

Biofuels and Their Environmental Implications



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Introduction

Biofuels are derived from plant and animal materials. These materials can be converted into liquid fuels (ethanol or biodiesel) or solid fuels (wood chips or other organic waste burned for heat and electricity). Biomass can also be gasified with oxygen to produce synthesis gas, which can be used directly as a fuel, or made into methanol, ammonia and diesel fuel. This ENE Issues Summary focuses on liquid biofuels and their potential to substitute for traditional transportation fuels. It also outlines recent research on the environmental implications of biofuels.

Using biofuels in the place of fossil fuels has the potential to reduce pollution and greenhouse gas emissions because the plant materials they are derived from (feedstocks) sequester carbon from the atmosphere as they grow. Biofuels can also reduce our dependence on foreign oil because feedstocks can be grown and refined in the United States. Though they have multiple potential benefits, biofuels can also have disadvantages, and their net environmental benefit depends greatly on how they are produced.

Liquid Biofuels: Ethanol and Biodiesel

Organic ethanol is produced by fermenting sugars derived from plant materials with yeast. The most common source of ethanol in the United States is corn grown in the Midwest. Brazilian sugarcane is another important source of ethanol. Sugars for ethanol can also be derived from the cellulose in plant materials to produce cellulosic ethanol.

Biodiesel can be produced from vegetable oils or animal fats using the process of transesterification, which removes the glycerin from the oil. In the United States, soybean oil is the most common source of biodiesel. In Europe, rapeseed oil is more commonly used, and palm oil is another important source internationally. Waste oils from restaurants have been converted to biodiesel on a small scale, but the overall availability for waste oil, no more than 100 million gallons annually, is low compared to other sources.¹

Advanced Biofuels. Concern about the potential impact of increased biofuel production on food prices and land use is driving research into advanced biofuels. Advanced biofuels typically refer to ethanol and biodiesel derived from non-food crops, or waste streams such as waste oil, agricultural and forestry residues, and the organic portion of municipal solid waste. These biofuels may be more efficient and sustainable because they require fewer inputs to grow, such as fertilizer, energy, irrigation and herbicides. Fuels derived from waste or grasses grown on marginal land also will not compete directly with productive agricultural land. However, the technologies to convert these feedstocks into fuel are still in the development stage, and it is unclear how much energy will be required to convert these crops into ethanol and biodiesel.

Cellulosic ethanol is commonly referred to as an advanced biofuel; its potential sources include wood, switchgrass and corn stalks. Non-food sources of biodiesel include jatropha, castor oil and algae.

¹ Radich, A. Biodiesel performance, costs and use. EIA. <http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/>

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Jatropha is a tropical plant that is very resistant to drought, with seeds that are 37% oil, making it very efficient in terms of energy output per acre. Some algae species also have very high oil content (over 50%) and very high growth rates.

Market Applications

Biofuels can be used in a variety of applications, including motor fuels, fuel additives and home heating fuel. In the U.S., ethanol is typically mixed with gasoline in a 10/90% mixture. Most traditional engines can use up to a 15% ethanol blend. Ethanol gives fuel a higher octane, resulting in more efficient burning of the gasoline. Biodiesel can be used in any concentration with petroleum based diesel fuel in existing diesel engines with little or no modification; however, higher concentrations of biodiesel can cause engine problems in cold weather. B20 (20% biodiesel) is the most common blend. Biodiesel has better lubricity than current low-sulfur petroleum diesel. However, the performance of biodiesel, particularly biodiesel derived from waste oil, is worse than petroleum diesel in cold weather conditions.

U.S. ethanol production grew from 175 million gallons (mg) in 1980 to 4,855 million gallons in 2006.² In addition, the U.S. imported 653.3 mg of ethanol in 2006, primarily from Brazil. Domestic production capacity is currently 7,229.4 mg per year (mgy) and an additional 6,216.9 mgy under construction. Global production of ethanol was 13,489 mg in 2006, with 69% of the world supply coming from Brazil and the United States.

U.S. biodiesel production was 450 mg in 2007, with production capacity of 1850 million gallons. This is projected to be 650 mg in 2008, with a production capacity of 3300 mgy.³ Global production of biodiesel was 9 million tons (approximately 2.4 billion gallons) in 2007, projected to grow to 11.1 million tons in 2008.

Environmental impacts

Burning biofuels has a mixed, though generally positive, impact on air pollution. Compared to gasoline, ethanol emits less carbon monoxide, nitrous oxides and sulfur dioxide. Added to gasoline, ethanol also decreases particulate matter emissions and reduces ground-level ozone by lowering volatile organic compound and hydrocarbon emissions. Biodiesel yields higher nitrous oxide emissions than petroleum diesel (2% higher for B20 blend, and 10% higher for B100), but particulate matter emissions are much lower (12% less for B20, and 48% less for B100).⁴

Biofuels require a higher amount of energy input per BTU than fossil fuels. Corn in particular requires large amounts of energy to grow, transport and to convert into ethanol. Furthermore, the energy content of biofuels tends to be lower than that of petroleum fuels. The energy content per gallon of

² Renewable Fuels Association statistics: <http://www.ethanolrfa.org/industry/statistics/#E>

³ Biodiesel 2020: A Global Market Survey: <http://www.emerging-markets.com/biodiesel/default.asp>

⁴ EPA420-P-02-001, October 2002.

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biodiesel is approximately 11% lower than that of petroleum diesel⁵ while the energy content of ethanol is about two-thirds that of gasoline, which means that biofuels get fewer miles-per-gallon.

Life-cycle Analysis of Emissions

If biofuels require large amounts of fossil fuel energy and nitrogen fertilizer to produce, they may not result in a large reduction in overall, life-cycle emissions of greenhouse gases. Calculating the greenhouse gas emissions associated with biofuels is complex. Because crops and other organic fuels sequester carbon dioxide from the atmosphere as they grow, sustainable cultivation of biofuels has been said to have relatively low life-cycle emissions. However, the net emissions are influenced by two factors: 1) the energy and fertilizer required to cultivate and process biofuels, which can be quite high; and 2) emissions caused by converting forestlands and grasslands to biofuel cultivation. Analyses that take into account only the first factor have found that using biofuel nets overall reductions in greenhouse gas emissions. For example, soybean biodiesel was found to produce 41% less greenhouse gas emissions than diesel fuel, while corn grain ethanol produced 12% less greenhouse gas emissions than gasoline.⁶

Studies that have attempted to incorporate indirect land use impacts, however, have cast further doubt on the ability of biofuels to reduce greenhouse gas emissions when compared to fossil fuels. This is particularly true as the scale of biofuels production increases and displaces large areas of land devoted to crop and meat production. Land displacement will either lead to new forest and grassland being cleared for crops, or increased cultivation of marginal agricultural lands that would otherwise have been allowed to revert back to forest. Globally, we may receive a much greater climate benefit by reforesting croplands and protecting forests than by cultivating biofuels.⁷

One recent study⁸ found that the increased greenhouse gas emissions from converting rainforests, peatlands, or grasslands to produce biofuels in the tropics and the United States was 17 to 420 times larger than the greenhouse gas reductions these biofuels could provide by displacing fossil fuel use. A second study⁹ found that using corn ethanol in place of fossil f

⁵ Radich, A. Biodiesel performance, costs and use. EIA. <http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/>

⁶ Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels.

Hill, J., Nelson, E., Tilman, D., Polasky, S. and D. Tiffany. Proceedings of the National Academy of Sciences.

www.pnas.org/cgi/doi/10.1073/pnas.0610061103

⁷ R. Righelato and D.V. Spracklen. 2007. Carbon mitigation by biofuels or by saving and restoring forests? *Science* 317: p. 902

⁸ J. Fargione, J. Hill, D. Tilman, S. Polasky, and P. Hawethorne. 7 February 2008. Land clearing and the biofuel carbon debt. *Science*. (10.1126/science.1152747).

⁹ T. Searchinger, R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hawes and T. Yu. 7 February 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land use change. *Science*. (10.1126/science.1151861).

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fuels doubles greenhouse gas emissions over 30 years. In contrast, biofuels made from waste biomass (municipal waste, crop waste and grass harvests) or from abandoned agricultural lands planted with perennial crops could offer sustained greenhouse gas benefits.

The projected impacts of land use conversion are not merely hypothetical. The European Union issued a directive in 2003 that established consumption targets for a minimum percentage of biofuels in EU transportation fuels (2% by 2005, 5.75% by 2010, and, 10% by 2020). While much of the biofuel was produced within Europe, the diversion of local vegetable oil to biofuels led to increased importation of vegetable oil for cooking uses. This increased demand for imported cooking oil and a perceived future demand for biofuels led to large scale draining of forested wetlands in Indonesia for palm plantations.¹⁰

Policy Considerations

Given the uncertainty over the benefits of using biofuels to replace transportation fuels, policies such as minimum blending requirements or a low carbon fuel standard should be tied to strict life-cycle analyses that include an assessment of indirect impacts on land use. While advanced biofuels may hold promise, experience has shown that a sober consideration of the impacts of bringing production up to a global scale must be done before mandatory policies are put into place.

¹⁰Clean Air Task Force. Leaping Before They Looked.
http://www.catf.us/publications/reports/Leaping_Before_They_Looked.pdf