Biodiesel Performance, Costs, and Use

by
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Biodiesel fuel for diesel engines is produced from vegetable oil or animal fat by the chemical process of esterification. This paper presents a brief history of diesel engine technology and an overview of biodiesel, including performance characteristics, economics, and potential demand. The performance and economics of biodiesel are compared with those of petroleum diesel.

Introduction

The idea of using vegetable oil for fuel has been around as long as the diesel engine. Rudolph Diesel, the inventor of the engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil. In the early 20th century, however, diesel engines were adapted to burn petroleum distillate, which was cheap and plentiful. In the late 20th century, however, the cost of petroleum distillate rose, and by the late 1970s there was renewed interest in biodiesel. Commercial production of biodiesel in the United States began in the 1990s.

The most common sources of oil for biodiesel production in the United States are soybean oil and yellow grease (primarily, recycled cooking oil from restaurants). Blends of biodiesel and petroleum diesel are designated with the letter "B," followed by the volumetric percentage of biodiesel in the blend: B20, the blend most often evaluated, contains 20 percent biodiesel and 80 percent petroleum diesel; B100 is pure biodiesel. By several important measures biodiesel blends perform better than petroleum diesel, but its relatively high production costs and the limited availability of some of the raw materials used in its production continue to limit its commercial application.

History

Rudolph Diesel was educated at the predecessor school to the Technical University of Munich, Germany. In 1878, he was introduced to the work of Sadi Carnot, who theorized that an engine could achieve much higher efficiency than the steam engines of the day. Carnot envisioned a cycle in which a gas is compressed, heated, allowed to expand, and then cooled. After the gas is cooled, the cycle begins anew. Mechanical energy is used to compress the gas and thermal energy to heat it. In turn, expansion of the gas yields mechanical energy, and its cooling yields thermal energy. The net result is conversion of thermal energy to mechanical energy.[1]

Diesel sought to apply Carnot's theory to the internal combustion engine. The efficiency of the Carnot cycle increases with the compression ratio—the ratio of gas volume at full expansion to its volume at full compression. Nicklaus Otto invented an internal combustion engine in 1876 that was the predecessor to the modern gasoline engine. Otto's engine mixed fuel and air before their introduction to the cylinder, and a flame or spark was used to ignite the fuel-air mixture at the appropriate time.[2] However, air gets hotter as it is compressed, and if the compression ratio is too high, the heat of compression will ignite the fuel prematurely. The low compression ratios needed to prevent premature ignition of the fuel-air mixture limited the efficiency of the Otto engine.

Rudolph Diesel wanted to build an engine with the highest possible compression ratio. He introduced fuel only when combustion was desired and allowed the fuel to ignite on its own in the hot compressed air. Diesel's engine achieved an efficiency higher than that of the Otto engine and much higher than that of the steam engine. It also eliminated the trouble-prone electric-spark ignition system. Diesel received a patent in 1893 and demonstrated a workable engine in 1897.[3] Today, diesel engines are classified as "compression-ignition" engines, and Otto engines are classified as "spark-ignition" engines.

Diesel's motivation was not only to improve efficiency but also to bring the benefits of powered machinery to smaller companies. Steam engines were so large that

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[1] Deutsches Museum, web site www.deutsches-museum.de/ausstell/meister/e_diesel.htm.
[2] Optecon, web site www.sh015a7585.pwp.blueyonder.co.uk/diesel.htm.
[3] Deutsches Museum, web site www.deutsches-museum.de/ausstell/meister/e_diesel.htm.

only the biggest firms could afford them, and Diesel wanted to enable smaller firms to compete against larger, steam-powered firms. He used peanut oil as the fuel for his demonstration engines at the 1900 World's Fair[4] and thought that oils from locally grown crops would be used to power his engines.

The early 20th century saw the introduction of gasoline-powered automobiles. Oil companies were obliged to refine so much crude oil to supply gasoline that they were left with a surplus of distillate, which is an excellent fuel for diesel engines and much less expensive than vegetable oils. On the other hand, resource depletion has always been a concern with regard to petroleum, and farmers have always sought new markets for their products. Consequently, work has continued on the use of vegetable oils as fuel.

Early durability tests indicated that engines would fail prematurely when operating on fuel blends containing vegetable oil. Engines burning vegetable oil that had been transesterified with alcohols, however, exhibited no such problems and even performed better by some measures than engines using petroleum diesel. The formulation of what is now called biodiesel came out of those early experiments.

The energy supply concerns of the 1970s renewed interest in biodiesel, but commercial production did not begin until the late 1990s. The National Biodiesel Board reported production of 500,000 gallons (32.6 barrels per day) in 1999 and 6.7 million gallons (437 barrels per day) in 2000.[5] In 2003, the U.S. Congress proposed that, for tax purposes:

> *The term "biodiesel" means the monoalkyl esters of long chain fatty acids derived from plant or animal matter which meet (A) the registration requirements for fuels and fuel additives established by the Environmental Protection Agency under section 211 of the Clean Air Act (42 U.S.C. 7545), and (B) the requirements of the American Society of Testing and Materials D6751.*[6]

That definition of biodiesel is used here, although other processes also can be used to produce high-quality diesel fuel from vegetable oil or animal fat.

Performance and Emissions Characteristics

One of the most important characteristics of diesel fuel is its ability to autoignite, a characteristic that is quantified by a fuel's cetane number or cetane index, where a higher cetane number or index means that the fuel ignites more quickly.[7] U.S. petroleum diesel typically has a cetane index in the low 40s, and European diesel typically has a cetane index in the low 50s.

Graboski and McCormick[8] have summarized several experimental studies of biodiesel characteristics. They report that the cetane number for biodiesel ranges from 45.8 to 56.9 for soybean oil methyl esters, with an average of 50.9. In comparison the cetane index for petroleum diesel ranges from 40 to 52. They imply that careful production control could result in biodiesel products with cetane numbers in the high end of the range, whereas petroleum diesel tends toward the low end of the range. U.S. refiners use the catalytic cracking and coking processes to increase gasoline output from oil refineries, yielding high-octane gasoline material but low-cetane diesel material.

Lubricity, another important characteristic of diesel fuel, is a measure of lubricating properties. Fuel injectors and some types of fuel pumps rely on fuel for lubrication. One study, published in 1998 and cited by the National Biodiesel Board, found that one-half of samples of petroleum diesel sold in the United States did not meet the recommended minimum standard for lubricity.[9] Biodiesel has better lubricity than current low-sulfur petroleum diesel, which contains 500 parts per million (ppm) sulfur by weight. The petroleum diesel lubricity problem is expected to get worse when ultra-low-sulfur petroleum diesel (15 ppm sulfur by weight) is introduced in 2006. A 1- or 2-percent volumetric blend of biodiesel in low-sulfur petroleum diesel improves lubricity substantially.[10] It should be noted, however, that the use of other lubricity additives may achieve the same effect at lower cost.

Biodiesel also has some performance disadvantages. The performance of biodiesel in cold conditions is markedly worse than that of petroleum diesel, and biodiesel

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[4] Western Biofuels, web site www.westernbiofuels.com/history.html.

[5] National Biodiesel Board, cited in G.G. Pearl, "Biodiesel Production in the U.S.," *Render Magazine* (August 2001), web site www.rendermagazine.com/August2001/TechTopics.html.

[6] Energy Policy Act of 2003, Conference Version, Section 1314.

[7] A cetane number is determined by an engine test using two reference fuel blends with known cetane numbers. A cetane index is a calculated value, derived from fuel density and volatility, that gives a reasonable approximation of the cetane number.

[8] M.S. Graboski and R.L. McCormick, "Combustion of Fat and Vegetable Oil Derived Fuels in Diesel Engines," *Progress in Energy and Combustion Science*, Vol. 24, No. 2 (1998), pp. 131-132.

[9] National Biodiesel Board, "Lubricity Benefits," web site www.biodiesel.org/pdf_files/Lubricity.PDF.

[10] *Ibid.*

made from yellow grease is worse than soybean biodiesel in this regard. At low temperatures, diesel fuel forms wax crystals, which can clog fuel lines and filters in a vehicle's fuel system. The "cloud point" is the temperature at which a sample of the fuel starts to appear cloudy, indicating that wax crystals have begun to form. At even lower temperatures, diesel fuel becomes a gel that cannot be pumped. The "pour point" is the temperature below which the fuel will not flow. The cloud and pour points for biodiesel are higher than those for petroleum diesel.

Vehicles running on biodiesel blends may therefore exhibit more drivability problems at less severe winter temperatures than do vehicles running on petroleum diesel.[11] This is a potential concern during the winter in much of the United States. The solvent property of biodiesel can cause other fuel-system problems. Biodiesel may be incompatible with the seals used in the fuel systems of older vehicles and machinery, necessitating the replacement of those parts if biodiesel blends are used.[12] The initial use of B20 or B100 in any vehicle or machine requires care. Petroleum diesel forms deposits in vehicular fuel systems, and because biodiesel can loosen those deposits, they can migrate and clog fuel lines and filters.[13]

Another disadvantage of biodiesel is that it tends to reduce fuel economy. Energy efficiency is the percentage of the fuel's thermal energy that is delivered as engine output, and biodiesel has shown no significant effect on the energy efficiency of any test engine. Volumetric efficiency, a measure that is more familiar to most vehicle users, usually is expressed as miles traveled per gallon of fuel (or kilometers per liter of fuel). The energy content per gallon of biodiesel is approximately 11 percent lower than that of petroleum diesel.[14] Vehicles running on B20 are therefore expected to achieve 2.2 percent (20 percent x 11 percent) fewer miles per gallon of fuel.

About 11 percent of the weight of B100 is oxygen. The presence of oxygen in biodiesel improves combustion and therefore reduces hydrocarbon, carbon monoxide, and particulate emissions; but oxygenated fuels also tend to increase nitrogen oxide emissions. Engine tests have confirmed the expected increases and decreases of each exhaust component from engines without emissions controls. Biodiesel users also note that the exhaust smells better than the exhaust from engines burning conventional diesel.[15]

The increase in nitrogen oxide emissions from biodiesel is of enough concern that the National Renewable Energy Laboratory (NREL) has sponsored research to find biodiesel formulations that do not increase nitrogen oxide emissions. Adding cetane enhancers—di-tert-butyl peroxide at 1 percent or 2-ethylhexyl nitrate at 0.5 percent—can reduce nitrogen oxide emissions from biodiesel, and reducing the aromatic content of petroleum diesel from 31.9 percent to 25.8 percent is estimated to have the same effect. In the case of petroleum diesel, the reduction in aromatic content can be accomplished by blending fuel that meets U.S. Environmental Protection Agency (EPA) specifications with fuel that meets California Air Resource Board (CARB) specifications. EPA diesel contains about 30 percent aromatics, and CARB diesel is limited to 10 percent aromatics.

Nitrogen oxide emissions from biodiesel blends could possibly be reduced by blending with kerosene or Fischer-Tropsch diesel.[16] Kerosene blended with 40 percent biodiesel has estimated emissions of nitrogen oxide no higher than those of petroleum diesel, as does Fischer-Tropsch diesel blended with as much as 54 percent biodiesel.[17] These results imply that Fischer-Tropsch diesel or kerosene could be used to reduce nitrogen oxide emissions from blends containing 20 percent biodiesel, although the researchers did not investigate those possibilities. Blending di-tert-butyl peroxide into B20 at 1 percent is estimated to cost 17 cents per gallon (2002 cents), and blending 2-ethylhexyl nitrate at 0.5 percent is estimated to cost 5 cents per gallon.[18]

Oxides of nitrogen and hydrocarbons are ozone precursors. Carbon monoxide is also an ozone precursor, but to a lesser extent than unburned hydrocarbons or nitrogen oxides. Air quality modeling is needed to determine whether the use of biodiesel without additives to prevent increases in nitrogen oxide emissions will increase or decrease ground-level ozone on balance.

Most biodiesel emission studies have been carried out on existing heavy-duty highway engines. The effects of biodiesel on emissions from heavy diesel engines meeting EPA's stringent Tier II emissions standards (slated for introduction in model year 2007) have not been

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[11] Graboski and McCormick, pp. 135-137.

[12] National Renewable Energy Laboratory, *Biodiesel—Clean, Green Diesel Fuel*, DOE/GO-102001-1449 (Golden, CO, September 2001), web site www.afdc.doe.gov/pdfs/Bio_CleanGreen.pdf.

[13] National Biodiesel Board, "Biodiesel Usage Checklist," web site www.biodiesel.org/pdf_files/bdusage.PDF.

[14] National Renewable Energy Laboratory, *Biodiesel—Clean, Green Diesel Fuel*.

[15] Biodiesel exhaust is said to smell like french fries. Petroleum diesel exhaust has an unpleasant sour odor.

[16] The Fischer-Tropsch process uses natural gas as its raw material and yields diesel fuel with a very high cetane number, no aromatics, and no sulfur.

[17] R.L. McCormick, J.R. Alvarez, and M.S. Graboski, *NO_x Solutions for Biodiesel*, NREL/SR-510-31465 (Golden, CO: National Renewable Energy Laboratory, February 2003).

[18] *Ibid.*

determined, and the EPA has concluded that the results of biodiesel tests in heavy-duty vehicles cannot be generalized to light-duty diesel vehicles or off-highway diesel engines.[19]

Biodiesel from virgin vegetable oil reduces carbon dioxide emissions and petroleum consumption when used in place of petroleum diesel. This conclusion is based on a life cycle analysis of biodiesel and petroleum diesel, accounting for resource consumption and emissions for all steps in the production and use of the fuel. NREL estimates that the use of soybean B100 in urban transit buses reduces net carbon dioxide emissions by 78.45 percent.[20] The comparison of carbon dioxide emissions and energy use begins with soybean cultivation and petroleum extraction, proceeds with all applicable processing and transportation, and ends with combustion in the bus engine. The growth of the soybean plant is assumed to absorb as much carbon dioxide as is emitted by decomposition of crop residue after the harvest and by combustion of biodiesel in the engine.[21] Petroleum-based chemicals and fuels are used to produce the soybeans, but soybean oil biodiesel contains energy from other sources, including solar energy. NREL estimates that B100 reduces life cycle petroleum consumption by 95 percent relative to petroleum diesel,[22] assuming that the quantity of biodiesel is small enough not to affect production levels of soybeans or other crops. If crop production patterns changed significantly, then NREL's analysis might not be valid.

Biodiesel Production and Costs

Biodiesel can be produced by several processes. Vegetable oils or fats can be converted to fatty acids, which in turn are converted to esters. Oils or fats can also be converted to methyl or ethyl esters directly, using an acid or base to accelerate (catalyze) the transesterification reaction. Base catalyzation is preferred, because the reaction is quick and thorough. It also occurs at lower temperature and pressure than other processes, resulting in lower capital and operating costs for the biodiesel plant.

The most common method of producing biodiesel is to react animal fat or vegetable oil with methanol in the presence of sodium hydroxide (a base, known as lye or caustic soda). This reaction is a base-catalyzed transesterification that produces methyl esters and glycerine.[23] If ethanol is substituted for methanol, ethyl esters and glycerine are produced. Methanol is preferred, because it is less expensive than ethanol.[24]

The Energy Information Administration (EIA) uses a process-costing approach to model the impacts of net feedstock production costs plus capital and operating costs. The feedstock cost of the oil or grease is the largest single component of biodiesel production costs. Yellow grease is much less expensive than soybean oil, but its supply is limited, and it has uses other than fuel—for example, yellow grease is used as an animal feed additive and in the production of soaps and detergents. From 1993 to 1998, the average supply of yellow grease in the United States was 2.633 billion pounds, enough to make 344 million gallons (22,440 barrels per day) of biodiesel.[25] EIA, however, assumes that competing uses would limit biodiesel production from yellow grease to 100 million gallons per year (6,523 barrels per day).[26]

EIA's price projections for soybean oil are based on data from the U.S. Department of Agriculture (USDA), Office of Energy Policy and New Uses.[27] The USDA estimated the effect on agricultural markets of a renewable fuels requirement for gasoline and diesel fuel by constructing two agricultural market forecasts: a renewable fuels standard case with, and a reference case without, biodiesel production from soybean oil. The EIA forecasts of soybean oil prices are based on an assumed quantity of oil used for biodiesel production in each forecast year (Table 1).

In the renewable fuels standard case, the quotient of the increase in soybean oil prices and the quantity of soybean oil used for biodiesel production provides the rate of change in soybean oil prices with respect to the quantity of soybean oil input to biodiesel production. The most current baseline soybean oil prices, assuming no biodiesel production, are also obtained from the

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[19] U.S. Environmental Protection Agency, *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions: Draft Technical Report*, EPA420-P-02-001 (Washington, DC, October 2002), pp. 75-84, web site www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf.

[20] J. Sheehan, V. Camobreco, J. Duffield, M. Graboski, and H. Shapouri, *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus: Final Report*, NREL/SR-580-24089 (Golden, CO: National Renewable Energy Laboratory, May 1998), p. v, web site www.nrel.gov/docs/legosti/fy98/24089.pdf.

[21] Sheehan et al., p. 98.

[22] Sheehan et al., p. v.

[23] National Biodiesel Board, "Biodiesel Production and Quality," web site www.biodiesel.org/pdf_files/prod_quality.pdf.

[24] Graboski and McCormick, p. 127.

[25] G.G. Pearl, "Biodiesel Production in the U.S.," *Render Magazine* (August 2001), web site www.rendermagazine.com/August2001/TechTopics.html.

[26] *Ibid*.

[27] U.S. Department of Agriculture, "Effects on the Farm Economy of a Renewable Fuels Standard for Motor Vehicle Fuel" (report attached to a letter from Keith Collins, Chief Economist, to Senator Tom Harkin, dated August 1, 2002), web site http://harkin.senate.gov/specials/20020826-usda-letter.pdf.

USDA.[28] The baseline forecast and the estimated rate of change are used to construct a cost curve for soybean oil relative to biodiesel production.

The USDA does not forecast yellow grease prices, although in the past the prices of yellow grease and soybean oil have moved together. Monthly soybean oil price data are obtained from the USDA, and monthly yellow grease price data are obtained from the Jacobsen Publishing Company. Unweighted averages are used to construct annual prices. The results of a linear regression are:

$$\textit{Yellow grease price} = 0.49 \times \textit{Soybean oil price} \quad .$$

Yellow grease price projections (Table 2) are estimated by using soybean oil price projections in the above equation.

NREL provided estimates of other components of biodiesel production costs, based on transesterification of oil with methyl alcohol catalyzed by sodium hydroxide, yielding methyl esters (biodiesel) and glycerol. Operating expenses were estimated at 31 cents per gallon (2002 cents), excluding the cost of the oil or grease and energy, and the sale of the glycerol was estimated to reduce the cost by 15 cents per gallon of biodiesel.[29]

Table 1. Soybean Oil Prices as a Function of Soybean Oil Use for Biodiesel Production, 2004-2013

(2002 Dollars per Gallon)

Marketing Year	50 Million Gallons of Soybean Oil Used for Biodiesel Production	200 Million Gallons of Soybean Oil Used for Biodiesel Production
2004/05	1.95	2.22
2005/06	1.91	2.17
2006/07	1.87	2.15
2007/08	1.84	2.12
2008/09	1.86	2.20
2009/10	1.89	2.25
2010/11	1.94	2.35
2011/12	1.99	2.41
2012/13	2.06	2.47

Notes: The marketing year for a crop is the 12-month period following the harvest. The soybean marketing year begins September 1 and ends August 31. The soybean oil marketing year begins 1 month after the soybean marketing year begins.

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

The biodiesel production process uses, for each gallon, 0.083 kilowatthours of electricity[30] and 38,300 British thermal units (Btu) of natural gas.[31,32] EIA estimates energy costs (in 2002 cents) of 18 cents per gallon in 2004 and 16 cents per gallon in 2005 and 2006.[33] A new biodiesel plant is estimated to cost $1.04 per annual gallon of capacity. EIA assumes that the plant is financed by equity with an annualized return of 10 percent over 15 years. Treating the hypothetical income stream as an annuity over the 15 years, the estimated capital cost is $1.36 million per year, or 13.6 cents per gallon (2002 cents) at full output.

The National Biodiesel Board claims that dedicated biodiesel plants with a total capacity of 60 to 80 million gallons per year (3,414 to 5,219 barrels per day) have already been built. In addition, 200 million gallons (13,046 barrels per day) of capacity are available from oleochemical producers, such as Proctor and Gamble.[34,35] Biodiesel producers will produce up to 80 million gallons per year at a price just high enough to

Table 2. Projected Prices for Yellow Grease, 2004-2013

(2002 Dollars per Gallon)

Marketing Year	Price
2004/05	1.09
2005/06	1.07
2006/07	1.05
2007/08	1.04
2008/09	1.08
2009/10	1.10
2010/11	1.15
2011/12	1.18
2012/13	1.21

Notes: The soybean oil marketing year is from October 1 to September 30. The price estimates assume 200 million gallons of soybean oil to biodiesel production.

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

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[28] U.S. Department of Agriculture, *USDA Agricultural Baseline Projections to 2012*, Staff Report WAOB-2003-1 (Washington, DC, February 2003), web site www.ers.usda.gov/publications/waob031/waob20031.pdf.

[29] R. Teall, *Study to Evaluate the Feasibility of Biodiesel Production Facilities in Nevada & California Utilizing Grease Trap & Waste Cooking Oils as Feedstocks* (Las Vegas, NV: Biodiesel Industries, March 19, 2002), Appendix #3—Feasibility Study, pp. 38-42, web site www.westbioenergy.org/reports/55034/55034fin.pdf.

[30] *Ibid*.

[31] E-mail from K. Shaine Tyson, National Renewable Energy Laboratory, January 11, 2002.

[32] One kilowatthour is equal to 0.003412 million Btu.

[33] Energy Information Administration, *Annual Energy Outlook 2004*, DOE/EOA-0383(2004) (Washington, DC, January 2004), Table 3, "Industrial Gas and Electricity Prices," web site www.eia.doe.gov/oiaf/aeo/pdf/aeotab_3.pdf.

[34] National Biodiesel Board, "U.S. Biodiesel Production Capacity," web site www.biodiesel.org/pdf_files/Capacity.PDF.

[35] These firms make methyl esters of fats and oils for use in consumer products such as soaps and detergents.

cover variable costs. The capacity in the oleochemical industry will not come on-stream unless the price of biodiesel is sufficiently high to draw methyl esters out of other uses. A comparison of total production costs of diesel fuel by type of feedstock is provided in Table 3.

There is currently excess production capacity in the biodiesel industry. Petroleum refiners, on the other hand, use more than 90 percent of their capacity, and additional capital investments are needed to keep up with increasing demand and tightening product specifications, such as the transition in 2006 from a highway diesel sulfur limit of 500 parts per million to 15 parts per million. Soybean oil biodiesel has essentially no sulfur. Because soybean biodiesel producers have overcapacity and a product that more than meets the upcoming highway diesel sulfur limit, they need make no additional capital investments to produce output up to 80 million gallons in 2006 and beyond.[36] The cost comparison in Table 3 is therefore between the cost of biodiesel, excluding capital, and the cost of petroleum diesel, including capital.

Table 3. Projected Production Costs for Diesel Fuel by Feedstock, 2004-2013
(2002 Dollars per Gallon)

Marketing Year	Soybean Oil	Yellow Grease	Petroleum
2004/05	2.54	1.41	0.67
2005/06	2.49	1.39	0.78
2006/07	2.47	1.38	0.77
2007/08	2.44	1.37	0.78
2008/09	2.52	1.40	0.78
2009/10	2.57	1.42	0.75
2010/11	2.67	1.47	0.76
2011/12	2.73	1.51	0.76
2012/13	2.80	1.55	0.75

Notes: The soybean oil marketing year is October 1 to September 30. Petroleum diesel cost is for the calendar year encompassing the last 9 months of the soybean oil marketing year. Cost is assumed to be the price at the refinery gate in Petroleum Administration for Defense District 3 (PADD 3; U.S. Gulf Coast) for low-sulfur diesel in 2005 and for ultra-low-sulfur diesel in 2006-2013. Biodiesel costs are for total output of 80 million gallons per year or less and do not include distribution or applicable taxes.

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting. Petroleum diesel cost from National Energy Modeling System run AEO2004.D101703E.

Incentives for Biodiesel Production

For the past several years, the USDA has offered grants for biodiesel production through the Commodity Credit Corporation (CCC). The CCC payments for expansion of biodiesel production in the fiscal years[37] 2004-06 are $1.45-$1.47 (2002 dollars) per gallon for soybean oil biodiesel (Table 4) and 89-91 cents per gallon for yellow grease biodiesel (Table 5). Base production payments apply to production up to the level of the prior fiscal year, and additional production payments are for production above the level of the prior fiscal year. CCC payments for producers with output levels of 65 million gallons per year or less are shown in Tables 4 and 5. Payments for output levels above 65 million gallons per year are approximately 30 percent lower than the values shown in Tables 4 and 5.

The CCC payments effectively reduce the variable cost of additional soybean oil and yellow grease biodiesel to $1.10 and 53 cents per gallon, respectively, in fiscal year 2004. Additional units produced in fiscal year 2004, however, become base units in fiscal year 2005 and are eligible only for much smaller, and declining, base production payments. The variable cost of soybean oil and yellow grease biodiesel added in fiscal year 2004 jumps to $2.32 and $1.27 per gallon, respectively, in fiscal year 2005.

The transportation bill passed by the Senate on February 12, 2004, includes excise tax credits for biodiesel blending. The legislation allows diesel blenders to claim a credit against the applicable Federal motor fuels excise tax if a batch of diesel fuel contains biodiesel. If the blender uses biodiesel made from virgin oil, such as soybean oil, the credit is $1 (nominal dollars) per gallon of biodiesel. If the blender uses biodiesel made from nonvirgin oil, such as yellow grease, the credit is 50 cents per gallon of biodiesel.[38] The proposed legislation also includes business income tax credits at the same rates for the blending of biodiesel from virgin or nonvirgin oil.[39] The proposed Federal tax credits would expire after 2006.[40]

Demand Projections

EIA has developed lower- and upper-bound demand projections for biodiesel fuel. The lower-bound projections are based on an assessment of potential fleet

[36] Yellow grease biodiesel may have up to 24 parts per million sulfur, which exceeds the limit for ultra-low-sulfur diesel. Until May 31, 2010, however, up to 20 percent of the highway diesel pool is subject to the less restrictive 500-ppm limit.

[37] The U.S. Government operates on a fiscal year starting October 1 and ending September 30. Fiscal year 2004 began in October 2003.

[38] U.S. Congress, "Safe, Accountable, Flexible, and Efficient Transportation Act of 2004," Section 5102.

[39] *Ibid.*, Section 5103.

[40] Ethanol-blended gasoline has been subject to a reduced rate of Federal motor fuels excise tax since the late 1970s. The tax reduction is currently equivalent to 52 cents per gallon of ethanol. It declines to 51 cents per gallon of ethanol in 2005 and expires on September 30, 2007. Section 5102, however, gives gasoline blenders a credit of 51 cents per gallon of ethanol against the motor fuels excise tax. This credit will last through 2010.

demand for biodiesel to comply with the Energy Policy Act of 1992 (EPACT). The upper-bound projections are based on biodiesel's potential use as a lubricity additive.

EPACT requires that a fraction of new purchases of light-duty vehicles[41] for qualified fleets be alternative-fuel vehicles (AFVs). Qualified fleets include vehicles owned by Federal and State agencies and alternative fuel providers that are capable of being fueled at central locations. Law enforcement, emergency, and military vehicles are excluded from qualification. The AFV requirement is 75 percent for Federal and State governments and 90 percent for alternative fuel providers.

In lieu of an AFV purchase, a fleet operator may purchase 450 gallons of pure biodiesel for use in a vehicle with GVWR over 8,500 pounds[42] and may offset up to one-half of the number of required AFV purchases with biodiesel purchases. Approximately 32,000 new fleet vehicle purchases were covered under EPACT in 2001,[43] and because purchases by alternative fuel providers are aggregated with government purchases, the 75-percent requirement was applied uniformly. The number of vehicle purchases covered under EPACT is assumed to grow at about the same rate as that projected for the light-duty vehicle stock, and every qualified fleet is assumed to use biodiesel purchases to offset one-half of the AFV requirement. Those assumptions result in EIA lower-bound projections for biodiesel demand of 6.5 million gallons (424 barrels per day) in 2010 and 7.3 million gallons (476 barrels per day) in 2020.

EIA's upper-bound projections recognize that low-sulfur diesel fuel marketed in the United States has lubricity problems and assume that the transition to ultra-low-sulfur diesel will make the problems worse. The upper-bound projections also assume that biodiesel will be blended into ultra-low-sulfur diesel at 1 percent by volume to improve lubricity, resulting in demand projections for biodiesel of 470 million gallons (30,654 barrels per day) in 2010 and 630 million gallons (41,959 barrels per day) in 2020. Sensitivity analysis of the higher biodiesel penetration rate indicated no significant impact on gasoline prices, but ethanol requirements to meet a proposed renewable fuels standard were reduced.[44]

Conclusion

Biodiesel from yellow grease is closer to being cost-competitive with petroleum diesel than is biodiesel from soybean oil, but the available supply of yellow grease will probably limit its use for biodiesel production to 100

Table 4. Soybean Oil Biodiesel Production Costs and Subsidies, 2004-2006
(2002 Dollars per Gallon)

Costs and Subsidies	Fiscal Year 2004	2005	2006
Variable Cost	2.55	2.54	2.49
CCC Base Production Payment	-0.43	-0.22	-0.00
Variable Cost of Base Production, Net	2.12	2.32	2.49
Variable Cost	2.55	2.54	2.49
CCC Additional Production Payment	-1.45	-1.46	-1.47
Variable Cost of Additional Production, Net	1.10	1.08	1.12

Note: CCC = Commodity Credit Corporation.

Sources: Energy Information Administration, Office of Integrated Analysis and Forecasting. Variable costs estimated assuming total annual output of 200 million gallons. Payment estimates based on 7 CFR Part 1424 (Bioenergy Program Final Rule). Soybean and soybean oil price projections from U.S. Department of Agriculture, *USDA Agricultural Baseline Projections to 2012*, Staff Report WAOB-2003-1 (Washington, DC, February 2003), web site www.ers.usda.gov/publications/waob031/waob20031.pdf.

Table 5. Yellow Grease Biodiesel Production Costs and Subsidies, 2004-2006
(2002 Dollars per Gallon)

Costs and Subsidies	Fiscal Year 2004	2005	2006
Variable Cost	1.42	1.41	1.39
CCC Base Production Payment	-0.27	-0.14	-0.00
Variable Cost of Base Production, Net	1.15	1.27	1.39
Variable Cost	1.42	1.41	1.39
CCC Additional Production Payment	-0.89	-0.90	-0.91
Variable Cost of Additional Production, Net	0.53	0.51	0.48

Note: CCC = Commodity Credit Corporation.

Sources: Energy Information Administration, Office of Integrated Analysis and Forecasting. Variable costs estimated assuming total annual output of 200 million gallons. Payment estimates based on 7 CFR Part 1424 (Bioenergy Program Final Rule). Soybean and soybean oil price projections from U.S. Department of Agriculture, *USDA Agricultural Baseline Projections to 2012*, Staff Report WAOB-2003-1 (Washington, DC, February 2003), web site www.ers.usda.gov/publications/waob031/waob20031.pdf.

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[41] EPACT defines light-duty vehicles as those with a gross vehicle weight rating (GVWR) less than or equal to 8,500 pounds.

[42] The U.S. Department of Energy made an administrative decision in January 2001 to accept biodiesel for credit under EPACT. See web site www.ott.doe.gov/epact/pdfs/biodiesel_guidance.

[43] Based on conversations with staff of the Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

[44] Energy Information Administration, *Impact of Renewable Fuels Standard/MTBE Provisions of S. 1766*, SR/OIAF/2002-06 (Washington, DC, March 2002), pp. 10-12, web site http://tonto.eia.doe.gov/FTPROOT/service/sroiaf(2002)06.pdf.

million gallons per year (6,523 barrels per day) or less. Unless soybean oil prices decline dramatically, it does not appear that biodiesel can be produced in large quantities at a cost that is competitive with petroleum diesel. The largest market for biodiesel probably will be as a fuel additive, because EPACT requirements are unlikely to increase significantly over the next 20 years. The ultra-low-sulfur diesel program will offer an opportunity for biodiesel as a lubricity additive and perhaps as a cetane booster as well. Biodiesel may also be marketed for applications in which reducing emissions of particulates and unburned hydrocarbons is paramount, such as school and transit buses. Because additives that improve diesel fuel properties can sell for a price above that of the diesel fuel, the cost disadvantage for biodiesel would not be as great in the additive market.