

Rapid Assessment on Biofuels and the Environment: Overview and Key Findings

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The Scientific Committee on Problems of the Environment (SCOPE) of the International Council for Science (ICSU) established the International SCOPE Biofuels Project to provide a comprehensive and objective, science-based analysis of the effects of biofuels on the environment. The SCOPE Biofuels Project held a workshop in Gummersbach, Germany from September 22-24, 2008 to develop a “rapid assessment” of these environmental consequences. More than 75 scientists from 21 countries and representing a diversity of disciplines participated in this assessment, either in person at Gummersbach, as co-authors or reviewers of chapters in the report, or as advisors to the Project. Here we summarize the report and provide the key findings of the rapid assessment. The information provided in this overview is fully supported with references in the report’s chapters. For ease of reading, the only references used here are citations to the pertinent chapters. The full report is available at <http://cip.cornell.edu/biofuels/>

Many countries and companies are investing heavily in biofuels for transport, motivated by concerns and opportunities related to global climate change, energy security, and rural development. Production targets and mandates for biofuels vary by country, but many governments have adopted goals to substitute 10% or more of transportation demand for liquid fossil fuels with biofuels within 10 to 20 years (Chapters 2 and 11). Governmental energy policies have focused largely on liquid biofuels (ethanol and biodiesel) rather than solid biofuels (wood and charcoal) in part because the liquid fuels can readily replace conventional transportation fuels without major modifications in current transportation technologies. The convenience of liquid fuels for transportation has long resulted in a price differential between liquid and solid fuels, and as of 2007, crude oil was

worth some 12-times more than coal per unit energy (Chapter 1).

Global production of liquid biofuels has grown exponentially in recent years, and 2007 production was 3-fold greater than that in 2000 (Figure 1a). Despite this growth, liquid biofuels are still small contributors to the global energy supply. As of 2006, they supplied 1.8% of the global use of liquid transportation fuels. This is equivalent to 1% of the total liquid fuel use globally (including liquid fuels used other than for transportation), or 0.4% of the total global energy consumption from all sources. By comparison, solid biofuels supplied approximately 10% to 13% of total global energy consumption, or some 30-fold more energy than liquid biofuels (Chapter 1).

Although many countries anticipate large increases in production, the current global

production of liquid biofuels is dominated by just a handful of countries. Brazil and the United States combined have accounted for 75% or more of the global ethanol production for decades (Figure 1b). Ethanol is the major liquid biofuel globally, with a production of approximately 1.2 EJ (1.2×10^{18} joules, or 55 billion liters) in 2007. China and India are the next largest producers, together accounting for 12% of global ethanol production in 2006. The global production of biodiesel in 2007 was approximately 0.4 EJ (12 billion liters) per year, about one-third the rate of ethanol production (by energy content). Almost 80% of the world's production of biodiesel occurs in the European Union, with almost 50% of global production in Germany alone (Chapter 1).

The vast majority of current production of liquid biofuels is based on crops that can also be used for food: corn (i.e. maize) in the United States (the world's largest producer), sugarcane in Brazil (the world's second largest producer), and rapeseed (i.e. canola) in Germany (the world's third largest producer). In 2007, the United States used 24% of its national corn harvest to produce ethanol, which contributed 1.3% of national liquid fuel use (transportation fuels plus other uses of liquid fuels) (Chapter 1). This illustrates the difficulty of reaching current mandates for production of liquid biofuels. Meeting a goal of 10% substitution of liquid transportation fuels globally would require some combination of a large increase in the area devoted to biofuels crops and an unprecedented increase in the yield of biofuel crops per unit of land, water, and fertilizers (Chapter 4). Estimates of the range of new agricultural land required to meet a global target of 10% biofuel substitution range from 118 to 508 million hectares, depending on the crop type and assumed productivity level. This compares with the current area of arable land in the world of 1,400 million hectares (Chapter 6).

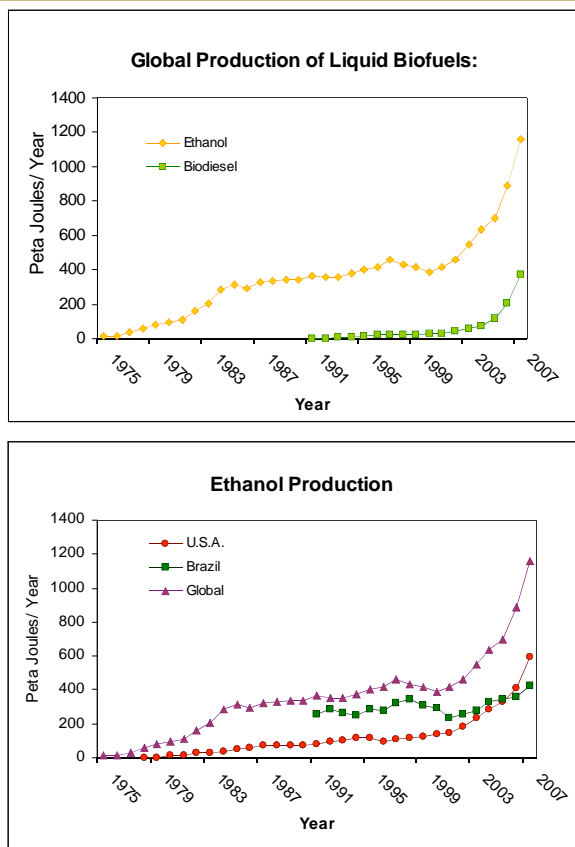


Figure 1. Global production of ethanol and biodiesel (1a, top) and comparison of production of ethanol in the the USA and Brazil with global production (1b, bottom) from 1975 to 2007. A petajoule is 10^{15} (one quadrillion) joules. One thousand petajoules equals an exajoule (EJ). Reprinted from Chapter 1

Because of constraints on the productivity of biofuel crops such as water availability, the higher end of estimates for land-use needs may be most reasonable (Chapters 4 and 16).

The challenge of meeting land needs for the expansion of biofuel production must be considered in the context of a growing demand for food. The global population has more than doubled since 1960, and world agricultural area per person decreased 2-fold. In the past, food production per person increased due to dramatic improvements in crop productivity per area. However, the ability to increase crop productivity is not infinite and

population growth and improved, higher protein diets are placing ever-greater demands on land for food production. Thus, competition and conflict with biofuel production using current methods will likely increase in a world where some one billion people are already underfed (Chapter 4).

Biofuel production and consumption have a variety of effects on the local and regional environment. Growing crops is essentially the same for biofuels as for other agricultural purposes. However, the environmental impacts of crop production often increase as more land is used, land is farmed more intensively, and so-called marginal lands are placed into agricultural production. The environmental consequences of biofuels depend on what crops or materials are used, where and how these feedstocks are grown, how the biofuel is produced and used, and how much is produced and consumed. Effects on the environment are both positive and negative.

Biofuels and the Emission of Greenhouse Gases

Biofuels are often promoted as a way to reduce global warming. However, some biofuel systems can increase the release of greenhouse gases relative to the fossil fuels they replace, thus aggravating global warming. Greenhouse gas emissions from biofuels occur from farming practices, refining operations, and the conversion of ecosystems to cropland for biofuel production. The details of how and where crops are grown, how crops are transported before being processed into fuels, and how fuels are made are all important in determining the net effect on greenhouse gas emissions. Most recent studies based on life-cycle analysis conclude that when ethanol from sugar cane is used to replace fossil fuels in transportation, a substantial reduction in net greenhouse gas emissions may result: 80%

to greater than 100% savings are recorded (when low emissions of nitrous oxide are assumed). On the other hand, using ethanol from corn is less favorable: 30% to a maximum of 50% savings or even an increase of greenhouse gas emissions relative to fossil fuels, depending on process-energy sources. Savings from rapeseed biodiesel fall between values reported for ethanol from sugar cane and ethanol from corn (20% to 85% relative to fossil fuels). The wide range of greenhouse-gas savings for all types of biofuels can be largely attributed to differences in co-product allocation methods (for example, whether or not waste products are used for animal feeds) and the type of energy inputs used to make biofuels and transport crops to processing sites. Greenhouse gas emissions are far higher when coal, rather than natural gas, is used as the energy source to distill ethanol, and the lowest values result when plant residues are used as an energy source (e.g. bagasse from sugarcane). In general, the agricultural and transformation phases account for the vast majority of total greenhouse gas emissions from biofuels (Chapter 5).

The studies summarized in the paragraph above may underestimate the release of one greenhouse gas – nitrous oxide (N₂O) – from biofuel production, and therefore are probably too optimistic. Nitrous oxide is not as abundant as carbon dioxide in the atmosphere, and is not as important as a driver of global warming. However, for an equivalent mass, it is almost 300-fold greater in its ability to warm the planet, and it is currently the third most important gas in causing global warming, after carbon dioxide and methane. Most studies on biofuels and greenhouse gas emissions have used the Intergovernmental Panel on Climate Change (IPCC) approach for estimating emissions of nitrous oxide. Recent evidence suggests that nitrous oxide emissions may well be 4-fold greater than this, with high

emissions both from agricultural fields and from downstream aquatic ecosystems resulting from the use of synthetic nitrogen fertilizer. If so, the increased N₂O flux associated with producing ethanol from corn is likely to more than offset any positive advantage from reduced carbon dioxide fluxes (compared to burning fossil fuels). Even for ethanol from sugar cane or biodiesel from rapeseed, emissions of nitrous oxide probably make these fuels less effective as an approach for reducing global warming than has been previously believed (Chapter 1).

A major criticism of the life-cycle analysis approaches described above is that they do not include indirect effects associated with the scaling up of production. There are multiple indirect effects of increased biofuels production, and researchers are only starting to unfold those effects and measure their environmental implications (Chapter 14). One of the greatest concerns is the effect of indirect land-use change on emission of greenhouse gases. The rapidly growing production of biofuels requires additional cropland. In some cases, this additional land comes from agricultural land previously used to grow food or feed crops. In a hungry world, these diverted crops must be made up elsewhere, thus driving land conversion—perhaps in different countries and on different continents – to compensate for the loss of food-crop production. Additional land for food and feed production usually comes from the conversion of native ecosystems such as grasslands, savannahs, and forests, or by returning permanent fallow or abandoned croplands to production. These land conversions can have a substantial impact on the greenhouse-gas balances of biofuels. In general, when biofuel cropping is associated with the conversion of native ecosystems (particularly forests, and especially peat land), the net greenhouse-gas balance is negative,



Figure 2. Oil palms can be an excellent source of oil for biodiesel when grown on previously degraded land. On the other hand, palm plantations established on newly cleared tropical forests result in loss of biodiversity from one of the world's hot spots of diversity and huge emissions of greenhouse gases, especially when grown on peat soils as is practiced in much of Southeast Asia. (photo by Jeff McNeeley).

and more greenhouse gases are emitted to the atmosphere than if fossil fuels were used instead. The carbon debt of this conversion in theory can eventually be re-paid through the extended use of biofuels over time, but this requires many decades or even hundreds of years to balance out the initial carbon losses. In the meanwhile, the biofuel system has aggravated rather than helped to mitigate global warming, even for systems where the life-cycle analyses indicate a positive influence on net greenhouse gas emissions (Chapter 6).

As one example, LCA studies indicate a greenhouse gas savings for palm oil, without considering emissions from land-use change, of approximately 80%. However, conversion of rainforests with peat soils to palm plantations can increase the net emissions of greenhouse gas emissions by 20-fold relative to simply using fossil fuels instead (Figure 2), reducing the greenhouse gas savings to a range of -800% to -2000% (Chapter 5). Plans for such development in Indonesia could cause a globally significant increase in emissions of carbon dioxide to the atmosphere (Chapter 1). If global warming is the primary concern, leaving natural ecosystems (particularly forests) alone is often a better strategy than clearing them to grow crops. Currently, the global emissions of greenhouse gases from deforestation are roughly equal to those emitted while burning fuels for transportation (Chapter 14).

Biofuel crops offer their greatest promise for greenhouse gas benefits if grown on abandoned, degraded, or marginal lands. On these lands, carbon losses from conversion to biofuels are often small. Of course, if the lands have the potential to revert to forests, conversion to biofuels represents a lost opportunity for carbon storage. The environmental consequences of inputs (irrigation water, fertilizer) required to make degraded and marginal lands productive must also be considered. Using wastes and agricultural and forest residues for biofuels is also likely to produce greenhouse gas benefits, but care must be taken to assure that enough residuals are left behind to protect soil health and productivity which depend on carbon levels.

Other Environmental Effects

Biodiversity: Increased biofuel production will have negative impacts on biodiversity due to

habitat loss, enhanced dispersion of invasive species, and agrochemical pollution. The consequences are likely to be very heterogeneous depending on the biodiversity characteristics and impact history of the region and the type of biofuel production. In already heavily impacted areas, a modest expansion of biofuel production could have large, negative effects on biodiversity. Communities with high species densities may lose more species than species-poor communities as a result of a similar disturbance. The degree of intensification of biofuel production has a direct impact on biodiversity, with larger losses scaling positively with increasing intensification (Chapter 7).

Land conversions are perhaps the greatest threat to biodiversity, particularly deforestation and conversion of grasslands and savannas to biofuel crops. Agro-ecological modeling indicates the expansion of sugarcane and crops for biofuels in Brazil will likely be focused on the Cerrado region of Central Brazil. This area represents about 9 % of the total area of tropical savannas in the world and is one of the world's biodiversity hotspots (Chapter 16). Biodiversity losses also occur from the conversion of rain forest to palm oil plantations in Southeast Asia, another globally important hotspot of biodiversity (Chapter 1). In the United States and European Union, some lands currently set aside for conservation reasons, including protection of biodiversity, are expected to be converted and used to grow crops for increased biofuel production (Chapter 16).

Small-scale biofuel production systems in which biodiversity is maintained are possible. Particularly promising is the management of natural grasslands and forests for harvest of biofuel material at moderate levels, providing

reasonable protection for biodiversity (Chapter 7).

Competition for freshwater: Freshwater is increasingly in short supply and may not meet future demands for food production in many regions. Using irrigation to grow biofuel crops will aggravate these shortages, reducing water available for other uses and further impacting freshwater (and in some cases coastal marine) ecosystems. The water requirements of biofuel-derived energy are 70 to 400 times larger than other energy sources such as fossil fuels, wind or solar. Roughly 45 billion cubic meters of irrigation water were used for biofuel production in the 2007, or some 6 times more water than people drink globally. The greatest use is for the production of the feedstock crops. Several approaches exist which could improve water productivity of agriculture for both biofuel and food crops. Also, alternative feedstock crops can be used to reduce the demand for water in biofuel production. However, the water implications of future

large-scale biofuel production remain uncertain (Chapter 8).

Local and regional air pollution: The use of ethanol and biodiesel as fuels or as fuel additives to fossil fuels can reduce the emissions of some pollutants from vehicle exhaust such as fine particles and carbon monoxide, but tends to increase other pollutant emissions such as nitrogen gases (Chapters 1 and 10). One of the largest sources of air pollution from biofuel production comes from the practice of burning sugarcane before harvest. The resulting smoke, fine particles, and nitrogen gases in the atmosphere cause acid rain and contribute to a variety of human health impacts (Figure 3). Burning as a practice is used to facilitate the cut of sugarcane stalks by manual harvesting and to reduce the risk to harvesters of being bitten by snakes, and can be avoided if mechanical harvesting equipment is used. However, manual harvesting remains dominant, and most sugarcane fields are burned before



Figure 3. In Brazil, air pollution is severely affected from ethanol production, particularly from the burning of sugar cane before manual harvest. Acid rain is occurring as a result. (photo by Edmar Mazzi).



Figure 4. Because of a shallow rooting system and short time period of active nutrient uptake, corn is a crop that is particularly leaky of nutrients. In regions where soils have artificial drainage, the nitrogen loss associated with growing corn can be quite high. This is the single largest source of nutrient pollution leading to the “dead zone,” or area of low-oxygen water in the plume of the Mississippi River in the Gulf of Mexico (Photo by Robert Howarth).

harvest. Also during the cultivation phase, large amounts of polluting nitrogen gases are emitted to the atmosphere from volatilization of fertilizers and nitrogen-containing wastes (Chapters 10 and 16).

Local and regional water pollution: Severe water pollution can result from runoff from agricultural fields and from waste produced during the production of biofuels. Nitrogen losses from cornfields are a particular problem (Figure 4). Compared to most crops, corn is especially leaky of nitrogen because of a shallow rooting system and a very short time period of active nutrient uptake. In regions where soils have artificial drainage such as much of the “corn belt” of the upper Mississippi River basin in the United States, the nitrogen loss associated with growing corn can be quite high. This is the single largest source of nutrient pollution leading to the “dead zone,” or area of low-oxygen water in the plume of the Mississippi River in the Gulf of Mexico. The increase in corn to support

ethanol goals in the United States is predicted to increase nitrogen inputs to the Mississippi River by 37%. This works against the national goal of reducing nitrogen inputs by at least 40% to mitigate the “dead zone.” When perennial crops such as switchgrass are used instead of annual ones such as corn, water pollution is much less (chapter 9).

Organic waste from the sugar cane-ethanol system (“vinasse”) is another serious problem. This waste is nutrient rich, and can thus be recycled onto fields as an effective fertilizer. However, excessive fertilization with vinasse results in polluted runoff to surface water and contamination of groundwater. Sometimes vinasse is directly discharged into surface water bodies. The high organic content of the vinasse rapidly consumes oxygen, severely degrading water quality. In Brazil, the government has enacted environmental laws that if followed will greatly reduce the potential impacts of the ethanol industry on water quality (chapter 9).

Future Biofuel Crops and Expansion of Lands Used for Biofuel Production

A small number of food-crop species such as corn, sugarcane, oil palm and rapeseed are currently used globally to produce biofuels. Their continued use as biofuel feedstocks in light of increasing food demand, limited land resources, and stagnant agricultural yields is problematic. Dedicated energy crops such as switchgrass in temperate areas and jatropha in the tropics have been proposed as a way to produce energy without impacting food security or the environment. However, such special energy crops require land, water, nutrients, and other inputs, and therefore compete with food crop for these resources. This competition contributes to conversion of grasslands, to deforestation, to and other land-use changes, with the associated adverse environmental effects (Chapter 4).

Use of marginal and degraded land (often abandoned farmland) has been proposed as a way to decrease competition with food production, although there is no evidence that non-food crops can be grown efficiently for energy production on land that could not also grow crops for food (Chapter 4). Nonetheless, some of these lands, which became marginal through human influence, may provide an opportunity to produce crops for biofuels while also restoring the landscape (Chapters 6 and 15). To use degraded lands productively will often require substantial investment in irrigation and fertilizer. The availability of water for irrigation is a particular concern, as irrigation for agriculture is already the largest single use of water by societies globally, and water is increasingly in short supply for all human uses. The processing of biofuels can also consume substantial quantities of water (Chapter 8).

There is substantial uncertainty over the magnitude of lands that could be farmed in a

sustainable, environmentally beneficial way for biofuels. Because of the high demand for land for other valuable purposes (including food, carbon storage and biodiversity), the area left for environmentally benign use by biofuel production is necessarily restrictive (Chapter 16). Lands classified as “marginal” are often sites of high biodiversity (Chapter 7) or lands that serve other conservation purposes, such as protecting water quality (Chapter 9). Land limits have a very strong social-economic component, sometimes more important than biophysical constraints, and in this sense local and regional contexts are critical (Chapters 11, 12, and 16).

Many developing countries in the tropics have advantages for expansion of biofuel production in that biomass production potential is much higher and production costs lower than that of developed countries in the temperate zone. Further, the prospects of increased farm income and rural economic development in the less developed countries is used as an argument for government intervention to promote biofuels production (Chapter 11). Export or internal markets will influence the type of biofuels grown as well as the potential local economic benefits, and rural development. Biofuel production opportunities in developing countries are being fuelled by the apparent relative availability of land to grow the feedstock crops. However, a biofuel boom in these countries raises concerns about the impacts of potential increases in food prices and food security in these low-income societies, as well as other effects resulting from land-use and land-cover change including greenhouse gas emissions, water stress, and loss of biodiversity. These impacts are poorly understood, but seem to depend on the premise that biofuels production can be sustained at a reasonable level, and with transparent and fair market



Figure 5. Oil from jatropha grown on degraded lands in Mali powers generators for electricity for cell phone microwave towers and provides local jobs with low environmental impact. This and other expanded biofuels production can be an important engine of rural development. Policies should be crafted to ensure equity in income distribution along the production chain. (photo by Jeff McNeeley)

prices to allow appropriate investment (Chapter 15).

Biofuel programs can be small-, medium- and large-scale with production for local use, national use, or export. These different scales have varied impacts on rural populations and environments and require different types of institutions and planning to assure positive outcomes (Chapter 15). Large-scale production poses the greatest social risks. In the developing world, the most capitalized producers will be able to compete on the international market and make money selling biofuel feedstock or processed biofuels, but likely at the cost of displacing small farmers,

increasing prices for food, and decreasing food security. Alternatively, small amounts of biofuel feedstock on small (and perhaps currently marginal for agriculture) pieces of land can provide easily processed and adequate fuels for local consumption. The choice of feedstock can be based on complementary roles, for example using jatropha as a biofuel crop but also as stakes for the valuable vanilla crop or as boundary markers, thereby maximizing the utility of resource inputs to the system. Negative social impacts are largely absent in such a system as long as this production does not compete with food production for land (Chapter 12).

Successful development will require investment. In contrast to the global pattern, yields of food crops in Africa have been stagnant, largely as a consequence of limited infrastructure and nutrient inputs.

Investments in agriculture in Africa could, if managed properly, help increase production of biofuels as well as food (Chapter 13). For example, oil from jatropha grown on degraded lands in Mali powers generators for electricity for cell phone microwave towers and provides local jobs with low environmental impact (Figure 5). This and other expanded biofuel production can be an important engine of rural development. However, the distribution of wealth is very uneven in many developing countries, in Africa and elsewhere. Policies should be crafted to ensure equity in income distribution along the production chain, and key environmental goals will need to be carefully managed (Chapters 15 and 16).

Future Biofuel Technologies and Systems

The current methods for making biofuels, often called first-generation biofuels, rely either on fermentation of sugars to produce ethanol or transesterification of plant oils to

produce biodiesel. A variety of other fuels, including other liquid fuels as well as solid and gaseous fuels, are possible, and these can be produced through a variety of technologies based on both thermal and biological processes (Chapter 3). Limitations with first generation biofuels are widely acknowledged, particularly for producing ethanol from corn. Looking into the future, much of the interest is with second-generation fuels, often called advanced biofuels. As one example, the United States has set a national goal of producing 70 billion liters (1.5 EJ, assuming ethanol is the fuel) of advanced biofuels by 2020, an amount roughly equal to the global production of all biofuels in 2007 (Chapter 1). Examples of advanced biofuels include ethanol made from cellulose (cellulosic ethanol) and non-oxygenated, pure hydrocarbon fuels such as “biomass-to-liquid” (or BtL) fuel. Both cellulosic ethanol and BtL are made from cellulose-rich feedstock such as wood or grasses. Also, methane gas (or biogas) and hydrogen show great promise as biofuels, and can be produced from a variety of feedstocks, including cellulose but also animal and human wastes (Chapters 1 and 3).

As with the first generation biofuels, the environmental consequences of the next generation depend significantly on the type of feedstock and how and where the feedstock is produced. The net greenhouse gas emissions from using either cellulosic ethanol or BtL are substantially less than for ethanol produced from corn, particularly if the feedstock comes from wood or from perennial grasses grown on non-agricultural lands (Chapters 1 and 5). The use of indigenous woody and grass species is particularly promising, both because these are likely to be well suited to the local environment and because they are less likely to adversely affect biodiversity than are non-native species, which are frequently invasive (Chapters 7 and 13). Using methane gas

produced from animal wastes as a fuel is among the most favourable alternatives for biofuels in terms of greenhouse gas emissions, with net reductions of up to 170% compared to fossil fuels (Chapters 1 and 5).

Also as with the first generation of biofuels, indirect land-use changes associated with a rapid expansion in area used to produce feedstock for second-generation biofuels may be problematic. These indirect effects result in a less favourable consideration of net greenhouse gas emissions and can be detrimental for biodiversity and water quality (Chapters 6 and 13). Hydrocarbon liquid fuels (BtL) and gases such as methane and hydrogen emerge with better environmental profiles relative to cellulosic ethanol when indirect land-use change is considered. Since these fuels can be produced from biomass with much greater efficiencies than ethanol can, less land is needed to produce an equivalent amount of energy. Greenhouse gas emissions and other environmental consequences associated with land conversions and intensive agriculture are reduced accordingly, as is the potential competition with food production. One further inherent problem with ethanol is the large amount of energy needed to distil ethanol from water after fermentation, with the consequent release of greenhouse gases (Chapter 1).

Another approach for biofuels is to burn solid biofuels or gases in stationary facilities to produce heat or to co-generate heat and electricity, rather than producing liquid fuels such as ethanol. This may be the most effective strategy for biofuels if the goal is to reduce consumption of crude oil. Globally, only 60% of liquid fossil fuels are used in the transportation sector, and the remainder is burned in stationary uses. Substitution in either sector can reduce overall crude-oil consumption. However, due to differences in

conversion efficiencies, the reduction is far greater if biofuels are used in stationary facilities. The conversion of biomass to liquid biofuels is 2.3 to 3-fold less efficient than that for converting crude oil to liquid fuels, while crude oil and solid biofuels are converted to heat and electricity in stationary plants with almost equal efficiencies (Chapter 1). The amount of biofuel that can be produced globally in an environmentally responsible way is limited, and land needs provide one of the major constraints. Per area of land required to produce biofuels, using switchgrass for direct stationary combustion can provide 2.6-fold more energy than can producing ethanol from switchgrass and 9-fold more energy than can producing ethanol from corn (Chapter 1), thus reducing the area of land required to meet an equivalent target for energy production. If the goal of using biofuels is to reduce global warming, stationary use makes even more sense, as long as it can displace burning of coal. Coal releases more greenhouse gases per unit of useful energy than crude oil. The reduction in greenhouse gas emissions is more than 10-fold greater when using switchgrass for heating - replacing coal - than when producing ethanol from corn - replacing gasoline (Chapter 1).

The direct combustion of biomass can also be used to generate electricity for electric propulsion, substituting liquid fuels for transportation, though recent research indicates that the energy conversion efficiency and environmental impact of electric vehicles varies greatly with different energy sources and further technological developments are needed (Chapter 3).

Key Findings and Recommendations

- Many of the adverse effects of biofuels on the environment could be reduced by using best agricultural management practices, if production is kept below sustainable production limits, although choice of feedstocks and the overall demand for biofuel and level of production remain critical.
- In general, biofuels made from organic waste are environmentally more benign than those from energy crops. Using biomass primarily for material purposes, reusing and recycling it, and then recovering its energy content can gain multiple dividends.
- Low-input cultivation of perennial plants, e.g. from short-rotation forestry and grasslands, may be an effective source of cellulosic biomass and provide environmental benefits (reduced pollution and lower greenhouse gas emissions). Careful attention to maintaining the long-term productivity of these systems through nutrient additions (particularly potassium) is required.
- New liquid hydrocarbon fuels (BtL) produced from cellulosic biomass are under development, and seem likely to offer several advantages over producing ethanol from cellulose in terms of more efficient yields and less environmental impact. The economic viability of this technology still needs to be proven, and potential conflicts with traditional wood-based industries should be considered.
- Opportunities for biofuel production that maximize social benefits while minimizing environmental impacts exist, but the extent of these win-win situations is limited, and their contribution to society's energy budget will be very small. As total biofuel production grows, the environmental costs increasingly overshadow societal benefits.

- Increasing evidence suggests that biomass can be used much more efficiently (and therefore with less environmental impact) through direct combustion to generate electricity and heat, rather than being converted to liquid fuels such as ethanol.
- Current mandates and targets for liquid biofuels should be reconsidered in light of the potential adverse environmental consequences, potential displacement or competition with food crops, and difficulty of meeting these goals without large-scale land conversion.
- The first steps towards sustainable energy and resource management should aim for significant reductions on the demand side, with greater conservation and improved efficiency. Government mandates and economic incentives aimed at expanding biofuel production should be coupled with policies that manage the overall demand for energy.
- On the production side, options exist for improving technologies in terms of new feedstocks and conversion technologies as well as more efficient use of biomass. Policies to enhance performance of biofuel production comprise:
 - ▶ guidelines for sustainable biofuel production and tools to monitor their implementation;
 - ▶ product-oriented certification of biofuels.
- The utility of guidelines for sustainable biofuel production and certification programs may be reduced if they are based only on product life-cycle and farming standards, as these cannot address the difficult issue of indirect land use resulting from growing demand. The risk of land displacement and conversion far from the site of biofuel production increases with the overall consumption of biomass-based products. Criteria that account for the effects of land-use change, or that restrict the types of biofuel feedstocks, could have greater utility. The development of such criteria is a difficult challenge, but a necessary one if biofuels are to be environmentally sustainable.
- Policy instruments are needed to help adjust the overall demand for (non-food) biomass at levels which can be supplied by sustainable production such as:
 - ▶ effective incentives to significantly increase efficient use of biomass and mineral resources;
 - ▶ incentives to reduce fuel consumption for transportation.
- Comprehensive land-use guidelines are needed that target biofuel production on marginal and degraded lands and preserve areas for agriculture, forestry, settlements/ infrastructure, and nature conservation on the regional, national, and international levels to avoid unintended consequences. This requires a spatial inventory of land resources and their potential competing uses at scales appropriate to crop production and nature conservation.
- National programs for sustainable resource management will also have to consider the global land use associated with the domestic consumption of biomass products (agriculture, forestry) in order to limit the shift of environmental pressure to other regions.
- Biofuels based on low input cultivation of non-food crops offers promise in developing countries as a source of energy,

in part because energy use is often very low at present. Biofuel markets can serve as an opportunity to trigger additional investments that could lead to increased production of food as well as biofuel crops by small-scale farmers. Further research on the use of indigenous non-food crops should be encouraged.

- The distribution of wealth is very uneven in many countries, and a high potential exists for the benefits of biofuels to accrue largely to those with wealth. Policies should be established to assure that rural poor populations would benefit from biofuel developments.

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