Biodiesel

Quick Facts

- In 2008, approximately 700 ***million*** gallons of biodiesel were consumed in the United States,[1] compared to 64 ***billion*** gallons of petroleum-based diesel fuel.[2]
- As of 2007, a total of 176 biodiesel plants were operating in 42 states, with a total production capacity of 2.6 billion gallons.
- The Energy Independence and Security Act (EISA) of 2007 requires that at least 500 million gallons of biodiesel is used in 2009 and calls for annual increases in use up to one billion gallons in 2012. For biodiesel to comply with this requirement, it must demonstrate that greenhouse gas (GHG) emissions over the life-cycle of the fuel – from production of the feedstock to processing of the fuel to combustion – achieve a 50 percent reduction in emissions per gallon relative to petroleum-based diesel fuel.

Background

Biodiesel is a non-petroleum-based diesel fuel composed of fatty acid methyl ester molecules[3] derived from vegetable oils, animal fats, or recycled greases. It is similar to conventional petroleum-based diesel fuel and can be used in compression-ignition (diesel) engines with little to no modification. Biodiesel also benefits from favorable properties compared to conventional diesel (no sulfur content, lower particulate matter and greenhouse gas emissions, etc.).

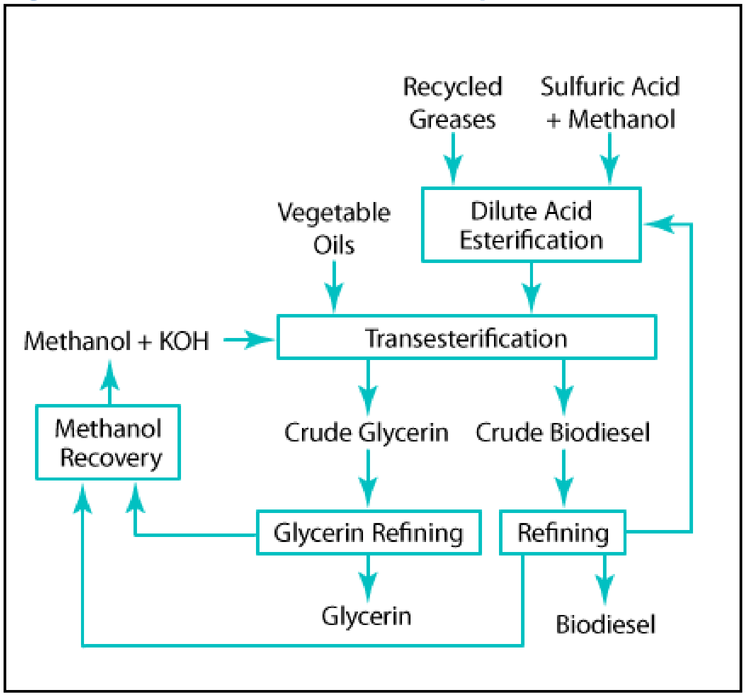
Description

Biodiesel production involves the extraction and esterification[4] of oils or fats using alcohols. Compared to the production of other biofuels, the technology used to produce biodiesel is relatively simple and well-developed.

- **Biodiesel feedstocks**
  The feedstocks used in biodiesel production vary by region. In the United States, soybean oil is most commonly used; in Europe, rapeseed (canola) and sunflower oil; and palm oil in Indonesia and Malaysia. Biodiesel can also be produced from numerous other feedstocks, including vegetable oils, tallow and animal fats, restaurant waste (also called yellow grease), and trap grease (also called brown grease, from restaurant grease traps). The relatively low price of soybean oil in the U.S. makes it the most common feedstock, accounting for approximately 60 percent of U.S. production.[5] The chemical properties of the biodiesel (cloud point, pour point, and cetane number[6]) depend on the type of feedstock used.

- **Production pathways**
  To produce biodiesel, the feedstock is chemically treated in a process called transesterification, in which the oils or fats are combined with an alcohol (usually methanol) and a catalyst to produce fatty acid methyl esters (the chemical name for biodiesel molecules). The major byproduct of the reaction, crude glycerin, is usually sold to the pharmaceutical, food, and cosmetics industries.

Figure 1: Biodiesel Production Pathways



Source: U.S. Department of Energy, Energy Efficiency and Renewable Energy. 2009. "Biodiesel Production." http://www.afdc.energy.gov/afdc/fuels/biodiesel_production.html.

Biodiesel has about 93 percent of the energy content of petroleum diesel, on a per gallon basis, and a cetane number between 50 and 60.[7] The chemical composition of biodiesel, especially its higher cetane number, translates to better engine performance and lubrication. However, its lower energy density results in a small decrease in fuel economy in terms of miles per gallon (2-8 percent).[8]

Since biodiesel's combustion properties are similar to that of petroleum-based diesel fuel, biodiesel can be legally blended with conventional diesel in any fraction. As opposed to ethanol, the use of biodiesel does not require many significant engine modifications. Individual engine manufacturers determine which blends can be used in their engines. The most common blend of biodiesel in the United States is 20 percent biodiesel, 80 percent petroleum diesel (B20). Many newer vehicles are also capable of using pure biodiesel, B100.[9]

Biodiesel is also commonly used as a fuel additive (in lower level blends of 2 and 5 percent) to reduce emissions of particulates, carbon monoxide, hydrocarbons, and other air pollutants from diesel-powered vehicles. For example, low-sulfur diesel fuel currently used in the United States is lower in lubricity—the characteristic of diesel fuel necessary to keep diesel fuel injection systems properly lubricated—than higher sulfur diesel fuels. Since biodiesel has no sulfur content and high lubricity, it can be blended with low-sulfur diesel to improve engine lubricity without increasing sulfur emissions.

One of the disadvantages of biodiesel is that it can freeze and cause engines to stall at colder temperatures. Proper blending with petroleum diesel and other fuel additives can counteract this problem.

Environmental Benefit / Emission Reduction Potential

By replacing conventional diesel fuel, the use of biodiesel can lower GHG emissions from the transportation sector. The potential GHG reductions from switching to biodiesel from petroleum-based diesel depend largely on the type of feedstock used to produce the fuel. Because the processing and production of biodiesel is simpler and less energy-intensive than that of corn ethanol, the life-cycle GHG reduction per gallon of biodiesel produced is potentially greater.

Depending on the feedstock used, one gallon of biodiesel can reduce GHG emissions by 30 to over 90 percent[10] when compared to a gallon of conventional diesel, on a life-cycle basis. The California Air Resources Board (CARB), as part of its analyses in support of California's proposed Low Carbon Fuel Standard, calculates that when soybean oil is used as a feedstock, the average reduction in life-cycle emissions per gallon is about 71 percent.[11] This reduction only considers the direct impacts of biodiesel production, processing, and combustion, and does not include any potential impacts of indirect land use change (see below). According to CARB, when the indirect land impacts are included, soybean-based biodiesel would reduce GHG emissions by only about 34 percent compared to petroleum-based diesel.[12]

Using animal fats and recycled greases instead of agricultural crops can result in greater GHG reductions since energy inputs (e.g., fertilizers and farming equipment) are not directly needed to grow the feedstocks. They also have the added benefit of recycling waste products, although the overall availability of these waste feedstocks is limited.

Cost

The cost of producing biodiesel depends on a number of factors, including the following:

- the feedstock used in the process;
- the capital and operating costs of the production plant;
- the current value and sale of byproducts, which can offset the per-gallon cost of production; and
- the yield and quality of the fuel and byproducts.

The overall cost of biodiesel production depends mainly on the feedstock used and its price;[13] the prices of most feedstocks are subject to market fluctuations, which can also make biodiesel production costs vary over time. Although the price of conventional diesel is not a direct component of production costs, it provides the baseline against which to compare the cost of biodiesel production and determines the economic viability of large-scale biodiesel production.

With soybean oil around $2 per gallon, the total cost of biodiesel production is $3 per gallon; this estimate includes feedstock costs and operating and capital costs for the conversion plant.[14]

The costs for biodiesel production from waste feedstocks (e.g., yellow or brown grease) depend on the source and procurement method. For example, in some areas, providers of these feedstocks pay biodiesel processors to collect waste materials; in other cases, biodiesel producers have to purchase them from these suppliers. In either case, biodiesel produced from waste feedstocks is cheaper, although the overall supply of these feedstocks is limited. The International Energy Agency estimates biodiesel from animal fat is currently the cheapest option for producing biodiesel, at about $1.80/gallon.[15]

Current Status of Biodiesel

The idea of using vegetable oil for fuel has been around since the invention of the diesel engine itself. The first diesel engine, invented by Rudolf Diesel in 1898, ran on a "biofuel"—peanut oil—although this was not the same as biodiesel used today since it was not transesterified. Although this engine type was later modified to run on petroleum-based fuels, the development of biodiesel continued over the 20th century. Unlike other biofuels, biodiesel can be produced using relatively little equipment; in fact, instructions and materials for "home brewing" biodiesel are readily available via the Internet.

Among biofuels, biodiesel production has grown the fastest, in recent years, on a percentage basis, although overall production is still significantly lower than ethanol. Globally, biodiesel production has increased from about 550 million gallons in 2004 to more than one billion gallons in 2005. Over this time period, production grew by more than 75 percent in Germany, France, Italy and Poland combined.[16] In the United States, production tripled from 2004 to 2005 and again from 2005 to 2006.[17] Currently, the European Union accounts for nearly 80 percent of the world's biodiesel production, with Germany producing about 50 percent of the world total. The United States produces about 15 percent of the world total.[18]

In the United States, reaching the EISA 2007-mandated one billion gallons of biodiesel use by 2012, if met through soybean-based biodiesel alone, would require about 690 million bushels of soybeans, about 22 percent of the U.S. annual soybean crop. Analysts believe that using more than 35 percent of the soybean crop for biodiesel would cause significant shocks in food and agricultural markets.[19] To increase consumption beyond 1.5 billion gallons of soy-based biodiesel, the United States would need to depend on imports, continue increasing soybean yields, or develop other feedstocks and/or conversion processes.[20]

In terms of waste feedstocks, approximately 390 million gallons of biodiesel could be made from waste feedstocks in the United States: 150 million gallons from yellow grease and 240 million gallons from animal fats.[21] Of the 700 million gallons of biodiesel produced in 2008 in the United States, about 60 percent was derived from soybean oil.

Significant research efforts are underway to develop new feedstocks, like jatropha, algae, and camelina, many of which could contribute to the biodiesel supply over the longer term. Researchers are also studying synthetic biofuel production that generates a diesel-type fuel through biomass gasification and catalytic conversion using the Fischer-Tropsch process (biomass-to-liquid, or BtL).[22] Fischer-Tropsch diesel has better cold weather performance compared to current biodiesel and could be substituted more easily and directly for petroleum-based diesel.

Obstacles to Further Development or Deployment of Biodiesel

- **Economic issues**
  The growth of the biodiesel industry has been significant in recent years, but it is not expected to continue growing at the same pace given challenging economic conditions and the leveling off of government requirements after 2012. As the price of petroleum-based diesel has dropped, the relative cost of biodiesel has increased, reducing the incentive to produce the fuel. In early 2009, several large biodiesel plants stopped producing fuel.[23] Some expect biodiesel production in 2009 to be lower than production levels for 2008.

- **Land use change**
  As with other biofuels produced from agricultural feedstocks, the production of biodiesel has direct and indirect impacts on land use. The clearing of grassland or forests to plant biofuel crops is a

direct land use change that can affect the GHG emissions due to the loss of a carbon sink. The practice of clearing peatland in Malaysia and Indonesia to produce palm oil for biodiesel has raised particular concerns about land and GHG impacts of biodiesel.[24]

Indirect land use change occurs when increased demand for a crop for fuel production leads to increased prices for the crop. This in turn results in more land diverted for biofuel production, since farmers can make more money by selling these crops, and in food and fuel crops being planted elsewhere. Although it is important to include emissions across the complete life-cycle of fuel production and use when examining potential GHG reductions from biodiesel use, accounting for land use changes is particularly challenging and uncertain, and it requires a number of estimates and assumptions.

- **Impact on agricultural commodities and environmental resources**
  Like corn ethanol, biodiesel produced from soy, palm, rapeseed, or sunflower oil competes with other agriculture uses for those products, including food, feed, and timber. In addition to impacts on land use and agricultural prices, biofuel production can also affect water supply, habitat and ecosystems, and soil, air, and water quality.

Policy Options to Help Promote Biodiesel

Federal, state, county, and local governments currently support biofuels in a variety of ways. Similar to policies to promote corn ethanol, government support includes: (1) mandates on the minimum levels of biodiesel consumption and (2) subsidies or tax credits for biodiesel production and/or use.

- **Mandates requiring biofuel use**
  The Energy Independence and Security Act of 2007 established a Renewable Fuel Standard that requires the use of 650 million gallons of biodiesel in 2009, with mandated use levels increasing annually until 2012 when the requirement reaches one billion gallons. After 2012, there is no biodiesel-specific mandate, although biodiesel can be used to comply with the “advanced biofuels” requirement in the Act, which starts at 600 million gallons in 2009 and increases to 21 billion gallons by 2022.

- **Subsidies and tax credits**
  Currently, blenders of biodiesel can claim a $1 per gallon tax credit. A biodiesel producer with a capacity less than 60 million gallons per year that uses virgin agricultural products, such as soybean oil or animal fats,[25] can also receive an additional tax credit of 10 cents per gallon on the first 15 million gallons produced in a given year. Both incentives are scheduled to terminate in 2009, unless renewed by new legislation.[26]

As with other biofuels, future policies should take life-cycle emissions into consideration to ensure that biodiesel production contributes effectively to greenhouse gas emission reductions. These policies can include a low carbon fuel standard, which is designed to lower the overall carbon intensity of the transportation fuel supply. For more information on biofuel policies, see *Climate TechBook: Biofuels Overview*.

Related Pew Center Resources

Agriculture's Role in Greenhouse Gas Mitigation, 2006. http://www.pewclimate.org/global-warming-in-depth/all_reports/agriculture_s_role_mitigation.

Climate TechBook: Biofuels Overview, 2009 http://www.pewclimate.org/technology/overview/biofuels

Climate TechBook: Ethanol, 2009 http://www.pewclimate.org/technology/factsheet/ethanol

Biofuels for Transportation: A Climate Perspective, 2008 http://www.pewclimate.org/biofuels-transportation

MAP: *State Mandates and Incentives Promoting Biofuels*
http://www.pewclimate.org/what_s_being_done/in_the_states/map_ethanol.cfm

Further Reading / Additional Resources

Ma, F. and M. A. Hanna. "Biodiesel Production: A Review." *Bioresource Technology* 70: 1-15. 1999. http://www.cti2000.it/Bionett/BioD-1999-101%20Biodiesel%20production%20review.pdf

National Biodiesel Board, http://www.biodiesel.org/

U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy

- *Biodiesel* http://www.afdc.energy.gov/afdc/fuels/biodiesel.html
- *Biomass Energy Data Book*, 2008 http://cta.ornl.gov/bedb/biofuels.shtml

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1 National Biodiesel Board, http://www.biodiesel.org/resources/faqs/.

2 Energy Information Administration (EIA), *Petroleum Navigator: Product Supplied*, 2008. http://tonto.eia.doe.gov/dnav/pet/pet_cons_psup_dc_nus_mbbl_a.htm.

3 Methyl ester is the chemical name for biodiesel molecules.

4 Esterification is the general name for a chemical reaction in which two reactants (typically an alcohol and an acid) form an ester, a type of organic compound, as the reaction product.

5 Schill, Susanne Retka. "Sizing Up the Soybean Market." *Biodiesel Magazine*, December 2008. http://www.biodieselmagazine.com/article.jsp?article_id=2973

6 Cloud point refers to the temperature below which the wax in diesel (or biowax in biodiesel) precipitates out and begins to "cloud." Pour point is temperature at which the diesel fuel thickens and will no longer pour, usually a temperature lower than the cloud point. Cetane number is a measure of the ignition quality of diesel-based fuels; a higher cetane number results in improved combustion.

7 This is compared to a cetane number between 38 and 42 for petroleum diesel sold in the United States.

8 U.S. Environmental Protection Agency (EPA), *Biodiesel*, updated 19 February 2008. http://www.epa.gov/smartway/growandgo/documents/factsheet-biodiesel.htm.

9 U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy, *B20 and B100: Alternative Fuels*, updated 3 February 2009. http://www.afdc.energy.gov/afdc/fuels/biodiesel_alternative.html

10 Greenhouse Gasses, Regulated Emissions, and Energy Use in Transportation Model GREET (version 1.8b), http://www.transportation.anl.gov/modeling_simulation/GREET/ (This calculates *direct* emissions only and does not include indirect imapcts, such as indirect land use change). See also Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, National Research Council. *Transitions to Alternative Transportation Technologies: A Focus on Hydrogen*. Washington, DC: National Academies Press, 2008.

11 California Air Resources Board (CARB), "Detailed California-Modified GREET Pathway for Biodiesel (Esterified Soyoil) from Midwest Soybeans," 2008. http://www.arb.ca.gov/fuels/lcfs/022709lcfs_biodiesel.pdf

12 Ibid.

13 EIA, *Biofuels in the U.S. Transportation Sector*, updated February 2007. http://www.eia.doe.gov/oiaf/analysispaper/biomass.html

[14] Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, National Research Council. 2008. *Transitions to Alternative Transportation Technologies: A Focus on Hydrogen*. Washington, DC: National Academies Press.

[15] International Energy Agency (IEA), *IEA Energy Technology Essentials: Biofuels Production.* Paris: IEA, 2007. http://www.iea.org/Textbase/techno/essentials2.pdf.

[16] Ibid.

[17] National Biodiesel Board, http://www.biodiesel.org/resources/faqs/.

[18] Howarth, R.W., et al. "Rapid assessment on biofuels and the environment: overview and key findings." *International SCOPE Biofuels Project*, 2009. http://cip.cornell.edu/biofuels/.

[19] Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, National Research Council, 2008.

[20] Ibid.

[21] Weber, J. Alan. *Feedstock Supplies for U.S. Biodiesel Production.* MARC-IV Consulting, Inc., 2008. http://www.biodieselsustainability.com/gao.pdf

[22] The Fischer-Tropsch process is a chemical reaction in which synthesis gas (often called syngas) – produced from a mixture of carbon monoxide and hydrogen from biomass or fossil fuels, such as natural gas and coal – is converted into liquid diesel

[23] Galbraith, Kate. "The Great Biodiesel Shutdown," *New York Times,* 3 April 2009. http://greeninc.blogs.nytimes.com/2009/04/03/the-great-biodiesel-shutdown/?scp=10&sq=biofuel%20land%20use&st=cse

[24] Rosenthal, Elisabeth. "Once a Dream Fuel, Palm Oil May Be an Eco-Nightmare," *New York Times*, 31 January 2007. http://www.nytimes.com/2007/01/31/business/worldbusiness/31biofuel.html?_r=1&scp=1&sq=palm%20oil&st=cse

[25] Virgin agricultural products are defined as a feedstock that is not a waste product.

[26] Yacobucci, Brent. *Biofuels Incentives: A Summary of Federal Programs.* Washington, DC: Congressional Research Service, 2009.