BIOFUELS FOR TRANSPORTATION

GLOBAL POTENTIAL AND IMPLICATIONS FOR SUSTAINABLE AGRICULTURE AND ENERGY IN THE 21st CENTURY

—EXTENDED SUMMARY—

Prepared by the Worldwatch Institute for the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), in cooperation with the Agency for Technical Cooperation (GTZ) and the Agency of Renewable Resourcs (FNR)

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TABLE OF CONTENTS

LIST OF TABLES, FIGURES, AND SIDEBARS

1. BACKGROUND OF THE REPORT

In view of the forecasted shortages and increasing prices of fossil fuels, climate change, and the need for new income and employment opportunities in rural areas, biofuels have taken center stage in policy debates.

The use of biofuels is developing favorably worldwide. Brazil, the United States, many European countries, and a growing number of countries in Southeast Asia are now pinning their hopes on biofuels. Brazil and the United States are the largest producers of ethanol in the world. China, too, has launched a program with a view to using ethanol as a fuel.

The German Federal Government welcomes and supports this development in the interest of global climate and resource protection and in order to seize the opportunities for rural development. However, the full potential of biofuels is only now becoming apparent.

What is now needed for targeted global action is a comprehensive account of the global options for the use of liquid biofuels. This concerns not only their technological potential, but also their sustainable economic potential. The German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) therefore commissioned the Agency for Technical Cooperation (GTZ) to draw up a study on this global potential, with the research support of the Worldwatch Institute.

The report, *Biofuels for Transportation: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century*, aims at presenting the opportunities, but also the limits, of global biofuel production and use in terms of energy, agricultural, environmental, and rural development aspects, as well as in economic terms. The report also examines the impact of globally expanded biofuel production on Germany's biofuel sector. Finally, the study presents detailed recommendations for action for decision-makers in politics, industry, and elsewhere.

Central elements of the study include:

- Consolidation of previous German studies and experience;
- Regional studies and workshops in Brazil, China, India, Tanzania, as well as the United States;
- Global analysis and derivation of recommendations for action; and
- Incorporation of the results into the international debate.

The regional studies (available at www.gtz.de) analyze the current market usage of liquid biofuels, new technologies, land availability, relevant trade issues, environmental risks and opportunities, social aspects, and many other factors. The global study assesses the potential role of biofuels in the future global energy matrix and in sustainable development. This provides a basis for developing recommendations for policymakers.

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2. EXTENDED SUMMARY

2.1 Biofuels: Current Status and Global Potential

The production and use of biofuels have entered a new era of global growth, experiencing acceleration in both the scale of the industry and the number of countries involved. Surging investment in biofuel production is being driven by a variety of factors, including the development of more efficient conversion technologies, the introduction of strong new government policies, and, primarily, the rising price of oil. Underlying the commitment of an increasing number of governments to biofuel development is the desire to find new markets for farmers and their products and to reduce emissions of greenhouse gases.

The two primary biofuels in use today are ethanol and biodiesel, both of which can be used in existing vehicles. Ethanol is currently blended with gasoline, and biodiesel is blended with petroleum-based diesel for use in conventional diesel-fueled vehicles. Ethanol accounts for about 90 percent of total biofuel production, with biodiesel making up the rest. Global fuel ethanol production more than doubled between 2000 and 2005, while production of biodiesel, starting from a much smaller base, expanded nearly fourfold. (See Figures 1 and 2, below.) By contrast, world oil production increased by only 7 percent during the same period.

Compared to petroleum refining, which is developed at a very large scale, biofuel production is lower volume and more decentralized. In the case of biodiesel in particular, where a wide range of plant and animal feedstock can be used, there has been a tendency for rather dispersed production facilities. Producers have the ability to extract the raw vegetable oil at one site and then send it to a different location for processing.

Figure 1. World Fuel Ethanol Production, 1975–2005

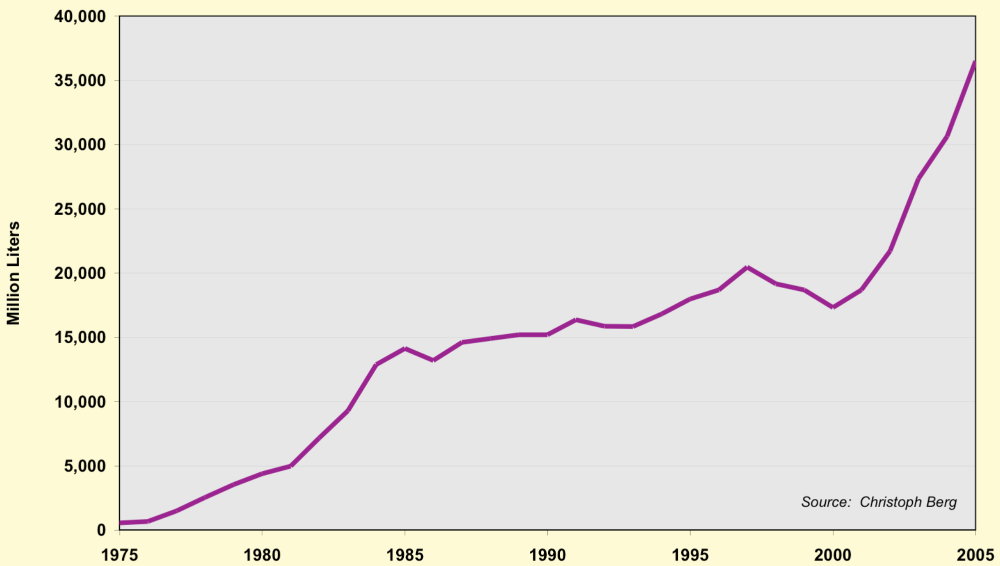
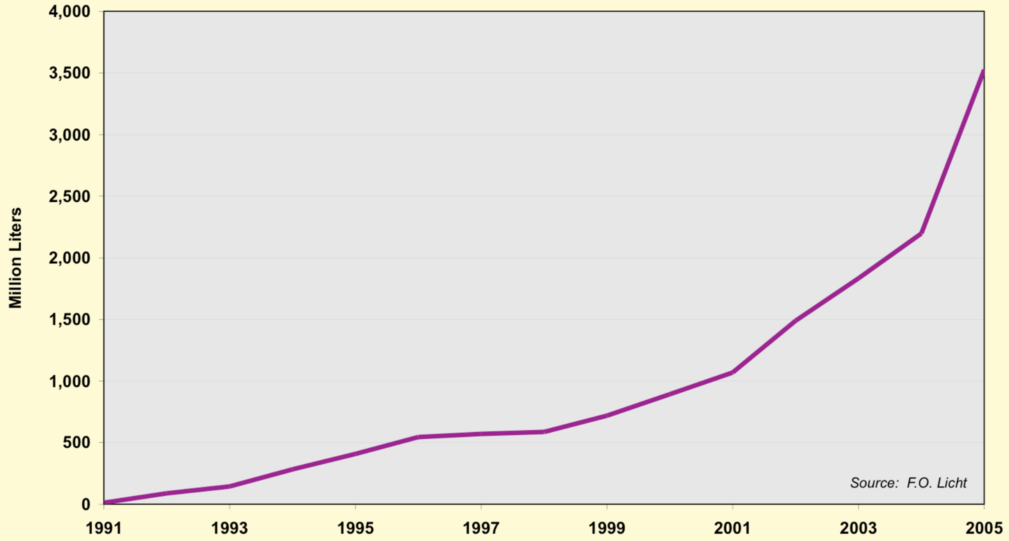


Figure 2. World Biodiesel Production, 1991–2005



Ethanol fuel production has tended to be more geographically concentrated than biodiesel, but it is typically broadly distributed among different facilities within a specific production region. In the United States, this production is concentrated predominantly in Midwestern states that have abundant corn supplies, such as Iowa, Illinois, Minnesota, Nebraska, and South Dakota. In Brazil, sugar cane and ethanol production are concentrated in the center-south region, mainly in the state of São Paulo.

Despite the two countries' somewhat similar overall ethanol output, Brazil is home to three times as many ethanol plants as the United States. Accordingly, the average capacity of plants in the U.S. is three times greater than the average capacity of those in Brazil. The largest plant in Brazil produces 328 million liters per year by crushing sugar cane, whereas in the United States the largest corn dry-milling ethanol plant produces 416 million liters per year. There are various reasons for the differences in plant capacities. One key reason corn-to-ethanol plants can be larger is because substantial amounts of harvested corn can be stored for long periods of time, whereas sugar cane must be processed shortly after it is harvested (preferably within 24–48 hours) to avoid deterioration of the sugar.

Since the 1970s, Brazil has been at the forefront of efforts to produce ethanol from sugar cane, the leading feedstock to date. Three decades of government support and private investment have allowed Brazil to steadily improve the efficiency of its production processes and to make ethanol economical for consumers. During the same period, the United States has been the leader in converting grains (mainly corn) into ethanol fuel, improving efficiency and lowering costs. Germany has been a leader in the large-scale production of biodiesel fuel from rapeseed and sunflower seed, crops commonly used to produce vegetable oil for human consumption. (See Tables 1 and 2.)

Table 1. Top Five Fuel Ethanol Producers in 2005

	Production (million liters)
Brazil	16,500
United States	16,230
China	2,000
European Union	950
India	300

Source: Christoph Berg

Table 2. Top Five Biodiesel Producers in 2005

	Production (million liters)
Germany	1,920
France	511
United States	290
Italy	227
Austria	83

Source: F. O. Licht

The recent pace of advancement in technology, policy, and investment suggest that the rapid growth of biofuel use could continue for decades to come and that these fuels have the potential to displace a significant share of the oil now consumed in many countries. A recent study found that advanced biofuel technologies could allow biofuels to substitute for 37 percent of U.S. gasoline within the next 25 years, with the figure rising to 75 percent if vehicle fuel efficiency were doubled during the same period. The biofuel potential of EU countries is in the range of 20–25 percent if strong sustainability criteria for land use and crop choice are assumed, and assuming that bioenergy use in non-transport sectors is growing in parallel.

The potential for biofuels is particularly large in tropical countries, where high crop yields and lower costs for land and labor—which dominate the cost of these fuels—provide an economic advantage that is hard for countries in temperate regions to match. When petroleum prices are above €41 ($50) per barrel, as they were for most of 2005 and early 2006, ethanol from sugar cane is significantly less expensive than gasoline, and biodiesel is also increasingly competitive with diesel. (See Figures 3 and 4, below.) It has been estimated that worldwide sugar cane production could be expanded to a level such that this crop alone could displace about 10 percent of gasoline use worldwide. This would allow scores of low-income countries to become significant producers—and potentially exporters—of a valuable new commodity.

Overall, biofuels have a large potential to substitute for petroleum fuels. Together with a host of other strategies, including the development of far more efficient vehicles, they can help the world achieve a more diversified and sustainable transportation system in the decades ahead. However, this promise will only be achieved if policies are enacted that steer biofuels in the right direction—policies that will need to be adjusted and refined as the state of knowledge advances and as the risks and opportunities of biofuel development become clearer.

Figure 3. Cost Ranges for Ethanol and Gasoline Production, 2006

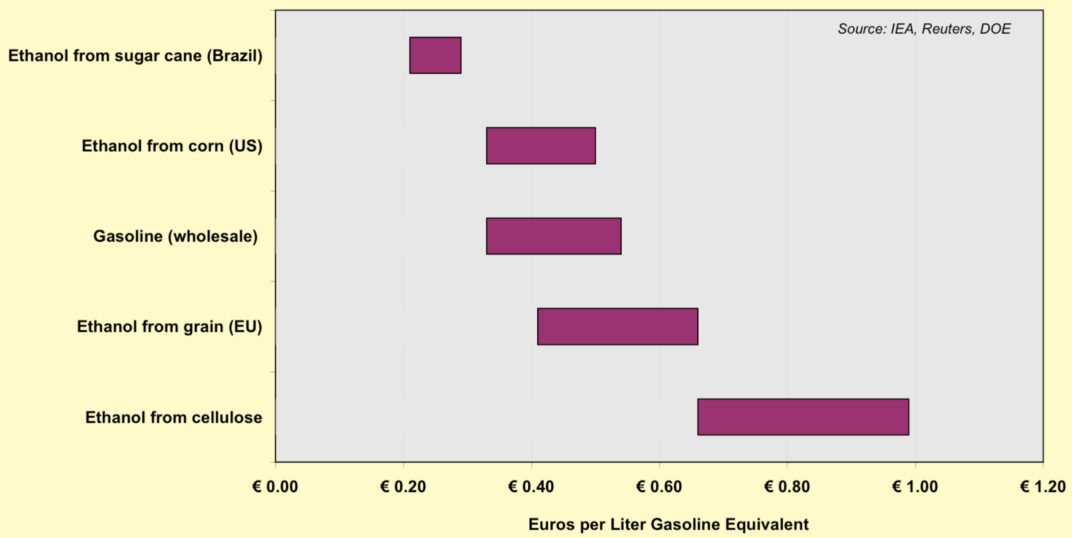
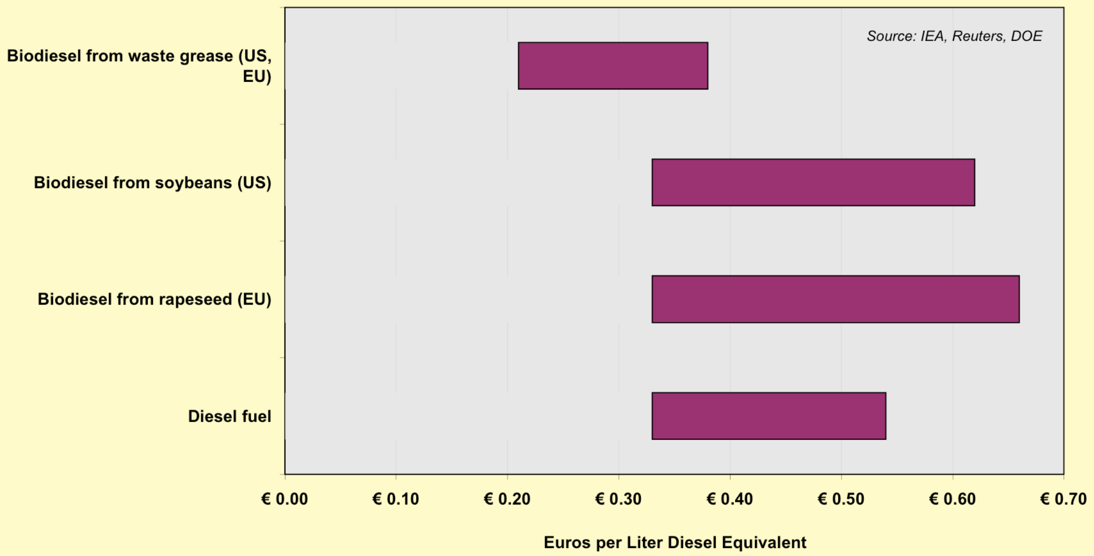


Figure 4. Cost Ranges for Biodiesel and Diesel Production, 2006



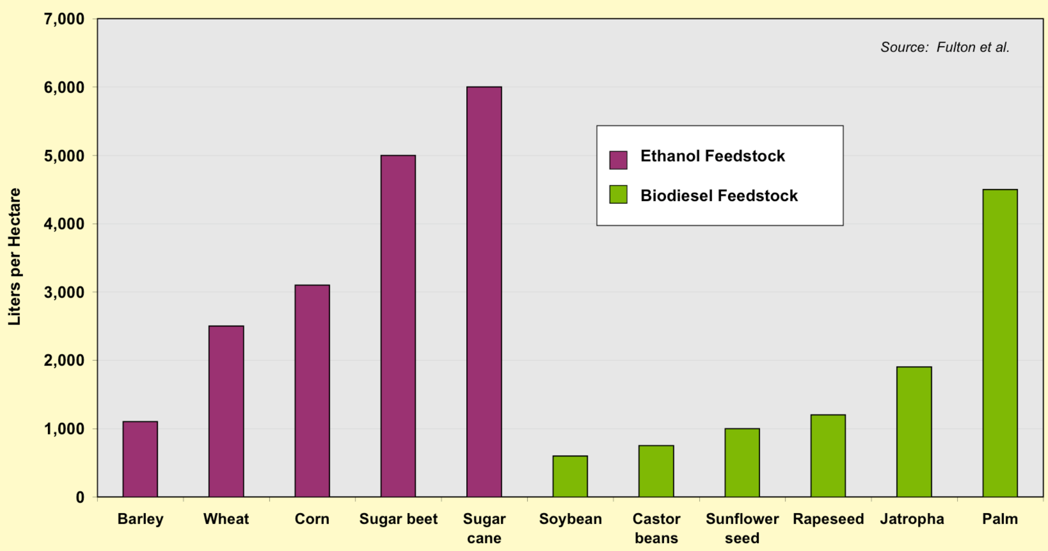
In the coming years, the international development of biofuels and bio-based co-products has the potential to increase energy security for many nations; to create new economic opportunities for people in rural, agricultural areas the world over; to protect and enhance the environment on local, regional, and global scales; and to provide new and improved products to millions of consumers. Key to shaping such a future, in which biofuels are produced in a sustainable manner and used on a large scale, is defining clear goals and enacting the policies necessary to achieve them.

2.2 New Feedstock, Technologies, and Prospects

New Feedstock

The various biomass feedstock used for producing biofuels can be grouped into two basic categories. The first is the currently available “first-generation” feedstock, which comprises various grain and vegetable crops. These are harvested for their sugar, starch, or oil content and can be converted into liquid fuels using conventional technology. The yields from the feedstock vary considerably, with sugar cane and palm oil currently producing the most liters of fuel per hectare. (See Figure 5.)

Figure 5. Biofuel Yields of Selected Ethanol and Biodiesel Feedstock



By contrast, the “next-generation” of biofuel feedstock comprises cellulose-rich organic material, which is harvested for its total biomass. These fibers can be converted into liquid biofuels only by advanced technical processes, many of which are still under development. Cellulosic biomass such as wood, tall grasses, and crop residues is much more abundant than food crops and can be harvested with less interference to the food economy and potentially less strain on land, air, and water resources. Promising energy crops include fast-growing woody crops such as willow, hybrid poplar, and eucalyptus, as well as tall perennial grasses such as switchgrass and miscanthus. Another potential “next-generation” feedstock is the organic portion of municipal solid waste.

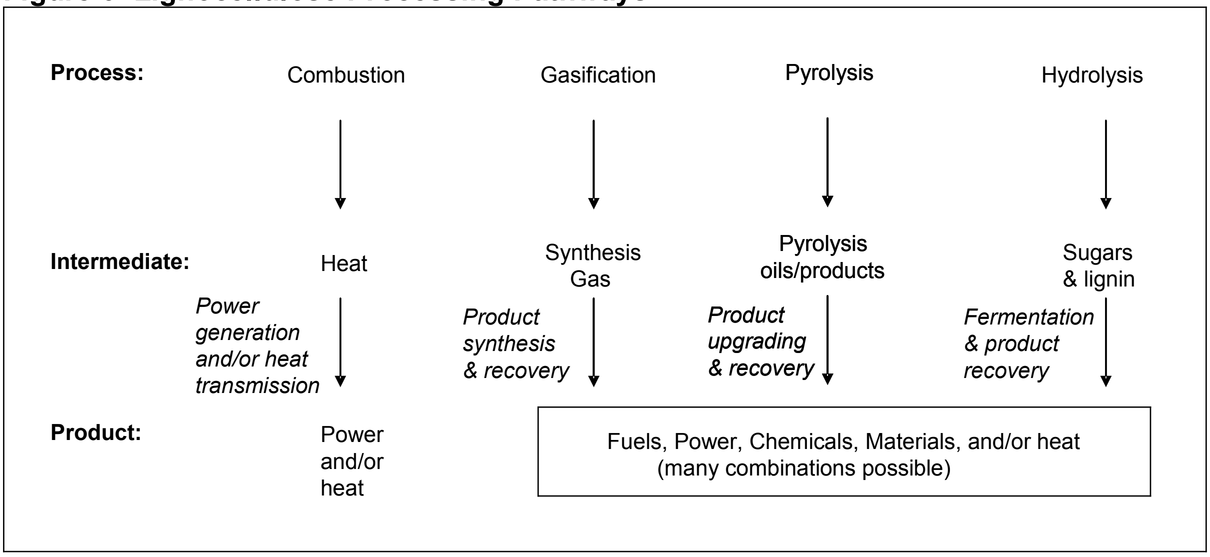
The use of “next-generation” cellulosic biomass feedstock has the potential to dramatically expand the resource base for producing biofuels in the future. Over the next 10–15 years, lower-cost sources of cellulosic biomass, such as the organic fraction of municipal waste and the residues from biomass processing, crops, and forestry, are expected to provide the initial influx of next-generation feedstock. Dedicated cellulosic energy crops, such as switchgrass, poplar, and other fast-growing plants, are expected to begin supplying feedstock for biofuel production toward the end of this period, then expanding rapidly in the years beyond.

New Technologies

For biofuels to reach their full potential in meeting future transportation needs, it is critical to develop and deploy economically competitive technologies that can convert abundant cellulosic biomass resources into liquid. Development efforts to date have demonstrated that it is possible to produce a variety of liquid fuels from cellulosic biomass for use in existing vehicles. As of mid-2006, however, the costs of producing liquid fuels from cellulosic biomass were not competitive with either petroleum-derived fuels or more conventional biofuels. Various government and industry-sponsored efforts are under way to lower the costs of making liquid fuel from cellulosic biomass by improving the conversion technologies.

Figure 6 below highlights four primary pathways for bioenergy production: combustion, gasification, pyrolysis, and hydrolysis. This report focuses primarily on *gasification* (a thermochemical pathway) and *hydrolysis* (a biochemical pathway). Both pathways can provide a variety of products in addition to producing liquid fuels for transportation uses.

Figure 6. Lignocellulose Processing Pathways



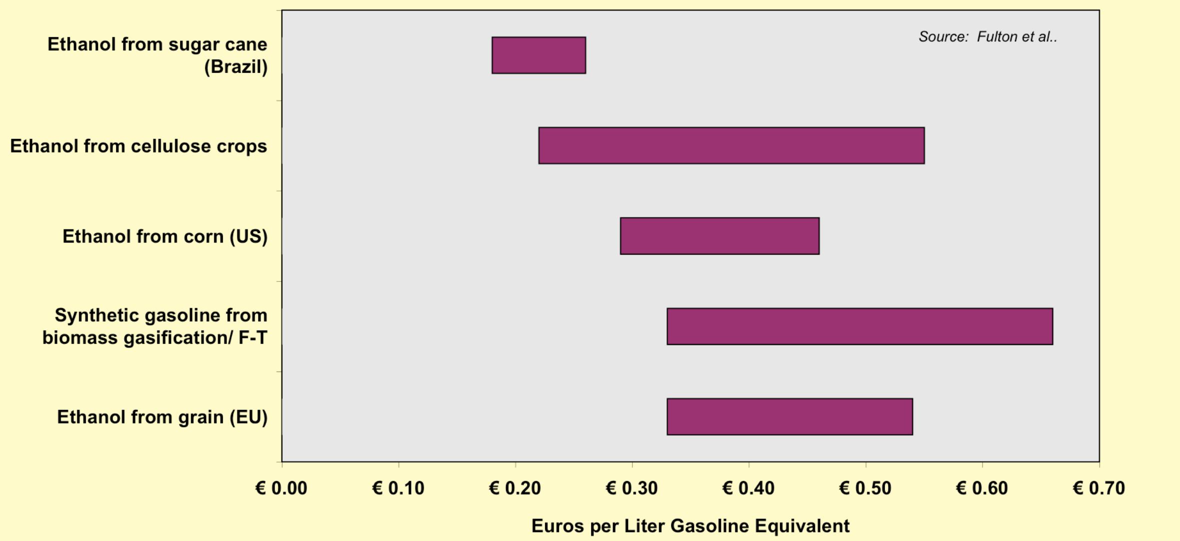
Source: Darmouth College and NRDC

The hydrolysis pathway relies on advanced enzymes that can catalyze cellulose and lignocellulose into sugars and then ethanol. The gasification (and specifically, the Fischer-Tropsch synthesis) pathway uses high temperatures, controlled levels of oxygen, and chemical catalysts to convert biomass into liquid fuels, including synthetic diesel and di-methyl ether (DME).

The gasification pathway is also called the biomass-to-liquid (BTL) pathway, and generally requires a larger-sized facility and a larger capital investment. In general, improvements in this area appear to be occurring more slowly than the advances in biotechnology that are propelling the hydrolysis pathway. However, the BTL pathway can also process lignin, which comprises about one-third of plant solid matter, and can thus achieve higher liquid yields, displacing more petroleum. Accordingly, one detailed analysis of different conversion pathways concluded that a combination of the hydrolysis and BTL pathways was the most economical and energetically efficient approach.

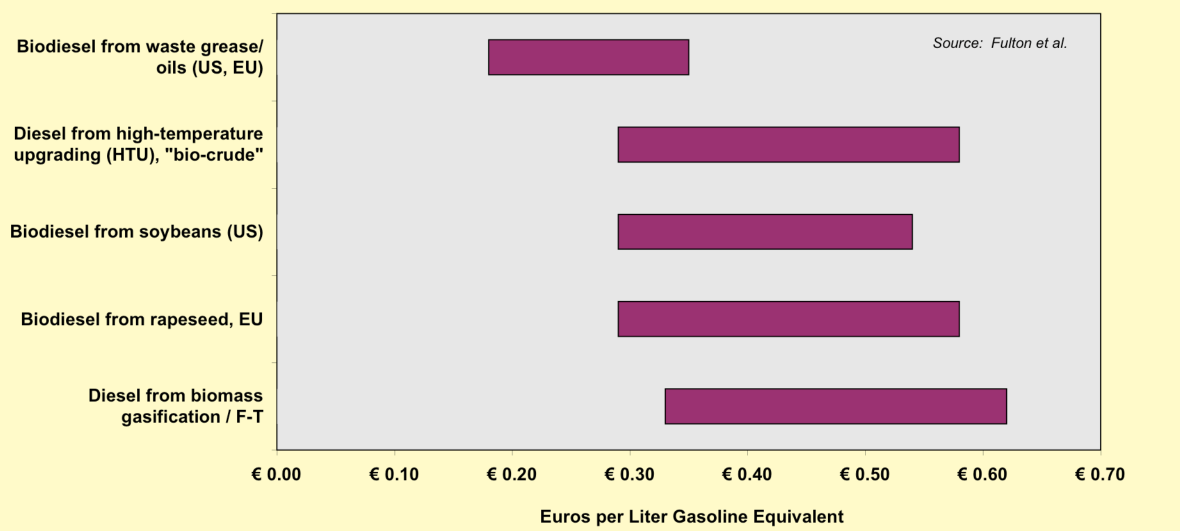
It is expected that the combination of cellulosic biomass resources and next-generation biofuel conversion technologies will be able to fully compete with conventional gasoline and diesel fuel without subsidies within the coming decades. Various efforts are under way to estimate the anticipated costs for biofuels in the future as progress is made in reducing the costs of advanced next-generation biofuels. Figures 7 and 8 below summarize the results of an International Energy Agency study that estimated the costs of biofuels after the year 2010, comparing both first-generation and next-generation technologies for producing gasoline and diesel substitutes.

Figure 7. Cost Ranges for Ethanol and Gasoline Production After 2010



Note: "F-T" means Fischer-Tropsch

Figure 8. Cost Ranges for Diesel and Biodiesel Production After 2010



Note: "F-T" means Fischer-Tropsch

The lowest-cost biofuels are expected to continue to be ethanol produced from sugar cane and biodiesel produced from recycled cooking oil and waste grease. Beyond these two least-cost options, the costs for producing next-generation biofuels are expected to be in a range that should make them generally competitive with first-generation technologies. The ability of next-generation technologies to use abundant cellulosic feedstock that do not rely on food crops offers the promise of dramatically expanding the amount of biofuels that could be produced for transportation needs in the future.

Yield Prospects

When considering the potential sources of biomass energy, a distinction can be made between biomass that is specifically cultivated for energy purposes (i.e. energy crops grown on existing agricultural or marginal lands), and primary, secondary, and tertiary residues and wastes:

- *Primary residues* are produced during production of food crops and forest products. They include straw, corn stover (stalks), or wood thinnings from commercial forestry. Such biomass streams are typically available “in the field” and must be collected to be available for further use.

- *Secondary residues* are generated during processing of biomass for production of food products or biomass materials. They include nutshells, sugar cane bagasse (the residue from cane crushing), and sawdust, and are typically available at food and beverage industries, saw and paper mills, etc.

- *Tertiary residues* become available after a biomass-derived commodity has already been used. A diversity of waste streams is part of this category, from the organic fraction of municipal solid waste (MSW) to waste and demolition wood, sludges, etc.

Table 3 on the following page provides an overview of the potential contribution of each of these biomass types to the global energy supply by the year 2050. (For a more detailed discussion of the potential ethanol yields from MSW, see also Sidebar 1.)

Bioenergy’s potential is enormous. Studies suggest that biomass could potentially supply anywhere from 0 EJ to more than 1,000 EJ of energy by the year 2050. In the most optimistic scenarios, bioenergy could provide for more than two times the current global energy demand, without competing with food production, forest protection efforts, and biodiversity. In the least favorable scenarios, however, bioenergy could supply only a fraction of current energy use by 2050, perhaps even less than it provides today.

Table 3. Bioenergy Production Potentials for Selected Biomass Types, 2050

Biomass Type	Bioenergy Potential (exajoules)	Main Assumptions and Remarks
Agricultural Residues	15–70	• Based on estimates from various studies. • Potential depends on yield/product ratios, total agricultural land area, type of production system. Extensive production systems require leaving of residues to maintain soil fertility; intensive systems allow for higher rates of residue energy use.
Organic Wastes	5–50+[b]	• Based on estimates from various studies. • Includes the organic fraction of MSW and waste wood. • Strongly dependent on economic development and consumption, and as well as use for biomaterials. • Higher values possible by more intensive biomaterials use.
Animal Dung	5–55 (or possibly 0)	• Use of dried dung. • Low range value based on current global use; high value reflects technical potential. • Utilization (collection) over longer term is uncertain.
Forest Residues	30–150 (or possibly 0)	• Figures include processing residues. • Part is natural forest (reserves). • The (sustainable) energy potential of world forests is unclear. • Low range value based on sustainable forest management; high value reflects technical potential.
Energy Crop Farming (current agricultural lands)	0–700 (100–300 is more average)	• Potential land availability of 0–4 global hectares (Gha), though 1–2 is more average. • Based on productivity of 8–12 dry tonne/ha/yr[a] (higher yields are likely with better soil quality). • If adaptation of intensive agricultural production systems is not feasible, bioenergy supply could be zero.
Energy Crop Farming (marginal lands)	60–150 (or possibly 0)	• Potential maximum land area of 1.7 Gha. • Low productivity is 2–5 dry tonne/ha/yr.[a] • Bioenergy supply could be low or zero due to poor economics or competition with food production.
Biomaterials	Minus 40–150 (or possibly 0)	• These provide an additional *claim* on biomass supplies. • Land area required to meet additional global demand is 0.2– 0.8 Gha • Average productivity is 5 dry tonnes/ha/yr.[a] • Supply would come from energy crop farming if forests are unable to meet this demand.
Total	**40–1,100 (250–500 is more average)**	• Pessimistic scenario assumes no land for energy farming, only use of residues; optimistic scenario assumes intensive agriculture on better quality soils. • More average range = most realistic in a world aiming for large-scale bioenergy use.

Notes: (a) heating value: 19 GJ/tonne dry matter; (b) the energy supply of biomaterials ending up as waste can vary between 20–55 EJ (or 1,100-2,900 million tonnes of dry matter per year). Biomass lost during conversion, such as charcoal, is logically excluded from this range. This range excludes cascading and does not take into account the time delay between production of the material and its 'release' as (organic) waste. Source: Andre Faaij, Copernicus Institute, Utrecht University, report submitted to Worldwatch Institute, 17 January 2005.

Sidebar 1. How Much Ethanol Could the Municipal Solid Waste from a City With One Million People Produce?

The average person in the United States generates approximately 1.8 kilograms of municipal solid waste (MSW) every day. Of this, typically about 75 percent is predominantly cellulosic organic material, including waste paper, wood wastes, cardboard, and waste food scraps. Thus, a city with 1 million people produces around 1,800 tonnes of MSW in total, or about 1,300 tonnes per day of organic material.

Using technology that could convert organic waste to ethanol, roughly 330 liters of ethanol could be produced per tonne of organic waste. Thus, 1,300 tonnes per day of organic waste from a city with 1 million people would be enough feedstock to produce about 430,000 liters of ethanol per day, or approximately 150 million liters per year. This is enough fuel to meet the needs of more than 58,000 people in the United States; 360,000 people in France; or nearly 2.6 million people in China at current rates of per capita fuel use.

Source: Jim Easterly, Easterly Consulting, personal communication with Peter Stair, Worldwatch Institute, March 2006.

Estimates of the longer-term potential for harnessing biomass energy range widely and depend on factors such as the extent to which the yields of both food and energy crops can increase, the size of the human population, and the per capita human demand for food and land. Theoretically, biomass supplies could be huge, rivaling current oil supplies.

Over the next two decades, existing starch, sugar, and oilseed crop varieties will continue to provide the bulk of the biomass supplies used for biofuel production. Biofuels grown in tropical areas are cheaper and can displace a larger share of petroleum than biofuels produced with more temperate feedstock. European countries will likely find it preferable to import biofuels rather than attempt to grow all of their own. The United States may be able to produce more indigenous biofuel, but will ultimately face similar limitations.

Since the next-generation conversion technologies are on the verge of viability, continued research and development could be helpful. But extensive deployment is perhaps more important. This will allow operators to streamline new facilities while also reducing the risk perceived by investors looking at an "unproven" technology.

2.3 Key Economic and Social Issues, including Agriculture and Rural Development

Energy Security

Petroleum is a highly concentrated energy resource, and the world's current transportation systems are almost completely dependent on it. As a result, the world economy is (or could be) at risk if oil supplies are disrupted in any of the relatively few countries that are significant oil exporters. As a result of concentrated wealth, social tensions, and inadequate political institutions, many of these countries are less-than-secure suppliers of the world's most vital commodity. Biofuels promise to bring a much broader group of countries into the liquid fuel business, diversifying supplies and reducing the risk of disruption. And because they can be produced in most regions of the globe, the risks inherent in transporting these fuels over long distances will be reduced as well. In the long run, this is likely to help stabilize fuel prices.

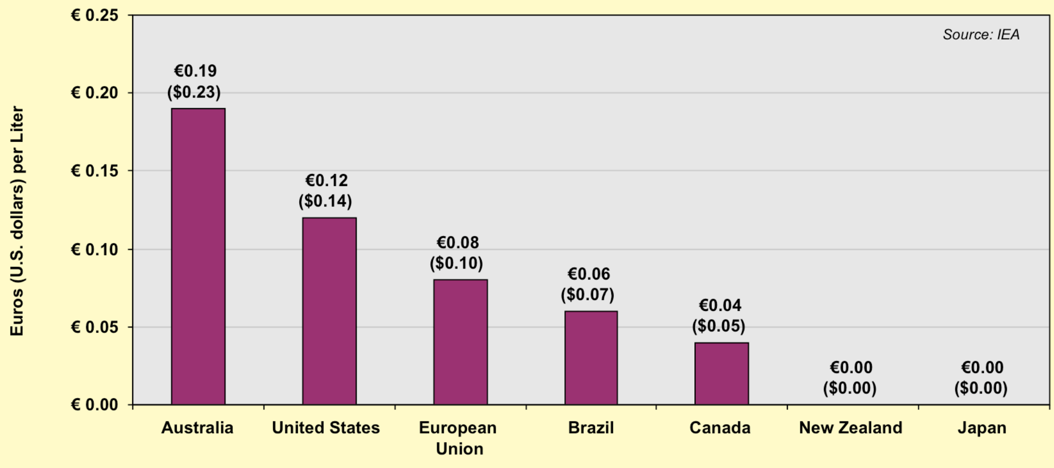
Food versus Fuel

Large-scale production of biofuels will tend to increase the price of agricultural commodities. This can benefit farmers, but may hurt those who can barely afford food. However, the situation is more nuanced than many have portrayed it to be: for example, the meat industry, one of the biggest purchasers of crops, will benefit from the increased production of high-protein feeds that are the co-products of corn ethanol, soybean biodiesel, and other biofuel production. And many of the world's hungry are also farmers. The poorest people will benefit more from the cultivation of biofuels if they are involved in the "value-added" stages of their production, such as processing and refining. In remote areas, poor farmers could benefit by producing their own fuels.

International Biofuel Trade

Many of the countries that consume large quantities of transportation fuels have limited land available for producing biomass feedstock, which leaves them unable to produce more than a fraction of their transportation fuels from domestic biomass. This will likely encourage many industrial countries to consider importing biofuels and to push for elimination of the tariffs and other trade barriers that have so far limited biofuel trade. (See Figure 9.) Ongoing negotiations at the World Trade Organization aimed at liberalizing trade in agricultural commodities are likely to spur the move to freer trade in biofuels, offering an opportunity for countries to provide new agricultural revenues as an offset to the loss of trade-distorting agricultural subsidies.

Figure 9. Ethanol Import Duties in Selected Countries, 2004



As the demand for non-fossil liquid fuels grows, countries will increasingly adopt and refine standards for biofuel quality and support advancements in compatible transportation infrastructure. However, careful policy planning will be needed to ensure opportunities for sustainable trading relationships that support socio-economic development in the world's rural and agricultural regions.

Impacts on Agriculture and Rural Development

Continued expansion of biofuel production will increase global demand for agricultural products and result in the creation of new jobs at every stage of the production process, from harvesting, to processing, to distribution. As more countries become producers of biofuels, their rural economies will likely benefit as they harness a greater share of their domestic resources.

But not everyone will benefit equally. Of all the participants in the biofuel economy, agribusinesses are most assured to profit, since mechanized harvesting and production chains are the easiest option for rapidly scaling up biofuel production. Large-scale agricultural processors and distributors will be responsible for supplying most of the refined fuels as well. The development of cellulosic conversion technologies will only further exaggerate the advantages of those interests with large pools of financial capital.

As policymakers proceed with biofuel programs, they will need to decide to what extent they want to encourage small farmers or laborers to share in the profits. If this is a priority for governments, then policy options include well-enforced labor standards and profit-sharing agreements, learning from policies implemented in the Brazilian state of São Paulo and in the U.S. state of Minnesota (where farmer cooperatives have been established for ethanol production). On the processing side, governments can support smaller-scale producers and cooperatives by requiring fuel blenders to purchase fuel from them at fair prices.

When considering biofuel programs for their capacity to promote rural development, decision makers in industrial countries must remain mindful of just how important agriculture is to the economies of the developing world. Advocates of rural development in industrialized countries might consider to what extent they also care about development in other countries. Restrictive tariffs can benefit rural communities in industrialized countries while disproportionately harming those in less-wealthy countries.

A biofuel industry that is locally oriented—in which farmer-owners produce fuel for their own use—is more likely to guarantee benefits to a rural community. In these situations, farmers may risk bad seasons and poor harvests but, by adding value to their own products and using these goods locally, they are also less vulnerable to external exploitation and disruptive market fluctuations. Although liquid fuels produced at home are often used for cooking or electricity, rather than transportation, it is worth noting that readily available technologies to convert "modern" biomass into energy promise to be a more directed way to alleviate poverty, especially in more remote, oil-dependent regions.

2.4 Environmental Issues

Petroleum fuels have exacted a heavy environmental toll on the planet, and their impact is likely to worsen as “dirtier” energy supplies, such as heavy oil and coal, are tapped. As an alternative, biofuels offer the opportunity to reduce the emissions of both greenhouse gases (GHGs) and urban air pollutants. Their cultivation could cause huge disruptions in land use, but, if managed properly, the cultivation of energy crops could also facilitate the sequestration of carbon in the soil and provide an economic incentive to protect and restore ecosystems previously degraded by human activities.

Energy Balance

One of the largest questions raised about biofuels is their net energy balance, particularly the question of whether the bio-based fuels produced contain more useful energy than the (fossil) fuels required to make them. This was a greater concern a decade ago than it is today, since advances in technology have improved production efficiency, giving virtually all current commercial biofuels a positive fossil energy balance. (See Table 4 on the following page.) Plants use photosynthesis to convert solar energy into chemical energy, and as technologies improve and facilities begin to use more biomass energy (e.g. from agricultural residues like sugar cane bagasse and corn stover), the amount of fossil energy used to produce the crops and convert them to biofuels will continue to decline.

There are two primary measures for evaluating the energy performance of biofuel production pathways. These are:

- *Energy balance*—the ratio of energy contained in the final biofuel to the energy used by human efforts to produce it. Typically, only fossil fuel inputs are counted in this equation, while biomass inputs, including the biomass feedstock itself, are not counted. A more accurate term for this concept is *fossil energy balance*, and it is one measure of a biofuel’s ability to slow the pace of climate change.

- *Energy efficiency*—the ratio of energy in the biofuel to the amount of energy input, counting all fossil and biomass inputs as well as other renewable energy inputs. This ratio adds an indication of how much biomass energy is lost in the process of converting it to a liquid fuel, and helps to measure more- and less-efficient conversions of biomass to biofuel.

Ethanol feedstock such as sugar beets, wheat, and corn have been criticized because their fossil energy balance is close to 1.0, a threshold many consider the line between an energy sink and an energy source. (Diesel and gasoline have fossil energy balances between about 0.8 and 0.9, numbers that may be more relevant for comparison than 1.0.) But this approach fails to account for two important nuances. First, ethanol is a liquid fuel that has qualities that make it useful in the existing transportation infrastructure. Since the natural gas and coal used to produce ethanol do not have this quality, it can be practical to lose energy in the process of converting these fuels into ethanol. Second, even crude petroleum must be refined into usable liquids.

Table 4. Fossil Energy Balances of Selected Fuel Types

Fuel (feedstock)	Fossil Energy Balance (approx.)	Data and Source Information
Cellulosic ethanol	2–36	(2.62) Lorenz and Morris (5+) DOE (10.31) Wang (35.7) Elsayed et al.
Biodiesel (palm oil)	~9	(8.66) Azevedo (~9) Kaltner (9.66) Azevedo
Ethanol (sugar cane)	~8	(2.09) Gehua et al. (8.3) Macedo et al.
Biodiesel (waste vegetable oil)	5–6	(4.85–5.88) Elsayed et al.
Biodiesel (soybeans)	~3	(1.43–3.4) Azevedo et al. (3.2) Sheehan et al.
Biodiesel (rapeseed, EU)	~2.5	(1.2–1.9) Azevedo et al. (2.16–2.41) Elsayed et al. (2–3) Azevedo et al. (2.5–2.9) BABFO (1.82–3.71) Richards; depends on use of straw for energy and cake for fertilizer. (2.7) NTB (2.99) ADEME/DIREM
Ethanol (wheat)	~2	(1.2) Richards (2.05) ADEME/DIREM (2.02–2.31) Elsayad et al. (2.81–4.25) Gehua
Ethanol (sugar beets)	~2	(1.18) NTB (1.85–2.21) Elsayad et al. (2.05) ADEME/DIREM
Ethanol (corn)	~1.5	(1.34) Shapouri 1995 (1.38) Wang 2005 (1.38) Lorenz and Morris (1.3–1.8); Richards
Diesel (crude oil)	0.8–0.9	(0.83) Sheehan et al. (0.83–0.85) Azevedo (0.88) ADEME/DIREM (0.92) ADEME/DIREM
Gasoline (crude oil)	0.80	(0.84) Elsayed et al. (0.8) Andress (0.81) Wang
Gasoline (tar sands)	~0.75	Larsen et al.

Note: Figures represent the amount of energy contained in the listed fuel per unit of fossil fuel input. The ratios for cellulosic biofuels are theoretical. Complete source information is in full report.

Clearly, some biofuel production pathways are more efficient than others, with climate being the principle determinant of efficiency. Tropical plants currently have more favorable energy ratios than plants grown in temperate climates because they grow in more ideal conditions for using sunlight and water and because they are often cultivated manually, with fewer fossil energy requirements and fewer inputs of fertilizer and pesticides. Temperate biofuel production pathways have become significantly more efficient in recent decades as agricultural practices have improved and fuel production mills have streamlined their operations. However, it is generally acknowledged that biofuels produced from temperate oil seeds, sugar beets, wheat, and corn have limited ability to displace other fuels, because of either their low yields or their high input requirements.

Since transportation energy accounts for only a small share of a biofuel's overall energy use, the above factors suggest that it would be more energetically efficient for countries with temperate climates to import biofuels (e.g. made from sugar cane or palm oil) than to produce them at home. It would be more efficient to transport the final fuel, rather than the feedstock, because the fuel is more energetically dense.

With regard to next-generation feedstock, the energy cost of producing biofuels from lcellulosic biomass will likely continue to exceed that of producing biofuels with conventional starch, sugar, and oil, considering all of the energy inputs (including the biomass) required for the conversion process. While conversion technologies will improve over time, in the near term cellulosic biomass has the greatest potential as a source of *processing* energy for conventional (first-generation) biofuels, providing a means to significantly improve the overall fossil energy balance of these fuels. As cellulosic conversion becomes more viable, analysts should continue to evaluate the most-efficient uses of cellulosic biomass, raising the importance of "energy efficiency" metrics as opposed to measures of fossil energy.

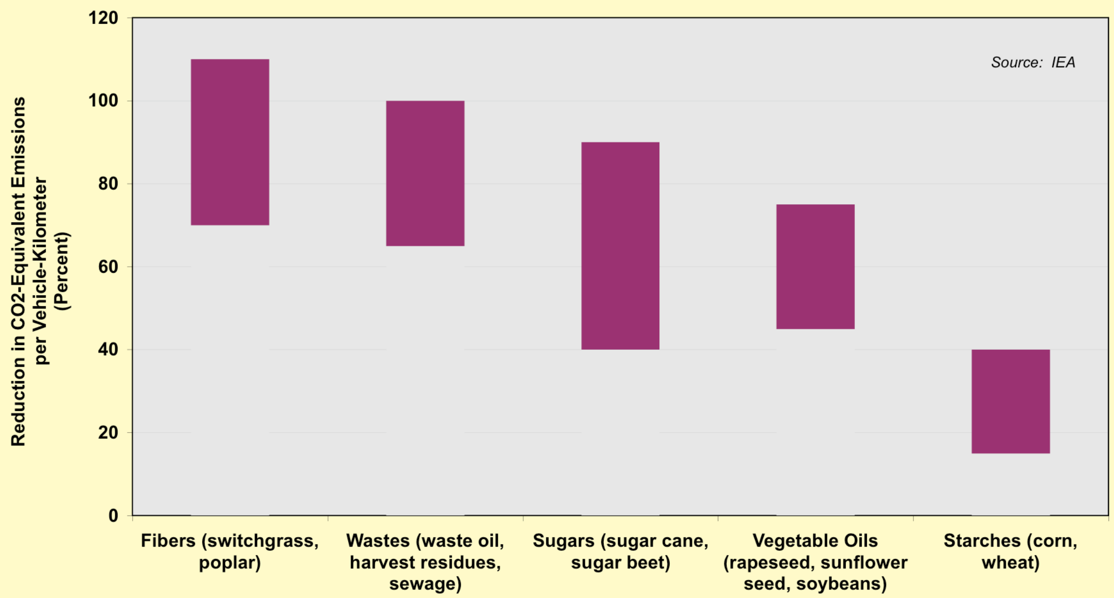
When considering strategies for slowing the pace of climate change, the fossil energy balance of different biofuel production pathways can be a useful measure of their relative effectiveness. It is worth emphasizing that the fossil energy balance of biofuels could theoretically approach infinity, but only if renewable energy alone is used to cultivate, harvest, refine, and deliver biofuels. However, fossil energy balance does not take into account other ways that biofuel production contributes to climate change, such as changes in land use.

Greenhouse Gas Emissions

The global transportation sector is responsible for 25 percent of the world's energy-related greenhouse gas (GHG) emissions, and this share is rising. A dramatic increase in the production and use of biofuels has the potential to significantly reduce those emissions, particularly with the development of advanced biofuel technologies that rely on agricultural wastes and dedicated cellulosic crops such as switchgrass. However, if biofuels are produced from low-yielding crops, are grown on previously wild grasslands or forests, and/or are produced with heavy inputs of fossil energy, they have the potential to generate as much or more GHG emissions than petroleum fuels do. For example, a key issue today is the transition from natural gas to coal energy at ethanol refineries in the United States: of the two energy sources, coal releases substantially more carbon per joule.

Figure 10 shows the range of potential GHG emissions reductions from the use of wastes and other next-generation feedstock, relative to current-generation feedstock.

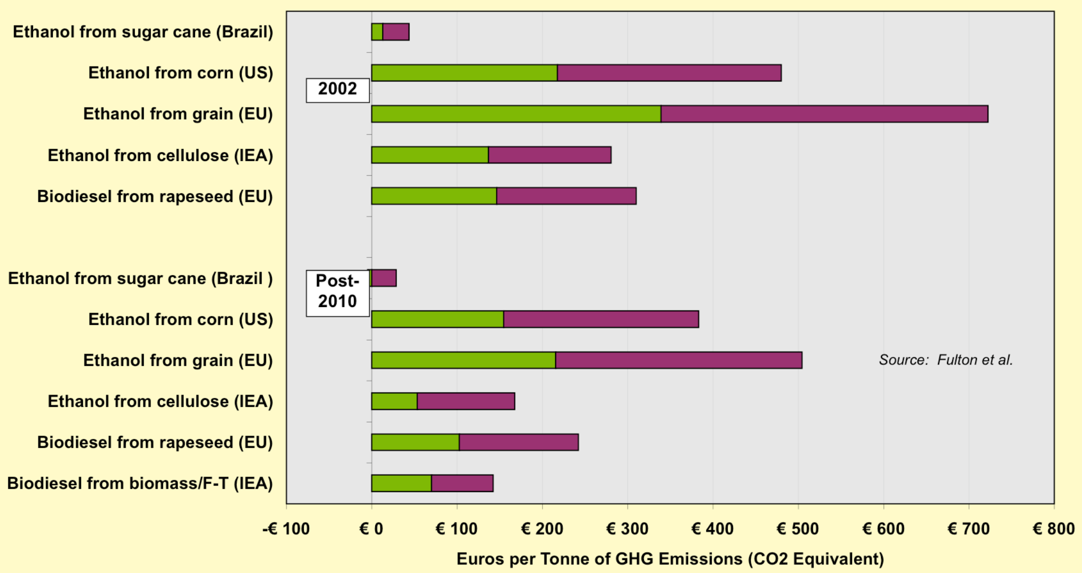
Figure 10. Potential Reductions in Greenhouse Gas Emissions, by Feedstock Type



Note: For biofuels from fibers and wastes, converting cellulose to ethanol through enzymatic hydrolysis provides the greatest potential for reductions, but gasification and conversion to diesel and di-methyl ether (DME) provide similar reductions. For the advanced technologies, it is assumed that biomass provides both the feedstock and much of the process energy.

Analyses from many countries indicate that biofuels are currently a relatively expensive means of reducing GHG emissions relative to other mitigation measures, with the cost of CO_2-equivalent emissions reductions exceeding €135 ($163) per tonne, according to estimates analyzed by Fulton et al. (2004). (See Figure 11.) The one exception is Brazil, where pure ethanol sold for nearly 40 percent less than the gasoline-ethanol blend in late 2005 (even accounting for the lower energy content in ethanol).

Figure 11. Biofuel Cost per Tonne GHG Reduction



Note: Low (green) and high (purple) ranges were developed using highest cost/ lowest GHG reduction estimate, and lowest cost/ highest GHG reduction estimate for each option, then taking the 25% and 75% percentile of this range to represent the low and high estimates in this figure. In some cases, ranges were developed around point estimates to reflect uncertainty.

Other Emissions

Replacing a portion of petroleum fuel with a biofuel generally brings a reduction in vehicle emissions of sulfur, particulates, and carbon monoxide. However, particularly in engines poorly calibrated to run on biofuels, nitrogen oxide (NO_x) emissions can increase, and in low-level blends with gasoline, ethanol can cause increased emissions of volatile organic compounds. Increasingly stringent standards for petroleum-based fuels will tend to reduce the emissions advantages offered by conventional biofuels, but the next generation of biofuels, including Fischer-Tropsch diesel and di-methyl ether (DME), can be tailored to meet certain emission specifications. Particularly in developing countries, ethanol and biodiesel could play a significant role in improving urban air quality and helping to phase out lead-based and otherwise toxic fuel additives.

Ecosystem Health

Biofuel production offers similar risks and opportunities with regard to the health of the world's ecosystems. Expanding the cultivation of biofuel crops has the potential to contribute to soil depletion and erosion, habitat loss, and reduced biodiversity. On the other hand, cellulosic biofuels could be produced from perennial grasses and trees that protect lands vulnerable to erosion and restore lands degraded by overuse. By diversifying monoculture ecosystems, such crops could also serve to increase local biodiversity. For these benefits to be realized, the expansion of biofuel production will need to be accompanied by a new generation of clear and strict land-use laws, particularly in countries with tropical forests that are at risk of destruction.

In general, any plan to promote the production and use of biofuels on a large scale must be part of a broader strategy to reduce total energy use in the transport sector. In addition to ending subsidies for conventional fuels (and for unconventional petroleum fuels), governments must encourage the development of lighter, more fuel-efficient vehicles, and promote and support smarter urban design and mass transit.

2.5 Market Introduction and Technology Strategies

Plant Infrastructure

The current trend toward larger-scale biofuel conversion facilities is likely to continue in the coming years. Future facilities for converting lignocellulosic feedstock into biofuels are expected to be even larger than facilities now used for the production of first-generation biofuels, and significant economy-of-scale advantages are expected to reduce the cost of production. However, the relatively dispersed nature of agricultural crops and the high cost of transporting solid biomass will put upper limits on the future scale of biofuel plants.

The development of biofuel facilities that deploy cellulosic biomass conversion will require substantial capital as well. Since investment in large new technologies is inherently risky, governments will need to play a key role in helping to reduce some of the risks involved, including assuring that the infrastructure is in place for transporting biofuels and integrating them into the transportation fuel market.

Vehicle and Engine Technologies

Biofuels need to be processed to consistent standards for optimal performance in internal-combustion engines (in general, warmer operating temperatures tend to allow for a larger margin of error). Vehicle manufacturers typically warrantee ethanol blends of 10 percent or less with gasoline in conventional spark-ignition engines. Specially designed flexible-fuel vehicles can run on a range of ethanol-gasoline blends.

Biodiesel blends of as high as 20 percent are authorized in the warrantees for most compression-ignition engines, and in a few instances warrantees allow for 100-percent biodiesel. Other biofuels, such as straight vegetable oil, methanol, di-methyl ether (DME), and biogas require more extensive engine modifications.

Fuel Distribution

Biofuels can generally be distributed via the petroleum distribution infrastructure, though in some cases special measures must be taken. Ethanol has a high affinity for water, which can cause it to separate from gasoline. For this reason, colder climates may require dedicated ethanol pipelines, which are the cheapest means of fuel distribution. And because of the relatively high solvency of ethanol and biodiesel, their introduction into tanks and facilities previously used only for petroleum-based fuels may initially cause a release of deposits left by gasoline and diesel.

Technology Transfer

With its success in commercializing sugar cane ethanol, Brazil has accumulated a reservoir of experience that will prove valuable for countries developing new biofuel programs. As other countries develop expertise in cultivating new crops and utilizing new technologies for converting these into fuels, they can expedite both the displacement of petroleum and global economic development by sharing their knowledge. This interchange of technology and ideas offers an opportunity to promote the sustainable use of biofuels. As the next generation of these fuels is developed, it will be important to develop efficient systems for harvesting, pre-processing, and delivering new types of feedstock to processing facilities.

2.6 Policy Recommendations

The increased worldwide demand for oil has kept prices high in 2006, and the situation is not expected to change anytime soon. The rapidly industrializing economies of China and India, in particular, are projected to increase their consumption of petroleum fuels dramatically in the coming decades as levels of consumer spending and car ownership rise. These and other developing countries are projected to account for more than two-thirds of global energy demand by 2030.

To achieve a rapid scaling-up in biofuel production that can be sustained over the long term, governments must enact a coordinated set of policies that are consistent, long-range, and informed by broad stakeholder participation. In the future, biofuel promotion policies should be tied to criteria that ensure sustainable production methods and equitable distribution of production revenues. They should also be crafted in the context of larger transportation goals; reducing petroleum subsidies and increasing the taxes on petroleum are indirect ways to promote biofuels while also helping to lessen the use of oil. Measures to increase efficiency remain the cheapest way to alleviate the pollution and security risks associated with petroleum use.

Government Policies

Supportive government policies have been essential to the development of modern biofuels over the past two decades. Blending mandates, tax incentives, government purchasing policies, and support for biofuel-compatible infrastructure and technologies have been the most successful in fostering biofuel production. Countries seeking to develop domestic biofuel industries will be able to draw important lessons—both positive and negative—from the industry pioneers: Brazil, the United States, and the European Union.

Efforts to commercialize new energy crops will require particular attention from governments, many of which already possess national agricultural policies that have a significant impact on the choice of which crops to grow. Government policies can help assure that particular crops are grown on lands that are appropriate for them. For example, perennial grasses for biofuel production may be grown on erosion-prone land that would be inappropriate for annual row crops. The environmental benefits associated with energy crop production can be “monetized” through government programs such as payments or tradable credits for reduced runoff of soil and agro-chemicals into streams, and greenhouse gas reductions due to increased storage of carbon in soils.

Financing

The emerging biofuel industry also faces challenges in obtaining financing for the first risky, commercial-scale systems for producing biofuels from cellulosic biomass. Governments and international financial institutions can play a critical role in providing financing and taking other actions to help reduce financial risks, in order to help the industry move quickly through early commercialization barriers for these technologies.

Standards and Certification

As biofuels are increasingly traded across international boundaries, biofuel standards can help ensure that the industry develops without exploiting laborers or degrading the resource base. In addition, some form of certification—developed collaboratively by industry and government—will be needed to verify the sustainability of feedstock production. This is particularly true with regard to greenhouse gas impacts, where countries are working to achieve measurable, verifiable reductions in carbon emissions.

Initially, such ecological and social standards can be based on existing certification schemes for forestry and farming practices. They will need to be strong enough that they are meaningful and limit the environmental and social damages associated with biofuels (and, preferably, maximize their benefits); however, it is important that such ecological and social standards not be unduly burdensome to infant biofuel industries, nor serve as surreptitious trade barriers. Based on lessons learned from organizations such as the Forest Stewardship Council, the approach used to establish policies and standards for feedstock sustainability should be transparent, independent, and participatory

Fuel Specifications

With regard to fuel quality, specifications for biodiesel require particularly close attention. This is due to the large variety of vegetable oils and animal fats that can be used for biodiesel production, and the variability in fuel characteristics that can occur with fuel produced from this feedstock. The European Union and the United States have developed their own unique biodiesel standards and are continuing to improve them. With worldwide demand for biodiesel escalating rapidly, there is a growing need for international collaboration on related standards and fuel quality in order to facilitate trade.

Comprehensive Approach

It is also essential that governments promote biofuels within the context of a broader transition to a more-efficient, less-polluting, and more-diversified global transport sector. These fuels must be part of a portfolio of options that includes dramatic improvements in vehicle fuel economy, investments in public transportation, better urban planning, and smarter and more creative means of moving around a village or across the globe. In combination with improved vehicle efficiency, smart growth, and other new fuel sources such as biogas (and eventually even renewable hydrogen or electricity), biofuels can drive the world towards a far less vulnerable and less-polluting transport system.

Key Recommendations

Key overarching recommendations for accelerating the development of biofuels, while maximizing the benefits and minimizing the risks, include:

- **Strengthen the Market**. Biofuel policies should focus on market development. An enabling environment for renewable fuel industry development must be created in order to draw in entrepreneurial creativity, private capital, and technical capacity.

- **Speed the Transition to Next-Generation Technologies.** Policies are needed to expedite the transition to the next generation of feedstock and technologies that will enable dramatically increased production at lower cost, combined with the real potential for significant reductions in environmental impacts.

- **Protect the Resource Base.** Maintenance of soil productivity, water quality, and myriad other ecosystem services is essential. The establishment of national and international environmental sustainability principles and certification is important for protecting resources as well as maintaining public trust in the merits of biofuels.

- **Facilitate Sustainable International Biofuel Trade.** The geographical disparity in production potential and demand for biofuels will necessitate the reduction in barriers to biofuel trade. Freer movement of biofuels around the world should be coupled with social and environmental standards and a credible system to certify compliance.

- **Distribute Benefits Equitably.** This is necessary in order to gain the potential development benefits of biofuels. Enabling farmers to share ownership throughout the production chain is central to this objective.

These recommendations are further elaborated in the following section, which is an excerpt of the Recommendations (Chapter 21) of the full report.

3. RECOMMENDATIONS FOR DECISION MAKERS (ABRIDGED VERSION OF CHAPTER 21)

3.1 Introduction

Some governments have already enacted policies to support biofuels production, use, and increasingly, trade. While specific policy decisions will have to be made on a country (or regional) basis, according to unique natural resource and economic contexts, this chapter elaborates overarching recommendations to policy makers and describes a number of policy options that governments should consider enacting in order to advance sustainable biofuel development. These recommendations are drawn from experiences to date with biofuels, with other fuels, and with other renewable energy technologies, and are also based on the challenges that biofuels face today.

3.2 Developing the Biofuel Market

The most efficient way to hasten a rapid expansion of biofuel production is for governments to create a policy environment that is conducive to private sector investment in the development of these fuels. Policy makers should focus on creating a predictable and growing market for biofuels. In turn, this market will draw in the substantial capital, entrepreneurial creativity, and competitive spirit required to advance technologies, build production infrastructure, and achieve the learning and the economies of scale that are necessary to drive down costs.

Policy actions that governments can take right away, at no- or low-net cost, to help develop the market include:

- **Enact Tax Incentives.** Tax incentives have been used effectively in Brazil, Germany, the United States and other countries to spur biofuel production and reduce biofuel prices at the pump. They can also be used to encourage certain types of biofuels development (i.e. small-scale, community oriented), and to speed the adoption of biofuel-compatible vehicles and other infrastructure. (Tax incentives for biofuels can be made revenue-neutral in a number of ways, for example, by increasing taxes on petroleum-based fuels. Governments that subsidize fossil fuels can save revenues and reduce the need to subsidize alternative fuels by reducing direct and indirect subsidies for the petroleum sector.)

- **Establish Mandates and Enforcement Mechanisms**. Blending mandates create consistent and expanding markets which, in turn, attract private sector investment in technology advancement, infrastructure development, etc. Voluntary targets have been somewhat effective, but have not achieved the level of success provided by mandatory schemes coupled with credible enforcement mechanisms. Enforcement is important to ensure that targets are met. Mandates can be designed to steadily increase requirements for the share that must come from next-generation fuels. Mandates should also be tied to environmental and social standards (see below).

- **Use Government Purchasing Power**. The enormous purchasing power of governments has been used successfully in a number of countries to expand the market for various products. Government purchasing of vehicles and fuels that are certified under sustainability schemes (which could eventually involve a GHG component), could provide a powerful market driver. Local governments can switch entire fleets to vehicles that run on biofuels, as many have already done. National governments could gradually increase the share of their fleets that are fueled by biofuels and ramp up to 100 percent; the one exception might be tactical military vehicles.

- **Collaborate to Set International Fuel Quality Standards.** While many nations have developed or adopted biofuel quality standards, others still need to take this step. In order to develop a significant international biofuel market, fuel quality standards need to be agreed upon and enforced on the international level. This is necessary for consumer confidence and will gain increased importance as international trade in biofuels expands. Automakers need assurances of consistent fuel characteristics so they can honor vehicle warranties.

- **Account for Externalities**. Although it is extremely difficult, decision makers should find ways to assign monetary values to currently uncounted externalities, including local and regional pollution, health problems, climate change, and other environmental costs, as well as potential benefits, such as job creation and rural revitalization. This can be done through tax increases or incentives. For example, in the case of climate change, this could be done through a carbon cap and trade system (note, however, that this would not likely benefit biofuels in the short term).

- **Facilitate Public-Private Partnerships.** Public-private partnerships have resulted in important technological breakthroughs that have led to dramatic cost reductions (for example, in the enzymes needed for the breakdown of cellulose via enzymatic hydrolysis), and will continue to play an important role in advancing next-generation technologies.

- **Increase Public Awareness.** Consumer demand could be a powerful driver of the renewable fuels market. Strategies to increase the public's awareness and comfort level with biofuels include various forms of public education, such as formal awareness campaigns, public announcements, university research, and signage along highways. Typically outside the government sphere, but also potentially effective, informal methods include discussions on radio, blogs, podcasts, and the use of biofuels in movies and television shows.

Mandates paired with subsidies have also proven to be an effective combination for biofuels industry promotion; however, subsidies should be phased-out once a domestic industry has been established. Subsidies are often difficult to discontinue once created, so phase-outs should be strategically designed into the enabling legislation. For instance, subsidies for current-generation biofuels can be phased out first, while those for next-generation feedstock and refineries continue.

Mandates and subsidies can be used together, or as in the case of Germany, mandates can follow subsidies. As of early 2006, the German government was in the process of replacing subsidies for first-generation biofuels with a fuel blending mandate, but intended to maintain the subsidy for next-generation biofuels to further their development. In the near term, the promotion of biomass generally for various bioenergy and materials uses will help develop the biomass feedstock production sector while the next-generation liquid fuel conversion technologies are developed.

Public concerns regarding possible environmental impacts of biofuel feedstock cultivation must also be addressed if biofuels are to gain broad public acceptance. (See section 3.8 for a discussion of certification and other proposed schemes to assure the sustainable production of biofuels.)

3.3 National and International Research, Development, and Demonstration

To date, the world's engineering and scientific skills have not been focused coherently on the challenges associated with large-scale biofuel development and use. Thus, there is enormous potential for dramatic breakthroughs in feedstock and technologies that could allow biofuels to play a major role in enhancing energy security, reducing greenhouse gas emissions, and providing much of the world community with economical transport.

There has been a tremendous surge in private-sector investment in biofuels in recent years, but this investment tends to be oriented towards short-term and high payoff research. There are many long-term research needs that governments are best-suited to address; governments and international organizations should help coordinate public and private efforts by bringing together the best minds and resources in national research facilities, universities, civil society, and industry. Because intermittent funding seriously hampers research efforts, funding for research, development, and demonstration must be consistent as well as long term. It is worth noting that much of this research will likely have applications across the broader agricultural sector.

Research is needed to develop feedstocks and sustainable management practices, as well as technologies for harvesting, processing, transporting, and storing feedstock and fuels. Research is also required to better understand the potential environmental and societal impacts of biofuels throughout the entire supply chain. Biofuels and bioenergy as a whole are a cross-sectoral topic, which can only be analyzed in an integrated way. Some of the key areas for further research are provided below.

3.3.1 Feedstock Production

- **Improve Conventional Feedstock**. Improve energy yields of conventional biofuel feedstock, while developing sustainable management systems that include minimizing the use of chemical inputs and water. This includes research into the potential for modifying food crops to maximize both food and cellulose (for energy) production.

- **Develop Next-Generation Feedstock**. Improve management techniques and develop high-yield perennial crops suited for biofuel applications that require low inputs, are location-appropriate, and can improve soil and habitat quality while sequestering carbon.

- **Advance Alternatives to Chemical Inputs**. Research the potential for integrated pest management and organic fertilizer development and use, including the use of mixed-crops, rotations, and other management techniques.

- **Assess the Risks of Genetic Modification**. Potential risks and costs of developing and using GM crops must be fully assessed to determine if benefits outweigh costs. It is also important to research and develop appropriate safeguards for the use of genetically modified industrial organisms required biological conversion of cellulosic biomass to ethanol.

- **Supplement Environmental Life-Cycle Studies**. Research is needed to fill in gaps in the existing body of analyses, with regard to global climate impacts and effects on local and regional air, soil, water quality, and habitat, including a better understanding of the impacts of land-use changes, and of the scale of N_2O emissions from feedstock production, and their potential impact on the global climate.

- **Develop Methodology for Measuring Life-Cycle GHG Emissions**. There is need for consistent, internationally used, methodology and assumptions for measuring GHG emissions associated with the production and use of biofuels from various feedstocks, associated land-use changes, management strategies, and processing practices.

3.3.2 Feedstock Collection and Handling

- **Improve Equipment and Harvesting Practices.** Agricultural equipment and harvesting practices must be optimized for both crop and residue harvesting, to maximize economic benefits for farmers while minimizing soil compaction, and minimizing interruption of primary food crop harvests.

- **Ascertain Sustainable Residue Removal Rates.** Conduct research to determine sustainable extraction levels of agriculture and forestry residues to maintain soil quality under varying conditions.

- **Improve Waste Handling Practices**. Develop optimal means for safe handling and collection of various municipal waste resources (e.g. waste grease, cardboard).

- **Optimize Feedstock Storage and Transport Methods**. For example, improved methods are needed to prepare feedstock for transport by reducing bulkiness and water content.

3.3.3 Processing

- **Maximize Efficiency of Input Use**. Technologies and practices should be optimized to make the most efficient use possible of water, energy, chemicals, and other inputs, and to minimize waste through recycling of wastewater, waste heat, etc.

- **Advance Biorefinery Concept**. Continue support for the integration of a variety of related operations, including use of animal and crop residues as fuel feedstock and/or for process energy, and co-products (such as wet-distillers grain) as animal feed, bio-plastics, etc.

3.3.4 Fuel Distribution and End Use

- **Advance Fuel and Power Train Development**. Combine research and design needs to optimize engine designs/performance to take full advantage of the unique properties of biofuels (e.g., higher oxygen content, higher octane, etc.), and evaluate fuel specification criteria to identify potential fuel changes that could improve engine performance.

- **Optimize Vehicles**. This includes fine-tuning control systems and engine designs to run on varying blends for maximum fuel efficiency and minimum emissions across the full range of potential blend mixes.

- **Develop Materials**. Research materials for higher-quality tubes, hoses, and other connectors to reduce evaporative emissions.

- **Develop Fuel Additives**. Additives are needed to reduce emissions of NO_x and other harmful emissions from blends of fossil and biofuels.

3.3.5 Demonstration and Field Trials

In addition to resource assessments, policy analyses, and applied crop and processing research, it will be critical to advance experience on the ground, in varied settings. This will include field trials of new energy crops in different climate and soil conditions. Pilot conversion facilities, using cutting-edge technologies, should be funded and constructed in a wide range of settings in order to work out any related problems or challenges and to develop and make use of in situ ingenuity and local adaptation of technologies, crops and crop management, and handling systems. This should involve well-organized and well-monitored efforts in several countries (with varying climates, soil conditions, social structures, etc., including heavily degraded and desert lands), to build a body of practical experience over the next decade.

3.3.6 Outreach/Extension

On the national level, findings need to be disseminated to producers through demonstration projects, extension services (where they exist), and other farmer education mechanisms, including feedstock demonstration projects. In addition, farmers will need the appropriate know-how, capital, and incentives to risk planting new crops and to follow best practices; sustainable management and good crop choices should be tied to existing or newly created government incentives.

3.3.7 Information Clearinghouse

On the international level, a clearinghouse is needed (such as the Renewable Energy Global Policy Network, REN21, or a small international institution) to gather and make available to the global community, information regarding relevant findings and experiences with biofuel research and policies from around the world. This could be a subset of REN 21 or a separate body focusing on biofuels and agriculture.

3.4 Incentives for Rapid Deployment of Advanced, Low-Impact Biofuels and Technologies

Policies are needed to expedite the transition to the next generation of feedstock and technologies that will enable dramatically increased production at lower cost, combined with the real potential for significant reductions in environmental impacts. To date, high costs and risks associated with construction of new conversion facilities have hampered the development of next-generation fuels. Governments and international financial institutions can play a critical role in reducing financial risks and providing low-cost capital, helping industry to move quickly through early commercialization barriers.

Specific actions that governments can take to expedite the transition include:

- **Provide Incentives**. Create tax structures and other incentives that favor next-generation biofuels and integrated “biorefineries” and bioprocessing.

- **Enact Mandates**. Mandates could require that an increasing share of total fuel come from advanced feedstock and technologies.

- **Fund RD&D**. More sustainable feedstock and technologies are needed, including those that provide enhanced net reductions in GHG emissions and in fossil inputs.

- **Support Farmers**. Farmers will need information, crop and equipment assistance, market access, and other help to make the transition to producing new feedstock.

- **Facilitate Conversion of Existing Plants**. Retraining and retooling are important for converting existing plants to next-generation facilities.

- **Provide Capital**. Low-interest, long-term loans and risk guarantees are required to facilitate the development of commercial cellulosic refineries and “biorefineries.”

- **Encourage the Development of New Uses and Demand for Co-products.**

- **Encourage Technology Transfer.** Transfer of technology and capacity building to countries with nascent industries (particularly those with great potential for producing sustainable feedstock and fuels) will be of utmost importance.

3.5 Infrastructure Development

Ethanol use can increase to 10 percent of gasoline, possibly more, with minimal changes to current car fleet or infrastructure; biodiesel blends can be higher. To go beyond this, however, governments need to address the 'chicken or the egg' dilemma: vehicles are needed that can run on high-blends of biofuels, but consumers will not buy them without a distribution system that assures access to these fuels; such a distribution system is not likely to develop without the vehicles to demand/use it. This dilemma can be resolved with technologies like flex-fuel vehicles (see below).

To enable the expansion of biofuels, infrastructure changes will also be required on the production side (especially for next-generation biofuel production). New crops and production methods, as well as associated distribution requirements, will necessitate substantial infrastructure planning and development. The existing infrastructure available for the use of agricultural and forestry resources should be evaluated to determine what expansion and refinements are required for renewable biomass resources to play an expanding role in providing sustainable transportation fuel supplies.

To *encourage the necessary infrastructure transition*, governments could:

- **Advance Flexible-Fuel Vehicle Technology**. Governments could advance the development and availability of flex-fuel vehicles, including those appropriate for high-blends, through legislative mandates or softer incentives (like targets—for example, governments could call for 100 percent of new cars available in the domestic marketplace to be biofuel-compatible within 10 years). In promoting FFV's, governments should not allow trade-offs in fuel economy or air quality standards.

- **Promote Use of Flex-Fuel Vehicles**. In addition or instead, governments could establish incentives for consumers who buy such vehicles and use them with biofuels. Governments should also commit to transitioning to flex-fuel vehicles for non-diesel, non-strategic fleets.

- **Require Fuel Companies to Provide Biofuels**. Because of the control the fossil fuel companies hold over fuel distribution and sale in most countries, most governments may have to require that these companies distribute and sell biofuels. Governments could, for example, require that all fueling stations over a certain size convert at least one pump to biofuels (this would have to be phased in as fuel becomes available). This may not be appropriate in countries where blending mandates exist, and such a requirement could destroy market niches for smaller distributors.

- **Support Small Fueling Stations.** Smaller petroleum dealers and “refueling stations” should be supported, as they have a higher change for success (as has occurred in Sweden).

- **Support Development of New Fuel Standards.** As higher blends become more desirable, the fuel standards will need to be modified. Because this is a lengthy process, this should start as soon as possible.

3.6 Optimizing Ecological Impacts

While many perceive biofuels as environmentally beneficial because they are “renewable,” these fuels have the potential to positively or negatively affect the natural world—everything from local soil and water quality, to biodiversity, to the global climate—and human health, depending on factors such as feedstock selection and management practices used. Whether the impacts are largely positive or negative will be determined, in great part, by policy.

As described in detail in the report, the most significant potential impacts associated with biofuel production result from changes in land use, including natural habitat conversion. With regard to climate change, land use changes (from razing of tropical forests to replacement of grasslands) for the production of biofuel feedstock can result in large releases of carbon from soil and existing biomass, negating any benefits of biofuels for decades. Therefore, governments must prioritize the protection of virgin ecosystems and should adopt policies that compel the biofuel industry to maintain or improve current management practices of land, water, and other resources.

Next-generation feedstock and technologies offer the potential to improve soil and water quality, enhance local species diversity, and sequester carbon if lands are managed sustainably. This provides governments with yet another reason to speed the transition.

In addition, national and international standards and certification schemes will be necessary to safeguard the resource base (see below). Standards and best management practices take time to develop properly, so it is critical to initiate practical, step-by-step processes that entail consistent progress towards increased sustainability. Work on this has begun but should be supported with more substantial resources and greater international coordination.

Some specific actions that governments should take to help safeguard the environment and human health, while ramping up biofuels production, are provided below.

3.6.1 Feedstock Production

- **Conserve Natural Resources.** Local, national, and regional policies and regulations should be enacted to ensure that impacts on wildlife, and on water, air, and soil quality are minimized. For example, payment systems for irrigation and processing water could be adopted to encourage more-efficient use, and nutrient and water recycling should be encouraged.

- **Protect Virgin and Other High-Value Habitats**. Governments must find ways to protect natural forests, wetlands, and other ecosystems that provide air and water purification, soil stabilization, climate regulation, and other vital services. Options include: enforcing bans on wild land conversion for biofuel feedstock production including strong penalties for noncompliance; using satellite and global imaging technology to track land use changes; tying tax incentives, carbon credits, qualification for government purchase, sustainable production certification, etc. to the maintenance of natural ecosystems; and requiring land preserves. Large-scale feedstock producers can be required to set aside a share of their land as natural reserve, as the Brazilian state of São Paulo has done.

- **Encourage Sustainable Crops and Management Practices.** Extension services for farmers should provide them with the proper resources and incentives to select sustainable crops (particularly native species that reduce need for water, fertilizers, and pesticides), reduce the frequency of tilling and replanting, and provide habitat for wildlife. They should encourage sustainable management practices, including minimal use of inputs, buffer zones between waterways or wildlands and crops, intercropping, crop rotation, and adjusting harvest schedules to minimize conflicts with wildlife, etc. Subsidies can be linked to meeting specific criteria.

- **Improve Degraded Lands**. Encourage the rehabilitation of degraded lands with monitored production of perennial feedstock.

- **Maximize GHG Benefits.** Feedstock should be selected to maximize GHG reductions

3.6.2 Processing, Distribution, and End Use

- **Develop Licensing Procedures**. Require that refineries meet strict environmental standards that include efficiency of water use and recycling, air and water pollution controls, etc.

- **Promote Use of Renewable Process Energy**. Provide incentives to use biomass as process energy and guarantee fair access to the grid for sale of excess electricity.

- **Establish Emissions Standards for Biofuels**. Just as regulations exist for conventional fuels, they are necessary for transport and combustion of biofuels, which can have different characteristics. Regulations are needed to minimize spills and hydrocarbon emissions during transport and fueling, and to minimize evaporative and combustion emissions from storage, handling, and combustion stages of the supply chain.

- **Encourage Rapid Transition to High-Blend Fuels**. High blends with properly optimized vehicles can minimize a variety of harmful emissions. High biodiesel blends, particularly in urban areas of developing countries (where there may be weak emissions standards), can reduce public health risks, especially from particulate emissions. Cities can commit to shifting public buses and other government vehicles to 100-percent biodiesel over a few years.

- **Encourage Biofuels for a Range of Uses**. In developing countries where lead is still used as a transport fuel oxygenate (particularly in Africa), ethanol should be phased in rapidly to replace it. Biofuel (especially pure biodiesel) use for marine applications is particularly beneficial and should also be encouraged. Biofuel use for agricultural machinery (as in Germany), and construction and other heavy equipment (that is generally far more polluting and has much slower turnover rate) should be encouraged as well.

3.7 Maximizing Rural Development Benefits

If biofuels continue their rapid growth around the globe, the impact on the agricultural sector will be dramatic. Increased jobs and economic development for rural areas in both industrialized and developing countries is possible if governments put the appropriate policies in place and enforce them. The more involved farmers are in the production, processing, and use of biofuels, the more likely they are to benefit from them.

Enabling farmer (and forest material producer) ownership over more of the value-added chain will improve rural livelihoods. This not only helps improve the well-being of farm families, it increases the positive effects as greater farm income is circulated in local economies and jobs are created in other sectors. As biofuel industries grow, this multiplier effect will have impacts on the regional, national, and international levels. Greater farmer ownership will also help prevent a repetition of the dynamics in the current global food industry, where very large processors are able to exert pressure on producers.

In regions where access to modern forms of energy is limited or absent, government and development agency support for small-scale biofuel production can help provide clean, accessible energy that is vital for rural development and poverty alleviation.

Specific options for decision makers include:

- **Cooperatives and Small-Scale Ventures.** Governments can provide support for cooperatives and small-scale biofuel production facilities—for example through tax structures that give preference to small-scale feedstock and fuel production, or preferential government purchasing from farmer/cooperative-owned facilities. Cooperatives allow small- and medium-size producers to share more in the economic gains of the biofuel industry and to negotiate on more equal footing.

- **Purchasing from Small Producers.** Governments can require fuel purchasers and distributors to buy a minimum share from farmer or cooperatively owned facilities.

- **International Development Funding.** National and international development institutions can provide financial and technical support for small-scale biofuel initiatives for rural energy provision and poverty alleviation.

- **Technical and Materials Assistance.** Governments, civil society, and others can provide assistance to small landholders in obtaining materials (energy crops seeds and seedlings), know-how, and market access.

- **Appropriate Fiscal Policies.** Governments can implement policies that allow for local approaches to be developed.

Government action to assure markets for biofuels and for energy crops (e.g. mandates, preferential purchasing, etc.) helps give producers the confidence to adopt new crops and crop management systems. In addition to providing markets for their products, ensuring fair prices for farmers is also essential to improving rural livelihoods.

3.8 Encouraging Sustainable Trade in Biofuels

For the dozens of nations that are just beginning to develop biofuel industries, many decisions will have to be made, including the type, scale, and orientation (i.e. for domestic consumption, for export, or both) of production. Policies will need to be designed appropriately based on domestic economic and resource situations, and with the rapid pace of biofuels development, they will need to be put in place soon. Decision makers will also need to factor in the impacts that the policies of other nations (e.g. the EU biofuels initiative) and international trade policies (e.g. continuing trade liberalization negotiations) will have on their own biofuel and biofuel feedstock markets. In general biofuels trade restrictions should be removed over time, respecting the fact the countries with nascent industries will want to protect them.

Integrated planning is necessary at the national level so that short-term or sectoral interests do not take precedence over strategic national priorities. For instance, market incentives at the microeconomic level might encourage biofuel exports. But when other factors—such as national employment needs, domestic energy and security needs, trade balance, food security and land use concerns, the condition of domestic transport and export infrastructure, and GHG reduction obligations—are taken into consideration, exports might not make sense at that point in time. In many nations where displacing a modest amount of petroleum could make a significant difference, production for domestic use should take precedence over export. Alternatively the value of biofuels as an export commodity to earn foreign exchange may be preferable in other instances. National leaders will need to weigh these factors for their countries.

Well-established markets such as the United States and the EU have enormous fuel needs and growing energy security concerns. Due to policy initiatives actively promoting the use of biofuels, markets in these countries are large enough to accommodate both domestic production and imports (and the more rapidly biofuel-compatible transport infrastructure is phased in, the faster their biofuels markets will grow). International trade may help to ease fuel supply issues, linking a larger number of producers in order to minimize the risk of supply disruption. Also as renewable fuel use becomes more widespread, opportunities for countries with more developed biofuel industries to export their technologies will expand.

Some agriculture incentive programs in wealthy countries have been blamed for supporting food production in a way that harms competitors in developing countries. These could be transformed into programs that instead support biofuel production, a process that has begun in Europe and is being discussed in the United States. While this is a step in the right direction, replacing highly subsidized and protected commodity food production in rich countries with highly subsidized and protected biofuel production is not the aim. Biofuel support strategies must be planned with gradual phase-outs, or other means of moving beyond the subsidies once they are no longer necessary.

3.8.1 Trade and the Environment

Energy crops and biofuels may be categorized as agricultural goods under the WTO Agreement on Agriculture. Industry proponents may seek an exemption from the Agreement's restrictions on domestic price supports by including biofuels subsidies in the so-called "Green Box." To qualify for Green Box status the incentives must be "non-trade distorting," meaning they do not affect global market prices. This will be a difficult test to meet if financial incentives for biofuels are tied to production levels, especially if the trade grows to a significant size. The more that incentives are clearly tied to producing public goods, such as clean water and air, wildlife habitat preservation, carbon sequestration and soil erosion control, unconnected to crop yields and refinery production levels, the more likely they are to pass muster.

Alternatively, if biofuels are categorized as industrial goods, they may qualify for treatment as "environmental goods." To be included in such a category they should be required to meet strict environmental standards for their production.

Developing countries have traditionally fought attempts to differentiate among traded goods based on Process and Production Methods (PPMs). However, some biofuels producers in developing countries could rank quite well in a scheme based on production standards. For example, the ethanol industry in Brazil has generally achieved very low net GHG emissions.

3.8.2 Standards and Certification

There are increasing calls in Europe and elsewhere for traded biofuels to be certified based in social and environmental standards. This could provide a means of ensuring that the production of these fuels provides net positive impacts for the planet and for society. However, if not developed in a participatory, transparent way, such a certification scheme could be viewed as a means for industrialized countries to erect new trade barriers to protect their domestic biofuel producers.

A certification framework based on sound standards could become a critical driver to facilitating development of sustainable trade in biofuels. A compromise must be reached between developing complicated certification schemes to ensure long-term sustainable biomass trade on the one hand and putting safeguards in place quickly to direct the rapidly growing market on the other. The *incremental* development of such a certification scheme is probably the most feasible option, allowing for gradual learning and expansion over time. Existing certification schemes provide useful models. While not all biomass types may fulfil the entire set of sustainability criteria initially, the emphasis should be on the continuous improvement of sustainability benchmarks.

While a certification scheme should be thorough, comprehensive, transparent, and reliable, it should also not create a significant hurdle for nascent biofuel industries. Criteria and indicators should be adaptable to the requirements of different regions, and be mindful of the implementation costs. It will be important to pair any certification scheme with technical assistance, incentives, and financing, so that small- and medium-scale producers can qualify as readily as large-scale producers. Furthermore, it is important to ensure that any standards and certification schemes for biofuels address the issue of possible leakage effects, through which benefits gained in one location could "leak away" to another.

Moving forward, additional research will be needed to determine whether an independent international certification body for sustainable biomass is feasible. This should be done in collaboration with a consortium of all stakeholders in the biomass-for-energy production chain. At this stage, and at later steps in the development process, public information dissemination and support will be critical. It will be important to evaluate how likely broad participation by the petroleum industry, biofuel industry, importers, and consumers will be. Their participation is necessary in order for such a scheme to be accepted in the market. Costs and benefits for the various participants need to be analyzed.

3.9 Conclusion

To achieve a rapid scale-up in biofuels production that can be sustained over the long term, governments must enact a coordinated set of policies that are consistent, long-term, and informed by broad stakeholder participation. Governments should promote biofuels within the context of a broader transformation of the transportation sector. Biofuels alone will not solve all of the world's transportation-related energy problems. Development of these fuels must occur within the context of a transition to a more-efficient, less-polluting and more-diversified global transport sector. They must be part of a portfolio of options that includes dramatic improvements in vehicle fuel economy, investments in public transportation, better urban planning, and smarter and more creative means of moving around a village or across the globe.

To achieve their full potential to provide security, environmental, and social benefits, biofuels need to represent an increasing share of total transport fuel relative to oil. In combination with improved vehicle efficiency, smart growth, and other new fuel sources such as biogas—and eventually even renewable hydrogen or electricity—biofuels can drive the world towards a far less vulnerable and less polluting transport system.

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