varieties can ensure that the right seed varieties are used and properly handled.
- *Primary education* An adequate quality of primary education should be available so that farmers can digest information given through extension services and others. Primary education has been shown to raise farmer productivity.
- *Credit market* If farmers are too poor to purchase new seed varieties or apply fertilizers and generally act upon advice given by extension service officers, no amount of research will help. Rural financial and credit markets are often poorly developed and difficult to establish.

5.19 In many poor rural areas, the above enabling environment is absent: road infrastructure is "notoriously weak" in some developing countries (World Bank 2000), extension services are not effective or efficient, farmers do not have primary education, and there is no credit market. Under these circumstances, creating demand—which echoes the mantra of "trade, not aid"—is not sufficient to "kick-start" agriculture. If this is the case, it might very well be more cost-effective to use the limited government resources for building infrastructure, funding agricultural research, or providing primary education first before considering giving support to biofuels.

Impact of policy

5.20 Macroeconomic stability, the foreign exchange regime, and the degree of nonagricultural protection have significant effects on agricultural growth. Inward-looking industrialization policies and overvalued exchange rates (which in turn are favored by an urban bias and protection of import-substitution industries) have been historically very damaging to agriculture. Another damaging policy has been the maintenance of low prices for agricultural products for the benefit of urban consumers. In Africa, the direct

and indirect transfers of income from agriculture to government and the rest of the economy have been greater than the public resources allocated to the sector. This in turn has slowed down the development of rural infrastructure, institutions, human capital, and support services, and the ability of the private sector to develop (World Bank 2000). Fortunately, most countries in Africa have undergone structural adjustment and farm prices are today near border price levels.

5.21 One manifestation of poor agricultural policy, leading to lackluster or even deteriorating agricultural performance, is excessive involvement of the government, often highly centralized, in the sector, ranging from procuring inputs to sales of outputs. Adverse state involvement can take the form of government control of procurement and distribution of fertilizer and seeds, controls on crop movements, and dominance of the output markets by marketing boards. Heavy government involvement can discourage free, competitive trade and reduce the incentives for private investment in agriculture and agribusiness. The end result may be insufficient adoption of appropriate technology resulting in low irrigation, low use of purchased inputs and machines, low yields, and low labor productivity, because it is not profitable to adopt productivity-enhancing technology.

5.22 Resources that flow to agriculture all too often benefit politically powerful large producers and modern enterprises disproportionately at the expense of smallholder farmers and landless workers. Examples include untargeted producer subsidies and distortionary subsidies for privately used inputs such as water and electricity. At the same time, public services provided in rural areas for road construction and maintenance, water supply, primary education, and primary health care can be woefully inadequate, despite the widely accepted observation that investments in these public services can increase private sector activity and returns to private investment in rural areas. Inadequate provision of rural services may be especially acute if local governments have trouble paying for these services because revenue collection and government expenditures are highly centralized. It is common for central governments to have a serious urban bias, devoting much of their expenditures to the rural elite and urban middle and upper classes (World Bank 2000, Binswanger and Deininger 1997). Inadequate transport and communication infrastructure in turn raise transaction costs, making agriculture uncompetitive. Inadequate infrastructure is a major constraint in Africa. These problems are exacerbated by inadequate market infrastructure and insufficient appropriate vertical integration.

Implications for biofuel programs

5.23 Given that institutional and policy failures are the primary underlying causes of poor agricultural development in many developing countries, it is important to assess the potential impact of a biofuel program that would likely require substantial government involvement, at least initially. There is thus the risk that promotion of a commodity that will require yet more direct government intervention may exacerbate, rather than alleviate, the problems faced by the agricultural sector in many developing countries.

5.24 Biofuels worldwide have required implicit subsidies in the form of partial or full tax exemptions and protectionist trade policies. Subsidies provided for biofuels tend to benefit primarily agribusiness firms rather than smallholder farmers or landless workers. These tendencies can further entrench, rather than lessen, the often-observed pattern of public resource flows benefiting large producers. Lessons from international experience should therefore be considered before establishing such a program.

5.25 Large-scale biofuels programs for transport are unlikely to help the poorest rural families: those who live in remote areas with a low-density, widely dispersed rural population. Unfortunately, much of Africa's agriculture tends to be concentrated in these areas (World Bank 2000). Small-scale decentralized biofuel programs for non-transport purposes in remote rural areas may offer an alternative to high-priced diesel fuel and kerosene for electricity generation and a range of productive rural activities.

5.26 Because sugarcane degrades soon after harvesting and its bulkiness makes it expensive to transport, local producers and processors are often locked in monopoly-monopsony relationships, resulting in scheduling and pricing conflicts. These relationships affect community incomes, assets, and profitability. Sugar processing, like ethanol production, is capital-intensive, and requires adequate working capital between the purchase of sugarcane and the sale of processed sugar. If sugar mills are not economically viable (because they are run by inefficient state operators or they rely on subsidies or both), then in times of economic downturn, millers can face serious financial difficulties. These concerns would be equally applicable to ethanol manufacturing plants based on cane. In contrast to capital-intensive sugar processing, on the production side, family-owned farms are among the world's most efficient sugar producers. In terms of efficiency, smallholder farms in Thailand compare favorably with large and medium-size sugar farms in Australia, France, and the United States (Larson and Borrell 2001). A large number of smallholders supplying to one large processor gives rise to an interesting power relationship. Scheduling and pricing conflicts would be damaging to all parties and to the industry. Consideration should be given to how to minimize excessive power imbalance and conflictual relationships and to foster cooperation along the supply chain.

Job Creation

5.27 One frequently cited benefit of biofuel manufacture closely linked to rural development is job creation. In Brazil, for example, Proálcool provided direct employment to about 40,000 permanent and 82,000 seasonal workers by 1980 (Pereira 1983). The disproportionately high percentage of seasonal work is undesirable, but by the 1990s, jobs created in the ethanol industry had a lower index of seasonal work (Moreira and Goldemberg 1999, see also annex 2). Two important questions here concern the net gain in the number of jobs created and in real income. An analysis of the first five years of Proálcool gives useful insights, especially for developing countries considering ethanol programs, and for this reason is cited in some detail in this section (Pereira 1983).

5.28 Net job creation can arise under two scenarios:

- Where growing crops for biofuel production is an additional activity and does not displace other agricultural activities

- Where growing crops for biofuel production displaces agricultural activities that utilize less labor.

During the first five years of Proálcool, about 376,000 hectares (or about 25 percent of the total sugarcane area) in the state of São Paulo was turned over to sugarcane, displacing crops (36 percent) and pastures (64 percent). Because sugarcane is approximately seven times more labor-intensive than pastures, this resulted in a net gain of some 25,500 worker-years of employment consisting of a total of 40,500 worker-years generated minus 15,000 worker-years lost.

5.29 The considerable amount of employment generated is an important benefit. A related question is the quality of jobs. Sugarcane harvesting creates many jobs but they are seasonal and offer very low wages even by developing country standards. In addition, as a country's economy develops, labor-intensive jobs, if mechanization is a viable alternative, are the first ones to disappear, so that the long-term prospect of creating a large number of permanent jobs with stable income is not necessarily favorable. In Brazil, even in the face of sharply increasing urban unemployment and underemployment, cane harvesting became increasingly mechanized (see the discussion of the "reservation wage" in this chapter). Biofuel production plants are another source of employment. Some of these jobs are seasonal. Sugarcane degrades soon after harvesting so that it needs to be processed immediately, as a result of which distilleries, for example, operate during the harvest season only.

5.30 Pereira's study found that for the largest class of employees—seasonal agricultural workers—wages were slightly above the minimum wage level but sometimes lower. There were reports of evictions of subsistence peasants in order to replace pastures and food crops by sugarcane monoculture. Such possibilities should be monitored carefully in implementing new programs in other countries. The most significant improvements appear to have taken place among semi-skilled industrial and agricultural workers such as lorry drivers, farm-machinery operators, and workers in vehicle and equipment maintenance. Because well-trained lorry drivers and farm-machine operators were in short supply, they tended to be given permanent employment even though there was much less to do during the off-season. While the number of jobs was limited, these workers were earning wages substantially higher than those for similar jobs in large cities.

5.31 The number of regions where there is both excess land and excess labor is small. For example, Zambia, which has a large amount of high-potential uncultivated land, does not have much excess labor, and certainly not during the agricultural season. That said, in land-surplus, labor-scarce areas, capital investment can substitute for labor. Zambia could become one of the world's leading sugar producers, but would need significant investment, including for infrastructure. In most countries, however, biofuel production would come from new energy crops substituting other activities.

5.32 If substitution is likely to be the prevalent model, it raises the question of whether energy crop cultivation is the best use of labor, capital, and entrepreneurial skills. An example of alternative use of resources is horticulture. Spurred by the secular decline in the prices of traditional commodities, a number of developing countries have begun to adopt high-value agricultural exports—typical examples of which include vegetables, fruits,

and flowers—to diversify production and achieve economic growth. As annex 3 shows, these high-value crops are generally labor-intensive; give significantly higher returns to land, labor, fertilizer, and water than other crops; and also generate jobs downstream in processing and packaging. It is difficult for government to pick “winners,” and quite common for government to end up picking the “wrong” industries for promotion. Prior to government’s committing to promotional policy for any particular agroindustry, alternatives should be explored and carefully examined.

Accounting for Poorly Priced Externalities

5.33 Biofuels can reduce GHG emissions and have other environmental benefits. While these considerations do not automatically justify support to biofuels, they may merit a policy that rewards actions that reduce GHG emissions or generate environmental benefits. Markets are currently emerging for GHG-reducing projects, and these markets may help move the industry toward sustainability. The externality argument, however, can also be used against some forms of biofuels, since expanding feedstock production can lead to water pollution and soil depletion, creating the need to price related negative externalities.

5.34 The environmental case for fuel ethanol was very strong when leaded gasoline was used extensively, and ethanol as an octane booster could help reduce and eliminate lead in gasoline. This was the case in Brazil, which became one of the first countries in the world to eliminate lead entirely from gasoline. More recently, the majority of developing countries have moved to ban lead in gasoline. The last region of the world to take this step, sub-Saharan Africa, is on its way to eliminating lead by end-2005 or shortly thereafter. As mentioned in chapter 4, Venezuela appears to have decided to use ethanol in its effort to eliminate lead. Most other countries have achieved lead elimination without much reliance on ethanol: by reducing unnecessarily high octane grades for gasoline and through less costly refining alternatives such as greater use of reforming and isomerization.

5.35 After lead elimination, the next high-priority local pollutant in the transport sector is particulate matter. As discussed in chapter 4, the two greatest sources of particulate emissions are gasoline vehicles with two-stroke engines and diesel vehicles. Chapter 4 discusses the impact of biofuels on both sources of particulate emissions. Adding ethanol to gasoline in two-stroke engine gasoline vehicles would have little impact; in fact, the report submitted by the Australian government’s biofuels taskforce recommends against using gasohol in two-stroke engine vehicles (Biofuels Taskforce 2005). B20 could reduce particulate emissions by 10 percent in properly operated vehicles. What is less understood is the impact of biodiesel on exhaust emissions from vehicles that are operated under conditions typical in developing countries: underpowered, overfueled, overloaded, with dirty injectors, worn-out injection nozzle tips, and overly retarded injection timing. More data on particulate emission reduction under the conditions typical of developing countries would be helpful to assess the impact of biodiesel on exhaust particulate emissions.

5.36 There are several ways of accounting for poorly priced environmental externalities from vehicular emissions. Fuel taxation is one, but, as discussed in chapter 3, fuel taxes are not very efficient in reducing externalities associated with negative health

effects of harmful pollutants in vehicle exhaust. These emissions and their environmental externalities depend not only on fuel choice but also on vehicle technology, vehicle maintenance, the vehicle driving pattern, and the location and time of emissions. Some examples of the effects of these factors are illustrative. Although diesel is generally the “dirtiest” transport fuel, “clean diesel” technology can be nearly as clean as natural gas. For a given fuel-driving cycle combination, poorly maintained vehicles generally have much higher emissions. Emissions occurring only in densely populated areas harm public health disproportionately. The high degree of differentiation of environmental damages from the same fuels across various users, technologies, and locations limits the effectiveness of fuel taxes set at the national or state level for controlling air pollution (Lvovsky and Hughes 1999). More precisely targeted alternatives to fuel taxes should be considered wherever possible.

5.37 Where the government has decided to use fuel tax to capture some or all of externalities linked to air pollution from urban transport, it can be shown that an efficient approach is to tax polluting goods accordingly, and not subsidize less-polluting alternatives. Taking the calculations in paragraph 3.66—bearing in mind that the computed estimates have very large uncertainties because of many simplifying assumptions that have had to be made—if diesel and gasoline are taxed an extra 16 and 4 US cents per liter to account for local air pollution, respectively, then bioethanol and biodiesel may be discounted by half of these amounts. This assumes that taxes accounting for environmental externalities are already in place on conventional gasoline and diesel—over and above fuel taxes for raising revenue, promoting efficient fuel consumption, financing road maintenance, reducing congestion, and redistributing income, implying a fairly high rate of fuel taxation from which a portion can be waived for biofuels. High fuel tax, however, is not common for diesel in developing countries.

5.38 Marine use of biodiesel may be one area where the biofuel could have a clear environmental advantage over petroleum fuels. The solubility of biodiesel methyl ester in water is much greater than that of petroleum diesel, leading to a lower rate of suffocation or coating of exposed gills and enabling marine life to survive at higher concentrations of biodiesel than those of petroleum diesel. A 1995 study found that biodiesel made from rapeseed oil would biodegrade twice as fast as petroleum diesel. Rapeseed biodiesel was also shown to increase the biodegradation rate of a biodiesel-petroleum diesel blend. If spilled or leaked, biodiesel would therefore be expected to have less adverse impact on aquatic and marine life than petroleum diesel (von Wendell 1999). Fuel tax differentiation to account for this effect is likely to be very small.

5.39 It is informative to estimate how much GHG emission reductions can contribute to the cost of biofuel production. For the first commitment period of the Kyoto Protocol (2008–2012), an estimated upper bound to the price of carbon is US\$10 per tonne of carbon dioxide (CO₂)-equivalent, and the subsequent period is unlikely to see a price above US\$15 per tonne. A well-to-wheel analysis of gasoline and diesel shows that producing and combusting a liter of gasoline or diesel gives off 2,000–3,500 grams (g) of CO₂-equivalent per liter. At US\$10 per tonne, a 100 percent reduction in GHG emissions to zero (representing the maximum financial benefit the industry can hope to achieve) would pay US\$0.02–0.035 per liter if the energy content is the same, and less if the biofuel has

lower energy content (as with ethanol). A rule-of-thumb estimate used for Clean Development Mechanism (CDM) projects in India is that 1,000 liters of diesel can offset about 1.5 tonnes of CO₂-equivalent (Mathur 2005), or US\$0.015 per liter at US\$10 per tonne, rising to US\$0.03 per liter at US\$20 per tonne. These are significantly below the tax exemptions granted around the world for biofuels and hence could not be expected to be the main instrument for making a biofuel industry sustainable for the foreseeable future.

5.40 Recently, the price of carbon in the European Union (EU) has risen to close to €30 per tonne. It is important to understand that this market is not the same as the carbon market that developing countries can look to for carbon trading. The EU Emissions Trading Scheme is an EU-wide cap-and-trade emissions trading system that buys and sells EU allowances (EUAs). EUAs are issued by national governments and allocated to emitters by auction, regulation, or specific decree. The holder of EUAs is permitted to emit the equivalent quantity of CO₂ toward meeting emissions obligations in the EU Emissions Trading Scheme. Throughout 2004, EUAs traded between €7 and €9 per tonne. By July 2005, EUA prices exceeded €28 per tonne due to a short-term demand and supply imbalance during the trial phase of this scheme in 2005–2007. The price fell in August 2005 to €20 per tonne, demonstrating the instability of the trial market, which is expected to stabilize further with more experience and additional supply. Developing countries will trade certified emissions reductions (CERs), which are units of GHG reductions generated through the CDM. Delivered CERs eligible for crediting under the EU Emissions Trading Scheme are eventually expected to trade at prices competitive with EUAs. That said, projects involving CERs have significant lead time, making delivery in the short term difficult. There is also uncertainty concerning the eligibility of CERs in the EU Emissions Trading Scheme as well as the conditions for transferability; many national governments have not yet clarified these rules.

5.41 “Modern” biomass—meaning the use of wood, crop wastes, and dedicated plants in cleaner combustion technologies—includes, but is not limited to, biofuels. Biomass in solid form can be burned in more efficient stoves and boilers with much lower emissions than traditional devices, while anaerobic fermentation and gasification of a broad array of biomass feedstocks are well-known and efficient ways of producing energy. The reason biofuels have attracted so much attention within the climate change debate is that transport is a significant contributor to overall GHG emissions, and there have been few other options identified to reduce GHG emissions in the transport sector. From a climate perspective, biofuels are a relatively expensive way of reducing GHG emissions compared to mitigation measures in other sectors. Even within the transport sector, the promotion of public transportation, non-motorized transport, vehicle energy efficiency improvements, and urban planning and land-use changes are expected to provide much larger and lower-cost GHG reductions than biofuels, and are strategically important in developing countries where transport demand is still growing rapidly.

Energy Diversification

5.42 Energy diversification is one of the main justifications cited for expanding the use of ethanol in the United States. Similarly, the mandates for the replacement of gasoline and diesel with biofuels in the European Union is driven in part by the desire to

diversify energy sources. In this policy area, biofuels are pursued to address two concerns: (1) disruptions to oil supply from political and other events, and (2) the damaging impact on the domestic economy of world oil price volatility (such as the oil price hikes of the 1970s and 1980s, and more recently in 2004–2005).

5.43 Diversifying supply of transportation fuels is possible with biofuels, and the question is at what cost. If costs are low, as in Brazil, biofuels could account for a sizable fraction of total transportation fuels. This is somewhat complicated by the fact that, for feedstocks with alternative markets, crop growers will sell into the higher-priced of the two commodity markets (ethanol and sugar in the case of Brazil), threatening the supply of ethanol in times of high world crop and low biofuel prices. Flex-fuel vehicles go a long way toward addressing this concern.

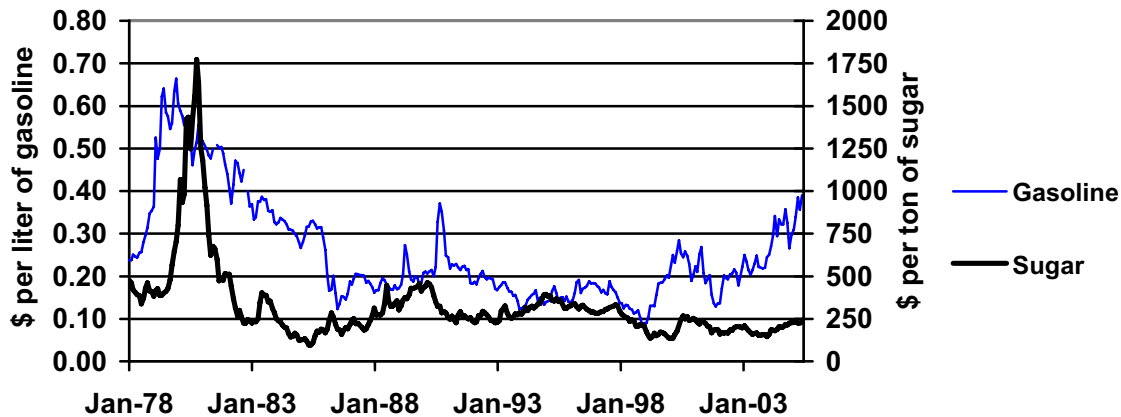
5.44 The benefits of diversification can be greatly enhanced if biofuel trade is liberalized. Currently, such trade is limited, to a large measure on account of protection of domestic producers and, historically, on account of the unwillingness of governments to subsidize imported biofuels. Liberalization of biofuel trade would be helpful for a number of reasons. First, the most efficient biofuel producers could expand their market share beyond their borders. Second, the political pressure to maintain large tax exemptions in favor of biofuels in any given country would be less or none if imported biofuels, not domestic producers, benefit from tax exemptions. Both would promote pressure to increase efficiency and close inefficient manufacturers. Growth of the most efficient biofuel manufacturers in turn would contribute to energy source diversification worldwide.

5.45 In a liberalized market, biofuels will be price takers in the oil market for the foreseeable future because their production will remain a small fraction of the total petroleum fuel production. As such, biofuels will not mitigate the impact of oil price volatility if there is free trade—biofuel prices will track those of substitute petroleum fuels. If international trade is restricted, or biofuel prices are not determined by the market on account of government intervention, then biofuel prices could be lower than petroleum fuel prices. Barriers to international trade prevent emergence of an efficient market, and government interventions in commodity pricing have historically resulted in distortions, black markets, and long-run disincentives to investors.

5.46 In a liberalized market, biofuel prices will track petroleum fuel prices and hence price volatility of the two fuels will be comparable. In a non-liberalized market (which is the situation today), their prices need not track each other. Because of the notion that biofuels could stabilize transport fuel prices, it is useful to compare the price volatility of sugar with that of gasoline. Figure 5.3 superimposes world raw sugar and gasoline prices for comparison. Between January 1978 and June 2005, price volatility was greater for raw sugar than for gasoline: the coefficient of variation, which gives an indication of fluctuations from the mean, was 48 percent for gasoline and 72 percent for raw sugar. Taking only the last two decades between July 1986 and June 2005 reduces the coefficient of variation for both commodities, but that for sugar is no lower: 29 percent for both gasoline and raw sugar. Because cane producers will try to sell to the market that offers a higher price, sugar or fuel, it is also informative to see if gasoline and sugar prices track each other. If not, there will be periods of high sugar and low gasoline prices, threatening

the supply of ethanol. Between January 1978 and June 2005, world raw sugar and gasoline prices were correlated with a correlation coefficient of 0.57. However, this correlation arises primarily from the price hikes for both gasoline and raw sugar in 1979–1981. The correlation coefficient between January 1982 and June 2005 falls to -0.05 : that is, the prices have not tracked each other.

Figure 5.3 World Raw Sugar and Gasoline Prices
(real prices in 1st quarter 2005 US\$)



Note: Regular unleaded gasoline, Northwest Europe monthly averaged prices, barges, free on board.

Source: USDA 2005c, Energy Intelligence 2005, U.S. GDP deflator from the IMF's *International Financial Statistics Online*

5.47 Against this backdrop, flex-fuel vehicles, enabling vehicle drivers to choose between two fuels, take advantage of swings in relative prices of sugar and gasoline. A fairly wide availability of the second fuel—a high-ethanol content fuel, such as hydrous ethanol or E85—would be a pre-condition for the success of flex-fuel vehicles. As mentioned in chapter 2, a number of flex-fuel vehicle models have been launched in Brazil. They make adjustments to shifting fuel supply easier, thereby reducing the chances of recurrence of the problems encountered beginning in 1989 when a shortage of hydrous ethanol led to a loss of consumer confidence and a rapid decline in the sale of single-fuel vehicles running on hydrous ethanol. Hybrid plants, capable of switching between sugar refining and ethanol production, are suited for this purpose. (In countries with domestic petroleum refineries, large swings in demand for gasoline could have a serious adverse effect on refinery economics.) The built-in excess capacity in hybrid plants comes at a cost, but this seems to be more than compensated by the gains in the overall economics. One disadvantage of flex-fuel vehicles is a large fuel economy penalty when running on a high-ethanol content fuel (U.S. DOE 2005).

Economic Analysis of Biofuel Programs

5.48 The economics of biofuel production is site- and situation-specific. Economic analysis is important in all cases, but especially when government support is justified on the basis of social benefits that are not necessarily captured in financial terms (such as environmental benefits). Economic analysis can also be a valuable tool in

reshaping planned or existing programs to maximize their efficiency and their net benefits to society. An economic analysis parallels a financial analysis that optimizes inputs for cost minimization. The first and critical step in an economic analysis of a domestic biofuel program would be to examine substitution of a petroleum fuel with the equivalent quantity of a biofuel (taking into account the differences in the fuel economy of the two fuels) to see if the net benefit is positive. For example, to examine the economics of manufacturing and consuming 1.3 billion liters of ethanol a year, the baseline case could be annual import and consumption of 1 billion liters of gasoline (if fuel economy is anticipated to decline by about 25 percent when switching from gasoline to ethanol).

5.49 Most countries considering biofuel programs are importers of oil or of refined products that plan to produce biofuels domestically for internal consumption. This chapter takes the example of an oil-importing country with domestic refining capacity. The two alternative supply chains for transport fuels may be broken down into five stages: (1) production of biomass or import of crude oil as feedstock, (2) feedstock transport to a processing plant (a biofuel processing plant or a refinery), (3) conversion of the feedstock to fuels, (4) transport of finished fuels to depots and on to retail outlets, and (5) consumption of fuels by end-users. If refined fuels are imported, then the first three stages can be skipped for the petroleum supply alternative, and the supply chain analysis for that alternative can start with the arrival of gasoline or diesel at an import terminal or crossing of the border by fuel tank lorries.

5.50 Figure 5.4 lists the costs and benefits that need to be calculated for the production and consumption of biofuels as well as the baseline case, which is continued use of petroleum products for transport. The costs and benefits are grossed up in the two cases and then the difference between the two alternatives is obtained to see if the net social benefit of fuel substitution is positive or negative. Where benefits do not appear in the figure, it is either because there are no net benefits going from the base case to the biofuel case, or because benefits cannot be reasonably counted and valued. The biofuel alternative is discussed first, followed by the baseline case of continued reliance on petroleum products.

5.51 Calculating the economic costs associated with biofuel programs begins with estimating the *economic opportunity* costs of land, water, fertilizers, herbicides, insecticides, electricity and diesel for irrigation and powering farm equipment, labor, seeds, and machinery used in feedstock production. Opportunity costs, rather than the financial prices paid, should be used in the economic analysis to ensure that the true costs of subsidized inputs as well as the forgone alternative uses of resources are properly reflected.

5.52 Research and development (R&D) can foster innovation and reduce costs. The funds to finance R&D will appear as costs, but if successful, they can be more than offset by lower costs in feedstock production or biofuel processing or both. R&D may also generate positive externalities for the wider agricultural sector.

5.53 Potential damage to the environment occurs throughout the supply chains for both alternatives. Possible environmental damages from the biofuel alternative include air emissions from field burning, operating tractors and vehicles, and splash blending of ethanol with gasoline; fuel spills into water and soil; adverse effects on soil from intensive

monocrop cultivation; and discharge of agrochemicals, untreated vinasse, and other waste products into water. If there is already a petroleum product pipeline, switching to ethanol, which will likely require switching the mode of fuel transport to trucking, will result in incremental air emissions and damage to roads. The impact of fuel spills on marine life will be more benign with biodiesel than petroleum diesel because of biodiesel's greater biodegradability. It is also possible under some circumstances that biofuel feedstock production mitigate soil erosion.

5.54 For converting the feedstock to a biofuel, costs include investment costs (which requires assumptions about the plant utilization rate, discount rate, and plant life), operation and maintenance costs, and the cost of waste disposal, if any. An important benefit is the sale of co-products, which can lower the net cost of biofuel production markedly. It is important to address whether the cost of production is lower than the financial and economic import-parity cost of the biofuel. If not, then the country does not have particular comparative advantage in biofuel manufacture and would be better off importing the biofuel.

5.55 At the retail and end-use levels, because of different physiochemical properties of biofuels, several modifications may be needed. Vehicle parts may have to be replaced more frequently or modified, purpose-built (such as flex-fuel) vehicles may have to be purchased, and splash blending facilities for ethanol may have to be built. Corrosion and greater deposition may increase the cost of vehicle maintenance. If the country is not importing refined products, then the displaced petroleum fuel may have to be exported. Because export-parity prices are typically lower than domestic prices, this could impose a financial loss on the refiner. If the refinery throughput is reduced instead, then the impact of lowering the plant utilization rate on refinery economics, as well as of producing less of other fuels on imports, will need to be considered. If gasoline is to be blended with ethanol, refining costs may change. The refiner may have to manufacture gasoline with a lower Reid vapor pressure (RVP), which will carry a cost, or may be in a position to manufacture gasoline with a lower octane, which will decrease the cost of refining.

5.56 Use of biofuels will change the vehicle exhaust emission characteristics. Calculating the economic impact of this change is accomplished in several stages. First the contribution of vehicle emissions to ambient air quality is estimated in a procedure called source apportionment. This requires detailed data on ambient concentrations of pollutants as well as sources of emissions. Next the impact on ambient pollutant concentrations of changes in emission levels as a result of fuel substitution is estimated. The costs of air pollution include reduced visibility and damage to vegetation and buildings, but by far the greatest cost is the damage to human health. For this reason, the incremental changes in the number of cases of illnesses and premature mortality are computed and evaluated using cost-utility and related calculations. Because these calculations involve ranges of estimates, sensitivity of overall economic analysis results are then evaluated against ranges of environmental values.

Figure 5.4 Financial and Economic Analysis of a Domestic Biofuel Program

Biofuels		Petroleum fuels	
	Costs	Benefits	Costs
Feedstock production	Cost of land, water, agrochemicals, diesel, electricity, labor, seeds, machinery Damage to environment: field burning, discharge into water streams, soil erosion Research and development	Slowing soil erosion	Crude oil procurement Import parity cost of oil Damage to environment at import terminals Discharge of oil into water and soil
Transport to biofuel plant	Cost of vehicle purchase, operation & maintenance, labor, transport fuel Road damage by transporting vehicles Air emissions during transport Damage to environment from fuel spills		Oil transport to refinery Pipeline operating cost: cost of energy, labor, maintenance & repair Or cost and environmental damage of trucking: vehicle purchase, operation and maintenance, transport fuel, labor, road damage, air emissions during transport Damage from fuel spills
Biofuel processing	Plant construction cost: plant utilization rate assumption, opportunity cost of capital Operation and maintenance: spare parts, repairs, consumables, opportunity cost of labor and energy Research and development Waste disposal Discharges to air, water, and soil	Co-product sales	Oil refining Operation and maintenance: cost of labor and energy, spare parts, repairs, consumables Waste disposal Discharges to air, water, and soil
Transport to market	Opportunity cost of labor and transport fuel Vehicle purchase, operation and maintenance Damage to road Air emissions during transport Damage from fuel spills		Transport to market Pipeline maintenance and operation Cost of labor and transport fuel Transport vehicle purchase, operation and maintenance Damage to road Air emissions during transport Damage from fuel spills
Retail & end use	Vehicle hardware modification Purchase of purpose-built vehicles Storage Splash blending facilities Retail outlet modification Damage from fuel spills Corrosion Difference between export-parity and domestic price of gasoline Incremental cost of making gasoline suitable for blending	Improved health from reduced exhaust emissions	Retail & end use Storage Damage from fuel spills
Economy-wide & global effects	Impact of higher food prices on economy Impact of poor harvest or crop failure	Technological innovation spillovers in other sectors Reduced GHG emissions Reduced supply disruption risks from diversified portfolio	

5.57 Biofuel production will also have economy-wide and global effects. Technological innovation from R&D can have important spillover effects in other sectors, spurring economic growth. Using biofuels is almost certain to reduce overall GHG emissions. Diversifying the fuel supply portfolio will also reduce supply disruption risks. Against this must be weighed the risk of poor harvests, which could worsen rather than mitigate supply disruptions. Unless feedstock production is entirely additional (that is, requires no switching of land, labor, and water from other crops), there is a possibility of increases in the prices of agricultural crops. The impact on the economy of such price increases will need to be taken into account, especially if food prices are expected to rise.

5.58 The baseline case entails apportioning the costs and benefits in the supply chain to the amount of petroleum fuel being displaced. Different factors that need to be considered in the baseline case are shown in Figure 5.4. The difference between the two cases is then computed.

5.59 Ideally, this set of calculations is repeated for a full project or program life cycle, and the discounted net present value computed to arrive at the final net benefit. If there is a net social benefit over and above the net financial benefits of involved entities, then financial assistance up to the size of the benefit may be merited. There are many uncertainties in the calculations. Some of the benefits and costs are difficult to quantify and to value in monetary terms. They include environmental damage and the impact of changes in vehicle exhaust emissions on public health. There are assumptions that concern future forecasts: future commodity prices, weather, the pace of technological change, how rapidly production costs are anticipated to fall, future demand for energy, GDP growth, and other uncertainties. There are also data that are needed for the economic analysis but are not readily available. This is especially true for computing the lifecycle GHG emissions: how fertilizers are manufactured and used, the degree of carbon sequestration, and the fuel economy of vehicles. There is a need for more data collection and studies, and in the mean time to run sensitivity analysis to strengthen policy recommendations.

5.60 Making the change to production and consumption of biofuels rather than continuing to use petroleum for transport will impose gains and losses on different parts of society—including workers who must switch jobs, consumers of alternative crops, and suppliers of inputs in each of the alternative supply chains.¹⁷ While the end objective of economic analysis is to tally the impacts upon society as a whole, the analysis also can be used to estimate the distribution of the impacts of a biofuel program. Setting up the accounts in Figure 5.4 first in financial terms and then in economic analysis terms before comparing the differences, entity by entity, in the related accounts yields a third set of accounts showing the distribution of the biofuel program's impacts on different parts of society.

5.61 The job creation objective makes farming systems research and farm budget analysis critical components of the financial and economic analyses. They can reveal three important “wage rates” that are relevant to the analysis and to program reshaping: (1) the

¹⁷ And users of foreign exchange who will realize an increase or decrease in its availability if the exchange regime is not market-based.

actual compensation received by the laborer (either as wages or as returns to work on a family farm); (2) the compensation given up in the alternative employment (called the opportunity cost of labor, which could be close to zero in extreme cases); and (3) the “reservation wage” that represents the minimum returns per hour of labor at which the worker will do the kind of work involved in the project or program. Employment creation projects have failed in the past when increased annual compensation meant a lower return per hour for many more hours of hard work than in the previous employment (unemployment) situation. The reservation wage has proved a relevant parameter in estimating the supply of labor for such activities as cane harvesting in some countries.

5.62 It is easier to have an open, public debate on when, where, and how to embark on a biofuel program if costs, benefits, and their distribution are transparent; carrying out this type of economic analysis is an important step in public consultation. Given the magnitude of uncertainties involved in these economic calculations, there could be a fair amount of discretion in judging when and where biofuels will be economic and in optimally reshaping programs to make them so. Involving the public from the outset and making financial support transparent throughout the program will go a long way toward enhancing accountability and ensuring efficient use of public funds.

Future Technologies

5.63 In the long run, production of biofuels from more widely available and cheaper biomass is likely to become commercially viable, enormously increasing the scope for economic production of biofuels both in terms of the total volume manufactured and the number of countries where manufacturing takes place. Agricultural residues, woody biomass, dedicated energy crops (such as switchgrass), and municipal solid waste are some of the potential feedstocks for ethanol production. While numerous technical issues remain to be addressed, the announcement by Iogen, an enzyme manufacturer, to build the world’s first commercial-scale cellulosic ethanol plant (Time Magazine 2005) is an indication of the pace of progress being made.

5.64 There are technical and financial risks associated with commercialization of new technology. The performance of the technology (biofuel production process and associated technologies in this case) is uncertain and can be assessed only after months or, more typically, years of application on a large commercial scale. Unforeseen technical problems are common, especially when the technology is deployed in different countries with wide disparities in income levels and managerial expertise. The costs associated with novel technology fall substantially with greater volume and experience. These technical and financial risks are probably best left to industrial countries, which have the resources to manage them. For developing countries, it would make sense to allow industrial countries to pay the premium to resolve problems with emerging technologies and to move the new technologies down the cost curve.

5.65 Given the current knowledge about the impact of economies of scale on the cost of biofuel production from cellulosic materials, small-scale applications are unlikely to be economic, although this situation could change. Conversion of plant seeds to oil for direct use, either blended or alone, without further reaction with methanol or ethanol to make biodiesel may be suitable for small-scale and decentralized application in rural areas.

Additional studies on the long-term use of such unmodified plant oils in diesel engines are needed. Earlier studies indicated that blends containing more than 20 percent oil often resulted in engine damage or maintenance problems. Few, if any, engine studies using low-level blends of unmodified plant oils appear to have been conducted (Jones and Peterson 2002). Given the relative simplicity of the technology for producing plant oils and the much lower upfront investment cost compared to that for biodiesel manufacture, this may merit further investigation.

5.66 Biodiesel is more expensive to manufacture than ethanol or unmodified plant oils. The need for methanol—typically made from fossil fuels—in the process adds to the complication of setting up economic biodiesel plants in rural areas where transporting methanol to the plant site may be costly. There is little experience and hence little information on the cost of biodiesel production from plants that grow on low-grade land without requiring fertilizer and pesticide application or irrigation. Obtaining data on the cost of oil produced, which is the largest single component of biodiesel production costs using traditional crops, is urgently needed.

6

Conclusions

6.1 Concerns about growing greenhouse gas (GHG) emissions in the transport sector in absolute as well as relative terms and energy source diversification are leading industrial countries to consider setting guideline targets for, and even mandating, biofuels. In quantitative terms, biofuels production is likely to expand in the coming years given the number of programs that have been established or expanded, especially in industrial countries. In Brazil, after a period of decline in ethanol consumption, there is a revival of the fuel ethanol market with the launch of flex-fuel vehicles capable of running on gasoline-ethanol blends or ethanol. These trends and similar considerations have prompted a number of developing countries to consider biofuels.

6.2 The continuation of high world oil prices over the next several years will provide extra incentives for biofuels programs. From a period of low prices in 1998–1999, oil prices have risen steadily and surpassed US\$50 and even US\$60 per barrel in 2005. Factors accounting for the price increase include unexpectedly strong demand, a reduction in surplus oil production and refining capacity, fear of disruptions to supply in oil-producing countries due to oil worker strikes and political events, and depreciation of the U.S. dollar. This report estimates that ethanol from sugarcane grown under conditions similar to those in the Center-South region of Brazil might be commercially viable with no government support at oil prices above about US\$35 per barrel.

6.3 Worldwide experience with biofuel manufacture to date has required active government support in the form of tax exemptions, mandates, and direct subsidies. Even at recent high oil prices, biodiesel does not yet appear to be commercially viable without government support and is unlikely to become so unless the price of oil rises further. The ethanol industry using sugarcane may be able to stand on its own under favorable conditions, most notably those in the Center-South of Brazil. One significant advantage of sugarcane is generation of bagasse as a by-product, which in turn can be used to generate electricity. This ability to generate electricity has enabled mills and distilleries to become self sufficient in energy. This energy generation capacity in Brazil is one of the important reasons why ethanol from sugarcane has flourished, while that from cassava has not been successful.

6.4 There is wide experience with sugarcane cultivation around the world: close to 100 countries are growing sugarcane. This extensive global experience with sugarcane notwithstanding, no other country in the world has been able to match Brazil's sugarcane cost structure. In mid-2005, sugar production costs in the three lowest-cost countries were estimated to be \$145 per tonne in Brazil (at R\$2.40 = US\$1.00), \$185 per tonne in Australia, and \$195 in Thailand. About one-quarter of the total worldwide sugar production is at \$200-250/tonne, above which the cost jumps to \$400/tonne and higher; these high-cost sugars in turn account for about one-half of the total world sugar production (Macedo 2005). It is estimated that ethanol as an automotive fuel becomes economic in Australia only if world oil prices remain at the levels seen in 2005 (Biofuels Taskforce). In other countries, this breakeven point will likely be higher.

6.5 If world oil prices continue to remain or rise above the 2005 level, some countries may be able to mount a commercially viable biofuel program without sustained financial support from the government. The government can help by removing regulatory barriers to investments in biofuels, informing the public about proper use of biofuels, and, where applicable, addressing concerns that the public may have. If an economic analysis demonstrates biofuels to be economic, early government support in the form of incentives, provided they are time bound, may be justified. There are several important considerations in deciding whether a biofuel program is likely to be commercially viable in the long run. A list is provided below for ethanol as an illustration:

- *Do climatic conditions favor sugarcane production?* Is there plentiful rainfall, or a good irrigation system that is sustainable without large subsidies, either directly or through subsidized electricity or diesel fuel (for water pumping), or good agricultural water resource management? Is soil fertility adequate for cane production? A region facing perennial water shortages for agriculture would not be a good candidate for an ethanol program.
- *Is there good road and communications infrastructure?* Fertile land with good rainfall must be accessible in order to minimize the costs of moving cane to processing plants and ethanol to consumption centers. There are economies of scale for biofuel production, requiring infrastructure for transport and distribution. Communication infrastructure is also essential to keep informed about weather and market conditions.
- *Is there good agricultural research and extension,* or a high probability of strengthening it? Brazilian experience underlines the benefits of developing new cane varieties to stay ahead of cane diseases and pests, identifying the right variety for each microclimate, disseminating knowledge through agricultural extension services, and ensuring that farmers implement them.
- *Are farmers provided with adequate primary education?* Especially in low-income countries, farmer education is often lacking. Farmers need to be able to absorb and apply advice provided by extension services, so as to be able to respond to new technical, marketing, organizational, and financial opportunities.
- *Is there a functioning credit market?* Farmers need access to credit in order to implement the advice of extension service officers on soil improvement, select

and plant the right cane varieties, and adopt adequate pest, weed, and disease control methods. Such measures are needed to improve cane yield to make ethanol production economic. A functioning capital market is needed for the construction of distilleries.

- *Is there a cadre of managers that can be called upon to manage the industry?* Managerial skills, including technical management, are needed across the supply chain, from optimizing seed selection and harvest timing to processing plant operations.
- *Is the sugar industry organized to foster cooperation across the supply chain for ethanol production?* Conflicts between sugar and ethanol producers, or between cane growers and distilleries, have slowed down the growth of the ethanol industry in some countries.
- *Is there a mechanism for capturing poorly priced externalities?* In some cases, the commercial viability of ethanol will depend on charging for externalities such as urban air pollution and GHG emission reductions that are not financially accounted for.

6.6 For situations where subsidies—indirect, direct, or both—would most likely be needed to launch and maintain a biofuels industry, additional issues would need to be carefully considered. This is important especially because, once granted and the industry has been launched, subsidies are difficult to withdraw. No country in the world has yet removed implicit and explicit subsidies entirely from the biofuels industry. Brazil comes closest to doing so, but it continues to maintain a large tax differential between gasoline and hydrous ethanol. The forgone tax revenue in the state of São Paulo alone is about US\$0.6 billion in 2005, taking the tax difference of US\$0.30 per liter and assuming annual consumption of about 2 billion liters.¹⁸

6.7 Principles of good governance dictate that government expenditures be transparent. Direct budgetary payments are generally the most transparent and efficient way of transferring resources. Historical experience, however, shows that it is politically easier to transfer public resources to private agents if an actual exchange of money is not involved. Taxes, administered pricing, and restrictive trade policies (all of which have been used to assist biofuel manufacturers) tend to be adopted and maintained more readily than direct government assistance provided as a line item in the annual budget. One universal instrument for supporting biofuels has been the use of tax expenditures—when the government collects less tax than from other goods with similar characteristics—which can take the form of tax exemptions, allowances, credits, deferrals, or relief. Once enacted, tax expenditures usually come under little scrutiny and are rarely repealed. While the use of tax expenditures has been a political reality in assisting biofuel industries around the world, it is preferable, from a good governance perspective, to have public support for

¹⁸ Although anhydrous ethanol is similarly exempt from the excise tax, because all fuel taxes are transferred to gasoline and all gasoline must contain anhydrous ethanol, the loss of government tax revenue is much less clear.

biofuels subject to normal budgetary scrutiny so that public expenditures on biofuels are weighed against other social priorities.

6.8 Where biofuels are not commercially viable on their own, the question is whether or not such interventions are justified. In general, if social benefits far exceed social costs, there is a case for government support. Economic and distributional analyses probe these questions. Because of large fluctuations in the world prices of both crude oil and potential biofuel crops (sugar, soybean, maize, rapeseed), it is necessary for the socio-economic analysis of a biofuel program to use a longer time frame than simply one or two years. Otherwise, the year(s) in which the data were collected would heavily bias the conclusions. For example, an analysis carried out using data in 2005 might show that bioethanol production is economic and socially beneficial, whereas another carried out using data from 1998 would likely show a large cost to the economy. A study on Brazil covering the longest time series data (Rask 1995) is discussed in Box 1.

6.9 This report considers several possible justifications for government interventions in biofuel manufacture: rural development, accounting for poorly priced externalities, and energy diversification. Foreign exchange savings remains a frequently cited benefit of domestic biofuel programs. However, foreign exchange benefits are much less important today as more countries maintain flexible exchange rates. If a country is pursuing a market-based approach to setting the exchange rate and the official rate reflects real economic values, then there would be no need to distinguish between local currency and foreign exchange costs or benefits of biofuel programs. In economies with under- or overvalued exchange rates, the addition of second- and third-best policy distortions (via import substitution, for example) has seldom proven a lasting solution to problems better handled through good macroeconomic management including market-oriented exchange rates.

6.10 Certain interventions are nearly universally regarded as being beneficial to rural development: strengthening property rights, removing barriers to trade both within the domestic market and with foreign markets, investment in rural education and health, agricultural research and extension, rural water supply, the provision of electricity, and transport infrastructure. Biofuel programs need to be integrated within a broader context of investment in rural infrastructure and human capital formation. The extent to which biofuel programs can contribute to rural development is dependent on the characteristics of the industry (scale, modernity, integration) and, ultimately, whether it is able to become financially viable without direct government financial support. The successful Brazilian ethanol model is based on modern and mechanized agricultural production, with many small-scale cane producers (but still large by developing country standards), large but not monopolistic mill/distillery complexes that generate electricity for themselves and for sale to the grid, and with a nationwide ethanol supply system well integrated with urban and industrial development. Low-income countries will need to assess whether the basic underlying conditions for a successful biofuel program exist or could be developed in the near term, including infrastructure and essential public services. If public funds are needed to support the industry, the question becomes whether government resources will be diverted from other programs, and the corresponding impact on rural incomes and growth.

Box 1 Net Economic Benefits: A Sample Calculation

Even something that is not the least-cost option may make sense for society as a whole if social benefits exceed social costs, that is, if the net social benefits are positive. An assessment from a social perspective of a decade of Proálcool in Brazil from 1978 to 1987 (Rask 1995) showed that there were large regional and temporal differences.

Rask (1995) used the methodology set forth by Little and Mirrlees for project appraisal for developing countries (Little and Mirrlees 1974). The analysis did not examine distributional and environmental benefits. The results showed that ethanol production in Brazil in 1978–1987 was economically viable only in the early 1980s, only in the Center-South region, and primarily in the mill/distillery complexes. The high social costs at the beginning and the end of the time period were not offset by the small net social gains in the early and mid-1980s. In particular, social costs in the North-Northeast area, where economic development was most needed, were extremely high. The findings indicated that the Brazilian economy had channeled more than US\$3.6 billion (1987 U.S. dollars) in resources into the two northern states to support ethanol production. If production had been limited to the southern region of Brazil, the overall net social costs would have been significantly smaller. From a strictly economic efficiency perspective, the analysis indicated that Brazil paid a high price for ethanol.

Over the time period studied, costs fell markedly, making, everything else being equal, the economics of ethanol production more favorable. The reasons appear to be two-fold: increasing efficiency, and falling real factor prices, in part as a result of the deep recession in Brazil. The most consistent factor price trend across the sugarcane producing states was falling real wages. Because sugarcane cultivation is labor-intensive and sugarcane costs represent a sizable portion of ethanol costs, falling agricultural labor costs would account for some of the overall decrease in unit costs of production.

The time period studied overlapped with the Brazil Alcohol and Biomass Energy Development Project funded by the World Bank from 1981 to 1987. The main objective of the loan, amounting to more than US\$200 million, was to support Proálcool to develop an economic, renewable liquid fuel energy source to substitute for imported gasoline. At the close of the project, an independent evaluation found the project unsustainable. The project was also faulted for its failure to reduce income inequalities through promotion of cassava-based distilleries in poorer areas of the country (World Bank 1990).

Since the above analyses were carried out, the cost of ethanol production from sugarcane in Brazil has fallen further: ethanol producers were paid about US\$0.40 per liter in 1987, and about US\$0.30 in 2001 (Goldemberg and others 2004). At the same time, world oil prices have risen sharply in the last couple of years, although still not as high as in 1980 when the price of crude reached today's equivalent of US\$80 per barrel. The combined effect of lower ethanol production costs and sharply higher world oil prices would make the social cost-benefit analysis of sugarcane-based ethanol production in the Center-South region of Brazil much more favorable today.

6.11 Accounting for poorly priced externalities arising from GHG emissions is likely to deliver US\$0.01–0.03 per liter based on the current estimates of carbon prices of US\$10–15 for the foreseeable future. For air pollution from urban transport, efficient fuel taxation requires that polluting goods be taxed more, and not that less-polluting alternatives be subsidized. In order to support biofuels through differentiated taxation to

reflect the cost of urban air pollution, there must be fuel taxes reflecting this externality in place initially. However, taxes are typically low on diesel in developing countries even though diesel emissions are damaging to public health. By contrast, gasoline often carries a high tax rate, but the tax difference that can be justified may not be much more than US\$0.02 per liter. These figures are much smaller than the tax exemptions currently given to ethanol, for example A\$0.38 (US\$0.28) per liter in Australia—the second lowest-cost producer of sugarcane—and 15 baht (US\$0.37) per liter in Thailand—the third lowest-cost producer. Marine applications of biodiesel hold promise, especially where environmental standards for marine vehicles are being tightened, but the high cost of biodiesel manufacture is likely to limit the large-scale commercial application for the foreseeable future. Biofuel production is not without environmental cost. The environmental costs of biofuel manufacture can include water and air pollution and soil depletion associated with feedstock production and biofuel processing.

6.12 Energy diversification as a justification for biofuels might make sense if large subsidies are not required. The benefits of diversification can also be greatly enhanced if trade of biofuels is liberalized. What is important for energy diversification through biofuels is that there be alternative, inexpensive sources of fuels from suppliers that are not traditional oil producers. Pursuing a policy of self-sufficiency in fuel production, irrespective of the cost, will not deliver the benefits of energy diversification. Although increasing the number of potential fuel suppliers can help against supply disruptions, diversifying into biofuels is unlikely to mitigate oil price volatility in a liberalized trade regime. Biofuel and petroleum fuel prices will equilibrate in a free trade regime on the international market and biofuels will be price takers. Barriers to biofuel trade or non-market-based biofuel pricing may de-link biofuel and petroleum product prices to an extent. Restrictions on world trade are damaging, however, and government interventions in commodity pricing typically offer at best short-term solutions to price volatility and introduce new distortions to the economy.

6.13 If the government decides to give protection to biofuels as an infant industry, it is important that the protection given be temporary, or else the policy will result in inefficient allocation of resources in the long run. The idea behind the infant industry argument is that the incentives can help the new industry become established and, as costs decline, eventually competitive without government support. Some studies suggest that maturation of the infant industry should not be longer than five to eight years for the benefits of the mature industries to compensate for the costs of infant industry support (Krueger and Tuncer 1982). If a new industry is soundly based and efficiently operated, it will experience declining costs as output expands and production experience is acquired.

6.14 Historically, biofuels programs have been motivated to a large extent by a desire to address problems in domestic agriculture. In the European Union and the United States, biofuel programs are closely linked to government protection of domestic farmers, which amounts to billions of dollars of support annually. In fact, were it not for support to maize farmers, it is unlikely that the U.S. Congress would have voted for the Renewable Fuels Standard, given the cost to the economy and questions about the impact on local air quality (ozone) and net savings in GHG emissions (when the feedstock is maize). Similarly it is not clear to what extent the European Union would be pursuing (non-binding) targets

for biofuels if substantial imports had to be used to meet the targets. In Australia, financial hardships faced by sugar growers have been the primary driver of government biofuel support, and the government has changed its support policy to make ethanol imports more expensive. In India, overcapacity in sugar production and molasses were the initial motivation for the ethanol program, which encountered major difficulties in obtaining adequate feedstocks following poor cane harvests in 2004. Thailand similarly wants to address agricultural crop surpluses through biofuel programs. Even the establishment of Proálcool in Brazil in 1975 has been described by some analysts as a way for the country to address sugar industry overcapacity more than a reaction to the energy crisis (Szmrecsányi and Moreira 1992). These political considerations can cloud decision-making on how, when, and where to undertake biofuel programs, and to what extent and how long government support should continue. Support for domestic agriculture has also led to the situation whereby countries with no comparative advantage in biofuel production have established the industry with substantial government subsidies and consequently have created barriers to imports and inhibited trade liberalization.

6.15 Trade liberalization will help the most efficient producers to expand their market share and reward innovation. The importance and benefits of liberalization of biofuel trade cannot be overemphasized. Trade liberalization in agriculture will help to level the playing field and benefit many developing countries. Trade liberalization would also likely affect biofuel economics by affecting feedstock prices. Trade liberalization is estimated to increase world sugar prices by 30–40 percent, at least in the short term; have a relatively small effect on world maize prices; and have virtually no impact on soybeans.

6.16 For the investment in a biofuel industry to be robust, serious consideration should be given to the question of how to manage the industry, given that prices of oil and feedstocks fluctuate widely. Even where biofuels are economic under long-run average prices for oil and feedstocks, there will inevitably be periods when, in the absence of subsidies, invested capacity will be seriously underutilized due to fluctuations in relative prices. The oil industry enjoyed a decade of very high oil prices beginning in 1973, only to be followed by two decades of relatively low prices, undermining even the ethanol industry in Brazil. The government may consider the benefits of biofuels (energy diversification, environmental) to be sufficiently important to consider giving direct subsidies in times of very low oil prices. Brazil has addressed this question in recent years by combined use of hybrid mill/distillery complexes and flex-fuel vehicles.

6.17 In the near term, ethanol from sugarcane is likely to offer the best chance of being commercially viable. The Australian experience suggests that it may be wise to limit the amount of anhydrous ethanol in gasoline to 10 percent or less when launching an ethanol program. Biodiesel remains expensive even against the backdrop of rising world oil price, and other feedstocks for ethanol increase the cost of production markedly. Cane production would require, amongst others, plentiful water and tropical climates. One issue for countries wanting to rely primarily or solely on domestic production of ethanol is how to manage poor harvests. A recent example is the 3 percent fall in world sugarcane production between 2003–2004 and 2004–2005. Hit by droughts, cane production in Thailand fell by 26 percent (Reuters News 2005a). The Thai ethanol program lost its urgency in the eyes of cane growers following the decline in cane

production and rise in the domestic and world prices of sugar. Any government embarking on an ethanol program based on cane should be mindful of these possibilities and look beyond its national boundary for supply. This in turn will be greatly helped by liberalization of ethanol trade.

6.18 In the medium term, biofuel production costs will come down and other feedstocks may become attractive, expanding feedstock options and enabling countries not suited for growing sugarcane to enter into biofuel production. If and as world agricultural trade undergoes deregulation, the price of cane sugar will rise, somewhat offsetting cost reductions. Of particular interest is the extent to which the cost of biodiesel production from plants not requiring much rainfall and nutrients will fall. The processing technology remains oil extraction followed by transesterification to make biodiesel, both well-proven processes with limited scope for cost reduction. For this production pathway, the greatest potential for biodiesel cost reduction lies in producing, harvesting, and transporting feedstock to processing plants. In parallel, international trade of biofuels may grow, making it easier for countries to hedge against poor harvests and large crop price fluctuations.

6.19 In the long run, one of the greatest promises lies in commercially viable manufacture of ethanol from cellulose: forest products, wood wastes, crop residues such as maize stover and sugarcane trash, and energy crops such as switch grass. Their widespread availability, abundance, low cost, and significant lifecycle GHG emission reduction potential make them suitable and attractive for diversifying energy sources and addressing climate change concerns. There may be breakthroughs in other alternative technologies, such as conversion of biomass to synthetic gas followed by liquid fuel production. At the same time, the world oil price as well as the price of carbon may rise appreciably, altering the comparative economics of biofuel manufacture greatly in its favor.

6.20 In all this, carrying out a sound economic analysis is an important first step. Each country will deliver a different answer. Such an analysis may not provide a definitive answer to the question of whether or not domestic production of biofuels will bring net social benefits. There are large uncertainties arising from lack of data and a large number of assumptions that have to be made: future prices of biofuel feedstocks and crude oil, advances in technology, and decline in future production costs, to name a few. Nevertheless, calculations using available data and reasonable assumptions will make costs and benefits transparent and facilitate a public debate about how best to use public funds.

Annex 1

Process Description

A1.1 Ethanol is produced from fermentation of sugars and biodiesel from the reaction of plant or animal oils with an alcohol, for which methanol is universally used in commercial application today. These processes are described below.

Ethanol

A1.2 All processes for ethanol production involve fermentation of sugars to ethanol using yeast microorganisms. These microorganisms, the most commonly used of which is Baker's yeast, work best with six-carbon sugars such as glucose. Therefore, biomass materials containing high levels of glucose are the easiest to convert to sugar. This makes conversion of sugarcane or sugar beet to ethanol the simplest process of all. In the process using sugarcane as the feedstock, used extensively in Brazil, sugarcane is crushed and soluble sugars are extracted by washing with water. The sugarcane residue, or bagasse, produced as a by-product can be burned to generate electricity, heat, or both.

A1.3 Yeast is added to effect fermentation at 32–35°C and a pH of 5.2 after the raw cane juice is filtered and heated. Fermentation of sugars produces ethanol and carbon dioxide (CO₂). Theoretically, 100 grams of glucose can produce 51.4 grams of ethanol and 48.8 grams of CO₂. The yield in practice is lower. The co-produced CO₂ can be purified, compressed, and sold, but the process is extremely energy-intensive. Ethanol is produced at low concentration and the solution is distilled to produce hydrous ethanol containing about 5 percent water. Distillation leaves stillage, which can be centrifuged and dried to make distiller's dried grains with solubles (DDGS), a livestock feed ingredient, or can be directly applied on fields as a fertilizer if there is no danger of contaminating near-surface groundwater. Further separation of water from ethanol to make anhydrous ethanol is achieved through additional distillation using cyclohexane or benzene as a third component, both harmful to human health, or using molecular sieves that eliminate the use of harmful compounds. Ethanol is "denatured" with a small addition of gasoline or other compounds to make it unfit for human consumption. About 64 liters of anhydrous ethanol can be manufactured from 1 tonne of sugarcane (Laydner 2004).

A1.4 If maize is used as the starting feedstock, it needs to be milled, either by wet or dry milling. In the United States where ethanol is produced mainly from maize, the split between wet and dry milling is fairly even. Dry mill processing plants typically sell ethanol and DDGS. Most do not capture and sell CO₂. Wet mill plants produce as co-products

maize gluten meal, maize gluten feed, maize germ meal, maize oil, high-fructose maize syrups, and in some cases commercial CO₂. Wet mill plants cost substantially more to build and have higher operating costs than dry mill processing plants.

A1.5 Starches in the maize are reacted with water (in hydrolysis) to break down the starch into fermentable sugars in a process called saccharification. Hydrolysis is typically carried out by mixing the starch with water to form a slurry that is stirred and heated to rupture the cell walls. Enzymes are used to break down the starches in the maize into six-carbon sugars, which are then fermented and distilled. Fermentation produced ethanol at 8–10 percent in the 1970s, but a concentration of as high as 15 percent has not been unusual over the past 10 years. In modern efficient plants, the production yield is approaching 10 liters of ethanol from a bushel of maize.

A1.6 If wheat is the feedstock, it is first crushed or milled. Malting is used to break down starches into six-carbon sugars under controlled conditions of temperature and humidity. The sugars are washed out of the wheat with water, fermented, and distilled as above.

A1.7 All the above ethanol processes are well established and unlikely to undergo significant improvements in productivity. Dramatic cost reductions may be possible if the processing of alternative feedstocks can be commercialized. By far the most promising, at least in theory, is the development of new technologies to cut the costs of converting cellulosic feedstocks to ethanol.

A1.8 Cellulosic materials consist of cellulose, hemicellulose, lignin, and a small amount of compounds known as extractives. Cellulose can be broken down into glucose, a six-carbon sugar, and hemicellulose into five-carbon sugars. Five-carbon sugars are more difficult to convert into ethanol than glucose. Lignin contains no sugars and encloses cellulose and hemicellulose, making it difficult to extract the latter two. There are three pathways for ethanol production from cellulosic feedstock: acid hydrolysis, enzymatic hydrolysis, and biomass gasification, all followed by fermentation.

A1.9 The most commonly used acid in acid hydrolysis is sulfuric acid. There are two types of processes: dilute acid and concentrated acid hydrolysis. Dilute acid hydrolysis occurs at higher temperature and pressure, and the sugar recovery efficiency is limited to about 50 percent, because the product sugar reacts further to form other chemicals under the same reaction conditions. These chemicals include furfural used in the plastics industry. To account for this phenomenon, a two-stage dilute acid hydrolysis process is used, and is the most proven technology today. The concentrated acid hydrolysis process has a high sugar-recovery efficiency, more than 90 percent. However, it is a slow process and acid recovery has been expensive, or else large quantities of lime must be used to neutralize the acid, resulting in large quantities of calcium sulfate with its disposal problem.

A1.10 Enzymatic hydrolysis holds promise because the efficiency can be high, by-product formation can be controlled, processing conditions are mild (no corrosive materials, mild temperature and pressure) and hence expensive materials of construction are not required, and process energy requirements are also relatively low. But because enzymes need to be able to access the molecules to be hydrolyzed, the first step is to break down the

lignin to expose cellulose and hemicellulose. This pretreatment step adds to the cost of production. Recovered lignin can be burned to produce electricity, heat, or both.

A1.11 Naturally occurring organisms do not ferment five-carbon sugars easily, and genetically engineered yeasts are required in their place. At present ethanol yields using these yeasts are too low for commercial viability. The key to making ethanol production from cellulosic materials commercially viable lies in achieving major technological breakthroughs to lower the costs of these conversion processes. Co-location of ethanol plants with existing biomass power plants is one way to improve the commercial viability of both the power and ethanol plants.

A1.12 Another pathway is to first gasify the biomass to form synthesis gas (hydrogen and CO). The synthesis gas can then be bubbled through a fermenter to produce ethanol, or alternatively the synthesis gas can be catalytically reacted without microorganisms to form ethanol. Either way, these processes have been expensive routes to ethanol production.

Biodiesel

A1.13 For biodiesel production, oil is extracted from oil seeds by mechanical crushing or solvent extraction. A by-product is a protein-rich residue cake that can be used for animal feed. Oil is filtered, washed, decanted, dried, and heated. It is reacted with methanol in the presence of a base catalyst (typically caustic soda or potash) at 50°C in a process called transesterification. The reaction produces fatty acid methyl ester (FAME), which is the basis for biodiesel, and the co-product glycerine, which can be used to manufacture soap. Approximately 100 kilograms (kg) of glycerine is produced for every tonne of biodiesel. Glycerine and biodiesel are separated, the excess alcohol in each phase is recovered, and the glycerine is neutralized and purified to 80–88 percent pure glycerine or distilled to achieve 99 percent or higher purity. The biodiesel is sometimes purified by washing with warm water. For trouble-free operation in diesel engines, biodiesel must be free of glycerine, catalyst, alcohol, and free fatty acids.

A1.14 An entirely different pathway is to gasify biomass to produce synthesis gas (hydrogen and CO) from which liquid fuels are produced via Fischer-Tropsch. Fischer-Tropsch has been used extensively in the Republic of South Africa based on coal and natural gas, and most recently by Shell in Malaysia based on natural gas, to make synthetic fuels. It produces excellent diesel: high cetane and no sulfur. However, the selectivity of Fischer-Tropsch is a problem, making hydrocarbons of varying chain length. Fischer-Tropsch production of diesel from biomass is costly, but there are moves to invest in Fischer-Tropsch biomass-to-liquid processes. For example, the French company Total Oil announced in the fall of 2005 that it would invest the equivalent of US\$125 million between now and 2010 in developing new Fischer-Tropsch gas-to-liquid and biomass-to-liquid fuel production processes. One of the planned projects is to build a unit capable of producing Fischer-Tropsch diesel from a combination of vegetable oils and animal fat (AWKnowledge 2005b).

Annex 2

Sugar and Ethanol Industry in Brazil

A2.1 The sugarcane and associated sugar and ethanol industries in Brazil lead the world in efficiency and cost-competitiveness. It is useful to review the factors that have contributed to Brazil's competitiveness today. The factors include Brazil's natural endowments (climatic, topographical, and soil conditions). They also include an effective industry structure, active research and development (facilitated by the size of the industry), concerted efforts to ensure the industry's sustainability, and development of managerial skills to optimize inputs and processing.

A2.2 Particularly impressive is the optimization of cane varieties for each microclimate. The same sugarcane stock is used for five to six harvests and replanted only after four to five years of commercial use. In response, the sugarcane industry in Brazil has developed and used more than 500 varieties of sugarcane, adapted primarily to resist diseases and pests. Two genetic improvement programs are mostly responsible for these varieties. In total, four programs, carried out at two private and two public institutions, are engaged in the genetic improvement of sugarcane varieties. Highly damaging epidemics have been controlled by fast replacement of varieties. Today, a given variety occupies a maximum of 10 to 15 percent of the total sugarcane area for each cane processor. In the future, genetically modified varieties resistant to herbicides, pests, diseases, droughts, and cold weather are expected to play an increasingly important role. Research in this area has been ongoing since the 1990s.

A2.3 This annex begins with various aspects of cane cultivation. It discusses how the problems that have invited criticism of Proálcool in the past have been systematically addressed. It describes how the sugarcane industry tackles pests, diseases, and weeds to minimize damage to cane yields. It concludes with a description of jobs in the three industries today. The information is taken from a forthcoming publication (Macedo 2005).

Field Burning

A2.4 The burning of sugarcane trash is the standard practice in nearly every cane-growing country. In 1998, the federal government passed a law requiring a gradual phase-out of field burning in areas where mechanical harvesting is possible (defined to be areas where the incline is less than 12 percent). In 2002, the state of São Paulo issued a decree requiring a phase-out of burning in all cane fields, with a slower phase-out in areas where mechanical harvesting is not possible. The timelines for the phase-out in the two pieces of

legislation are shown in Table A2.1. While the federal government is requiring a complete phase-out of field burning three years earlier than the state of São Paulo in areas where mechanical harvesting is possible, currently only São Paulo State Decree 2002 is being enforced.

**Table A2.1 Legislation Requiring Phase-out of Sugarcane Field Burning in Brazil
Percentage of Land Where Burning Is Phased Out**

Year	<i>São Paulo State Decree 2002¹</i>		Year	<i>Federal Law 1998²</i>	
	<i>Mechanical harvesting³</i>	<i>No mechanical harvesting⁴</i>		<i>Mechanical harvesting³</i>	<i>No mechanical harvesting⁴</i>
2002	20%		1998	—	—
2006	30%		2003	25%	—
2011	50%	10%	2008	50%	—
2016	80%	20%	2013	75%	—
2021	100%	30%	2018	100%	—
2026		50%			
2031		100%			

— Not applicable.

¹ Law number 11,241 of September 19, 2002.

² Decree number 2,661 passed by the Federal Government on July 8, 1998.

³ Areas where mechanical harvesting is possible; an incline of less than 12 percent.

⁴ Areas where mechanical harvesting is possible; an incline of more than 12 percent.

A2.5 The federal law does not prohibit field burning where mechanical harvesting is not possible. In the state of São Paulo, where field burning must terminate by 2031 even in areas where mechanical harvesting is not possible, it is expected that cane cultivation will move away from these areas to other areas with more favorable topographic characteristics. Attempts to increase yields in areas where mechanical harvesting is possible by adopting new technologies are also likely.

A2.6 At present, it is estimated that cane is manually harvested in 65 percent of the total area and mechanically harvested in the remaining 35 percent. Field burning has ceased in 20 percent of the total land growing cane. Employment will fall as a result of switching to mechanical harvesting. Collection of trash for energy generation in the future is likely to compensate some for this employment reduction, but not fully.

Water Use and Effluents

A2.7 Although sugarcane cultivation is water-intensive, under the conditions found in São Paulo, irrigation is not used. Use of irrigation is more widespread in the Northeast, and is gradually growing in the Center-West and some areas of the Southeast.

A2.8 Net water consumption in sugarcane agribusiness has been falling. A contributing factor is the evolution of the legal framework to bill for use of water, particularly in the state of São Paulo.

A2.9 Historically, one of the serious concerns has been the discharge of vinasse, which has a high organic load. Vinasse used to be discharged to water streams in the early days of Proálcool. For each liter of ethanol, 10 to 15 liters of vinasse are produced. It began to be recycled to the fields in 1978 when the first ordinance was issued by the National Integration Ministry prohibiting release of vinasse onto surface fountainheads. Vinasse and wastewaters are now recycled for ferti-irrigation. The application of vinasse is optimized for specific topographic, soil, and environmental conditions. Nutrient recycling through application of vinasse and filtercake has limited use of fertilizers in Brazil. Australia uses nearly 50 percent more fertilizer.

Pest Control

A2.10 For tackling pests, biological control methods as well as pesticides are used. Mechanical harvesting unfortunately increases occurrence of infestation by certain pests: spittlebugs (*mahanarva fimbriolata*), leaf-cutting ants, and sugarcane weevil (*sphenophorus levis*). These and other pests are often controlled through the following methods:

- The sugarcane beetle (*diatraea saccharalis*) is controlled using mainly biological control. The method consists of releasing parasitoids in the most severely infected sugarcane fields.
- Spittlebugs are most effectively controlled by application of the *metarhizium anisopliae* fungus.
- Leaf-cutting ants are controlled by specialized teams that search through cane crops at the mills and apply an insecticide mixture.
- The migdolus beetle is controlled by application of insecticides to seedlings.
- The sugarcane weevil is tackled using a cultural method, consisting of early destruction of rootstocks in the infested areas to be replanted.
- Termites and other pests are controlled using chemicals where there is potential for damage.

A2.11 In parallel, development of a pest-resistant variety of sugarcane has been one of the primary objectives of Brazil's cane genetic improvement programs since their inception in the early 1980s.

Crop Disease Control

A2.12 Because a given cane variety is used for four to five years, the only economically viable option for disease control is to use varieties genetically resistant to the main crop diseases. Disease control is one of the main reasons for the replacement of a commercial variety of sugarcane. A total of 177 pathogens are known to cause sugarcane crop diseases worldwide, of which 40 have been reported in Brazil.

A2.13 There are more than 500 commercial varieties of sugarcane. The top 20 occupy 80 percent of the total cane area. The leading variety occupies only 12.6 percent. The duration of use for each variety is becoming increasingly shorter, and at the same time, the number of varieties in use at any given time has been growing. Diversification of cane varieties is part of the pest and disease control strategy.

A2.14 Mechanical harvesting without field burning provides crops with different biological conditions. The industry has adapted quickly to these changes and identified suitable varieties for these new conditions.

Weed Control

A2.15 Mechanical, cultural, and chemical methods are used in Brazil to control weeds. The main weed control method is chemical, through use of herbicides. Sugarcane uses more herbicides per hectare than coffee and maize, less than citric crops, and about the same amount as soybeans.

A2.16 Preventive measures seek to prevent weeds from being introduced, for example by using seedlings from areas that are free of a particular weed while controlling weeds in vinasse channels. Integrated weed management helps to minimize the amount of herbicides used. This involves using preventive, mechanical, and chemical methods in parallel: using seedlings produced in weed-free areas, and preparing the soil to limit the chemical control to the use of pre-emergent herbicides to prevent germination of weed seeds.

A2.17 The number of herbicide-resistant weeds is growing rapidly. To combat these weeds, cane growers have been using crop rotation, mechanical control, use of different herbicides, and integrated control.

Employment Generation

A2.18 The sugarcane industry had 320 processing plants in the form of sugar mills and distilleries as of December 2004 (Nastari 2005a). Cultivation areas for these plants range from 5,000 to 50,000 hectares. Harvesting, the most labor-intensive period, is limited to six to seven months a year. The ratio of hours of labor employed during the harvesting period to those between harvests is called a seasonal index. The higher the seasonal index, the more use is made of temporary labor, and the lower the average salary. This is a universal problem in agriculture.

A2.19 Labor use per unit of production is much greater in the North-Northeast compared to the Center-South, in some cases as much as three-fold. In the Center-South, and particularly in the state of São Paulo, salaries are higher and working conditions are better, but there are also much fewer jobs on account of greater efficiency and mechanization.

A2.20 The domestic content of the equipment for sugar and ethanol production and combined heat and power generation is close to 100 percent (that is, virtually nothing is imported). Dedini, the largest manufacturer, has built 106 plants, 726 distillation units, 112 cogeneration plants, and 1,200 boilers.

A2.21 The numbers of people working in the formal and informal sectors in the sugarcane industry are available from the National Household Sample Survey conducted by the Brazilian Institute of Geography and Statistics. Including everyone working in the sugarcane sector in some capacity (including employers and non-paid workers), employees in the formal sector (those who possess formal working papers) were 59percent in 2003, compared to 27 percent for those who did not possess working papers. The percentage of

those employed in the formal sector was higher in the Center-South (74 percent) than in the North-Northeast (49 percent), and highest in São Paulo at 85 percent.

A2.22 Information is also available for the numbers of permanent and temporary workers. The data from 1992 to 2003 are shown in Table A2.2. The total number of employees in the country fell by one-third during this period, in part on account of increasing reliance on mechanical harvesting. The percentage of temporary employees fluctuated, first declining and then increasing in recent years to about one-half of the total.

Table A2.2 Number of Workers in the Sugarcane Sector

<i>Year</i>	<i>Permanent workers</i>		<i>Temporary workers</i>		<i>Total Number</i>
	<i>Number</i>	<i>Percent</i>	<i>Number</i>	<i>Percent</i>	
1992	368,684	55	305,946	45	674,630
1993	373,903	61	242,766	39	616,669
1995	380,099	61	238,797	39	618,896
1996	378,273	59	260,873	41	639,146
1997	323,699	58	236,012	42	559,711
1998	322,601	71	133,368	29	455,969
1999	300,098	65	161,410	35	461,508
2001	222,418	54	192,671	46	415,089
2002	246,357	55	205,000	45	451,357
2003	229,981	51	218,902	49	448,883

Note: Data are not available for 1994 and 2000.

Source: Macedo 2005

A2.23 The seasonal index for sugarcane was 2.2 in the late 1970s. Mechanization of harvesting and utilization of harvesting laborers for soil conservation and maintenance tasks have led to a decline in the seasonal index. It fell to an estimated 1.8 in the 1980s. On the basis of Table A2.2, while hours of labor are not shown and hence precise calculations cannot be carried out, there does not appear to have been a marked decrease in the seasonal index between 1992 and 2003.

A2.24 Detailed information is available on the composition of those in the formal sector for sugarcane, sugar, and ethanol industries from the Administrative Records of the Labor and Employment Ministry. The data include the education levels and corresponding monthly earnings. They are summarized in Table A2.3 for the year 2002. In all the three industries, those who were literate but had completed less than four years of schooling made up the highest proportion. Earnings in the Center-South were markedly higher than those in the North-Northeast for comparable levels of education, except those who had gone beyond high school in the sugar and ethanol industries, for which the earnings were higher in the North-Northeast region.

A2.25 Average earnings and years of schooling in 2003 in agriculture for different crops are given in Table A2.4. In Brazil as a whole, sugarcane ranks third in income after soybeans and citrus. The North-Northeast region again stands out for having much lower levels of education among workers and lower monthly income.

Table A2.3 Breakdown of Formal Sector Workers by Education, 2002

<i>Education</i>	<i>Brazil</i>	<i>North-Northeast</i>			<i>Center-South</i>		
		<i>Cane</i>	<i>Sugar</i>	<i>Ethanol</i>	<i>Cane</i>	<i>Sugar</i>	<i>Ethanol</i>
	<i>Number</i>						
Illiterate	117,289	33,722	59,349	4,140	12,845	3,644	3,589
4th grade not completed	287,744	39,571	73,565	15,604	107,230	35,265	16,509
4th grade	142,072	5,806	12,522	2,548	78,556	28,317	14,323
8th grade not completed	101,130	3,134	16,031	3,182	44,430	21,447	12,906
8th grade	40,103	1,679	3,968	900	17,404	10,032	6,120
High school started but not completed	23,880	868	2,649	519	7,990	8,174	3,680
High school	39,453	1,231	5,365	1,010	10,006	14,090	7,751
College started but not completed	3,795	102	334	78	966	1,639	676
College graduates	9,127	216	1,151	263	1,864	4,331	1,302
Total	764,593	86,329	174,934	28,244	281,291	126,939	66,856
	<i>Percentage</i>						
Illiterate	15	39	34	15	5	3	5
Up to 4th grade	56	53	49	64	66	50	46
5–8th grade	18	6	11	14	22	25	28
9–11th grade	8	2	5	5	6	18	17
College started but not completed	0	0	0	0	0	1	1
College graduates	1	0	1	1	1	3	2
	<i>Monthly earning in R\$</i>						
Illiterate	300	256	294	285	389	423	398
4th grade not completed	390	290	316	389	436	477	470
4th grade	513	336	489	425	490	625	524
8th grade not completed	524	371	410	423	506	647	582
8th grade	620	409	574	556	564	736	686
High school started but not completed	603	410	563	637	542	677	636
High school	788	649	805	787	734	846	763
College started but not completed	1,161	773	1,295	1,284	958	1,276	1,150
College graduates	2,361	2,308	2,908	2,581	2,415	2,141	2,493
Total	483	297	373	428	496	679	608

Note: The school system in Brazil comprises grades 1 to 4 for elementary school, 5 to 8 for middle school, and 9 to 11 for high school.

Source: Macedo 2005

Table A2.4 Mean Income and Years of Education in Agriculture, 2003

<i>Region</i>	<i>Crop</i>	<i>Rice</i>	<i>Banana</i>	<i>Coffee</i>	<i>Sugarcane</i>	<i>Citrus</i>	<i>Manioc</i>	<i>Corn</i>	<i>Soybean</i>
Brazil	R\$/month	318	348	358	447	489	218	214	1,044
	Education ¹	2.3	3.1	3.6	2.9	3.8	1.8	2.3	4.9
North-Northeast	R\$/month	191	262	223	283	289	211	133	378
	Education ¹	1.8	2.5	2.3	2.0	1.7	1.6	1.5	4.2
Center-South	R\$/month	788	467	376	679	565	278	326	1,071
	Education ¹	4.4	4.0	3.8	4.0	4.6	3.0	3.2	4.9
São Paulo	R\$/month	—	452	635	797	584	—	620	864
	Education ¹	—	3.9	5.5	4.2	4.8	—	3.9	5.8

— Fewer than 10 observations in the sample.

¹ Average number of years of education

Source: Macedo 2005

Annex 3

Labor Intensity of Different Crops

A3.1 Spurred by the secular decline in the prices of traditional commodities, a number of developing countries have begun to adopt high-value agricultural exports to diversify production and achieve economic growth. These high-value crops—typical examples of which include vegetables, fruits, and flowers—are generally labor intensive (see Table A3.1); give significantly higher returns to land, labor, fertilizer, and water (see Table A3.2); and also generate jobs downstream in processing and packaging. Over the last decade, these exports have generated significant amounts of foreign exchange and contributed to job creation and increasing agricultural production skills. Therefore, it might be worth comparing land use for transport fuel production with these alternatives.

Table A3.1 Average Labor Use in Person Days per Hectare in Indochinese Countries

<i>Crop group</i>	<i>Cambodia</i>	<i>Lao People's</i>	<i>Vietnam</i>		<i>Overall</i>
		<i>Democratic</i>	<i>North</i>	<i>South</i>	
		<i>Republic</i>			
Cereals	81	101	216	111	127
Overall vegetables	437	227	468	297	357
Tubers	79		294	303	225
Allium	542	191	454	317	376
Cucurbits	373	309	533	264	370
Leafy vegetables	502	207	517	253	370

Tubers include potatoes. Allium includes onions, leeks, shallots, and garlic. Cucurbits include cucumbers, squashes, pumpkins, and melons.

Source: Barghouti and others 2004

A3.2 The benefits of increased employment from diversifying to high-value crops are not only substantial but can also be pro-poor because they are distributed across a broad spectrum of the economy. Employment-enhancing opportunities include seed and seedling production; precision land preparation; and the irrigation, harvesting, cleaning, grading, and packaging of high-value crops (Barghouti and others 2004). Supplementary irrigation may help to use the land all year round, thereby generating permanent jobs and stable incomes. In this regard, sugarcane cultivation is an intensive consumer of water and other inputs, and

raises questions about whether there are better uses of the same resources in agriculture. Horticulture is playing an important role in agriculture in middle-income countries such as Chile. Even low-income countries, such as Kenya, Uganda, and Zambia, are beginning to diversify into high-value crops.

Table A3.2 Resource Use Efficiency in Vegetables Versus Rice Cultivation

<i>Crop/input</i>	<i>Vietnam, south</i>	<i>Lao People's Democratic Republic</i>	<i>Cambodia</i>	<i>Bangladesh</i>
Land (US\$/hectare)				
Vegetables	1,151	696	452	553
Cereal	120	80	48	30
Labor (US\$/hectare)				
Vegetables	7.7	5.9	3.8	4.4
Cereal	4.1	1.6	2.0	1.4
Water (% return on irrigation cost)				
Vegetables	21	11	8	65
Cereal	15	42	21	40
Net revenue/total cost				
Vegetables	1.06	1.7	0.96	0.81
Cereal	0.43	0.54	0.53	0.13

Source: Barghouti and others 2004

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Joint UNDP/World Bank
ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

LIST OF REPORTS ON COMPLETED ACTIVITIES

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>
SUB-SAHARAN AFRICA (AFR)			
Africa Regional	Anglophone Africa Household Energy Workshop (English)	07/88	085/88
	Regional Power Seminar on Reducing Electric Power System Losses in Africa (English)	08/88	087/88
	Institutional Evaluation of EGL (English)	02/89	098/89
	Biomass Mapping Regional Workshops (English)	05/89	--
	Francophone Household Energy Workshop (French)	08/89	--
	Interafrican Electrical Engineering College: Proposals for Short- and Long-Term Development (English)	03/90	112/90
	Biomass Assessment and Mapping (English)	03/90	--
	Symposium on Power Sector Reform and Efficiency Improvement in Sub-Saharan Africa (English)	06/96	182/96
	Commercialization of Marginal Gas Fields (English)	12/97	201/97
	Commercializing Natural Gas: Lessons from the Seminar in Nairobi for Sub-Saharan Africa and Beyond	01/00	225/00
	Africa Gas Initiative – Main Report: Volume I	02/01	240/01
	First World Bank Workshop on the Petroleum Products Sector in Sub-Saharan Africa	09/01	245/01
	Ministerial Workshop on Women in Energy	10/01	250/01
	Energy and Poverty Reduction: Proceedings from a Multi-Sector And Multi-Stakeholder Workshop Addis Ababa, Ethiopia, October 23-25, 2002.	03/03	266/03
	Opportunities for Power Trade in the Nile Basin: Final Scoping Study	01/04	277/04
	Énergies modernes et réduction de la pauvreté: Un atelier multi-sectoriel. Actes de l'atelier régional. Dakar, Sénégal, du 4 au 6 février 2003 (French Only)	01/04	278/04
	Énergies modernes et réduction de la pauvreté: Un atelier multi-sectoriel. Actes de l'atelier régional. Douala, Cameroun du 16-18 juillet 2003. (French Only)	09/04	286/04
	Energy and Poverty Reduction: Proceedings from the Global Village Energy Partnership (GVEP) Workshops held in Africa	01/05	298/05
	Power Sector Reform in Africa: Assessing the Impact on Poor People	08/05	306/05
	The Vulnerability of African Countries to Oil Price Shocks: Major Factors and Policy Options. The Case of Oil Importing Countries	08/05	308/05
Angola	Energy Assessment (English and Portuguese)	05/89	4708-ANG
	Power Rehabilitation and Technical Assistance (English)	10/91	142/91
	Africa Gas Initiative – Angola: Volume II	02/01	240/01
Benin	Energy Assessment (English and French)	06/85	5222-BEN
Botswana	Energy Assessment (English)	09/84	4998-BT
	Pump Electrification Prefeasibility Study (English)	01/86	047/86
	Review of Electricity Service Connection Policy (English)	07/87	071/87
	Tuli Block Farms Electrification Study (English)	07/87	072/87
	Household Energy Issues Study (English)	02/88	--
	Urban Household Energy Strategy Study (English)	05/91	132/91
Burkina Faso	Energy Assessment (English and French)	01/86	5730-BUR
	Technical Assistance Program (English)	03/86	052/86
	Urban Household Energy Strategy Study (English and French)	06/91	134/91
Burundi	Energy Assessment (English)	06/82	3778-BU

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>
Burundi	Petroleum Supply Management (English)	01/84	012/84
	Status Report (English and French)	02/84	011/84
	Presentation of Energy Projects for the Fourth Five-Year Plan (1983-1987) (English and French)	05/85	036/85
	Improved Charcoal Cookstove Strategy (English and French)	09/85	042/85
	Peat Utilization Project (English)	11/85	046/85
	Energy Assessment (English and French)	01/92	9215-BU
Cameroon	Africa Gas Initiative – Cameroon: Volume III	02/01	240/01
Cape Verde	Energy Assessment (English and Portuguese)	08/84	5073-CV
	Household Energy Strategy Study (English)	02/90	110/90
Central African Republic	Energy Assessment (French)	08/92	9898-CAR
Chad	Elements of Strategy for Urban Household Energy		
	The Case of N'djamena (French)	12/93	160/94
Comoros	Energy Assessment (English and French)	01/88	7104-COM
	In Search of Better Ways to Develop Solar Markets: The Case of Comoros	05/00	230/00
Congo	Energy Assessment (English)	01/88	6420-COB
	Power Development Plan (English and French)	03/90	106/90
	Africa Gas Initiative – Congo: Volume IV	02/01	240/01
Côte d'Ivoire	Energy Assessment (English and French)	04/85	5250-IVC
	Improved Biomass Utilization (English and French)	04/87	069/87
	Power System Efficiency Study (English)	12/87	--
	Power Sector Efficiency Study (French)	02/92	140/91
	Project of Energy Efficiency in Buildings (English)	09/95	175/95
	Africa Gas Initiative – Côte d'Ivoire: Volume V	02/01	240/01
Ethiopia	Energy Assessment (English)	07/84	4741-ET
	Power System Efficiency Study (English)	10/85	045/85
	Agricultural Residue Briquetting Pilot Project (English)	12/86	062/86
	Bagasse Study (English)	12/86	063/86
	Cooking Efficiency Project (English)	12/87	--
	Energy Assessment (English)	02/96	179/96
Gabon	Energy Assessment (English)	07/88	6915-GA
	Africa Gas Initiative – Gabon: Volume VI	02/01	240/01
The Gambia	Energy Assessment (English)	11/83	4743-GM
	Solar Water Heating Retrofit Project (English)	02/85	030/85
	Solar Photovoltaic Applications (English)	03/85	032/85
	Petroleum Supply Management Assistance (English)	04/85	035/85
Ghana	Energy Assessment (English)	11/86	6234-GH
	Energy Rationalization in the Industrial Sector (English)	06/88	084/88
	Sawmill Residues Utilization Study (English)	11/88	074/87
	Industrial Energy Efficiency (English)	11/92	148/92
	Corporatization of Distribution Concessions through Capitalization	12/03	272/03
Guinea	Energy Assessment (English)	11/86	6137-GUI
	Household Energy Strategy (English and French)	01/94	163/94
Guinea-Bissau	Energy Assessment (English and Portuguese)	08/84	5083-GUB
	Recommended Technical Assistance Projects (English & Portuguese)	04/85	033/85
	Management Options for the Electric Power and Water Supply Subsectors (English)	02/90	100/90
	Power and Water Institutional Restructuring (French)	04/91	118/91
Kenya	Energy Assessment (English)	05/82	3800-KE
	Power System Efficiency Study (English)	03/84	014/84
	Status Report (English)	05/84	016/84

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>
Kenya	Coal Conversion Action Plan (English)	02/87	--
	Solar Water Heating Study (English)	02/87	066/87
	Peri-Urban Woodfuel Development (English)	10/87	076/87
	Power Master Plan (English)	11/87	--
	Power Loss Reduction Study (English)	09/96	186/96
	Implementation Manual: Financing Mechanisms for Solar Electric Equipment	07/00	231/00
Lesotho	Energy Assessment (English)	01/84	4676-LSO
Liberia	Energy Assessment (English)	12/84	5279-LBR
	Recommended Technical Assistance Projects (English)	06/85	038/85
Madagascar	Power System Efficiency Study (English)	12/87	081/87
	Energy Assessment (English)	01/87	5700-MAG
	Power System Efficiency Study (English and French)	12/87	075/87
Malawi	Environmental Impact of Woodfuels (French)	10/95	176/95
	Energy Assessment (English)	08/82	3903-MAL
	Technical Assistance to Improve the Efficiency of Fuelwood Use in the Tobacco Industry (English)	11/83	009/83
Mali	Status Report (English)	01/84	013/84
	Energy Assessment (English and French)	11/91	8423-MLI
Islamic Republic of Mauritania	Household Energy Strategy (English and French)	03/92	147/92
	Energy Assessment (English and French)	04/85	5224-MAU
Mauritius	Household Energy Strategy Study (English and French)	07/90	123/90
	Energy Assessment (English)	12/81	3510-MAS
Mozambique	Status Report (English)	10/83	008/83
	Power System Efficiency Audit (English)	05/87	070/87
	Bagasse Power Potential (English)	10/87	077/87
	Energy Sector Review (English)	12/94	3643-MAS
	Energy Assessment (English)	01/87	6128-MOZ
	Household Electricity Utilization Study (English)	03/90	113/90
Namibia	Electricity Tariffs Study (English)	06/96	181/96
	Sample Survey of Low Voltage Electricity Customers	06/97	195/97
	Energy Assessment (English)	03/93	11320-NAM
Niger	Energy Assessment (French)	05/84	4642-NIR
	Status Report (English and French)	02/86	051/86
	Improved Stoves Project (English and French)	12/87	080/87
	Household Energy Conservation and Substitution (English and French)	01/88	082/88
Nigeria	Energy Assessment (English)	08/83	4440-UNI
	Energy Assessment (English)	07/93	11672-UNI
	Strategic Gas Plan	02/04	279/04
Rwanda	Energy Assessment (English)	06/82	3779-RW
	Status Report (English and French)	05/84	017/84
	Improved Charcoal Cookstove Strategy (English and French)	08/86	059/86
	Improved Charcoal Production Techniques (English and French)	02/87	065/87
	Energy Assessment (English and French)	07/91	8017-RW
	Commercialization of Improved Charcoal Stoves and Carbonization Techniques Mid-Term Progress Report (English and French)	12/91	141/91
	SADC Regional Power Interconnection Study, Vols. I-IV (English)	12/93	-
SADCC Regional Sector: Regional Capacity-Building Program for Energy Surveys and Policy Analysis (English)	11/91	-	
Sao Tome and Principe	Energy Assessment (English)	10/85	5803-STP
Senegal	Energy Assessment (English)	07/83	4182-SE

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>
Senegal	Status Report (English and French)	10/84	025/84
	Industrial Energy Conservation Study (English)	05/85	037/85
	Preparatory Assistance for Donor Meeting (English and French)	04/86	056/86
	Urban Household Energy Strategy (English)	02/89	096/89
	Industrial Energy Conservation Program (English)	05/94	165/94
Seychelles	Energy Assessment (English)	01/84	4693-SEY
	Electric Power System Efficiency Study (English)	08/84	021/84
Sierra Leone	Energy Assessment (English)	10/87	6597-SL
Somalia	Energy Assessment (English)	12/85	5796-SO
Republic of South Africa	Options for the Structure and Regulation of Natural Gas Industry (English)	05/95	172/95
Sudan	Management Assistance to the Ministry of Energy and Mining	05/83	003/83
	Energy Assessment (English)	07/83	4511-SU
	Power System Efficiency Study (English)	06/84	018/84
	Status Report (English)	11/84	026/84
	Wood Energy/Forestry Feasibility (English)	07/87	073/87
Swaziland	Energy Assessment (English)	02/87	6262-SW
	Household Energy Strategy Study	10/97	198/97
Tanzania	Energy Assessment (English)	11/84	4969-TA
	Peri-Urban Woodfuels Feasibility Study (English)	08/88	086/88
	Tobacco Curing Efficiency Study (English)	05/89	102/89
	Remote Sensing and Mapping of Woodlands (English)	06/90	--
	Industrial Energy Efficiency Technical Assistance (English)	08/90	122/90
	Power Loss Reduction Volume 1: Transmission and Distribution System Technical Loss Reduction and Network Development (English)	06/98	204A/98
	Power Loss Reduction Volume 2: Reduction of Non-Technical Losses (English)	06/98	204B/98
Togo	Energy Assessment (English)	06/85	5221-TO
	Wood Recovery in the Nangbeto Lake (English and French)	04/86	055/86
	Power Efficiency Improvement (English and French)	12/87	078/87
Uganda	Energy Assessment (English)	07/83	4453-UG
	Status Report (English)	08/84	020/84
	Institutional Review of the Energy Sector (English)	01/85	029/85
	Energy Efficiency in Tobacco Curing Industry (English)	02/86	049/86
	Fuelwood/Forestry Feasibility Study (English)	03/86	053/86
	Power System Efficiency Study (English)	12/88	092/88
	Energy Efficiency Improvement in the Brick and Tile Industry (English)	02/89	097/89
	Tobacco Curing Pilot Project (English)	03/89	UNDP Terminal Report
	Energy Assessment (English)	12/96	193/96
	Rural Electrification Strategy Study	09/99	221/99
Zaire	Energy Assessment (English)	05/86	5837-ZR
	Energy Assessment (English)	01/83	4110-ZA
Zambia	Status Report (English)	08/85	039/85
	Energy Sector Institutional Review (English)	11/86	060/86
	Power Subsector Efficiency Study (English)	02/89	093/88
	Energy Strategy Study (English)	02/89	094/88
	Urban Household Energy Strategy Study (English)	08/90	121/90
	Energy Assessment (English)	06/82	3765-ZIM
	Power System Efficiency Study (English)	06/83	005/83
Zimbabwe	Status Report (English)	08/84	019/84

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>
Zimbabwe	Power Sector Management Assistance Project (English)	04/85	034/85
	Power Sector Management Institution Building (English)	09/89	--
	Petroleum Management Assistance (English)	12/89	109/89
	Charcoal Utilization Pre-feasibility Study (English)	06/90	119/90
	Integrated Energy Strategy Evaluation (English)	01/92	8768-ZIM
	Energy Efficiency Technical Assistance Project: Strategic Framework for a National Energy Efficiency Improvement Program (English)	04/94	--
	Capacity Building for the National Energy Efficiency Improvement Programme (NEEIP) (English)	12/94	--
	Rural Electrification Study	03/00	228/00
EAST ASIA AND PACIFIC (EAP)			
Asia Regional China	Pacific Household and Rural Energy Seminar (English)	11/90	--
	County-Level Rural Energy Assessments (English)	05/89	101/89
	Fuelwood Forestry Preinvestment Study (English)	12/89	105/89
	Strategic Options for Power Sector Reform in China (English)	07/93	156/93
	Energy Efficiency and Pollution Control in Township and Village Enterprises (TVE) Industry (English)	11/94	168/94
	Energy for Rural Development in China: An Assessment Based on a Joint Chinese/ESMAP Study in Six Counties (English)	06/96	183/96
	Improving the Technical Efficiency of Decentralized Power Companies	09/99	222/99
	Air Pollution and Acid Rain Control: The Case of Shijiazhuang City and the Changsha Triangle Area	10/03	267/03
Fiji	Toward a Sustainable Coal Sector In China	07/04	287/04
	Energy Assessment (English)	06/83	4462-FIJ
Indonesia	Energy Assessment (English)	11/81	3543-IND
	Status Report (English)	09/84	022/84
	Power Generation Efficiency Study (English)	02/86	050/86
	Energy Efficiency in the Brick, Tile and Lime Industries (English)	04/87	067/87
	Diesel Generating Plant Efficiency Study (English)	12/88	095/88
	Urban Household Energy Strategy Study (English)	02/90	107/90
	Biomass Gasifier Preinvestment Study Vols. I & II (English)	12/90	124/90
	Prospects for Biomass Power Generation with Emphasis on Palm Oil, Sugar, Rubberwood and Plywood Residues (English)	11/94	167/94
Lao PDR	Urban Electricity Demand Assessment Study (English)	03/93	154/93
	Institutional Development for Off-Grid Electrification	06/99	215/99
Malaysia	Sabah Power System Efficiency Study (English)	03/87	068/87
	Gas Utilization Study (English)	09/91	9645-MA
Mongolia	Energy Efficiency in the Electricity and District Heating Sectors	10/01	247/01
	Improved Space Heating Stoves for Ulaanbaatar	03/02	254/02
	Impact of Improved Stoves on Indoor Air Quality in Ulaanbaatar, Mongolia	08/05	309/05
Myanmar	Energy Assessment (English)	06/85	5416-BA
Papua New Guinea	Energy Assessment (English)	06/82	3882-PNG
	Status Report (English)	07/83	006/83
	Institutional Review in the Energy Sector (English)	10/84	023/84
	Power Tariff Study (English)	10/84	024/84

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>	
Philippines	Commercial Potential for Power Production from Agricultural Residues (English)	12/93	157/93	
	Energy Conservation Study (English)	08/94	--	
	Strengthening the Non-Conventional and Rural Energy Development Program in the Philippines: A Policy Framework and Action Plan	08/01	243/01	
	Rural Electrification and Development in the Philippines: Measuring the Social and Economic Benefits	05/02	255/02	
	Solomon Islands	Energy Assessment (English)	06/83	4404-SOL
	Energy Assessment (English)	01/92	979-SOL	
South Pacific	Petroleum Transport in the South Pacific (English)	05/86	--	
Thailand	Energy Assessment (English)	09/85	5793-TH	
	Rural Energy Issues and Options (English)	09/85	044/85	
	Accelerated Dissemination of Improved Stoves and Charcoal Kilns (English)	09/87	079/87	
	Northeast Region Village Forestry and Woodfuels Preinvestment Study (English)	02/88	083/88	
	Impact of Lower Oil Prices (English)	08/88	--	
	Coal Development and Utilization Study (English)	10/89	--	
	Why Liberalization May Stall in a Mature Power Market: A Review of the Technical and Political Economy Factors that Constrained the Electricity Sector Reform in Thailand 1998-2002	12/03	270/03	
	Reducing Emissions from Motorcycles in Bangkok	10/03	275/03	
Tonga	Energy Assessment (English)	06/85	5498-TON	
Vanuatu	Energy Assessment (English)	06/85	5577-VA	
Vietnam	Rural and Household Energy-Issues and Options (English)	01/94	161/94	
	Power Sector Reform and Restructuring in Vietnam: Final Report to the Steering Committee (English and Vietnamese)	09/95	174/95	
	Household Energy Technical Assistance: Improved Coal Briquetting and Commercialized Dissemination of Higher Efficiency Biomass and Coal Stoves (English)	01/96	178/96	
	Petroleum Fiscal Issues and Policies for Fluctuating Oil Prices In Vietnam	02/01	236/01	
	An Overnight Success: Vietnam's Switch to Unleaded Gasoline	08/02	257/02	
	The Electricity Law for Vietnam—Status and Policy Issues—The Socialist Republic of Vietnam	08/02	259/02	
	Petroleum Sector Technical Assistance for the Revision of the Existing Legal and Regulatory Framework	12/03	269/03	
	Western Samoa	Energy Assessment (English)	06/85	5497-WSO
	SOUTH ASIA (SAS)			
	Bangladesh	Energy Assessment (English)	10/82	3873-BD
Priority Investment Program (English)		05/83	002/83	
Status Report (English)		04/84	015/84	
Power System Efficiency Study (English)		02/85	031/85	
Small Scale Uses of Gas Pre-feasibility Study (English)		12/88	--	
Reducing Emissions from Baby-Taxis in Dhaka		01/02	253/02	
India	Opportunities for Commercialization of Non-conventional Energy Systems (English)	11/88	091/88	
	Maharashtra Bagasse Energy Efficiency Project (English)	07/90	120/90	
	Mini-Hydro Development on Irrigation Dams and Canal Drops Vols. I, II and III (English)	07/91	139/91	

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>	
India	WindFarm Pre-Investment Study (English)	12/92	150/92	
	Power Sector Reform Seminar (English)	04/94	166/94	
	Environmental Issues in the Power Sector (English)	06/98	205/98	
	Environmental Issues in the Power Sector: Manual for Environmental Decision Making (English)	06/99	213/99	
	Household Energy Strategies for Urban India: The Case of Hyderabad	06/99	214/99	
	Greenhouse Gas Mitigation In the Power Sector: Case Studies From India	02/01	237/01	
	Energy Strategies for Rural India: Evidence from Six States	08/02	258/02	
	Household Energy, Indoor Air Pollution, and Health	11/02	261/02	
	Access of the Poor to Clean Household Fuels	07/03	263/03	
	The Impact of Energy on Women's Lives in Rural India	01/04	276/04	
	Environmental Issues in the Power Sector: Long-Term Impacts And Policy Options for Rajasthan	10/04	292/04	
	Environmental Issues in the Power Sector: Long-Term Impacts And Policy Options for Karnataka	10/04	293/04	
	Nepal	Energy Assessment (English)	08/83	4474-NEP
		Status Report (English)	01/85	028/84
Energy Efficiency & Fuel Substitution in Industries (English)		06/93	158/93	
Pakistan	Household Energy Assessment (English)	05/88	--	
	Assessment of Photovoltaic Programs, Applications, and Markets (English)	10/89	103/89	
Pakistan	National Household Energy Survey and Strategy Formulation Study: Project Terminal Report (English)	03/94	--	
	Managing the Energy Transition (English)	10/94	--	
	Lighting Efficiency Improvement Program Phase 1: Commercial Buildings Five Year Plan (English)	10/94	--	
	Clean Fuels	10/01	246/01	
Regional	Toward Cleaner Urban Air in South Asia: Tackling Transport Pollution, Understanding Sources.	03/04	281/04	
Sri Lanka	Energy Assessment (English)	05/82	3792-CE	
	Power System Loss Reduction Study (English)	07/83	007/83	
	Status Report (English)	01/84	010/84	
	Industrial Energy Conservation Study (English)	03/86	054/86	
	Sustainable Transport Options for Sri Lanka: Vol. I	02/03	262/03	
	Greenhouse Gas Mitigation Options in the Sri Lanka Power Sector: Vol. II	02/03	262/03	
	Sri Lanka Electric Power Technology Assessment (SLEPTA): Vol. III	02/03	262/03	
	Energy and Poverty Reduction: Proceedings from South Asia Practitioners Workshop How Can Modern Energy Services Contribute to Poverty Reduction? Colombo, Sri Lanka, June 2-4, 2003	11/03	268/03	
EUROPE AND CENTRAL ASIA (ECA)				
Armenia	Development of Heat Strategies for Urban Areas of Low-income Transition Economies. Urban Heating Strategy for the Republic Of Armenia. <i>Including a Summary of a Heating Strategy for the Kyrgyz Republic</i>	04/04	282/04	
Bulgaria	Natural Gas Policies and Issues (English)	10/96	188/96	
	Energy Environment Review	10/02	260/02	
Central Asia and The Caucasus	Cleaner Transport Fuels in Central Asia and the Caucasus	08/01	242/01	

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>
Central and Eastern Europe	Power Sector Reform in Selected Countries	07/97	196/97
Central and Eastern Europe	Increasing the Efficiency of Heating Systems in Central and Eastern Europe and the Former Soviet Union (English and Russian)	08/00	234/00
	The Future of Natural Gas in Eastern Europe (English)	08/92	149/92
Kazakhstan	Natural Gas Investment Study, Volumes 1, 2 & 3	12/97	199/97
Kazakhstan & Kyrgyzstan	Opportunities for Renewable Energy Development	11/97	16855-KAZ
Poland	Energy Sector Restructuring Program Vols. I-V (English)	01/93	153/93
	Natural Gas Upstream Policy (English and Polish)	08/98	206/98
	Energy Sector Restructuring Program: Establishing the Energy Regulation Authority	10/98	208/98
Portugal	Energy Assessment (English)	04/84	4824-PO
Romania	Natural Gas Development Strategy (English)	12/96	192/96
	Private Sector Participation in Market-Based Energy-Efficiency Financing Schemes: Lessons Learned from Romania and International Experiences.	11/03	274/03
Slovenia	Workshop on Private Participation in the Power Sector (English)	02/99	211/99
Turkey	Energy Assessment (English)	03/83	3877-TU
	Energy and the Environment: Issues and Options Paper	04/00	229/00
	Energy and Environment Review: Synthesis Report	12/03	273/03

MIDDLE EAST AND NORTH AFRICA (MNA)

Arab Republic of Egypt	Energy Assessment (English)	10/96	189/96
	Energy Assessment (English and French)	03/84	4157-MOR
	Status Report (English and French)	01/86	048/86
Morocco	Energy Sector Institutional Development Study (English and French)	07/95	173/95
	Natural Gas Pricing Study (French)	10/98	209/98
	Gas Development Plan Phase II (French)	02/99	210/99
Syria	Energy Assessment (English)	05/86	5822-SYR
	Electric Power Efficiency Study (English)	09/88	089/88
	Energy Efficiency Improvement in the Cement Sector (English)	04/89	099/89
	Energy Efficiency Improvement in the Fertilizer Sector (English)	06/90	115/90
Tunisia	Fuel Substitution (English and French)	03/90	--
	Power Efficiency Study (English and French)	02/92	136/91
	Energy Management Strategy in the Residential and Tertiary Sectors (English)	04/92	146/92
	Renewable Energy Strategy Study, Volume I (French)	11/96	190A/96
	Renewable Energy Strategy Study, Volume II (French)	11/96	190B/96
	Rural Electrification in Tunisia: National Commitment, Efficient Implementation and Sound Finances	08/05	307/05
Yemen	Energy Assessment (English)	12/84	4892-YAR
	Energy Investment Priorities (English)	02/87	6376-YAR
	Household Energy Strategy Study Phase I (English)	03/91	126/91

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>
LATIN AMERICA AND THE CARIBBEAN REGION (LCR)			
LCR Regional	Regional Seminar on Electric Power System Loss Reduction in the Caribbean (English)	07/89	--
	Elimination of Lead in Gasoline in Latin America and the Caribbean (English and Spanish)	04/97	194/97
LCR Regional	Elimination of Lead in Gasoline in Latin America and the Caribbean - Status Report (English and Spanish)	12/97	200/97
	Harmonization of Fuels Specifications in Latin America and the Caribbean (English and Spanish)	06/98	203/98
	Energy and Poverty Reduction: Proceedings from the Global Village Energy Partnership (GVEP) Workshop held in Bolivia	06/05	202/05
	Power Sector Reform and the Rural Poor in Central America	12/04	297/04
	Estudio Comparativo Sobre la Distribución de la Renta Petrolera en Bolivia, Colombia, Ecuador y Perú	08/05	304/05
Bolivia	Energy Assessment (English)	04/83	4213-BO
	National Energy Plan (English)	12/87	--
	La Paz Private Power Technical Assistance (English)	11/90	111/90
	Pre-feasibility Evaluation Rural Electrification and Demand Assessment (English and Spanish)	04/91	129/91
	National Energy Plan (Spanish)	08/91	131/91
	Private Power Generation and Transmission (English)	01/92	137/91
	Natural Gas Distribution: Economics and Regulation (English)	03/92	125/92
	Natural Gas Sector Policies and Issues (English and Spanish)	12/93	164/93
	Household Rural Energy Strategy (English and Spanish)	01/94	162/94
	Preparation of Capitalization of the Hydrocarbon Sector	12/96	191/96
	Introducing Competition into the Electricity Supply Industry in Developing Countries: Lessons from Bolivia	08/00	233/00
	Final Report on Operational Activities Rural Energy and Energy Efficiency	08/00	235/00
	Oil Industry Training for Indigenous People: The Bolivian Experience (English and Spanish)	09/01	244/01
	Capacitación de Pueblos Indígenas en la Actividad Petrolera. Fase II	07/04	290/04
	Estudio Sobre Aplicaciones en Pequeña Escala de Gas Natural	07/04	291/04
Brazil	Energy Efficiency & Conservation: Strategic Partnership for Energy Efficiency in Brazil (English)	01/95	170/95
	Hydro and Thermal Power Sector Study	09/97	197/97
	Rural Electrification with Renewable Energy Systems in the Northeast: A Preinvestment Study	07/00	232/00
	Reducing Energy Costs in Municipal Water Supply Operations "Learning-while-doing" Energy M&T on the Brazilian Frontlines	07/03	265/03
Chile	Energy Sector Review (English)	08/88	7129-CH
Colombia	Energy Strategy Paper (English)	12/86	--
	Power Sector Restructuring (English)	11/94	169/94
Colombia	Energy Efficiency Report for the Commercial and Public Sector (English)	06/96	184/96
Costa Rica	Energy Assessment (English and Spanish)	01/84	4655-CR
	Recommended Technical Assistance Projects (English)	11/84	027/84
	Forest Residues Utilization Study (English and Spanish)	02/90	108/90
Dominican Republic	Energy Assessment (English)	05/91	8234-DO

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>
Ecuador	Energy Assessment (Spanish)	12/85	5865-EC
	Energy Strategy Phase I (Spanish)	07/88	--
	Energy Strategy (English)	04/91	--
	Private Mini-hydropower Development Study (English)	11/92	--
	Energy Pricing Subsidies and Interfuel Substitution (English)	08/94	11798-EC
	Energy Pricing, Poverty and Social Mitigation (English)	08/94	12831-EC
Guatemala	Issues and Options in the Energy Sector (English)	09/93	12160-GU
	Health Impacts of Traditional Fuel Use	08/04	284/04
Haiti	Energy Assessment (English and French)	06/82	3672-HA
	Status Report (English and French)	08/85	041/85
Honduras	Household Energy Strategy (English and French)	12/91	143/91
	Energy Assessment (English)	08/87	6476-HO
	Petroleum Supply Management (English)	03/91	128/91
Jamaica	Energy Assessment (English)	04/85	5466-JM
	Petroleum Procurement, Refining, and Distribution Study (English)	11/86	061/86
	Energy Efficiency Building Code Phase I (English)	03/88	--
	Energy Efficiency Standards and Labels Phase I (English)	03/88	--
	Management Information System Phase I (English)	03/88	--
Jamaica	Charcoal Production Project (English)	09/88	090/88
	FIDCO Sawmill Residues Utilization Study (English)	09/88	088/88
	Energy Sector Strategy and Investment Planning Study (English)	07/92	135/92
	Improved Charcoal Production Within Forest Management for the State of Veracruz (English and Spanish)	08/91	138/91
	Energy Efficiency Management Technical Assistance to the Comisión Nacional para el Ahorro de Energía (CONAE) (English)	04/96	180/96
Mexico	Energy Environment Review	05/01	241/01
	Modernizing the Fuelwood Sector in Managua and León	12/01	252/01
Nicaragua	Power System Efficiency Study (English)	06/83	004/83
Panama	Energy Assessment (English)	10/84	5145-PA
	Recommended Technical Assistance Projects (English)	09/85	--
	Status Report (English and Spanish)	09/85	043/85
Paraguay	Energy Assessment (English)	01/84	4677-PE
	Status Report (English)	08/85	040/85
	Proposal for a Stove Dissemination Program in the Sierra (English and Spanish)	02/87	064/87
	Energy Strategy (English and Spanish)	12/90	--
	Study of Energy Taxation and Liberalization of the Hydrocarbons Sector (English and Spanish)	120/93	159/93
	Reform and Privatization in the Hydrocarbon Sector (English and Spanish)	07/99	216/99
	Rural Electrification	02/01	238/01
Peru	Energy Assessment (English)	09/84	5111-SLU
	Energy Assessment (English)	09/84	5103-STV
Saint Lucia	Environmental and Social Regulation of Oil and Gas Operations in Sensitive Areas of the Sub-Andean Basin (English and Spanish)	07/99	217/99
St. Vincent and the Grenadines	Energy Assessment (English)	09/84	5103-STV
Sub Andean	Energy Assessment (English)	12/85	5930-TR
Trinidad and Tobago	Energy Assessment (English)	12/85	5930-TR

GLOBAL

Energy End Use Efficiency: Research and Strategy (English)	11/89	--
Women and Energy--A Resource Guide		
The International Network: Policies and Experience (English)	04/90	--
Guidelines for Utility Customer Management and Metering (English and Spanish)	07/91	--
Assessment of Personal Computer Models for Energy Planning in Developing Countries (English)	10/91	--
Long-Term Gas Contracts Principles and Applications (English)	02/93	152/93
Comparative Behavior of Firms Under Public and Private Ownership (English)	05/93	155/93
Development of Regional Electric Power Networks (English)	10/94	--
Roundtable on Energy Efficiency (English)	02/95	171/95
Assessing Pollution Abatement Policies with a Case Study of Ankara (English)	11/95	177/95
A Synopsis of the Third Annual Roundtable on Independent Power Projects: Rhetoric and Reality (English)	08/96	187/96
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Reducing the Cost of Grid Extension for Rural Electrification	02/00	227/00
Undeveloped Oil and Gas Fields in the Industrializing World	02/01	239/01
Best Practice Manual: Promoting Decentralized Electrification Investment	10/01	248/01
Peri-Urban Electricity Consumers—A Forgotten but Important Group: What Can We Do to Electrify Them?	10/01	249/01
Village Power 2000: Empowering People and Transforming Markets	10/01	251/01
Private Financing for Community Infrastructure	05/02	256/02
Stakeholder Involvement in Options Assessment: Promoting Dialogue in Meeting Water and Energy Needs: A Sourcebook	07/03	264/03
A Review of ESMAP's Energy Efficiency Portfolio	11/03	271/03
A Review of ESMAP's Rural Energy and Renewable Energy Portfolio	04/04	280/04

<i>Region/Country</i>	<i>Activity/Report Title</i>	<i>Date</i>	<i>Number</i>
	ESMAP Renewable Energy and Energy Efficiency Reports 1998-2004 (CD Only)	05/04	283/04
	Regulation of Associated Gas Flaring and Venting: <i>A Global Overview and Lessons Learned from International Experience</i>	08/04	285/04
	ESMAP Gender in Energy Reports and Other related Information (CD Only)	11/04	288/04
	ESMAP Indoor Air Pollution Reports and Other related Information (CD Only)	11/04	289/04
	Energy and Poverty Reduction: Proceedings from the Global Village Energy Partnership (GVEP) Workshop on the Pre-Investment Funding. Berlin, Germany, April 23-24, 2003.	11/04	294/04
	Global Village Energy Partnership (GVEP) Annual Report 2003	12/04	295/04
	Energy and Poverty Reduction: Proceedings from the Global Village Energy Partnership (GVEP) Workshop on Consumer Lending and Microfinance to Expand Access to Energy Services, Manila, Philippines, May 19-21, 2004	12/04	296/04
	The Impact of Higher Oil Prices on Low Income Countries And on the Poor	03/05	299/05
	Advancing Bioenergy for Sustainable Development: Guideline For Policymakers and Investors	04/05	300/05
	ESMAP Rural Energy Reports 1999-2005	03/05	301/05
	Renewable Energy and Energy Efficiency Financing and Policy Network: Options Study and Proceedings of the International Forum	07/05	303/05
	Implementing Power Rationing in a Sensible Way: Lessons Learned and International Best Practices	08/05	305/05
	Pioneering New Approaches in Support of Sustainable Development In the Extractive Sector: Community Development Toolkit, also Includes a CD containing Supporting Reports	10/05	310/05
	Analysis of Power Projects with Private Participation Under Stress	10/05	311/05
	Potential for Biofuels for Transport in Developing Countries	10/05	312/05

Last report added to this list: ESMAP Formal Report 312/05



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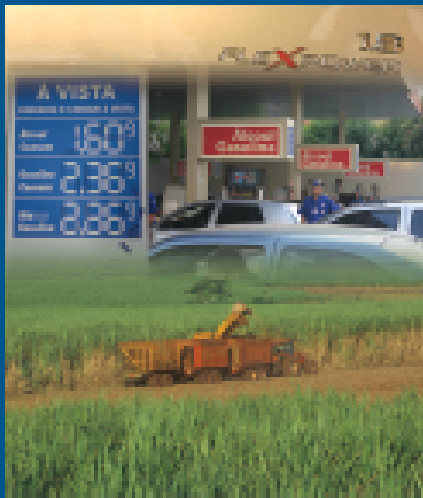
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