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Biodiesel Fuel

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There are broad and increasing interests across the nation in using domestic, renewable bioenergy. Virginia farmers and transportation fleets use considerable amounts of diesel fuel in their operations. Biodiesel is an excellent alternative fuel for the diesel engines. Biodiesel can be produced from crops commonly grown in Virginia, such as soybean and canola, and has almost the same performance as petrodiesel. The purpose of this publication is to introduce the basics of biodiesel fuel and address some myths and answer some questions about biodiesel fuel before farmers and fleet owners use this type of fuel.

ASTM standard for biodiesel (ASTM D6751)

Biodiesel fuel, hereafter referred to as simply biodiesel, is composed of long-chain fatty acids with an alcohol attached. It is produced through a reaction called transesterification in which fresh vegetable oil, used cooking oil, or rendered animal fat reacts with alcohol (usually in the methyl form) in the presence of a catalyst (Ma and Hanna, 1999). When cooking oil or rendered animal fat is used, two additional steps (before transesterification) are needed to avoid excessive soap formation: (1) water removal and (2) titration for determining the extra amount of lye used (Canakci and Van Gerpen, 2001).

After transesterification, the raw biodiesel (methyl esters) are washed and filtered to meet the American Society of Testing and Materials (ASTM) standard (D6751); then, the refined biodiesel can be used as an alternative fuel for diesel engines. The ASTM Biodiesel Standard is shown in Table 1 below.

Table 1. ASTM Biodiesel Standard (ASTM D6751).

Property	Test Method	Specification
Flash Point, Closed Cup	ASTM D93	130°C (266°F), Min
Water and Sediment	ASTM D2709	0.050 Vol. % ,Max
Kinematic Viscosity, 40°C	ASTM D445	1.9-6.0 mm^2/s
Sulfated Ash	ASTM D874	0.020 Mass %, Max
Sulfur	ASTM D5453	0.0015 Mass %, Max
Copper Strip Corrosion	ASTM D130	No. 3, Max
Cetane Number	ASTM D613	47, Min
Cloud Point, °C	ASTM D2500	Report to customer
Carbon Residue	ASTM D4530	0.050 Mass %, Max
Acid Number	ASTM D664	0.80 mg KOH/g, Max
Free Glycerin	ASTM D6584	0.020 Mass %, Max
Total Glycerin	ASTM D6584	0.240 Mass %, Max
Phosphorous Content	ASTM 4951	0.001 Mass %, Max
Distillation Temperature	ASTM D1160	360°C (680°F), Max

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Pure or blends

Although biodiesel contains no petroleum, it can be blended at any level with petroleum diesel by simply pouring the two products together to create a biodiesel blend. A pure, or 100 percent, biodiesel fuel is referred to as B100. Biodiesel blends are referred to as Bxx; the xx indicates the amount of biodiesel in the blend (i.e., a B20 blend is 20 percent by volume biodiesel and 80 percent by volume petrodiesel). Currently, most biodiesel at public pumps is sold in one of two blend levels: B2 or B20.

Can I use biodiesel in my existing diesel engine?

Biodiesel blended up to B20 can work in any diesel engine with few or no modifications to the engine or the fuel system. However, because of the solvent nature of biodiesel, deposits that have accumulated on tank walls and inside pipes from previous diesel use and storage may be released and clog the fuel filter. When initially switching to a B20 blend, fuel filters should be monitored periodically to prevent the filter from clogging. The solvent effect is more dramatic and noticeable with B100 than B20 blend. Therefore, use only fuel meeting the ASTM standard.

Engine warranty

All diesel engine manufacturers only offer a warranty on the "materials and workmanship" of their engines. Companies do not cover or offer warranties for damage caused by fuels of any kind, whether the fuel is biodiesel or petrodiesel fuel. Engine problems caused by fuel are the responsibility of the fuel supplier and not the engine manufacturer. Therefore, two important considerations regarding engine warranties and the use of biodiesel are: (1) whether an engine manufacturer will void its warranty on parts and workmanship when biodiesel is used; and (2) whether the fuel producers or marketers will guarantee their fuels should problems occur.

Most major engine companies have stated formally that the use of blends up to B20 will not void their parts and workmanship warranties. However, it should be noted that those engine companies specify that the biodiesel must meet the ASTM standard. The specific position and warranty statement from the major engine companies is available at the National Biodiesel Board website (*www.biodiesel.org/resources/fuelfactsheets/standards_and_warranties.shtm*).

Storage and material compatibility

The standard storage procedures used for petroleum diesel can be used for biodiesel blends up to B20. Acceptable tank materials include aluminum, steel, fluorinated polyethylene, fluorinated polypropylene, and Teflon. B100 or blended biodiesel should not be stored for more than six months. If biodiesel is stored longer than six months, the acid value should be monitored or fuel storage-enhancing additives may need to be added. B20 will degrade and create sediments when left in contact with brass, bronze, copper, lead, tin, and zinc for a prolonged period of time. Lead solders, zinc lining, copper pipes, brass regulators, and copper fittings should be avoided. Affected equipment should be replaced with steel or aluminum components.

B100 can soften and degrade certain types of gasket, hose, and sealing compounds like natural rubber, Buna-N, and nitrile, which can create fuel-system leaks. This effect has NOT been observed with B20 and lower blends over the past 10 years, indicating B20 or lower blends can be used without engine modifications. If blends higher than B20 are desired for engine use, the engine or vehicle manufacturer should be consulted to determine if the seals, hoses, and gaskets are compatible.

Cold temperature concern

In cold temperatures, the flow properties (e.g., cloud point, pour point, and cold filter-plugging point) of the fuel may be a concern because the fuel tends to gel if the temperature is near freezing. Cold point (CP) is the temperature at which small solid crystals are first visualized as the fuel is cooled; pour point (PP) is the temperature at which the fuel is no longer pumpable; and cold filter-

Table 2. Cold flow properties of diesel and biodiesel derived from various sources.[a]

Test method	Cloud point		Pour point		Cold filter-plugging point	
#2 Diesel	5°F	-15°C	-31°F	-35°C	-4°F	-20°C
Canola - B100	26°F	-3°C	25°F	-4°C	24°F	-4°C
Soybean - B100	38°F	3°C	25°F	-4°C	28°F	-2°C
Lard - B100	56°F	13°C	55°F	13°C	52°F	11°C
Inedible Tallow - B100	61°F	16°C	59°F	15°C	50°F	10°C
Edible Tallow - B100	66°F	19°C	60°F	16°C	58°F	14°C

[a] *Data are adapted from Biodiesel Handling and Use Guidelines (2006) and Graboski and McCormick (1998).*

plugging point (CFPP) is the temperature at which fuel will cause a filter plug due to the crystallization of fuel.

Table 2 lists the cold-flow properties of biodiesel produced from different sources. All biodiesel, especially the animal-fat derived B100, exhibit poor flow properties compared with those of number 2 diesel. However, when B100 is blended with number 2 diesel, the biodiesel blend will significantly enhance the flow properties. For example, the cold flow properties of soybean oil-based B20 are only 2˚ to 10˚F higher than those of number 2 diesel (*www.biodiesel.org/pdf_files/fuelfactsheets/Performance.PDF*). For many users this small increase in temperature has adequately decreased cold filter plugging. Indeed, B20 has been used in a variety of climates, including winter usage in Northern Minnesota and Montana without cold-flow problems. However, users should be cautious when using animal-fat based biodiesel because the fuel tends to gel at a much higher temperature than plant-oil based biodiesel.

Overall, the solutions for winter operability with biodiesel are similar to those used for low-sulfur number 2 diesel (i.e., blend the fuel with kerosene, use cold-flow enhancing additives, employ fuel-filter or fuel-line heaters, or store vehicles inside a garage). However, it should be noted that the National Biodiesel Board hasn't been provided (nor does it endorse any) analytical data on any additive to formulate an opinion, although several commercial cold-flow additives specific for biodiesel have been available in the market (*http://www.biodiesel.org/askben/top10*). Currently, the board works closely with the nation's largest additive manufactures and continues to work diligently to support technology that can be validated and approved to work on pure biodiesel.

Performance

Energy content: The energy content of diesel fuel, expressed as British thermal units (BTU) per pound or per gallon at 60°F, is the heat released when a known quantity of fuel is burned under specific conditions. The energy content of biodiesel meeting the ASTM standard is more dependent on the raw materials used during biodiesel production than the particular process. However, the energy content of biodiesel is much less variable than petrodiesel. Table 3 represents the density and energy content of average number 2 diesel and av-

Table 3. Comparison of density and heating value of biodiesel and diesel fuel.

Fuel	Density lbs/gal	Cetane Number[1]	Viscosity Centistokes[2]	Energy content BTU/gal	% Difference vs. #2 Diesel
#2 Diesel	7.02	48	3.0	129,500	
B100	7.27	55	5.7	118,296	- 8.65%
B20	7.07	50	3.5	127,259	- 1.73%
B2	7.03	48	3.1	129,276	- 0.17%

[1] *The cetane number of the fuel is a measure of its ignition delay with higher cetane number indicating shorter time between the initiation of fuel injection and ignition.*

[2] *High viscosity leads to poor atomization of the fuel spray and less accurate operation of the fuel injection*

erage biodiesel in the U.S. The energy contents of B20 and B2 are less than 2 percent lower than that of number 2 diesel.

Engine power and fuel economy: Engine configuration (i.e., turbocharged, after-cooler, etc.), the efficiency of the engine, and the fuel's volumetric energy content are the main factors that affect vehicle fuel economy, torque, and power. The engine type and efficiency are the same whether using biodiesel, diesel, or biodiesel blends, so the differences in power, torque, or fuel economy depends entirely on the volumetric energy content of the fuels. Although the energy contents of B20 and B2 are lower than number 2 diesel (Table 3), the slight difference in fuel economy, torque, and power is hardly noticeable with day-to-day operation. In more than 50 million on-road miles and countless marine and off-road applications, biodiesel has shown similar fuel consumption, power, torque, and haulage rates as conventional diesel fuel.

Lubricity: Lubricity is the fuel quality that prevents or minimizes wear in diesel fuel injection equipment. Diesel lubricity occurs with trace levels of naturally occurring polar compounds, which form a protective layer on metal surfaces.

The Environmental Protection Agency (EPA) has mandated that no diesel fuel sold at retail outlets after October 15, 2006, can exceed 15 ppm sulfur content. Refinery hydrotreating processes used to reduce the sulfur content of diesel also remove the polar compounds. Therefore, because the polar compounds necessary for lubricity have been removed, most of the diesel fuel produced by refineries to meet ultra-low sulfur diesel (ULSD) sulfur specifications will not have adequate lubricating properties to meet the new ASTM lubricity specification. When biodiesel is added to conventional diesel fuel, there is marked improvement in lubricity. It has been shown that a 2-percent blend of biodiesel offers the highest amount of lubricity benefit for the least incremental cost; B2 can provide any type of distillate fuel with sufficient lubricity. Both plant-oil and animal-fat based biodiesel are beneficial for lubricity enhancement; there is no significant effect of biodiesel fatty acid composition on lubricity (Knothe, 2005).

Table 4. Average Biodiesel Emissions Compared to #1 or #2 Diesel.

Emission Type	B100	B20
Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate matter	-47%	-12%
Sulfates	-100%	-20%
PAH (Polycyclic Aromatic Hydrocarbons)	-80%	-13%
nPAH (nitrated PAHs)	-90%	-50%
Ozone potential of speciated HC	-50%	-10%
NOx	+10%	+2%

Emissions: The use of biodiesel in a conventional diesel engine, when compared to emissions from diesel fuel, results in a substantial reduction of unburned hydrocarbons, carbon monoxide, and particulate matter. However, nitrogen-oxide (NOx) emissions are slightly higher (Table 4).

Benefits of using biodiesel

Environmental benefits: B100 contains no sulfur or aromatics, and the use of biodiesel in a conventional diesel engine results in a substantial reduction of unburned hydrocarbons, carbon monoxide, and particulate matter. To address the slight increase in NOx emissions (Table 4), the biodiesel industry is developing an additive that reduces NOx emissions. For B5 or lower blends, the NOx increase is negligible.

Energy security: The U.S. uses approximately 20 million barrels of oil a day, and more than half is imported. By 2025, the demand is expected to rise to 26 million barrels a day. It is estimated that the country spends $475,000 a minute on foreign oil. Because biodiesel can be manufactured using existing industrial production capacity, and used with conventional equipment, it provides substantial opportunity for addressing U.S. energy security issues.

Economic benefits: Using biofuels can result in significant microeconomic benefits to both the urban and rural sectors and the balance of trade. In 2001, a USDA study indicated that an average annual increase of 200 million gallons of soy-based biodiesel demand would boost total crop cash receipts by $5.2 billion by 2010, resulting in an increase in average net farm income of $300 million per year. The price for a bushel of soybeans would increase by an average of 17 cents annually during the ten-year period.

EPAct benefits: In January 2001, federal, state, and certain fuel provider fleets became eligible for EPAct (Energy Policy Act) credit for using biodiesel blends of at least 20 percent. This rule gives one credit for every 450 gallons of pure biodiesel used in biodiesel blends. The act is accessible at *www.eere.energy.gov/afdc/pdfs/FedRegBioFinal.pdf*. The Congressional Budget Office and the USDA have confirmed that the biodiesel option is the least-cost alternative fuel option for meeting the federal government's EPAct compliance requirements. Because biodiesel works with existing diesel engines, biodiesel offers an immediate and seamless way to transition existing diesel vehicles into a cleaner burning fleet.

Consumer myths and facts

Myth: Biodiesel is an experimental fuel and has not been thoroughly tested.

Fact: Biodiesel is one of the most thoroughly tested alternative fuels on the market. A number of independent studies have been completed with results showing biodiesel performs similar to petroleum diesel and benefits the environment and human health when compared to diesel. Biodiesel is the first and only alternative fuel to have completed the rigorous Health Effects testing requirements of the Clean Air Act. Biodiesel has been proven to perform similarly to diesel in more 50 million successful road miles in virtually all types of diesel engines, countless off-road miles, and marine hours.

Myth: A low-blend of biodiesel in diesel fuel will cost too much.

Fact: Using a 2-percent blend of biodiesel is estimated to increase the cost of diesel by 2 or 3 cents per gallon, including the fuel, transportation, storage, and blending costs. Any increase in cost will be accompanied by an increase in diesel quality since low-blend levels of biodiesel greatly enhance the lubricity of diesel fuel.

Myth: Biodiesel causes filters to plug.

Fact: Biodiesel can be operated in any diesel engine with little or no modification to the engine or the fuel system. B100 has a solvent effect, which may release deposits that have accumulated on tank walls and pipes from previous diesel fuel use and cause plugging. With blends of B20 or higher biodiesel, the release of deposits may clog filters initially and precautions should be taken to replace fuel filters until the petroleum build-up is eliminated. This issue is less prevalent with B20 blends, and there is no evidence that lower-blend levels such as B2 have caused filters to plug.

Myth: Biodiesel causes degradation of engine gaskets and seals.

Fact: The recent switch to low-sulfur diesel fuel has caused most Original Equipment Manufacturers (OEMs) to switch to components that are also suitable for use with biodiesel. In general, B100 can soften and degrade certain types of elastomers and natural rubber compounds through time. Using high-percent blends can impact fuel system components (i.e., primarily fuel hoses and fuel pump seals) that contain elastomer compounds incompatible with biodiesel, although the effect is less with lower biodiesel blend levels. Experience with B20 has found that no changes to gaskets, hoses, or the maintenance program are necessary.

Myth: No objective biodiesel fuel formulation standard exists.

Fact: The biodiesel industry has been active in setting standards for biodiesel since 1994 when the first biodiesel taskforce was formed within ASTM. ASTM approved a standard for biodiesel specification in December 2001.

Myth: Biodiesel does not have sufficient shelf life.

Fact: Today, most fuel is used within six months. Many petroleum companies do not recommend storing petroleum diesel for more than six months. The current industry recommendation is that biodiesel be used within six months, or reanalyzed after six months to ensure the fuel meets ASTM standard.

Incentive/tax credit of using biodiesel

At the federal level, starting in January 2005, producers or blenders receive 1-cent tax credit per percentage of agricultural-biodiesel (such as soy-biodiesel), and 0.5-cent tax credit for nonagricultural-based biodiesel (such as biodiesel produced from used cooking oil or animal fat) blends up to 20 percent. A fact sheet of the tax code can be reviewed at *www.biodiesel.org/news/taxincentive*. At the state level, some states have passed legislation to reduce fuel excise taxes or provided incentives for biodiesel use or sale. Specific incentives and laws can be viewed at *www.eere.energy.gov/afdc/laws/incen_laws.html*.

Virginia established the Biofuels Production Fund to provide grants to biodiesel producers. A biofuels producer is eligible for a grant of 10 cents per gallon of pure biofuels equivalent sold in the commonwealth between January 2007 and January 2017. To qualify, a biofuels producer must produce at least 10 million gallons of pure biofuels in the calendar year the incentive is effective. Each producer is only eligible for six calendar years of grants. State agencies are requested and encouraged to implement the use of biodiesel fuels, where feasible, in fleet vehicles owned or operated by agencies. The Secretary of Administration must submit to the Division of Legislative Automated Systems an executive summary and report of each agency's progress by the first day of the 2007 Regular Session of the General Assembly. The summary reports can be accessed at *www.eere.energy.gov/afdc/progs/state_summary.cgi?afdc/VA*.

Fleet usage of biodiesel

Across the nation, hundreds of major fleets are using biodiesel, including all branches of the U.S. military; U.S. Forest Service; USDA Beltsville ARS; U.S. Department of Interior; U.S. Botanical Garden; Yellowstone National Park; NASA; Delaware and New Jersey Departments of Transportation; and Florida Power and Light. Cities such as Seattle and more than 100 school districts use B20 in their fleets. Businesses that use biodiesel include New Belgium Brewery, L.L. Bean, and Choptank Electric.

The U.S. Navy is currently the largest user of diesel fuel in the world. The Navy has provided guidance for all Navy and Marine stations, mandating B20 should be used, where adequate fuel tanks are available. However, the policy does not apply to deployable commercial equipment indented to support contingency operation. Some naval facilities that already use biodiesel are Port Hueneme, Calif.; Navy Public Work Center (NPWC), San Diego; NPWC, Washington D.C., and NPWC, Pearl Harbor.

Biodiesel used in Virginia

Economic impact: The use of biodiesel in Virginia can have positive benefits for the state economy. Currently, for every $1 spent buying diesel in Virginia, large portion of the premium goes to crude oil with only $0.134 staying locally through state tax and local distributor income (Figure 1). If locally produced biodiesel was used, for every $1 spent, potentially 90 cents would stay in the local or state economy (Figure 2).

Commercial producers: Virginia biodiesel production is still in the developmental stage. The Virginia Biodiesel Refinery (*www.virginiabiodiesel.com*) in West Point, Virginia, is the only commercial producer of biodiesel in the state. By April 2006, the annual production capacity of the plant was 2 million gallons per year (*www.nbb.org/buyingbiodiesel/producers_marketers/ProducersMap-Existing.pdf*). Currently, the plant is expanding its production capacity. A new plant

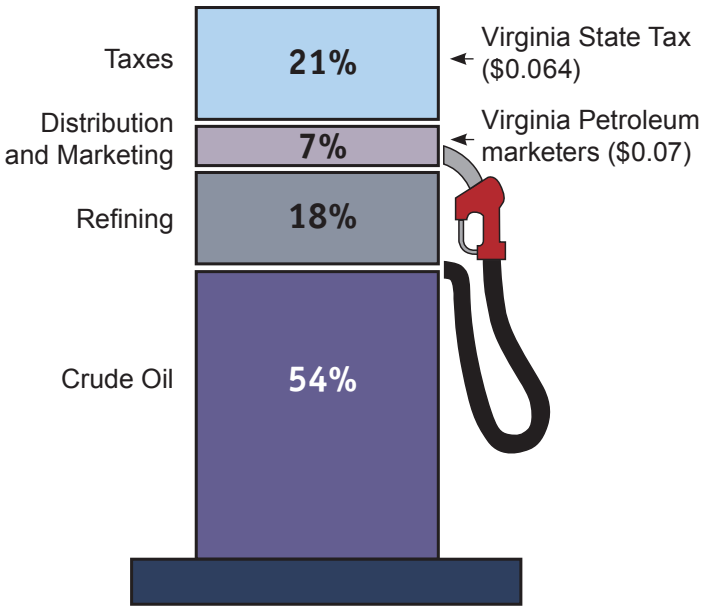
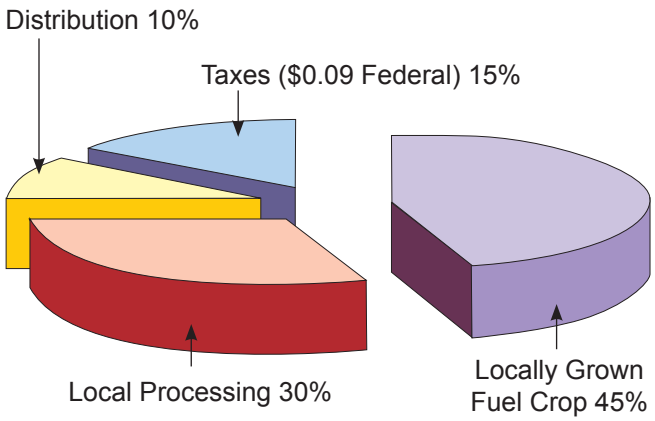


Figure 1. Distribution of $1 cost of diesel fuel at public pumps



Potentially $0.90 of every dollar stays local

Figure 2. Distribution of $1 cost of biodiesel fuel at public pumps

(RECO Biodiesel, LLC) is under construction in Richmond, Virginia. The capacity of this plant will be about 5 million gallons per year. Soybean oil is and will be the feedstock for both of the plants.

Fleet usage: The Virginia fleets using biodiesel include University of Virginia, City of Charlottesville, James Madison University, Arlington County, and the City of Harrisonburg.

The City of Chesapeake and James City County are doing pilot projects; Gloucester and Westmoreland counties are using biodiesel in their school bus fleets. In addition, several fuel blenders/distributors, including Papco, Phillips Oil and Gas, and Domestic Fuels and Lubes, are now making plans/or have started handling biodiesel.

Promotion programs: The current Virginia programs to promote the usage of biodiesel across the state are the Hampton Road Clean Cities Coalition (HRCCC) and the Blue Ridge Clean Fuels Inc. (BRCFI). BRCFI is also guided by the principles of the U.S. DOE's Clean Cities Program and works closely with HRCCC. In addition, the Virginia Soybean Association is considering some programs to promote the biodiesel production and usage in Virginia.

James Madison University and Virginia Tech have education programs to promote the public awareness of biodiesel. Information about these educational programs can be accessed at *www.cisat.jmu.edu/biodiesel* and *www.filebox.vt.edu/users/lschwei/Biodiesel.htm*.

Distributors and retailers: Biodiesel is available nationwide. It can be purchased directly from biodiesel producers and marketers, petroleum distributors, and some public pumps throughout the nation. To get a listing of all the current producers, distributors, and public pumps nationwide, go to *www.nbb.org/buyingbiodiesel/guide/default.shtm*. For biodiesel retailers and distributors in Virginia, visit *www.nbb.org/buyingbiodiesel/distributors/showstate.asp?st=VA* and *www.nbb.org/buyingbiodiesel/retailfuelingsites/showstate.asp?st=VA*.

Interested in making your own biodiesel?

Compared to other types of biofuel, biodiesel is easy to make. The raw materials (vegetable oil, used cooking oil, or animal fat) and other reaction regents (methanol, lye, etc.) are easy to obtain. Used cooking oil and animal fats take additional processing to make biodiesel compared to vegetable oils. The reaction can be performed in various types of tanks or barrels. For details on small-scale biodiesel production, refer to the factsheet series, "Making Your Own Biodiesel Fuel." VCE publication 442-881.

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