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Biofuels and environmental impacts

Scientific analysis and
implications for sustainability



Many countries and companies are investing heavily in biofuel production, motivated by potential benefits in terms of improving energy security, reducing greenhouse gas emissions and contributing to rural development. Whether biofuels can deliver these benefits and at what environmental and social cost is increasingly debated.

The biofuels debate

While biofuels already provide some developing and developed countries with a local source of renewable energy and jobs for rural populations, both positive and negative environmental effects can occur as a result of biofuel production.

The environmental consequences of biofuel production 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.

SCOPE (the Scientific Committee on Problems of the Environment) established the International SCOPE Biofuels Project to provide a comprehensive, objective, science-based analysis of the environmental benefits and problems of commonly-used and potential future biofuels. This Policy Brief summarizes the main results of this project.

Biofuels are combustible materials

derived directly or indirectly from biomass (plants or organic waste). They include:

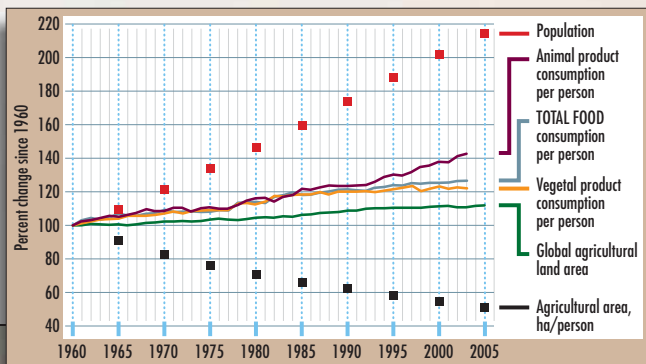
Solid fuels: directly burned for heating and cooking (wood, dried dung);

Liquid fuels: ethanol, other alcohols and several oils commonly referred to as biodiesel;

Methane gas made by fermentation.

Since 1960, the global population more than doubled, and world agricultural area per person decreased two-fold

Food consumption per person was able to increase due to a dramatic enhancement in crop productivity per area. Growing population and improved diets are placing ever greater demands on land for food production so that competition and conflict with biofuel production using current methods can only increase in a world where more than 900 million are already underfed.



Global trends

Governmental energy policies have focused largely on liquid biofuels (ethanol and biodiesel), in part because liquid fuels can readily replace conventional transportation fuels without major modifications in current transportation technologies.

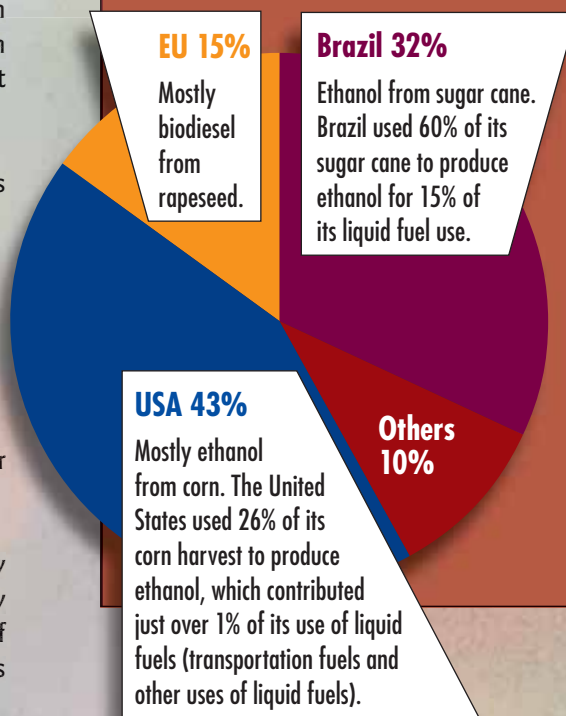
Global production of liquid biofuels has grown exponentially in recent years, and 2007 production was three-fold greater than that in 2000.

Global production of liquid biofuels in 2007 required 5-6% of the global harvest of all grains (corn, wheat, rice, and others), 8% of vegetable oil, and 28% of the sugar cane harvest.

Production targets for biofuels vary by country, but many governments have already adopted goals to substitute 10% or more of transportation demand for liquid fossil fuels with biofuels within 10 to 20 years.

Meeting these goals would require a combination of a large increase in the area devoted to biofuel crops and an unprecedented increase in the yield of biofuel crops per unit of land, water and fertilizers.

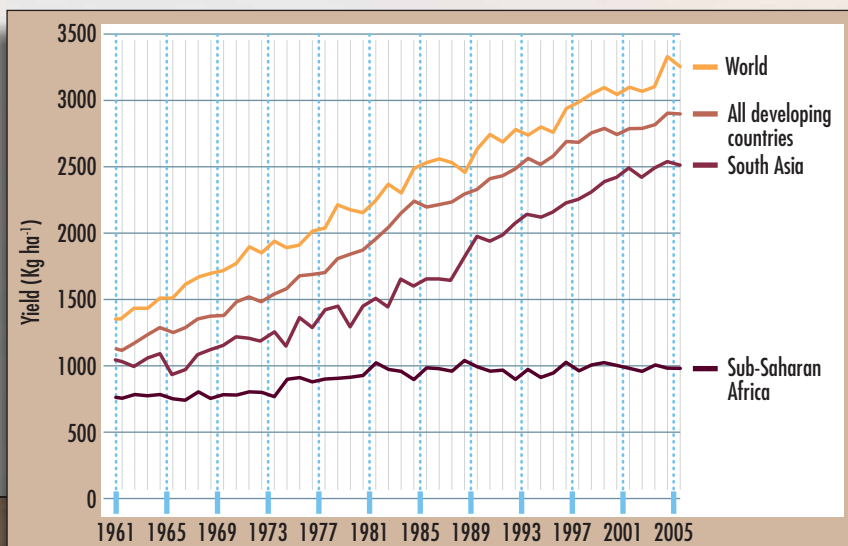
Proportion of global production of liquid biofuels in 2007



In light of increasing food demand and limited land resources, any unsustainable increase in biofuel production could lead to severe competition for food and exacerbate environmental degradation, including increase in net greenhouse gas emissions.

Global trends in cereal yield by region (1961-2005)

In contrast to the global pattern, yields of food crops in Africa have been stagnant, largely as a consequence of limited infrastructure and investment. Investments in agriculture in Africa could, if managed properly, help increase production of biofuels as well as food.



Biofuels and the environment

Greenhouse gas (GHG) emissions

from biofuels occur from farming practices, refining operations and the conversion of landscapes to biofuel agriculture.

If **biofuel crops** are grown on cleared forests or grasslands, the release of GHG from soils and vegetation almost systematically exceeds reduction of GHG emission that could result from the use of biofuels for some decades.

Diverting land previously used for food crops to biofuel production often leads farmers to clear other lands (forests or grasslands) to maintain food production. GHG emissions from such clearing can be quite large, making the overall biofuel production systems net releasers of GHG.

Releases of nitrous oxide, a much more powerful GHG than carbon dioxide, often increase with enhanced use of nitrogen fertilizer and crop burning, both of which are common in biofuel production. Poor management of nitrous oxide emissions can reduce or even eliminate the greenhouse gas benefits of a biofuel operation.

Biofuel crops offer their greatest promise for GHG benefits if grown on abandoned, degraded or marginal lands. On these lands, carbon losses from conversion to biofuels are often small. If the lands have the potential to revert to forests, conversion to biofuels represents a lost opportunity for carbon storage. The environmental and social consequences of inputs 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 GHG benefits. However, enough residuals have to be left behind to protect soil health and carbon levels.

Freshwater

is increasingly in short supply in many regions. Irrigation for agriculture is already the largest single use of water by societies globally. 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 processing of biofuels can also consume substantial quantities of water, thus the ability to provide more for biofuel crop production and processing of biofuels requires careful analysis at local and regional scales.

Water pollution

can result from runoff from agricultural fields and from wastes created during the production of biofuels. Nutrient losses from corn fields and organic wastes from sugar cane processing pose particular problems in terms of eutrophication, oxygen depletion, and disruption of ecological functioning in surface waters. Water pollution is significantly reduced when perennial crops such as switchgrass are used instead of annual ones such as corn.

Biodiversity

is greatly threatened by the expansion of biofuel production because land suitable for food, biofuel production and conservation is a finite resource. Therefore, expansion of biofuels in a world with a growing demand for food necessarily leads to increased deforestation and conversion of grasslands and savannas to biofuel crops.

There are opportunities at small scale and moderate levels of production for natural grasslands and forests to be managed for harvest of biofuel material, providing reasonable protection for biodiversity.

Large areas of marginal and degraded lands exist in many areas, often on abandoned farmland. They provide an opportunity to produce crops for biofuels while also restoring the landscape. However, often this land needs substantial investment in irrigation and fertilizer. Some of these regions include areas of high biodiversity.

There is substantial uncertainty over the magnitude of lands that could be farmed in a sustainable, environmentally beneficial way for biofuels.

Air pollution

from the burning of sugar cane before manual harvest contributes smoke, fine particles, and nitrogen gases to the atmosphere, causing acid rain and a variety of human health impacts. Ethanol and biodiesel can reduce the emissions of some pollutants from vehicle exhaust (e.g. fine particles and carbon monoxide), but tend to increase other pollutant emissions such as nitrogen gases.

Oil palms

are 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.

Corn

is a crop that is particularly leaky of nutrients, because of a shallow rooting system and short time period of active nutrient uptake.

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.

The increase in corn production 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'.

Mixed with the tan sediment are blue and green swirls that indicate a bloom of phytoplankton. Such blooms can deplete life-giving oxygen from the waters, creating massive dead zones.



Photo: R.W. Howarth

Photo: USDA Natural Resources Conservation Service

Photo: Luiz Martinelli

Photo: NASA

In Brazil, ethanol production has important impacts on air pollution, particularly from the burning of sugar cane before manual harvest. Acid rain is occurring as a result.

Improving biofuels systems

Many of the adverse effects of biofuels on the environment could be reduced by using best agricultural management practices, although choice of feed-stocks and systems, and the overall demand remain critical.

In general, biofuels made from organic waste are environmentally more benign than biofuels from energy crops. Multiple dividends can be gained by using biomass primarily for material purposes, reusing and recycling it, and then recovering its energy content.

Different types of feed-stocks and conversion technologies may provide advantages:

- Low input cultivation of perennial plants, e.g. from short-rotation forestry

and grasslands, may be an effective source of cellulosic biomass, which offers potential to reduce pollution and contributes to lower greenhouse gas emissions.

- New liquid hydrocarbon fuels that can be 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.

- 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.

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 biofuel production can be an important driver of rural development. Policies should be crafted to ensure equity in income distribution along the production chain.



Goals of increased production of liquid biofuels	Concerns, issues and qualifiers
Increased energy independence and security, with biofuels serving as an alternative to oil and a local renewable energy resource.	The capacity to produce biofuels in an environmentally sustainable manner is limited. Solid biofuels have a greater potential than liquid biofuels as a significant energy source and currently contribute over 10% of global energy. Global production of liquid biofuels tripled between 2000 and 2007, yet in 2007: <ul style="list-style-type: none"> ■ Liquid biofuels supplied only 0.4% of total energy consumption. ■ Biofuels contributed to 1.8% of liquid fuels used for transportation.
Reduced emissions of carbon dioxide and other greenhouse gases and mitigation of global warming. When production is steady over time, the use of liquid biofuels reduces net carbon dioxide emissions compared to burning fossil fuels, particularly for ethanol made from sugar cane.	Two issues make the overall reduction of greenhouse gas emissions far less favorable: <ul style="list-style-type: none"> ■ Rapid increases in the rate of production create pressures for creation of more cropland, in a world where cropland is limited and many people are already underfed. Deforestation and other land conversions can result, causing large increases in carbon dioxide emissions. ■ Biofuel production can release large amounts of another greenhouse gas, nitrous oxide. This can offset the positive advantages from reduced carbon dioxide fluxes from biofuels.
Enhanced rural development, particularly in developing countries in the tropics, and especially where biofuels can help accelerate agricultural development for food or where biofuels can be grown on marginal or degraded lands.	While marginal and degraded lands provide an opportunity for biofuel development, and biofuel production can serve as an engine of rural growth, some major concerns exist: <ul style="list-style-type: none"> ■ The total area of suitable land remains highly uncertain, especially given constrained supplies of irrigation water. ■ Competition between food and fuel can occur. ■ A potential exists for domination by large, heavily-capitalized players, to the detriment of rural populations.

Fuel use in production and consumption needs to become drastically more efficient

Reducing the fuel consumption of car fleets may be much more sustainable than increasing the supply with biofuels. Reducing the fuel consumption of the German car fleet in the medium term by 30% (130 g CO₂ equivalents per km) would result in about 30 Mt GHG savings, much more than the maximum effect of the envisaged ambitious biofuel blending targets.

Meeting these targets would require significant imports and induce land use changes in the tropics, particularly for biodiesel, which limit their climate change mitigation potential.

Way forward

■ **Targets for liquid biofuels production** should be reconsidered in light of the potential adverse environmental consequences, potential displacement or competition with food crops, and difficulty of meeting these targets without large-scale land conversion.

■ **Sustainable energy and resource management** should aim for significant reductions on the demand side, with greater conservation and improved efficiency. Biofuels development should be embedded in larger Resource Efficiency and Renewable Energy Strategies and considered in the context of integrated spatial planning.

■ **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.

■ **Options exist for improving technologies** in terms of feed-stocks and conversion technologies as well as more efficient use of biomass. Policy tools to enhance performance of biofuel production comprise:

- guidelines for sustainable biofuel production and tools to monitor their implementation;
- product-oriented certification of biofuels.

■ **Direct use of biomass** for electric power and heat generation can be more efficient than conversion to liquid biofuels for transport. These alternatives may be the best use of biomass for energy, particularly as electric vehicles and vehicles powered by hydrogen fuel cells become commercially viable in future decades.

■ **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.

■ **Biofuels based on low input cultivation** of non-food crops offer 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. In parallel, policies need to be crafted to ensure equity in income distribution along the production chain.

■ **Further research** on the use of indigenous crops, including non-food crops, should be encouraged in the context of biofuel production.

Biofuel policies will be most successful if integrated in comprehensive plans for climate, biodiversity protection, food and energy security.

Plans should address conservation and efficiency as well as new sources of energy.

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More information

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The full report is available at: <http://cip.cornell.edu/biofuels>

Useful links

International Panel for Sustainable Resource Management:
<http://www.unep.fr/scp/rpanel>

United Nations Educational, Scientific and Cultural Organization (UNESCO):
<http://www.unesco.org>

Scientific Committee on Problems of the Environment (SCOPE):
<http://www.icsu-scope.org>

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