Biodiesel

Quick Facts

- In 2009, approximately 317 ***million*** gallons of biodiesel were consumed in the United States,[1] compared to roughly 49 ***billion*** gallons of petroleum-based diesel fuel.[2]
- As of 2011, a total of 158 biodiesel plants were operating in 42 states[3], with a total production capacity of 2.7 billion gallons.[4] Despite high production capacity, only 310 million gallons of biodiesel were produced in the U.S. in 2010.[5]
- In November 2010, the Environmental Protection Agency (EPA) finalized the annual renewable fuels standards for cellulosic, biodiesel, advanced biofuel, and total renewable fuels that apply to all gasoline and diesel produced or imported in 2011. The requirement for biodiesel is that 800 million gallons must be consumed in the U.S. in 2011 and one billion gallons in 2012. For biodiesel to comply with this requirement, it must demonstrate that greenhouse gas (GHG) emissions over the lifecycle 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.[6]

Background

Biodiesel is a non-petroleum-based diesel fuel composed of fatty acid methyl ester molecules[7] 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 has some favorable properties compared to conventional diesel (no sulfur content, lower particulate matter and greenhouse gas (GHG) emissions, etc.).

Description

Biodiesel production involves the extraction and esterification[8] 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.

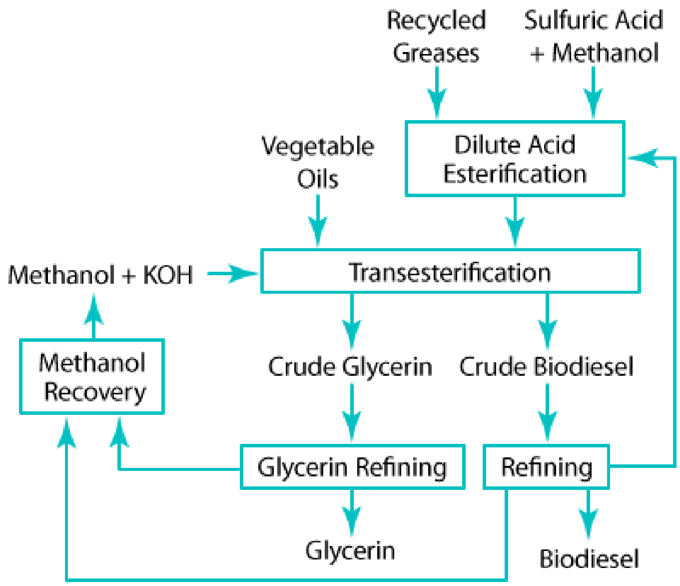
- **Biodiesel feedstocks**

  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.[9] The chemical properties of the biodiesel (cloud point, pour point, and cetane number[10]) 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.[11] 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).[12]

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). Some newer vehicles are also capable of using pure biodiesel, B100.[13]

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 lifecycle GHG reduction per gallon of biodiesel produced is potentially greater.

Depending on the feedstock used, one gallon of biodiesel can reduce GHG emissions by 12 to over 80 percent[14] when compared to a gallon of conventional diesel, on a lifecycle basis. The California Air Resources Board (CARB), as part of its analyses in support of California's Low Carbon Fuel Standard, calculated that when soybean oil is used as a feedstock, the average reduction in direct emissions per gallon is about 78 percent.[15] 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 *Obstacles to Further Development or Deployment of Biodiesel*). According to CARB, when the indirect land impacts are included, soybean-based biodiesel would reduce GHG emissions by only about 12 percent compared to petroleum-based diesel.[16]

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;[17] 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.[18]

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.[19]

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.[20]

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 almost 5 billion gallons in 2009.[21] Between 2005 and 2009, production more than doubled in Europe, with Germany, France, and Italy as top three producers.[22] In the United States, production has gone up more than 5-fold in the same time period, rising to its highest level ever in 2008 before declining in the next two years.[23] In 2009, the European Union still accounted for the majority of the world's biodiesel production, at roughly 55 percent. The United States produced about 10 percent of the world total in 2009.[24]

In the United States, reaching the Energy Independence and Security Act (EISA) of 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.[25] 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.[26]

In terms of potential for waste feedstocks, approximately 1.2billion gallons of biodiesel could be made from waste feedstocks in the United States per year: 380 million gallons from yellow grease, 525 million gallons from recycled trap grease (brown grease), and 300 million gallons from animal fats.[27] Of the 506 million gallons of biodiesel produced in 2009 in the United States, a little more than half was derived from soybean oil.[28]

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).[29] 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.[30] In the United States, biodiesel production actually dropped from 2008 to 2009, and again in 2010, and globally, the increase in production from 2008 to 2009 was the smallest since the data has been gathered.[31]

- 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.[32]

  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 lifecycle 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**

  Under authority given to it by the EISA of 2007, the EPA mandates annual renewable fuels volumes for sales of cellulosic, biodiesel, advanced biofuel, and total renewable fuels from 2008 to 2022. The EPA's policy is called the Renewable Fuels Standard (RFS2). In order to qualify under the RFS2, biomass-based diesel fuels must meet a 50 percent reduction (below traditional diesel fuels) in lifecycle GHG emissions. The RFS2 made important changes from the RFS1 (mandated under the Energy Policy Act of 2005), including the extension to 2022 of renewable fuel mandates and the inclusion of biodiesel in addition to gasoline replacements.

- **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,[33] 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 expire on December 31, 2011, unless renewed by new legislation.[34]

As with other biofuels, future policies should consider lifecycle emissions to ensure that biodiesel production contributes effectively to GHG 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

Hill, Jason, et al. "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels." *Proceedings of the National Academy of Sciences,* Vol 103, No 30: 11206-11210. 2006. http://www.pnas.org/content/103/30/11206.full.pdf+html

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*, 2010 http://cta.ornl.gov/bedb/biofuels.shtml

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[1] Energy Information Administration (EIA), *Petroleum and Other Liquids Navigator, Biodiesel Overview.* http://www.eia.gov/totalenergy/data/monthly/pdf/sec10_8.pdf.

[2] Energy Information Administration (EIA), *Annual Energy Outlook, 2011, Oil/Liquids Chapter* http://www.eia.doe.gov/forecasts/aeo/MT_liquidfuels.cfm.

[3] National Biodiesel Board, www.biodiesel.org

[4]U.S. Energy Information Administration, Annual Energy Outlook 2011, http://www.eia.doe.gov/forecasts/aeo/MT_liquidfuels.cfm.

[5] Energy Information Administration (EIA), *Petroleum and Other Liquids Navigator, Biodiesel Overview.* http://www.eia.gov/totalenergy/data/monthly/pdf/sec10_8.pdf.

[6] Under the Clean Air Act Section 211(o), as amended by the Energy Independence and Security Act of 2007 (EISA), the Environmental Protection Agency (EPA) is required to set renewable fuel standards each November for the following year based on gasoline and diesel projections from the Energy Information Administration (EIA).

[7] Methyl ester is the chemical name for biodiesel molecules.

[8] 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.

[9] Schill, Susanne Retka. “Sizing Up the Soybean Market.” *Biodiesel Magazine*, December 2008. http://www.biodieselmagazine.com/article.jsp?article_id=2973

[10] 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 the 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.

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

[12] U.S. Environmental Protection Agency (EPA), *Biodiesel: Technical Highlights*, updated February 2010. http://www.epa.gov/otaq/renewablefuels/420f10009.htm#3.

[13] 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

[14] CARB. (2011, July 1). Detailed California-Modified GREET Pathway for Transportation Fuels. Retrieved July 11, 2011, from California Air Resources Board: http://www.arb.ca.gov/fuels/lcfs/workgroups/workgroups.htm#pathways.

[15] Ibid.

[16] Ibid.

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

[18] 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.

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

[20] For example: http://www.make-biodiesel.org/

[21] Energy Information Administration (EIA), International Energy Statistics, Biodiesel Production tables, http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=79&pid=81&aid=1&cid=regions&syid=2005&eyid=2009&unit=TBPD.

[22] Ibid.

[23] Energy Information Administration (EIA), *Petroleum and Other Liquids Navigator, Biodiesel Overview.* http://www.eia.gov/totalenergy/data/monthly/pdf/sec10_8.pdf.

[24] Ibid.

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

[26] Ibid.

[27] National Biodiesel Board, *Biodiesel: Feedstock Supply*, http://www.biodiesel.org/resources/sustainability/pdfs/Achieving%201%20billion%20gallons%20of%20fuel%20While%20Protecting%20Valuable%20Feedstocks%20_June%209_.pdf.

[28] U.S. DOE, Energy Information Administration, Monthly Biodiesel Production Report, December 2009, http://www.eia.gov/cneaf/solar.renewables/page/biodiesel/biodiesel.pdf.

[29] 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

[30] 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

[31] Energy Information Administration (EIA), International Energy Statistics, Biodiesel Production tables, http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=79&pid=81&aid=1&cid=regions&syid=2005&eyid=2009&unit=TBPD.

[32] 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

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

[34] U.S. Department of Energy, *Federal & State Incentives and Laws: Federal Incentives and Laws for Biodiesel,* http://www.afdc.energy.gov/afdc/laws/laws/US/tech/3251