



Biodiesel Fuel

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Biodiesel is a renewable fuel that can be made from vegetable oil, animal fat, and recycled cooking oils. Oils produced from algae, fungi, bacteria, molds, and yeast can also be used to make biodiesel.

The production and use of biodiesel is increasing across the United States. Commonly cited advantages of using biodiesel compared to petroleum diesel include:

- Biodiesel is a good substitute for petroleum diesel fuel.
- Up to a 20% blend can be used in most diesel equipment with no/minor modifications.
- It burns clean, resulting in reduced toxic tailpipe emissions and gases associated with global warming.
- Biodiesel is nontoxic, biodegradable, and suitable for use in sensitive environments.
- It can provide an additional market for vegetable oils and animal fats.
- Biodiesel enables farmers to grow the fuel they need to operate farm machinery.
- Biodiesel decreases U.S. dependence on imported oil if fuel feedstocks are grown locally.

Biodiesel is currently being used in Virginia as an alternative fuel for diesel engines on farms and transportation fleet vehicles. It is mainly produced from crops commonly grown in Virginia, such as soybean and canola. This publication addresses facts about using biodiesel fuel, and the basic properties of biodiesel fuel.

Facts about Biodiesel

Biodiesel is a clean burning alternative to diesel fuel made from recycled cooking oil, animal fats, and vegetable oils. There is ongoing research to produce biodiesel from algae. It is a domestically produced renewable energy source and readily available in Virginia.

Using a 2 percent blend (B2) 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.

Biodiesel can be used in any diesel engine with little or no modification to the engine or the fuel system. However, it is important to remember that biodiesel is a stronger solvent compared to petroleum-based diesel. Thus, biodiesel may partially dissolve deposits left in the fuel lines by petroleum-based diesel, resulting in

plugging or clogging of filters. This will likely happen when changing from petroleum-based diesel to biodiesel fuels. Therefore, it is important to check and change fuel filters promptly until the petroleum-diesel-based buildup is eliminated. Clogging of filters is common with blends that have more than 20 percent biodiesel. This issue is less prevalent with B20 blends, and there is no evidence that lower percentage blends such as B2 have caused filters to plug.

In general, 100 percent biodiesel (B100) can soften and degrade certain types of elastomers and natural rubber compounds through time. Using high percentage blends can impact fuel system components (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.

The biodiesel industry uses the American Society of Testing Materials (ASTM) standard D6751 to guide the specifications and desired properties of biodiesel.

Today, most fuel is used within six months, and many petroleum companies do not recommend storing petroleum diesel for longer than six months. The current industry recommendation is that biodiesel be used within six months or be reanalyzed after six months to ensure the fuel is still compliant with the ASTM standard.

Biodiesel Production and Quality Specification

Biodiesel is produced from feedstocks such as vegetable oil, used cooking oil, or rendered animal fat. Bio-diesel is made by reacting the feedstock with an alcohol (usually methanol or ethanol) in the presence of a catalyst (potassium hydroxide or sodium hydroxide). This process is called transesterification and produces biodiesel and glycerin. Used cooking oil, waste oil, and rendered animal fat feedstocks contain contaminants (for example, water, meat scraps) that present challenges for biodiesel production. These contaminants must be removed before use as a feedstock. After transesterification, the raw bio-diesel (methyl esters) are washed and filtered to remove impurities such as residual catalysts and monoglycerides. The filtered pure or “neat” biodiesel (usually labeled as B100) should be tested for quality and compliance with the ASTM standard D6751 specifications summarized in table 1 before use as an alternative fuel for diesel engines.

Note: The ASTM D6751 specifications for biodiesel are updated frequently with the year reflected by the last two digits after the dash.

Additionally, the biodiesel industry has instituted a fuel quality program called the BQ-9000 Quality Management Program (www.bq-9000.org). This is a cooperative and voluntary program for accrediting producers and marketers of biodiesel fuel. The goals of the program are to promote the commercial success and public acceptance of biodiesel and to help ensure that biodiesel fuel is produced to and maintained at the industry standard, ASTM D6751.

Biodiesel Blends

Although biodiesel contains no petroleum, it can be directly mixed with petroleum diesel to make a biodiesel blend. Biodiesel blends are commonly denoted as BXX. The “XX” indicates the percentage by volume of the biodiesel in the blended fuel; for example, a B20 blend contains 20 percent biodiesel and 80 percent petroleum-based diesel by volume. Pure or neat biodiesel contains 100 percent biodiesel fuel (B100). B20 is a commonly used blend in the U.S. Note that ASTM has published specifications (ASTM D7467; table 2) to provide property compliance guidance for B6 to B20 biodiesel blends.

Table 1. ASTM D6751-20a specifications for biodiesel (B100).

Property	Test method	Limits	Units
Flash point, closed cup	ASTM D93	130 (266) minimum	°C (°F)
Water and sediment	ASTM D2709	0.050 maximum	% volume
Kinematic viscosity at 40°C	ASTM D445	1.9 to 6.0	mm ² /s
Sulfated ash	ASTM D874	0.020 maximum	% mass
Sulfur	ASTM D5453	0.0015 (for S15) and 0.05 (for S500) maximum	% mass (ppm) maximum
Copper strip corrosion	ASTM D130	No. 3, maximum	
Cetane number	ASTM D613	47 minimum	
Cloud point	ASTM D2500	Report	°C
Carbon residue	ASTM D4530	0.050 maximum	% mass
Acid number	ASTM D664	0.50 maximum	mg KOH/g
Free glycerin	ASTM D6584	0.020 maximum	% mass
Total glycerin	ASTM D6584	0.240 maximum	% mass
Phosphorous content	ASTM D4951	0.001 maximum	% mass
Distillation temperature	ASTM D1160	360 (680) maximum	°C (°F)

Using Biodiesel in Existing Diesel Engines

The performance properties of B100 can be significantly different from petroleum diesel. However, blending biodiesel into petroleum diesel minimizes these property differences while retaining some of the benefits of B100. Currently, biodiesel blends up to B20 are in use in a variety of applications. These blends can work in any diesel engines with minimal or no modifications. B20 is popular because it represents a good balance of cost, emissions, cold weather performance, and materials compatibility. However, because biodiesel is a good solvent, if used, deposits that have accumulated on tank walls and inside pipes from petroleum diesel use and storage may be released and cause clogging in the fuel system. When switching to a B20 blend, periodically monitor fuel filters to prevent clogging. The solvent effect is more dramatic and not the B20 blend. It is important that only fuel meeting the ASTM specifications be used. Vehicles with diesel engines manufactured after 1993 can use the B20 biodiesel blend with minimal impact on operating performance.

Storage, Stability, and Material Compatibility

The standard storage procedures for petroleum diesel can be used for biodiesel blends up to B20. Storage containers should be made from aluminum, steel, fluorinated polyethylene, fluorinated polypropylene, fiberglass, or Teflon materials. Biodiesel blends have adequate stability for normal use over short time periods. If storage over extended periods (longer than six months) is desired, special precautions must be taken: monitor the acid value and, if necessary, add fuel-storage-enhancing additives. Long-term storage may occur in equipment that is used seasonally, like snowplows, farm equipment, or backup generator fuel tanks.

Biodiesel can degrade due to oxidation, contact with water, and/or microbial activity. Generally, biodiesel degrades more quickly than petroleum diesel. This characteristic is good from an environmental perspective: a biodiesel spill will biodegrade quickly compared to a petroleum spill, making the spill easier to remediate. Oxidation of biodiesel causes sediments to form in the fuel. Heat, sunlight, and oxygen will also cause biodies-

Table 2. ASTM D7467 specification for B6 to B20 diesel blends.

Property	Test method	Limits	Units
Flash point	ASTM D93	52 (126) minimum	°C (°F)
Water and sediment	ASTM D2709	0.05 maximum	% volume
Kinematic viscosity at 40°C	ASTM D445	1.9 to 6.0	mm ² /s
Ash content	ASTM D482	0.01 maximum	% mass
Sulfur			
S15	ASTM D5453	15	µg/g
S500	ASTM D2622	0.05	% mass
S5000	ASTM D129	0.50	% mass
Copper corrosion, 3 hours at 50°C	ASTM D130	No. 3, maximum	
Cetane number	ASTM D613	40 minimum	
Cetane index*	ASTM D976-80	40 minimum	
Aromaticity*	ASTM D1319-03	35 maximum	% volume
Carbon residue on 10% bottoms	ASTM D524	0.35 maximum	% mass
Acid number	ASTM D664	0.30 maximum	mg KOH/g
Lubricity, HFRR at 60°C	ASTM 6079	520 maximum	µm
Distillation temperature	ASTM D86	343 (649) maximum	°C (°F)

*Must meet one of the properties indicated with an asterisk.

el to degrade more rapidly; therefore, exposure to these conditions should be minimized during storage. Biodiesel will degrade in the presence of water, and microbes will grow in the biodiesel if the water content is more than 1,500 parts per million. Additionally, excess water in the biodiesel can cause engines and storage tanks to rust. Chemicals (called biocides) that inhibit microbial growth can be added to the fuel. The chemicals are available from diesel fuel supplies.

Contaminants resulting from degradation of biodiesel will plug fuel dispensers and vehicular fuel filters. Avoid using fittings, valves, and piping (conduits) that contain lead, zinc, copper, brass, and other reactive materials. In general, biodiesel is compatible with materials used in diesel fuel systems after 1993. Pure (B100) biodiesel and blends with higher percentages of biodiesel can degrade some gaskets, hoses, and seals. Acceptable materials include Teflon, Viton, fluorinated plastics, and nylon. Ask vendors about the suitability of using pure or higher percentage blends of biodiesel in their equipment.

Biodiesel Use in Cold Weather

The flow properties (e.g., cloud point, pour point, and cold filter plugging point) of biodiesel may be a concern as the temperature nears freezing. Cloud point is the temperature at which small solid crystals are first visualized as the fuel is cooled. Pour point is the temperature at which the fuel is no longer pumpable. Cold filter plugging point is the temperature at which fuel

will cause a filter plug due to the crystallization of fuel. Table 3 lists the cold flow properties of biodiesel produced from different sources.

All biodiesel, especially the animal-fat-derived B100, have poor flow properties compared with those of No. 2 diesel, the standard petroleum-based diesel used in vehicles and stationary engines. However, when B100 is blended with No. 2 diesel, the biodiesel blend will significantly enhance the flow properties (see <http://www.nbb.org/>). B20 has been used in a variety of climates, including winters 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.

Performance Energy Content

The energy content of diesel fuel is the heat released when a known quantity of fuel is burned under specific conditions. The energy content is usually expressed as British thermal units (BTU) per pound or per gallon. The energy content of biodiesel may vary depending on the feedstock (table 3). Methods used to refine and/or blend biodiesel have no significant effect on the energy content. B100 has a slightly lower energy content (8 percent per gallon or 12.5 percent per pound) compared to No. 2 diesel. The energy content of biodiesel blends

Table 3. Cold flow properties and heat of combustion of diesel and B100 biodiesel derived from various sources.*

Fuel	Cloud point	Pour point	Cold filter plugging point	Heat of combustion (BTU/gal)
No. 2 diesel	5°F (-15°C)	-31°F (-35°C)	-4°F (-20°C)	129,050
Canola – B100	26°F (-3°C)	25°F (-4°C)	24°F (-4°C)	115,785
Soybean – B100	32°F (0°C)	25°F (-4°C)	28°F (-2°C)	116,362
Lard – B100	56°F (13°C)	55°F (13°C)	52°F (11°C)	115,639
Inedible tallow – B100	61°F (16°C)	59°F (15°C)	50°F (10°C)	115,639
Edible tallow – B100	66°F (19°C)	60°F (16°C)	58°F (14°C)	115,931
Yellow grease 2 – B100	46°F (8°C)	43°F (6°C)	34°F (1°C)	114,683

*Data adapted from "Biodiesel Handling and Use Guide" (Alleman et al. (2016) and Graboski and McCormick (1998)).

are proportional to the amount and the heating value of biodiesel in the blend. In general, the energy contents of B20 and B2 blends are 2 percent lower than No. 2 diesel. The average densities, viscosities, and cetane numbers of No. 2 diesel and biodiesel in the U.S. are presented in table 4.

Table 4. Density and heating value of biodiesel and No. 2 diesel fuel.

Fuel	Density (lb./gal.)	Cetane number*	Viscosity centistokes†
No. 2 diesel	7.02	40-55	1.3-4.1
B100	7.27	48-65	4.0-6.0
B20	7.07	50	3.5
B2	7.03	48	3.1

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

† High viscosity leads to poor atomization of the fuel spray and less accurate operation of the fuel injection.

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 No. 2 diesel, 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 U.S. Environmental Protection Agency has mandated that no diesel fuel sold at retail outlets after Oct. 15, 2006, can exceed a sulfur content of 15 parts per million. Some refinery processes used to reduce the sulfur content of diesel also remove the polar compounds. Therefore, most of the diesel fuel produced by refineries to meet ultra-low-sulfur diesel may not have adequate lubricating properties to meet the ASTM lubricity spec-

ification. Adding biodiesel to ultra-low-sulfur diesel will improve the lubricity.

Blending as little as 0.25 percent biodiesel increases lubricity of diesel significantly. 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).

Emissions

Using biodiesel in conventional diesel engines compared to petroleum-based diesel substantially reduced unburned hydrocarbons, carbon monoxide, and particulate matter emissions (fig. 1). Emissions reductions increase with the amount of biodiesel in the blend; however, nitrogen oxide (NOx) emissions are slightly higher. Some studies show that NOx emissions increase by 2 percent for B20 blends.

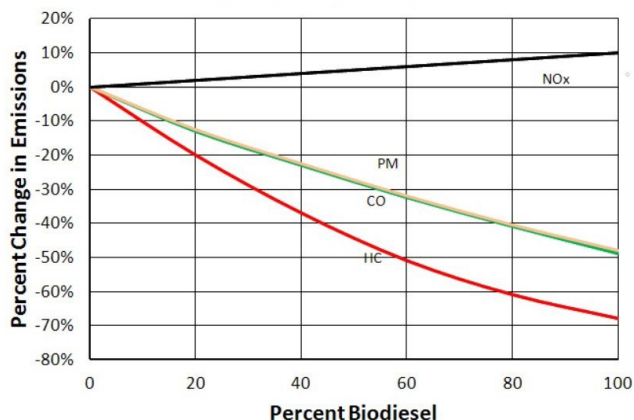


Figure 1. Average emissions reductions of using biodiesel for heavy-duty highway engines (NREL (2009)).

Engine Warranty

All major original engine manufacturers selling diesel equipment in the U.S. support at least B5 and lower percentage blends provided they are made with biodiesel meeting ASTM D6751 specifications. Additionally, most original engine manufacturers recommend the use of a BQ-9000 supplier. Diesel engine manufacturers offer a warranty on their products. These warranties cover materials and workmanship of the engines, but they do not cover damage caused by fuels or fuel components. Engine problems not related to fuel (biodiesel or petroleum diesel) use must be covered by the manufacturer.

Federal law prohibits manufacturers from cancelling a warranty just because biodiesel fuel was used. The warranty can only be cancelled if biodiesel is the cause of the engine problem. Therefore, two important considerations regarding engine warranties and use of biodiesel are: (1) whether there is an engine manufacturer warranty policy and (2) whether the fuel suppliers have general liability insurance to cover engine damage directly attributable to biodiesel use. Pay attention and avoid blends that original engine manufacturers specify have harmful effects on their equipment. The specific position and warranty statement from the major engine companies is available at www.biodiesel.org/usingbiodiesel/oem-information.

Benefits of Using Biodiesel Environmental Benefits

Biodiesel 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. Biodiesel has a positive energy balance, and studies have shown that at least 4.5 units of energy are gained for every unit of energy needed to produce a gallon of biodiesel.

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 a 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 10-year period.

EPAct Benefits

In January 2001, federal, state, and certain fuel provider fleets became eligible for Energy Policy Act (EPAct) credit for using biodiesel blends of at least 20 percent. This rule gave one credit for every 450 gallons of pure

biodiesel used in biodiesel blends. The act is accessible at www.afdc.energy.gov/pdfs/FedRegBioFinal.pdf. The Congressional Budget Office and the U.S. Department of Agriculture 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.

Incentive/Tax Credit for Biodiesel

A biodiesel tax incentive was implemented in 2005 and played a significant role in stimulating the growth of the industry in the U.S. The production of biodiesel grew from 100 million gallons in 2005 to 1.8 billion gallons in 2013. The National Biodiesel Board attributes part of the growth to the \$1 per gallon tax credit that expired in Dec. 31, 2013, and has not been renewed. The uncertainty associated with the biodiesel tax credit calls for a stable tax policy to assure a continued meaningful growth. A summary of federal laws and incentives related to biodiesel is available from the U.S. Department of Energy at www.afdc.energy.gov/fuels/laws/BIOD/US.

Virginia state laws and incentives related to biodiesel are available at www.afdc.energy.gov/fuels/laws/BIOD/VA. The incentive programs include a green job tax credit, biofuels production grants, clean energy manufacturing grants, a biodiesel production tax credit, clean transportation technology investment funding, an alternative fuel tax exemption, alternative fuel vehicle and fueling infrastructure loans, alternative fuel grants and loans, agriculture and forestry biofuel production grants, a biofuel feedstock registration exemption, and an alternative fuel job creation tax credit. The biodiesel production tax credit, for example, allows 1 cent per gallon of biodiesel or green diesel fuels for producers who make up to 2 million gallons a year. This annual credit may not exceed \$5,000.

Biodiesel Usage in Fleet Vehicles

Across the nation, hundreds of major fleets of vehicles are using biodiesel, including all branches of the U.S. military; the U.S. Forest Service; the USDA Agricultural Research Service in Beltsville, Maryland; the U.S. Department of the Interior; the U.S. Botanical Garden; Yellowstone National Park; NASA; the Delaware and New Jersey departments of transportation; and Florida Power & Light. Cities such as Seattle and more than 100 school districts use B20 in their fleets. A partial list of businesses that use biodiesel include New Belgium

Brewery, L.L. Bean, and Choptank Electric Cooperative. 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 that B20 should be used where adequate fuel tanks are available. However, the policy does not apply to deployable commercial equipment intended to support contingency operation. Some naval facilities that already use biodiesel are Port Hueneme, California, and the Navy Public Works Centers in San Diego, Washington, and Pearl Harbor, Hawaii.

Biodiesel Distributors and Retailers in Virginia

Biodiesel is available nationwide. It can be purchased directly from biodiesel producers and marketers, petroleum distributors, and some public pumps throughout the nation. A listing of all the current producers, distributors, and public pumps in Virginia and nationwide is available at <https://www.biodiesel.org/>.

Thinking About Making Your Own Biodiesel?

CAUTION: Anyone interested in making biodiesel must have a good understanding of the underlying chemistry to ensure production of quality fuel in a safe manner.

Compared to other types of biofuel, biodiesel is easy to make. The raw materials needed are feedstock (vegetable oil, used cooking oil, or animal fat) and other reagents (methanol, lye, etc.). Used cooking oil and animal fats may need additional processing to make biodiesel similar in quality to that produced from vegetable oils. The reaction can be performed in various types of tanks or barrels. It is also necessary to learn and know relevant regulations associated with biodiesel production with regard to air pollution and water and wastewater requirements from the Virginia Department of Environmental Quality regional office before any construction or operation can take place. A list of DEQ regional offices along with contact information may be found at www.deq.virginia.gov/Locations.aspx.

Additional Resources

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Virginia Department of Environmental Air Quality (DEQ) - Biodiesel: <https://www.deq.virginia.gov/Programs/PollutionPrevention/VirginiaInformationSourceforEnergy/AlternativeFuelsforTransportation/Biodiesel.aspx>

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