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Biodiesel Handling and Use Guide

Fourth Edition

Notice

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Abbreviations and Acronyms

AFV . . . . . . .alternative fuel vehicle
ASTM . . . . .ASTM International
B100 . . . . . .100% biodiesel
B20 . . . . . . .20% biodiesel, 80% petroleum diesel
Btu . . . . . . .British thermal unit
Ca . . . . .calcium
CFPP . . . . . .cold filter plug point
CI . . . . .compression ignition
CO. . . . . . . .carbon monoxide
COA. . . . . . .certificate of analysis
CO_2 . . . . . . .carbon dioxide
DOE. . . . . . .U.S. Department of Energy
DOT. . . . . . .U.S. Department of Transportation
ECRA. . . . . .Energy Conservation Reauthorization Act of 1998
EPA . . . . . . .U.S. Environmental Protection Agency
EPAct. . . . . .Energy Policy Act of 1992 (amended in 1998)
FAME. . . . . .fatty acid methyl esters
GHG. . . . . . .greenhouse gas
HC. . . . . . . .hydrocarbon
HFRR. . . . . .high-frequency reciprocating rig
IRS . . . . . . .Internal Revenue Service
K . . . . .potassium
KOH. . . . . . .potassium hydroxide
LTFT . . . . . .low-temperature flow test
Mg. . . . . . . .magnesium
MSDA . . . . .material safety data sheet
MSHA . . . . .U.S. Department of Labor Mining Safety Health Administration
Na . . . . .sodium
NBB. . . . . . .National Biodiesel Board
NOx . . . . . . .nitrogen oxides
NFPA . . . . . .National Fire Protection Association
NREL . . . . . .National Renewable Energy Laboratory
OEM . . . . . .original equipment manufacturer
OSHA. . . . . .Occupational Safety and Health Administration
OSI . . . . . . .Oil Stability Index
PAH . . . . . . .polyaromatic hydrocarbons
PM. . . . . . . .particulate matter
ppm. . . . . . .parts per million
RCRA. . . . . .Resource Conservation & Recovery Act of 1976
RFS . . . . . . .Renewable Fuels Standard
SO_2 . . . . . . .sulfur dioxide
UL . . . . .Underwriters Laboratories
VOC . . . . . . .volatile organic compound

1.0 Introduction

This document is a guide for those who blend, store, distribute, and use biodiesel and biodiesel blends. It provides basic information on the proper and safe use of biodiesel and biodiesel blends in compression-ignition engines and boilers, and it is intended to help fleets, individual users, blenders, distributors, and those involved in related activities understand procedures for handling and using biodiesel fuels.

Biodiesel is manufactured from plant oils, animal fats, and recycled cooking oils. Biodiesel's advantages are as follows:

- It is renewable.
- It is energy efficient.
- It displaces petroleum-derived diesel fuel.
- It can be used as a 20% blend in most diesel equipment with no or only minor modifications.
- It can reduce global warming gas emissions.
- It can reduce tailpipe emissions, including air toxics.
- It is nontoxic, biodegradable, and suitable for sensitive environments.

In this report, biodiesel refers to the fuel produced from renewable sources that meets ASTM International D6751, the standard for biodiesel. A number following the "B" indicates the percentage of biodiesel in a gallon of fuel; the remainder of the gallon can be No. 1 or No. 2 diesel, kerosene, jet A, JP8, heating oil, or any other distillate fuel. Pure biodiesel is also known as B100.

Biodiesel is most commonly used as a blend with petroleum diesel. At concentrations of up to 5 vol % (B5) in conventional diesel fuel, the mixture will meet the ASTM D975 diesel fuel specification and can be used in any application as if it were pure petroleum diesel; for home heating oil, B5 will meet the D396 home heating oil specification. At concentrations of 6% to 20%, biodiesel blends can be used in many applications that use diesel fuel with minor or no modifications to the equipment, although certain manufacturers do not extend warranty coverage if equipment is damaged by these blends. The B6 to B20 blends are covered by the ASTM D7467 specification that was approved in June 2008 and will be published later in 2008. Biodiesel can even be used as a fuel in its pure form (B100) if proper precautions are taken.

B20 is the most commonly used biodiesel blend in the United States because it provides a good balance between material compatibility, cold weather operability, performance, emission benefits, and costs. B20 is also the minimum blend level allowed for compliance with the Energy Policy Act of 1992 (EPAct), which requires the use of renewable fuels and/or alternative fuel vehicles (AFVs) by certain covered fleets. Equipment that can use B20 includes compression-ignition (CI) engines, fuel oil and heating oil boilers, and turbines.

B100 or higher blend levels such as B50 require special handling and may require equipment modifications. These issues can potentially be managed with heaters and/or changing engine seal and gasket materials. However, because the level of special care needed is high, the National Renewable Energy Laboratory (NREL) and the U.S. Department of Energy (DOE) do not recommend the use of high-level biodiesel blends, except where human exposure to diesel particulate matter (PM) is elevated and health concerns merit the additional attention to equipment and fuel handling. Always consult your engine or combustion equipment manufacturer for further information about procedures before using biodiesel blends higher than B20.

2.0 Biodiesel Basics

This section provides a basic overview of biodiesel. You can also refer to Section 9 (Frequently Asked Questions) for answers to general questions from your management, customers, or reporters. Technical details about many aspects of biodiesel are provided in Sections 3 to 8.

2.1 What Is Biodiesel?

Biodiesel is a diesel replacement fuel for use in CI engines. It is manufactured from plant oils (soybean oil, cottonseed oil, canola oil), recycled cooking greases or oils (e.g., yellow grease), or animal fats (beef tallow, pork lard). Because plants produce oils from sunlight and air, and can do so year after year on cropland, these oils are renewable. Animal fats are produced when the animal consumes plants or animals, and these too are renewable. Used cooking oils are mostly plant based, but may also contain animal fats. Used cooking oils are both recycled and renewable.

The biodiesel manufacturing process converts oils and fats into chemicals called long-chain mono alkyl esters, or biodiesel. These chemicals are also referred to as fatty acid methyl esters (FAME) and the process is referred to as transesterification. Figure 1 provides a simplified diagram of the transesterification process. Roughly speaking, 100 pounds of oil or fat are reacted with 10 pounds of a short-chain alcohol (usually methanol) in the presence of a catalyst (usually sodium hydroxide [NaOH] or potassium hydroxide [KOH]) to form 100 pounds of biodiesel and 10 pounds of glycerin. Glycerin is a sugar, and is a coproduct of the biodiesel process.

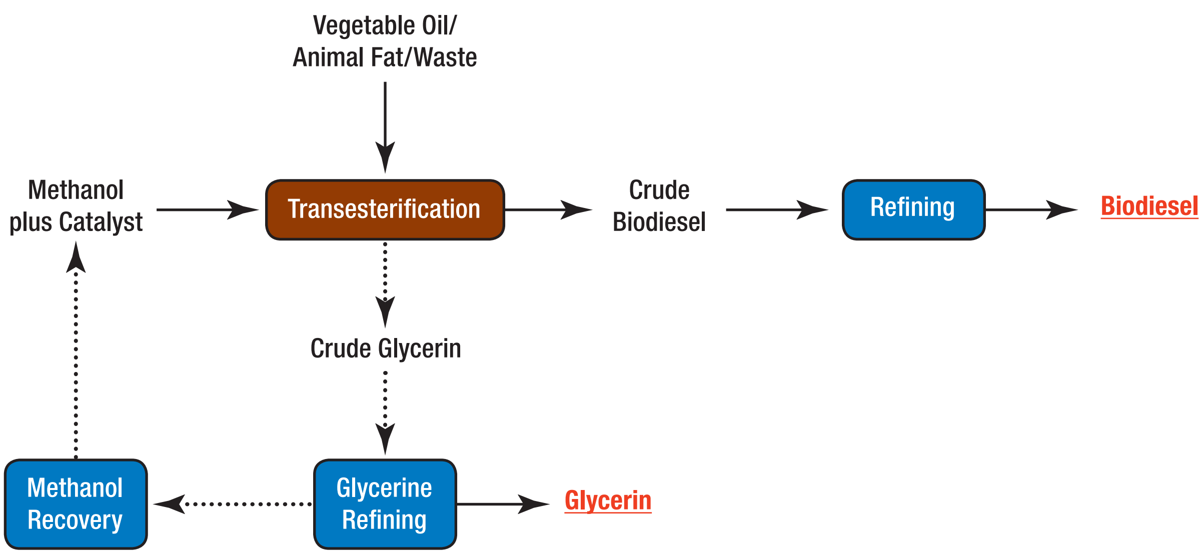


Figure 1. Basic Transesterification Process

Raw or refined plant oil, or recycled greases that have not been processed into biodiesel, are not biodiesel and should be avoided. Research shows that plant oils or greases used in CI engines at concentrations as low as 10% to 20% can cause long-term engine deposits, ring sticking, lube oil gelling, and other maintenance problems and can reduce engine life. These problems are caused mostly by the greater viscosity, or thickness, of the raw oils (around 40 mm^2/s) compared with that of the diesel fuel, for which the engines and injectors were designed (1.3 to 4.1 mm^2/s). Through the process of converting plant oils or greases to biodiesel by transesterification, the viscosity of the fuel is reduced to values similar to conventional diesel fuel (biodiesel values are typically 4 to 5 mm^2/s).

Biodiesel is a legally registered fuel and fuel additive with the U.S. Environmental Protection Agency (EPA). The EPA registration includes all biodiesel that meets the ASTM biodiesel specification, ASTM D 6751,[2] and does not depend on the oil or fat used to produce the biodiesel or the specific production process employed.

Other products, many of which are offered to consumers without the benefit of EPA registration or extensive testing and demonstrations, are mislabeled as "biofuels." If you purchase methyl ester that does not meet ASTM biodiesel standards, it is not legal biodiesel and should not be used in diesel engines or other equipment designed to operate on diesel fuel. Methyl esters are used as an industrial lubricant and solvent in some applications, so be sure to purchase only ASTM grade methyl esters (biodiesel).

ASTM International[3] is a consensus-based standards group that comprises engine and fuel injection equipment companies, fuel producers, and fuel users whose standards are recognized in the United States by most government entities. The specification for biodiesel (B100) is ASTM D6751. This specification is a compilation of efforts from researchers, engine manufacturers, petroleum companies and distributors, and many other fuel-related entities, and it is intended to ensure the quality of biodiesel used as a blend stock at 20% and lower blend levels. Any biodiesel used in the United States for blending should meet ASTM D6751 standards.[4]

The ASTM D6751 definition of biodiesel states that biodiesel is composed of mono-alkyl esters of long-chain fatty acids derived from plant oils or animal fats. The term mono-alkyl esters indicates that biodiesel contains only one ester linkage in each molecule. Plant oils contain three ester linkages and are therefore not legally biodiesel. Biodiesel can be made from methyl, ethyl, isopropyl, and other alcohols, but most biodiesel research focuses on methyl esters. Virtually all commercial production in the United States today is based on methyl esters. Some research has been conducted on ethyl esters (biodiesel produced with ethanol as the alcohol rather than methanol); however, higher ethanol prices relative to methanol, lower ethyl ester conversions, and the difficulty of recycling excess ethanol internally in the process have hampered ethyl ester production in the marketplace. Therefore, in this document we will consider only methyl esters.

The definition of biodiesel recognized by both the EPA for fuel registration purposes and the Internal Revenue Service (IRS) for the blender's tax credit is essentially the same as the definition in ASTM D6751:

A fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751.

Biodiesel is a recognized alternative fuel under the Energy Policy Act of 1992 (EPAct), as amended in 1998. EPAct requires that more than 75% of new vehicle purchases by certain federal, state, and alternative fuel provider fleets be alternative fuel vehicles (AFVs). As a recognized alternative fuel, any vehicle certified to run on B100 could qualify under the AFV purchase provisions of EPAct, but no generally available vehicles are intended to run on B100. B100 is more expensive than other alternative fuel options, and the original equipment manufacturer (OEM) community has had little interest in certifying vehicles on B100, so this vehicle credit has not created a market for biodiesel.

EPAct was amended in 1998 by the Energy Conservation and Reauthorization Act (ECRA). The amendment allowed qualified fleets to use B20 in existing vehicles to generate AFV purchase credits, with some limitations. This has created significant demand for B20 by government and alternative fuel provider fleets.

2.2 Benefits of Biodiesel Use

Biodiesel Provides a High Energy Return and Displaces Imported Petroleum

Life-cycle analyses show that biodiesel contains 2.5 to 3.5 units of energy for every unit of fossil energy input in its production, and because very little petroleum is used in its production, its use displaces petroleum at nearly a 1-to-1 ratio on a life-cycle basis.[5,6,7] This value includes energy used in diesel farm equipment and transportation equipment (trucks, locomotives); fossil fuels used to produce fertilizers, pesticides, steam, and electricity; and methanol used in the manufacturing process. Because biodiesel is an energy-efficient fuel, it can extend petroleum supplies.

Biodiesel Reduces Life-Cycle Greenhouse Gas Emissions

When biodiesel displaces petroleum, it significantly reduces greenhouse gas (GHG) emissions. By one estimate, GHG emissions (including carbon dioxide [CO_2], methane, and nitrogen oxide [NOx]) are reduced by 41%, if biodiesel is produced from crops harvested from fields that were already in production.[5] When plants such as soybeans grow, they take CO_2 from the air to make the stems, roots, leaves, and seeds (soybeans). After the oil is extracted from the soybeans, it is converted into biodiesel. When the biodiesel is burned, CO_2 and other emissions are released and return to the atmosphere. This cycle does not add to the net CO_2 concentration in the air because the next soybean crop will reuse the CO_2 as it grows. When fossil fuels such as coal or diesel fuel are burned, however, 100% of the CO_2 released adds to the CO_2 concentration levels in the air.

Biodiesel Reduces Tailpipe Emissions

Biodiesel reduces tailpipe PM, hydrocarbon (HC), and carbon monoxide (CO) emissions from most modern four-stroke CI or diesel engines. These benefits occur because biodiesel contains 11% oxygen by weight. The fuel oxygen allows the fuel to burn more completely, so fewer unburned fuel emissions result. This same phenomenon reduces air toxics, which are associated with the unburned or partially burned HC and PM emissions. Testing has shown that PM, HC, and CO reductions are independent of the biodiesel feedstock. The EPA reviewed 80 biodiesel emission tests on CI engines and has concluded that the benefits are real and predictable over a wide range of biodiesel blends (Figure 2).[8] EPA's review also indicated that B20 increased NOx by about 2% relative to petroleum diesel use. A more detailed analysis of the database examined by EPA, plus more recently published results, confirms the positive impact of B20 on emissions of HC, CO, and PM.[9] However, examination of the NOx results shows that the effect of biodiesel can vary with engine design, calibration, and test cycle. At this time, the data are insufficient for users to conclude anything about the average effect of B20 on NOx, other than that it is likely very close to zero.

In contrast, when biodiesel is used in boilers or home heating oil applications, NOx tends to decrease because the combustion process is different (open flame for boilers, enclosed cylinder with high-pressure spray combustion for engines). The NOx reduction seen with biodiesel blends used in boilers appears to be independent of the type of biodiesel used. In blends with heating oil up to 20% biodiesel, NOx is reduced linearly with increasing biodiesel content. For every 1% biodiesel added, NOx decreases by 1%. A B20 heating oil fuel will reduce NOx by about 20%.[10,11] Sulfur dioxide (SO_2) emissions were also reduced when the two fuels were blended, because biodiesel contains much less sulfur than typical heating oil does. A 20% blend of biodiesel in heating oil will reduce SO_2 by about 20%.

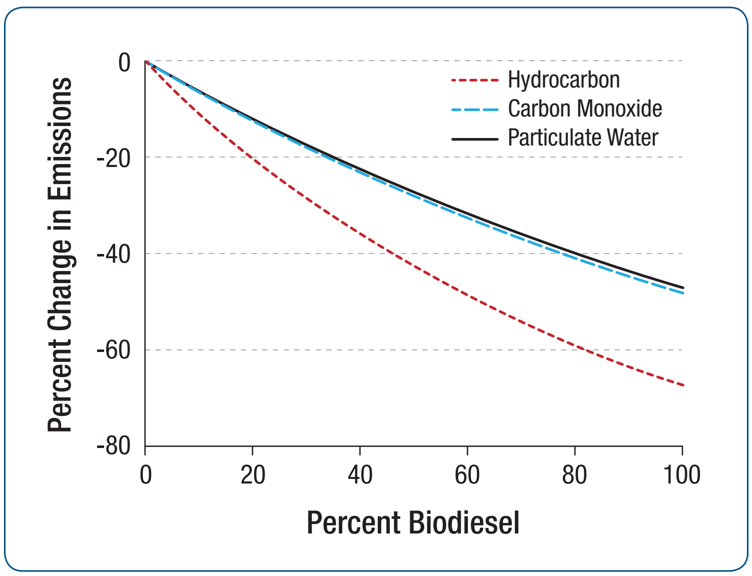


Figure 2. Average Emission Impacts of Biodiesel Fuels in CI Engines[12]

Heating oil and diesel fuel dyed red for off-road use (agriculture, power, boiler fuels, construction, forestry, and mining) can contain as much as 500 ppm sulfur. Blending biodiesel into off-road diesel fuel can significantly reduce SO_2 emissions. Nonroad diesel will transition to 15 ppm sulfur beginning in 2010.

Biodiesel and Human Health

Some PM and HC emissions from diesel fuel combustion are toxic or carcinogenic. Using B100 can eliminate as much as 90% of these air toxics. B20 reduces air toxics by 20% to 40%. The positive effects of biodiesel on air toxics have been shown in numerous studies.

Recently, the U.S. Department of Labor Mining Safety Health Administration (MSHA) has implemented rules for underground mines that limit workers' exposure to diesel PM. MSHA found that switching from petroleum diesel fuels to high blend levels of biodiesel (B50 to B100) significantly reduced PM emissions from underground diesel vehicles and substantially reduced workers' exposure. However, even low concentrations of biodiesel reduce PM emissions and provide significant health and compliance benefits wherever humans receive higher levels of exposure to diesel exhaust.

Biodiesel Improves Engine Operation

Even in very low concentrations, biodiesel improves fuel lubricity and raises the cetane number of the fuel. Diesel engines depend on the lubricity of the fuel to keep moving parts, especially fuel pumps, from wearing prematurely. One unintended side effect of the federal regulations, which have gradually reduced allowable fuel sulfur to only 15 ppm and lowered aromatics content, has been to reduce the lubricity of petroleum diesel. The hydrotreating processes used to reduce fuel sulfur and aromatics contents also reduces polar impurities such as nitrogen compounds, which provide lubricity. To address this, the ASTM D975 diesel fuel specification was modified to add a lubricity requirement (a maximum wear scar diameter on the high-frequency reciprocating rig [HFRR] test of 520 microns). Biodiesel can impart adequate lubricity to diesel fuels at blend levels as low as 1%.

Biodiesel Is Easy To Use

Finally, one of the biggest benefits to using biodiesel is that it is easy. Blends of B20 or lower are literally a "drop in" technology. No new equipment and no equipment modifications are necessary. B20 can be stored in diesel fuel tanks and pumped with diesel equipment. B20 does present a few unique handling and use precautions, but most users can expect a trouble-free B20 experience.

2.3 Other Biodiesel Attributes

Lower Energy Density

Biodiesel contains 8% less energy per gallon than typical No. 2 diesel in the United States and 12.5% less energy per pound. The difference between these two measurements is due to the higher density of biodiesel compared with diesel fuel. All biodiesel, regardless of its feedstock, provides about the same amount of energy per gallon or per pound. Typical values are as follows:

	Btu/lb	Btu/gal
Typical Diesel No. 2	18,300	129,050
Biodiesel (B100)	16,000	118,170

The difference in energy content between petroleum diesel and biodiesel can be noticeable with B100. For B20, the differences in power, torque, and fuel economy are 1% to 2%, depending on the base petroleum diesel. Most users report little difference in fuel economy between B20 and No. 2 diesel fuel. As the biodiesel blend level is lowered, differences in energy content become proportionally less significant; blends of B5 or lower cause no noticeable differences in performance in comparison to No. 2 diesel.

Low-Temperature Operability

In some areas of the country, the cold flow properties of biodiesel are important. Unlike gasoline, petroleum diesel and biodiesel both freeze or gel at common winter temperatures; however, biodiesel's freeze point may be 20º to 30ºF higher than that of petroleum diesel. If the fuel begins to gel, it can clog filters and eventually become so thick that it cannot be pumped from the fuel tank to the engine. However, with proper handling, B20 has been used successfully all year in the coldest U.S. climates.

Soy biodiesel, for example, has a cloud point (the temperature at which crystals begin to form) of 32ºF (0ºC). In contrast, most petroleum diesels have cloud points of about 10º to 20ºF (-12º to -5ºC). Blending of biodiesel can significantly raise the cloud point above that of the original diesel fuel. For example, a recent study[13] showed that, when soy biodiesel was blended into a specially formulated cold weather diesel fuel (cloud point of -36ºF [-38ºC]) to make a B20 blend, the cloud point of the blend was -4ºF (-20ºC). In very cold climates, this cloud point may still not be adequate for wintertime use. To accommodate biodiesel in cold climates, low cloud point petroleum diesel or low-temperature flow additives, or both, are necessary.

Storage Stability

Although biodiesel blends have adequate storage stability for normal use, special precautions must be taken if they are to be stored for extended periods. This might occur in a snow plow or farm implement used seasonally, or in the fuel tank of a backup generator. If the fuel will be stored for more than a few months, a stability additive is recommended, and acidity should be measured monthly.

Finally, biodiesel is generally more susceptible than petroleum diesel to microbial degradation. In the case of spills in the environment, this is a positive attribute because it biodegrades more rapidly. However, microbial contamination of fuel storage tanks can plug dispensers and vehicle fuel filters and cause vehicles to stall. This is not unheard of for petroleum diesel, but anecdotal evidence suggests it is a greater problem for biodiesel blends. The best way to deal with this issue (for both petroleum diesel and biodiesel) is adequate fuel storage tank housekeeping and monitoring, especially minimizing water in contact with the fuel. Water bottoms must be removed from tanks, and standing tanks should be sampled and tested for microbial contamination.

3.0 Biodiesel (B100)

This section describes the basic considerations for handling and blending B100. In the United States it is equally common to handle B99 and B99.9 blends, as these qualify for a federal blender's tax credit. The considerations in this section also apply to B99 and B99.9. The storage and handling procedures for B100 are very different from those for B20 and lower biodiesel blends, and they vary significantly from those of diesel fuel. Table 1 lists some of the physical and chemical properties of B100 and petroleum diesel. Using B20 and lower blends significantly reduces or eliminates the effects of these property differences for use as an engine fuel. However, since many distributors store and handle B100 before blending, a good understanding of B100 properties is valuable. Following are several significant attributes specific to B100 that should be considered when handling, storing, and using it.

- B100 is a good solvent. It may loosen or dissolve varnish and sediments in fuel tanks and fueling systems left by conventional diesel over time. If your system contains sediments, you should definitely clean your tanks and fuel system before handling or using B100.
- B100 freezes at higher temperatures than most diesel fuel. This must be taken into account if handling or using B100, especially in aboveground storage tanks. Most B100 starts to cloud at 35º to 60ºF (2º to 15ºC), so heated fuel lines and tanks may be needed, even in moderate climates, during winter. As B100 begins to gel, the viscosity also begins to rise to much higher levels than most diesel fuel does, which can increase the stress on pumps. The high cloud point makes B100 use challenging in colder climates.
- B100 is not compatible with some hoses and gaskets. B100 may soften and degrade certain types of rubber compounds used for hoses and gaskets (buna-N, nitrile, natural rubber) and may cause them to leak and degrade to the point where they crumble and become useless. For bulk handling of B100, seals, gaskets, and hoses must be compatible with B100. (See Appendix E for information about material compatibility.) Using

B100 in an engine constructed with incompatible materials can cause a fuel spill on a hot engine, ruin a fuel pump, or clog a filter as the hose material gradually erodes. Use extreme care to ensure any part of the fuel system that touches the fuel is compatible with B100. Some systems already have biodiesel-resistant materials, but many do not, because these materials are usually slightly more expensive.

- B100 is not compatible with some metals and plastics. Biodiesel will degrade and form high sediment levels if contacted for long periods by copper or copper containing metals (brass, bronze) or with lead, tin, or zinc (galvanized surfaces). These high sediment levels may clog filters. B100 may also permeate some common plastics (polyethylene, polypropylene) over time, so these should not be used for storing B100.

Table 1. Select Properties of Typical No. 2 Diesel and Biodiesel Fuels

Fuel Property	Diesel	Biodiesel
Fuel Standard	ASTM D975	ASTM D6751
Higher Heating Value, Btu/gal	~137,640	~127,042
Lower Heating Value, Btu/gal	~129,050	~118,170
Kinematic Viscosity, @ 40°C (104°F)	1.3–4.1	4.0–6.0
Specific Gravity kg/l @ 15.5°C (60°F)	0.85	0.88
Density, lb/gal @ 15.5°C (60°F)	7.1	7.3
Carbon, wt %	87	77
Hydrogen, wt %	13	12
Oxygen, by dif. wt %	0	11
Sulfur, wt %	0.0015 max	0.0–0.0024
Boiling Point, °C (°F)	180–340 (356–644)	315–350 (599–662)
Flash Point, °C (°F)	60–80 (140–176)	100–170 (212–338)
Cloud Point, °C (°F)	-35 to 5 (-31 to 41)	-3 to 15 (26 to 59)
Pour Point, °C (°F)	-35 to -15 (-31 to 5)	-5 to 10 (23 to 50)
Cetane Number	40–55	48–65

3.1 B100 Quality Specification

The ASTM specification for biodiesel (B100) is ASTM D6751. This specification is frequently updated, and as of this writing the most current version is D6751-08a, summarized in Table 2.

Table 2. Requirements for Biodiesel (B100) Blend Stock as Listed in ASTM D6751

Property	Test Method	Limits	Units
Calcium and Magnesium Combined	EN14538	5 max.	ppm
Flash Point	D93	93.0 min.	ºC
Alcohol Control - One of the following must be met:			
1. Methanol Content	EN14110	0.2 max.	vol %
2. Flash Point	D93	130 min.	ºC
Water and Sediment	D2709	0.050 max.	vol %
Kinematic Viscosity, 40ºC	D445	1.9–6.0	mm^2/s
Sulfated Ash	D874	0.020 max.	% mass
Sulfur	D5453	0.0015 max. (S15) 0.05 max. (S500)	% mass
Copper Strip Corrosion	D130	No. 3 max.	
Cetane Number	D613	47 min.	
Cloud Point	D2500	Report to customer	ºC
Carbon Residue[a]	D4530	0.050 max.	% mass
Acid Number	D664	0.50 max.	mg KOH/g
Free Glycerin	D6584	0.020 max.	% mass
Total Glycerin	D6584	0.240 max.	% mass
Phosphorus Content	D4951	0.001 max.	% max.
Distillation Temperature, 90% Recovered (T90)[b]	D1160	360 max.	ºC
Na and K Combined	EN14538	5 max.	ppm
Oxidation Stability	EN14112	3 min.	h
Cold Soak Filterability	Annex A1	360 max.[c]	s

[a] Carbon residue shall be run on the 100% sample.

[b] Atmospheric equivalent temperature.

[c] B100 intended for blending into diesel fuel that is expected to give satisfactory vehicle performance at fuel temperatures at or below 10ºF (-12ºC) shall comply with a cold soak filterability limit of 200 s maximum.

This specification is intended to ensure the quality of biodiesel to be used as a blend stock at 20% and lower levels. Any biodiesel used in the United States for blending must meet ASTM D6751 before blending. ASTM D6751 is based on the physical and chemical properties needed for safe and satisfactory diesel engine operation. It is not based on the specific raw materials or the manufacturing process used to produce the biodiesel. The finished blend stock must meet the properties specified in Table 2 as well as the following definition:

Biodiesel, *noun,* a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100.

This specification was not intended to be applied to B100 used in a pure form. However, buyers and sellers are encouraged to use ASTM D6751 for the commercial trading of biodiesel (B100) whether the fuel is planned for B100 use or for blending. Other arrangements or specifications can be legally used if the buyer and seller agree as long as they meet pertinent local, state, and federal regulations (EPA sulfur limits, Occupational Safety and Health Administration [OSHA] safety limits on flash point, etc.). However, B100 must meet the requirements of D6751 for blends to be legal fuels under the Clean Air Act fuel registration requirements, to legally claim the biodiesel blender's tax credit, and to be a legal blending component under many state regulations.

The intent of each quality requirement in Table 2 is described here:

- **High levels of Group I and II metals.** Sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg) can cause deposits to form, catalyze undesired side reactions, and poison emission control equipment. The Group I and II metals are limited as the combination of metals in each category, Na+K and Ca+Mg. For each combination, the limit is 5 ppm.
- **Flash point.** A minimum flash point for diesel fuel is required for fire safety. B100's flash point is required to be at least 93ºC (200ºF) to ensure it is classified as nonhazardous under the National Fire Protection Association (NFPA) code.
- **Alcohol.** It is critical to ensure that the manufacturer has removed excess methanol used in the manufacturing process. Residual methanol in the fuel is a safety issue, because even very small amounts reduce the flash point; can affect fuel pumps, seals, and elastomers; and can result in poor combustion properties. The intent of the alcohol control requirement is to limit methanol to less than 0.2 wt %. This can be accomplished by meeting a higher flash point requirement of 130ºC (266ºF); or by measuring methanol content by gas chromatography.
- **Water and sediment.** This refers to free water droplets and sediment particles. The allowable level for B100 is set at the same level allowed for conventional diesel fuel. Poor drying techniques during manufacturing or contact with excessive water during transport or storage can cause B100 to be out of specification for water content. Excess water can lead to corrosion and provides an environment for microorganisms. Fuel oxidation can also raise sediment levels, so this test can be used in conjunction with acid number and viscosity to determine if fuels have oxidized too much during storage.
- **Viscosity**. A minimum viscosity is required for some engines because of the potential for power loss caused by injection pump and injector leakage. This is not an issue for B100, and the minimum is set at the same level as for petroleum diesel. The maximum viscosity is limited by the design of engine fuel injection systems. Higher viscosity fuels can cause poor fuel combustion that leads to deposit formation as well as higher in-cylinder penetration of the fuel spray, which can result in elevated engine oil dilution with fuel. The maximum allowable viscosity in ASTM D975 for No. 2 diesel is 4.1 mm^2/s at 104ºF (40ºC). ASTM D6751 allows for slightly higher viscosity than D975, primarily because that is where the normal viscosity of B100 lies. Biodiesel blends of 20 vol % or lower should have a viscosity within the range allowed by D975.

- **Sulfated ash test.** This test measures the amount of residual alkali catalyst in the biodiesel as well as any other ash-forming compounds that could contribute to injector deposits or fuel system fouling.
- **Sulfur.** This is limited to reduce sulfate and sulfuric acid pollutant emissions and to protect exhaust catalyst systems when they are deployed on diesel engines in the future. Sulfur content of 15 ppm or lower is also required for proper functioning of diesel particle filters. Biodiesel generally contains less than 15 ppm sulfur. The test for low-sulfur fuel (ASTM D5453) should be used for accurate results instead of D2622, which will provide falsely high results caused by the test's interference with the oxygen in the biodiesel.
- **Copper strip corrosion test.** This test is used to indicate potential difficulties with copper and bronze fuel system components. The requirements for B100 and conventional diesel are identical, and biodiesel meeting other D6751 specifications always passes this test. Copper and bronze may not corrode in the presence of biodiesel fuel, but prolonged contact with these catalysts can degrade the fuel and cause sediment to form.
- **Cetane number.** An adequate cetane number is required for good engine performance. Conventional diesel must have a cetane number of at least 40 in the United States. Higher cetane numbers help ensure good cold start properties and minimize the formation of white smoke. The ASTM limit for B100 cetane number is set at 47, because this is the level identified for "Premium Diesel Fuel" by the National Conference of Weights and Measures. Also, 47 has been the lowest cetane number found in U.S. biodiesel fuels. The cetane index (ASTM D976) is not an accurate predictor of cetane number for biodiesel or biodiesel blends, because it is based on a calculation that uses specific gravity and distillation curve, both of which are different for biodiesel than for petroleum diesel.
- **Cloud point.** This is the most commonly used measure of low-temperature operability; fuels are generally expected to operate at temperatures as low as their cloud point. The B100 cloud point is typically higher than the cloud point of conventional diesel. Cloud point must be reported to indicate biodiesel's effect on the final blend cloud point. Low-temperature properties and strategies for ensuring good low-temperature performance of biodiesel blends are discussed in more detail in later sections.
- **Carbon residue.** This measures the carbon-depositing tendency of a fuel and is an approximation of the tendency for carbon deposits to form in an engine. For conventional diesel fuel, the carbon residue is measured on the 10% distillation residue. Because B100 boils entirely at the high end of the diesel fuel range and in a very narrow temperature range, it is difficult to leave only a 10% residual when distilling biodiesel. So, biodiesel carbon residue specifies that the entire biodiesel sample be used rather than the 10% distilled residue.
- **Acid number.** The acid number for biodiesel is primarily an indicator of free fatty acids (natural degradation products of fats and oils) and can be elevated if a fuel is not properly manufactured or has undergone oxidative degradation. Acid numbers higher than 0.50 have been associated with fuel system deposits and reduced life of fuel pumps and filters.
- **Free and total glycerin.** These numbers measure the amount of unconverted or partially converted fats and by-product glycerin in the fuel. Incomplete conversion of the fats and oils into biodiesel can lead to high total glycerin. Incomplete removal of glycerin can lead to high free glycerin and total glycerin. If these numbers are too high, the storage tank, fuel system, and engine can be contaminated. Fuels that exceed these limits are highly likely to plug filters and cause other problems. One of the major shortcomings of the D6584 gas chromatograph (GC) method is its sensitivity to diesel fuel. Diesel fuel components react differently on the column used in the GC—they make the determination of free glycerin very difficult and may damage the column. Thus, many labs are unable to determine free and total glycerin by this method in samples with even small amounts of diesel fuel, such as B99.9.
- **Phosphorus content.** This is limited to 10 ppm maximum in biodiesel because it can damage catalytic converters; phosphorus above 10 ppm can be present in some plant oils. Biodiesel produced in the United States generally has phosphorus levels of about 1 ppm.

- **T90 distillation specification.** This specification was incorporated to ensure that fuels have not been contaminated with high boiling materials such as used motor oil. B100 exhibits a boiling point rather than a distillation curve. The fatty acids from which biodiesel are produced are mainly straight-chain HCs with 16 to 18 carbons that have similar boiling point temperatures. The atmospheric boiling point of biodiesel is generally 626º to 675ºF (330º to 357ºC).
- **Oxidation stability.** Biodiesel can oxidize during storage and handling, leading to the formation of peroxides, acids, gums, and deposits. The minimum oxidation stability requirement is intended to ensure the storage stability of B100 and biodiesel blends.
- **Cold soak filterability.** This is the newest requirement. It was added in 2008 in response to data indicating that some B100 could, in blends with petroleum diesel of up to 20%, form precipitates above the cloud point. B100 meeting the cold soak filterability requirements does not form these precipitates. This, along with cloud point, is needed to predict low-temperature operability.

The D6751 specification also includes the following workmanship statement:

The biodiesel fuel shall be visually free of undissolved water, sediment, and suspended matter.

B100 should be clear, although it may come in a variety of colors. The biodiesel's color does not indicate fuel quality.

ASTM recently passed specifications for biodiesel blends. These include the allowance of up to 5% biodiesel in D975-compliant diesel fuel, with no changes to the allowable diesel fuel performance properties. A separate specification for B5 to B20 blends is discussed in Section 4.

3.2 Variation in Biodiesel Properties

As with petroleum-based fuels, the ASTM specifications for biodiesel allow a variety of feedstocks and processes to be used in its production. The specifications prescribe a largely feedstock-neutral, performance-based set of requirements that ensure the B100 is fit to be used in diesel engines. Biodiesel can be produced commercially from a variety of oils and fats:

- **Animal fats.** Edible, inedible, and all other variations of tallow, lard, choice white grease, yellow grease, poultry fats, and fish oils
- **Plant oils.** Soy, corn, canola, sunflower, rapeseed, cottonseed
- **Recycled greases.** Used cooking oils and restaurant frying oils.

Biodiesel can also be made from other oils, fats, and recycled oils such as mustard, palm, coconut, peanut, olive, sesame, and safflower oils, trap greases, and even oils produced from algae, fungi, bacteria, molds, and yeast. Some properties of finished biodiesel such as cetane number, cloud point, and stability depend heavily on the feedstock.

Compared with the chemistry of diesel fuel, which contains hundreds of compounds, the chemistries of different fats and oils typically used for biodiesel are very similar. Each fat or oil molecule is made up of a glycerin backbone of three carbons, and on each carbon is attached a long-chain fatty acid that reacts with methanol to make the methyl ester, or biodiesel. The glycerin backbone is turned into glycerin and sold as a by-product of biodiesel manufacturing. The fats and oils contain 10 common types of fatty acids that have 12 to 22 carbons, more than 90% of which are 16 to 18 carbons. Some of these chains are saturated, some are monounsaturated, and others are polyunsaturated. Within the limits of the specifications, the differing levels of saturation can affect some biodiesel fuel properties.

Each feedstock is set apart from the others because it is made of different proportions of saturated, monounsaturated, and polyunsaturated fatty acids (Figure 3).

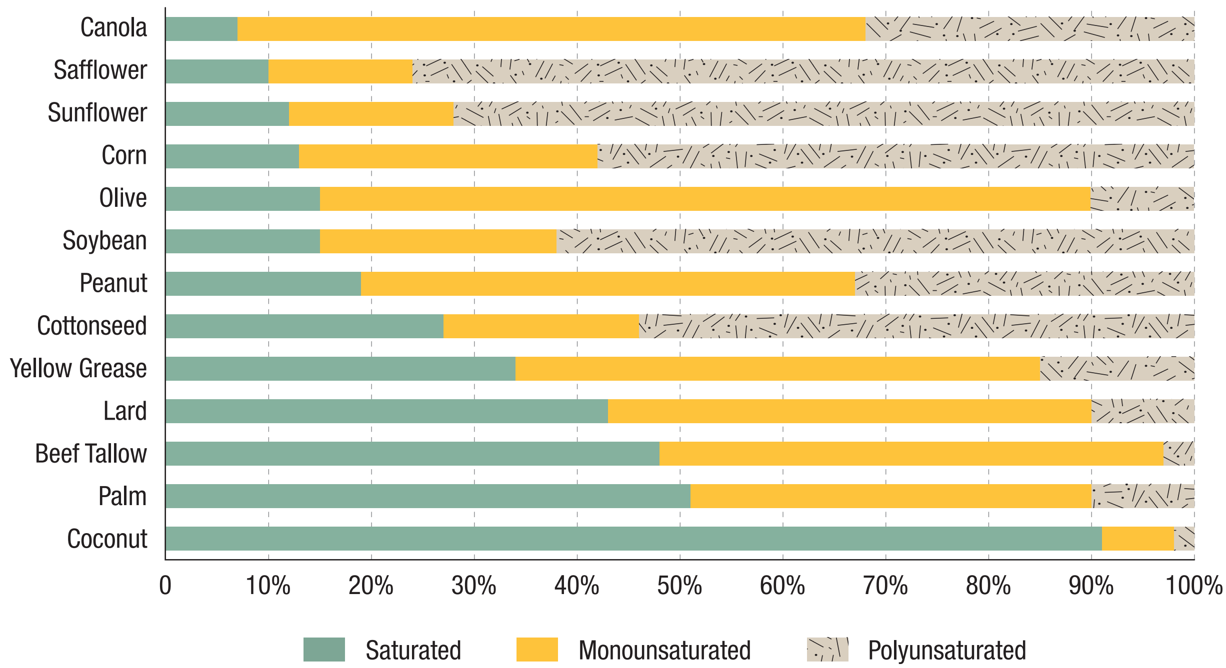


Figure 3. Composition of Various Biodiesel Feedstocks in Order of Increasing Saturated Fatty Acid Content

Under each category of fatty acids in Table 3 is shown its general impact on fuel properties and emissions. These are trends only; other factors such as additives may modify these trends.

As with conventional diesel fuel, the best type of biodiesel for your applications will be based on several factors. A No. 2 petroleum diesel fuel with a cetane number of 50 and a cloud point of 40ºF (4ºC) may be suitable for December in Texas, but a No. 1 petroleum diesel with a cetane number of 42 and a cloud point of -20ºF (-29ºC) may be best for a December in Minnesota. The considerations and trade-offs are like those made for petroleum diesel fuel. The following data provide more detail about B100 properties and considerations.

Table 3. Fuel Properties as a Function of Fuel Composition in Diesel Engines

	Saturated	Monounsaturated	Polyunsaturated
Cetane Number	High	Medium	Low
Cloud Point	High	Medium	Low
Stability	High	Medium	Low

3.3 Energy Content

With conventional diesel fuels, the inherent energy content of the fuel (typically measured in British thermal units [Btu] per gallon) is the largest factor affecting the fuel economy, torque, and horsepower delivered by the fuel. The energy content of conventional diesel can vary up to 15% from supplier to supplier and from summer to winter. This variability is due to changes in its composition determined by the petroleum feedstock, as well as refining and blending practices. No. 2 diesel fuel usually has a higher energy content than No. 1 diesel fuel, and blend values are somewhere in between.

With biodiesel, or B100, the refining (esterification or transesterification process) and blending methods have no significant effect on energy content. B100 varies little because the energy content of the fats and oils used to make biodiesel are similar. Therefore, B100 made from most of the common feedstocks will have the same fuel economy, power, and torque. Compared with most No. 2 diesel fuel in the United States, B100 has a slightly lower energy content (12.5%/lb or 8%/gal). Typical No. 2 diesel fuel has an energy content of around 18,600 Btu/lb. The energy in a pound of biodiesel made from several feedstocks is shown in Table 4. Losses in power, torque, and fuel economy would be expected to be proportional to the difference in energy content.

The energy content of biodiesel blends and diesel fuel is proportional to the amount of biodiesel in the blend and the heating value of the biodiesel and diesel fuel used to make the blend. For example, B20 users experience a 1% loss in fuel economy on average and rarely report changes in torque or power.

Table 4. Heating Value of Diesel and Some Biodiesel (B100) Fuels[14]

Fuel	Heat of Combustion
Typical No. 2 Diesel	About 18,300 Btu/lb
Soy Methyl Ester	15,940 Btu/lb
Canola Methyl Ester	15,861 Btu/lb
Lard Methyl Ester	15,841 But/lb
Edible Tallow Methyl Ester	15,881 Btu/lb
Inedible Tallow Methyl Ester	15,841 Btu/lb
Low Free Fatty Acid Yellow Grease Methyl Ester	15,887 Btu/lb
High Free Fatty Acid Yellow Grease Methyl Ester	15,710 Btu/lb

3.4 Low-Temperature Properties

The low-temperature properties of biodiesel and conventional petroleum diesel are extremely important. Unlike gasoline, petroleum diesel and biodiesel can freeze or gel as the temperature drops. Different diesel fuel formulations are sold during the winter in colder climates. If the fuel begins to gel, it can clog filters on dispensing equipment and may eventually become too thick to pump. B100 is commonly stored in heated above-ground tanks for blending in winter. Important low-temperature performance metrics for handling and blending of B100 are as follows:

- **Cloud point.** The temperature at which small solid crystals are first visually observed as the fuel is cooled. Below cloud point, these crystals might plug filters or could drop to the bottom of a storage tank. However, fuels can usually be pumped at temperatures below cloud point.
- **Pour point.** The temperature at which the fuel contains so many agglomerated crystals that it is essentially a gel and will no longer flow. Distributors and blenders use pour point as an indicator of whether the fuel can be pumped, even if it would not be suitable for use without heating or taking other steps.

These guidelines should be followed for storing biodiesel (B100) in winter:

- B100 should be stored at temperatures at least 5º to 10ºF higher than the cloud point. A storage temperature of 40º to 45ºF (4º to 7ºC) is fine for most B100, although some B100 fuels may require higher storage temperatures.

- B100 can be stored underground in most cold climates without additional considerations because underground storage temperatures are normally above 45ºF (7ºC). Aboveground storage and handling systems should be protected with insulation, agitation, heating systems, or other measures if temperatures regularly fall below the cloud point. This precaution includes piping, tanks, and pumping equipment.

The cloud point of B100 starts at 30º to 32ºF (-1º to 0ºC) for most plant oils that are composed primarily of mono- or polyunsaturated fatty acid chains; the cloud point can go as high as 80ºF (27ºC) or higher for animal fats or frying oils that are highly saturated. Examples of the cloud and pour points of B100 made from various sources are listed in Table 5. The pour point of B100 is usually only a few degrees lower than the cloud point, so once biodiesel begins to freeze, gelling can proceed rapidly if the temperature drops only a few degrees further.

Table 5. Cold Flow Data for Various B100 Fuels[15]

Test Method for B100 Fuel	Cloud Point (ASTM D2500)		Pour Point (ASTM D97)	
	(ºF)	(ºC)	(ºF)	(ºC)
Soy Methyl Ester	32	0	25	-4
Canola Methyl Ester	26	-3	25	-4
Lard Methyl Ester	56	13	55	13
Edible Tallow Methyl Ester	66	19	60	16
Inedible Tallow Methyl Ester	61	16	59	15
Yellow Grease 1 Methyl Ester	–	–	48	9
Yellow Grease 2 Methyl Ester	46	8	43	6

B100 tanks and fuel lines should be designed for the cold flow properties of the biodiesel used and the local climate. Fuel pumps, lines, and dispensers must be protected from the cold and wind chill with properly approved heating and insulating equipment. Fuel in aboveground tanks should be heated to 5º to 10ºF (-15º to -12ºC) above the fuel cloud point.

Once crystals begin to form, they will go back into solution as the fuel warms. However, that process can be slow if the fuel is heated only slightly above the cloud point. Crystals formed in biodiesel or diesel fuel can drift to the bottom of the tank and begin to build up a gel layer. Slow agitation can prevent crystals from building up on the tank bottom or, once present in the fuel, can help to bring the crystals back into liquid form. If B100 has gelled completely, the B100 should be heated to 100º to 110ºF (38º to 43ºC) to melt the most highly saturated biodiesel components if the fuel needs to be used immediately. Lower temperatures can be used if there is more time to allow the biodiesel to liquefy.

Some additive manufacturers provide data that show their cold flow additives can reduce the pour point of a B100 by as much as 30ºF (12ºC), but only with very large amounts of additives. At more typical treat rates, benefits were below detection levels.

B100 in the United States cannot be effectively managed with current cold flow additives, as can some petroleum diesel or European rapeseed-oil-based biodiesel. The level of saturated compounds in U.S. oils and fats is too high for most additives to be effective. Cold flow additives' effectiveness can also change dramatically, depending on the exact type of biodiesel and the processing it has undergone; this is much like the situation with diesel fuel. Cold flow additives have been used much more successfully with biodiesel blends. You should work directly with the additive manufacturers on this issue.

3.5 Cetane Number

Cetane number is a measure of the ignition delay (the time from fuel injection into the chamber to ignition); higher cetane numbers are believed to provide easier starting and quieter operation. The ASTM D6751 specification for biodiesel requires a minimum cetane number of 47; the cetane number required of petroleum diesel fuel is only 40. B100 produced from highly saturated feedstocks (such as lard, tallow, and used cooking oils) can have a cetane number of 60 or higher. Soy-, sunflower-, corn-, and canola-based biodiesel will have cetane numbers closer to 47. Figure 4 shows the cetane numbers of various biodiesel samples and compares them with those of diesels.

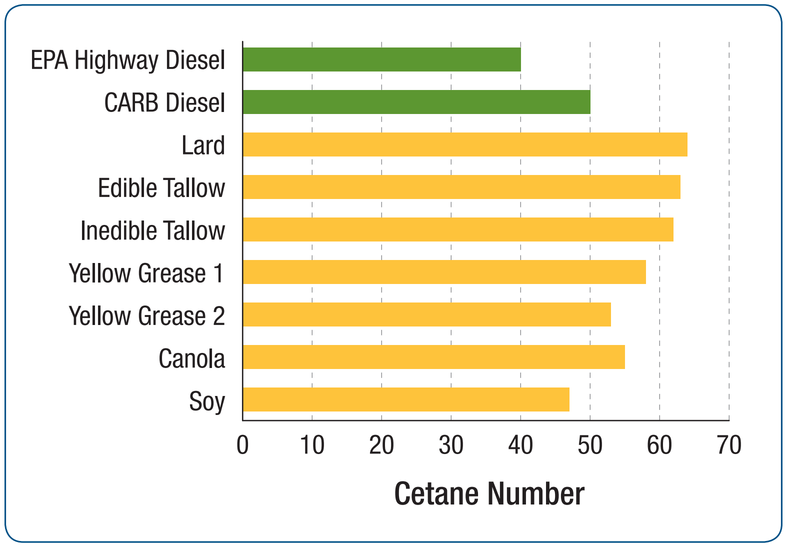


Figure 4. Cetane Number of Two Petroleum Diesels and Several Biodiesels

3.6 Transport and Storage

3.6.1 Stability

Stability can refer to two issues for fuels: long-term storage stability or aging and stability at elevated temperatures or pressures as the fuel is recirculated through an engine's fuel system. For petroleum diesel, long-term storage stability is commonly referred to as oxidative stability. Thermal stability is the common term for the stability of fuels at elevated fuel system temperatures. For B100, storage stability is the paramount concern; thus, D6751 includes an oxidation stability requirement.

The oxidation stability test, EN14112 (also referred to as the Oil Stability Index [OSI] or the Rancimat test), involves heating a specified quantity of B100 to 230ºF (110ºC) while air is bubbled through at a specified flow rate. The air then passes through a water bath that collects the volatile acids formed in oxidation. A conductivity meter is used to monitor the water. A stable B100 can go for many hours under these conditions without forming volatile oxidation products. This period of time, before oxidation products form, is called the induction time or induction period. The stability requirement in D6751 is that B100 have a minimum three-hour induction time. Because this requirement applies at the time of blending, many biodiesel producers make B100 with a four- or five-hour induction time.

In biodiesel, fuel aging and oxidation can lead to high acid numbers, high viscosity, and the formation of gums and sediments that clog filters. If the oxidation stability, acid number, viscosity, or sediment measurements exceed the limits in ASTM D6751, the B100 is degraded to the point where it is out of specification and should not be used. Biodiesel with high oxidation stability (longer induction time) will take longer than biodiesel with low oxidation stability to reach an out-of-specification condition. Monitoring the acid number and viscosity of B100 over time can indicate whether it is oxidizing. B100 should be tested at receipt to ensure that it is within specification.

In some cases, deposits from the cleaning or solvent effect of B100 have been confused with gums and sediments that could form in storage as the B100 ages. Although sediment can clog a filter in either case, care should be taken to make sure the reason for the clogging is properly identified. For example, if oxidation stability and acid number are within specification, the formation of sediment is most likely due to the cleaning effect and not to aging or oxidation.

Guidelines to help identify biodiesel and storage conditions that will provide the highest levels of stability follow:

- The higher the level of unsaturation, the more likely that the B100 will oxidize. Saturated fatty acids are usually stable, and each time the level of unsaturation increases (for example, from a saturated fat to a mono-saturated fat), the stability of the fuel decreases by a factor of 10. The points of unsaturation on the biodiesel molecule can react with oxygen, forming peroxides that break down into acids, sediments, and gums.

- Heat and sunlight will accelerate this process.
- Certain metals such as copper, brass, bronze, lead, tin, and zinc will accelerate the degradation process and form even higher levels of sediment. B100 should not be stored in systems that contain these metals. Metal chelating additives, which deactivate these metals, may reduce or eliminate their negative impact.
- Some types of feedstock processing and biodiesel processing can remove natural antioxidants, potentially lessening stability. Plant oils and fats are produced with natural antioxidants—nature's way of protecting the oil from degradation. Bleaching, deodorizing, or distilling oils and fats, either before or as part of the biodiesel process, can remove these natural antioxidants; other processes leave the antioxidants in the finished biodiesel.
- Keeping oxygen from the biodiesel reduces or eliminates fuel oxidation and increases storage life. Commercially, this is done by using a nitrogen blanket on storage tanks or storing biodiesel in sealed drums or totes.
- Antioxidants, whether natural or incorporated as additives, can significantly increase the storage life or stability of B100.

The ASTM D4625 test is used to simulate storage in underground storage tanks. The test is accelerated by a factor of 4 for petroleum fuels; that is, one week of storage at D4625 conditions (43ºC or 110ºF, open to air) simulates one month of storage in an underground tank. This acceleration factor has not been validated for B100, but it is still a useful guide. ASTM D4625 data (see Figure 5) indicates that B100 will rapidly lose oxidation stability

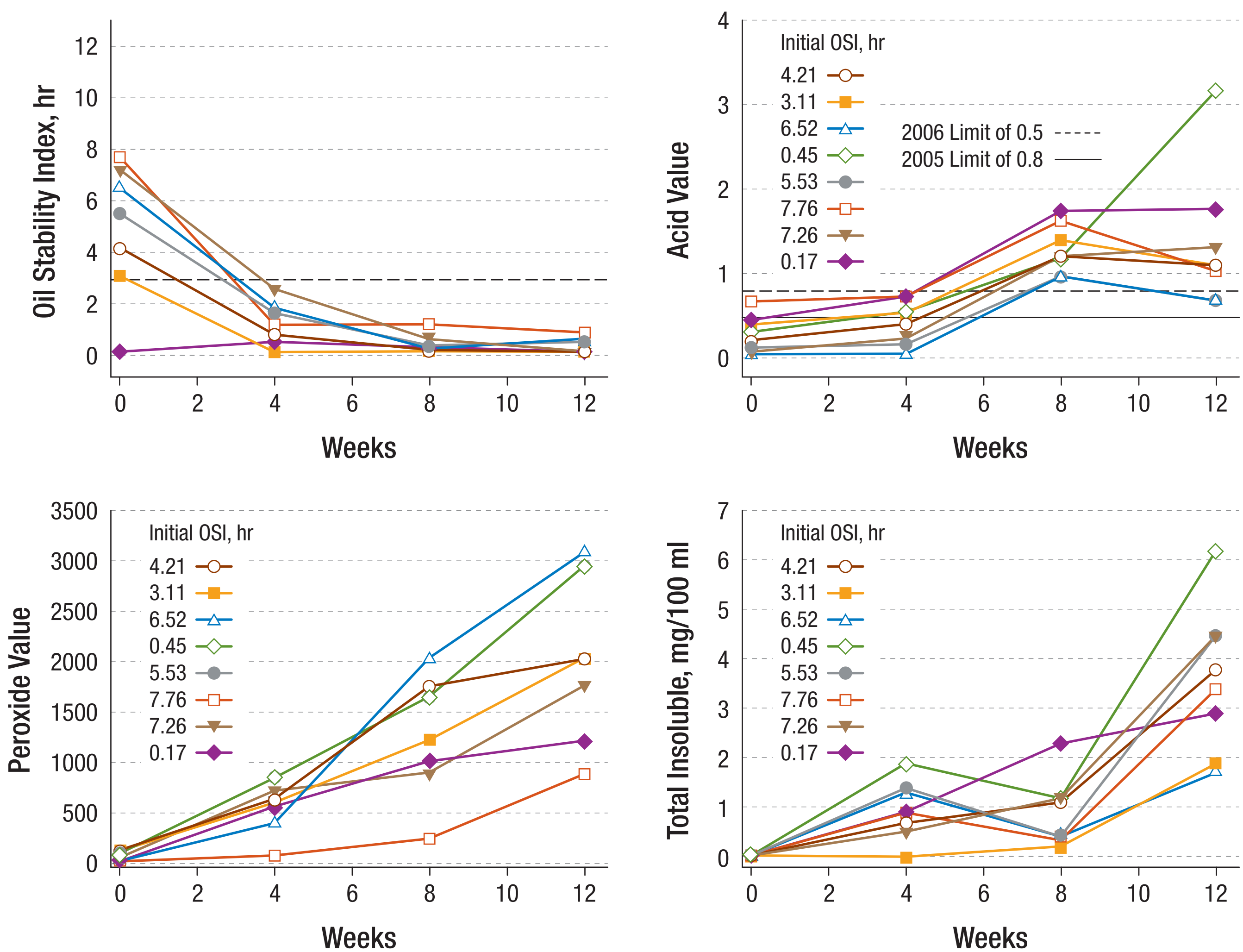


Figure 5. ASTM D4625 Long-Term Storage Stability for B100 Samples Having a Range of Initial Induction Periods

under these storage conditions, and even a nearly eight-hour induction time sample can be reduced to less than three hours in four weeks (simulated four months of storage). Figure 5 also shows that these materials, with one exception, are oxidizing and not just losing "oxidation reserve" because of the increasing peroxide value. Acid values remain relatively constant for the first four weeks of storage. Insoluble formation does not become significant until after eight weeks (simulated eight months) of storage.

B100 should not be stored longer than four months unless it has been treated with synthetic antioxidants. Nonoxidizing storage conditions in containers with little head space or under a nitrogen blanket will also be helpful. In fact, when B100 is being stored longer than about two months, it should be tested for oxidation stability every two weeks. One of the best ways to stabilize biodiesel is to blend it with petroleum diesel.

3.6.2 Microbial Contamination

Biocides are recommended for conventional and biodiesel fuels wherever biological growth in the fuel has been a problem. If biological contamination occurs, water contamination should be suspected and will need to be controlled because the aerobic fungus, bacteria, and yeast HC-utilizing microorganisms usually grow at the fuel-water interface. Anaerobic colonies, which usually reduce sulfur, can be active in sediments on tank surfaces and cause corrosion. Because the biocides work in the water phase, products that are used with diesel fuels work equally well with biodiesel.

3.6.3 Cleaning Effect

Methyl esters have been used as low-VOC (volatile organic compound) cleaners and solvents for decades. Methyl esters make excellent parts cleaners, and several companies offer methyl esters as a low-VOC, nontoxic replacement for the volatile solvents used in parts washers. Because B100 comprises methyl esters that meet ASTM D6751, it will dissolve the accumulated sediments in diesel storage and engine fuel tanks. These dissolved sediments can plug filters. If this happens, it can cause injector deposits and even fuel injector failure. If you plan to use or store B100 for the first time, clean the tanks and any parts in the fuel system where sediments or deposits may occur before filling the tanks with B100.

The level of cleaning depends on the amount of sediment in the system (if the system is sediment-free there should be no effect) as well as the biodiesel blend level (the higher the blend level, the greater the cleaning potential). The cleaning effect is much greater with B100 and blends with 35% or more biodiesel, in comparison to B20 and lower blends.

Biodiesel spills should be cleaned up immediately, because biodiesel can damage some types of body and engine paint. Biodiesel can also remove decals from tanks or vehicles near fueling areas. All materials that are used to absorb biodiesel spills should be considered combustible and stored in a safety can.

3.6.4 Materials Compatibility

B100 will degrade, soften, or seep through some hoses, gaskets, seals, elastomers, glues, and plastics with prolonged exposure. Some testing has been done with materials common to diesel systems, but more data are needed on the wide variety of grades and variations of compounds that can be found in these systems, particularly with B100 in U.S. applications. Nitrile rubber compounds, polypropylene, polyvinyl, and Tygon® materials are particularly vulnerable to B100. Before handling or using B100, ask the equipment vendor or OEM if the equipment is suitable for B100 or biodiesel. In some cases, the vendor may need the chemical family name for biodiesel (the methyl esters of fats and oils) to look up the information or even the exact chemical name of some of the biodiesel components, such as methyl oleate, methyl linoleate, methyl palmitate, or methyl stearate. Oxidized biodiesel and biodiesel blends can contain organic acids and other compounds that can significantly accelerate elastomer degradation. (Published data on B100 material compatibility are summarized in Appendix E.) There have been no significant material compatibility issues with B20, unless the B20 has been oxidized.

If your equipment is not compatible with B100, the materials should be replaced with materials such as Teflon, Viton, fluorinated plastics, and nylon. Consult B100 suppliers and equipment vendors to determine materials compatibility, and ask B100 vendors in other regions what problems they have experienced and what kind of replacement materials they are using. It is advisable to set up a monitoring program to visually inspect the equipment once a month for leaks, seeps, and seal decomposition. It would be wise to continue these inspections even after one year, as experience with B100 is still relatively limited.

3.6.5 Storage Tanks and Dispensing Equipment

Most tanks designed to store diesel fuel will store B100 with no problem. Acceptable storage tank materials include aluminum, steel, fluorinated polyethylene, fluorinated polypropylene, Teflon®, and most fiberglass. If you are in doubt, contact the tank vendor or check the National Biodiesel Board (NBB) Web site (*www.biodiesel.org*). Brass, bronze, copper, lead, tin, and zinc may accelerate the oxidation of diesel and biodiesel fuels and create fuel insolubles (sediments) or gels and salts when reacted with some fuel components. Lead solders and zinc linings should be avoided, as should copper pipes, brass regulators, and copper fittings. The fuel or fittings tend to change color, and insolubles may plug fuel filters. Affected equipment should be replaced with stainless steel, carbon steel, or aluminum.

In some locales, an Underwriters Laboratories (UL) listing is required by insurance companies or by state or local regulations for the tanks used for fuel storage and for equipment used to dispense fuels. (UL is an independent, not-for-profit, nongovernmental organization that tests products for public safety.) As biofuels use has become more widespread, the issue of UL listing has become a larger concern as UL-certified equipment for biodiesel and biodiesel blend service is extremely limited. Vendors must submit examples of their equipment to UL for testing. UL testing programs are currently underway for equipment to be used with biodiesel and biodiesel blends, including dispensers, aboveground steel tanks, underground steel tanks, nonmetallic tanks, aboveground and below-ground piping, coatings, sumps, and heating equipment. However, until UL certification is available, the lack of permissible equipment may be a barrier to biodiesel and biodiesel blend storage and use in some locations.

3.6.6 Transport

As with petroleum diesel, B100 must be transported in a way that does not lead to contamination. The following procedures are recommended for trucks and railcars and are used by distributors and transporters of petroleum-derived diesel:

- Ensure that trucks and railcars are constructed of aluminum, carbon steel, or stainless steel.
- Ensure proper inspection or washout (washout certificate) before loading.
- Check for previous load carried and residual. Generally only diesel fuel or biodiesel is acceptable as a residual. If the vessel has not gone through a washout, some residuals (including food products, raw plant oils, gasoline, or lubricants) may not be acceptable.
- Ensure that there is no residual water in the tank.
- Check that hoses and seals are clean and made from materials that are compatible with B100.
- Determine the need for insulation or a method to heat truck or rail car contents if shipping during cold weather. B100 is challenging to ship in cold weather. In the winter, most B100 is shipped in one of the following ways:
  - Hot (or at least warm), in trucks for immediate delivery at 27º to 54ºC (80º to 130ºF)
  - Hot, around 50ºC (122ºF), in railcars for delivery in seven to eight days (arrives warm if only one week has passed since loading)
  - Frozen, in railcars equipped with external steam coils (the fuel in the tank cars is melted at the final destination with steam)
  - In a blend with winter diesel, kerosene, or another low-cloud-point fuel in either railcars or trucks.

Regardless of how the biodiesel arrives, procedures that prevent the temperature of B100 from dropping below its cloud point must be used to store and handle it. The cloud point of the biodiesel, ambient temperatures, and the time the fuel is in transport should all be considered when transporting B100 to ensure that the fuel does not freeze.

3.7 Use of B100 and High Blend Levels

Most biodiesel currently in use involves blends of B20 or lower in a variety of applications. The price and lack of regulatory incentives have limited the experience with blend levels of B50 and higher. (One market actively involved in high blend levels is the underground mining industry, which is trying to limit workers' exposure to diesel PM.) Thus, most of the information in this section is intended for biodiesel use as a blending component. In particular, the D6751 specification does not claim to provide biodiesel of adequate quality for use as a pure fuel. If you want to use B100 as a fuel, these recommendations should help:

- Contact other B100 users. The NBB has names of individuals and businesses as well as reference materials about B100 storage, handling, and use. If you manage a fleet, contact your Fleet Management Association or Clean Cities Coalition to find out if anyone near you has experience with B100. Ask your B100 vendor for some recommendations.
- Ask other users what they did, how they did it, how long it took, how much it cost, what problems they encountered, how long they have been using B100, and what kinds of engines and equipment they use B100 in.
- Discuss your needs with your vehicle dealership and ask for advice, including any recommendations from European distributors or other U.S. fleet customers. You are probably not alone.
- Replace materials you know will be problematic and institute a monitoring program based on the information presented in Section 3.6.4, Materials Compatibility.
- Plan and budget for the time and expense of increased fuel filter changes or cleaning your fuel system when first starting to use B100.
- Read "Guidance on Blends Above B20" from the NBB.[16]

4.0 Biodiesel Blends

This section focuses on blending B100 with petroleum diesel to make B20, but the approach is similar for other blend levels, such as B2 or B5. As discussed in the previous sections, the performance properties of B100 can be significantly different from those of conventional diesel. Blending biodiesel into petroleum diesel can minimize these property differences and retain some of the benefits of B100. B20 is popular because it represents a good balance of cost, emissions, cold weather performance, materials compatibility, and ability to act as a solvent. B20 is also the minimum blend level that can be used for EPAct compliance for covered fleets.

4.1 Specifications

4.1.1 B5 and Lower Blends

The specification for conventional diesel fuel, ASTM D975, allows up to 5 vol % biodiesel to be blended into compliant diesel fuels. The biodiesel must meet D6751. The biodiesel blend must meet all the numeric requirements for diesel fuel properties specified in D975; none were changed or relaxed to accommodate biodiesel. ASTM Method D7371 Standard Test Method for Determination of Biodiesel (Fatty Acid Methyl Esters) Content in Diesel Fuel Oil Using Mid Infrared Spectroscopy (FTIR-ATR-PLS Method) must be used to determine the biodiesel blend percentage.

4.1.2 B6 to B20 Blends

A new ASTM specification (D7467) was recently published for blends containing 6 vol % to 20 vol % biodiesel. The biodiesel must meet D6751. The requirements of this new specification are shown in Table 6. The requirements are based on those in D975, with some additions. The 90% distillation temperature is allowed to be 5ºC higher than that for D975 diesel fuel. New requirements for acid number, biodiesel content, and oxidation stability are included. The specification is designed such that if a D6751-compliant B100 and a D975-compliant diesel fuel are blended, the resultant blend will meet the specification. However, diesel fuel that does not meet D975 can also be used (for example, by having inadequate lubricity, high sulfur, or high aromatics), and biodiesel can be used to blend these properties into compliance.

Table 6. ASTM D7467 Specification for Diesel Blends B6 to B20

Property	Test Method	Grade		
		B6 to B20 S15	B6 to B20 S500 [j]	B6 to B20 S5000 [k]
Acid Number, mg KOH/g, max.	D664	0.3	0.3	0.3
Viscosity, mm2/s at 40ºC	D445	1.9–4.1 [a]	1.9–4.1 [a]	1.9–4.1[a]
Flash Point, ºC, min	D93	52 [b]	52 [b]	52 [b]
Cloud Point, ºC, max	D2500	[c]	[c]	[c]
Sulfur Content, (µg/g)d mass %, max. mass %, max.	D5453 D2622 [e] D129	15 – –	- 0.05 –	- - 0.50
Distillation Temperature, ºC, 90% evaporated, max.	D86	343	343	343
Ramsbottom carbon residue on 10% bottoms, mass %, max.	D524	0.35	0.35	0.35
Cetane Number, min.	D613 [f]	40 [g]	40 [g]	40 [g]
One of the following must be met:				
(1) Cetane index, min.	D976-80 [e]	40	40	40
(2) Aromaticity, vol %, max.	D1319-88 [e]	35	35	-
Ash Content, mass %, max.	D482	0.01	0.01	0.01
Water and Sediment, vol %, max.	D2709	0.05	0.05	0.05
Copper Corrosion, 3 h @ 50ºC, max.	D130	No. 3	No. 3	No. 3
Biodiesel Content, % (V/V)	DXXXX [h]	6–20	6–20	6–20
Oxidation Stability, hours, min.	EN14112	6	6	6
Lubricity, HFRR @ 60ºC, micron, max.	D6079	520 [i]	520 [i]	520 [i]

[a] if Grade No. 1-D or blends of Grade No. 1-D and Grade No. 2-D diesel fuel are used, the minimum viscosity shall be 1.3 mm^2/s.

[b] If Grade No. 1-D or blends of Grade No. 1-D and Grade No. 2-D diesel fuel are used, or a cloud point of less than -12ºC) is specified, the minimum flash point shall be 38ºC.

[c] It is unrealistic to specify low-temperature properties that will ensure satisfactory operation at all ambient conditions. However, satisfactory operation below the cloud point (or wax appearance point) may be achieved depending on equipment design, operating conditions, and the use of flow-improver additives as described in X3.1.2. Appropriate low-temperature operability properties should be agreed upon between the fuel supplier and purchaser for the intended use and expected ambient temperatures. Test Methods D4539 and D6371 may be useful to estimate vehicle low temperature operability limits when flow improvers are used, but their use with Bxx blends from a full range of biodiesel feedstock sources has not been validated. Because of fuel delivery system, engine design, and test method differences, low-temperature operability tests may not provide the same degree of protection in various vehicle operating classes. Tenth percentile minimum air temperatures for U.S. locations are provided in Appendix X3 as a means of estimating expected regional temperatures. The tenth percentile minimum air temperatures may be used to estimate expected regional target temperatures for use with Test Methods D2500, D4539, and D6371. Refer to X3.1.3 for further general guidance on test application.

Footnotes d through k for Table 6 continued on next page.

Footnotes for Table 6 continued from previous page

[d] Other sulfur limits can apply in selected areas in the United States and in other countries.

[e] These test methods are specified in 40 CFR Part 80.

[f] Calculated cetane index approximation, Test Method D 4737, is not applicable to biodiesel blends.

[g] Low ambient temperatures as well as engine operation at high altitudes may require the use of fuels with higher cetane ratings. If the diesel fuel is qualified under Table 1 of D 975 for cetane, it is not necessary to measure the cetane number of the blend. This is because the cetane number of the individual blend components will be at least 40, so the resulting blend will also be at least 40 cetane number.

[h] Where specified, the blend level shall be +/- 2% volume unless a different tolerance is agreed to by the purchaser and the supplier.

[i] If the diesel fuel is qualified under Table 1 of D 975 for lubricity, it is not necessary to measure the lubricity of the blend. This is because the lubricity of the individual blend components will be at least 520 microns, so the resulting blend will also be at least 520 microns.

[j] Under U.S. regulations, if Grades B20 S500 are sold for tax-exempt purposes, then, at or beyond terminal storage tanks, it is required by 26 CFR Part 48 to contain the dye Solvent Red 164 at a concentration spectrally equivalent to 3.9 lb per thousand barrels of the solid dye standard Solvent Red 164, or the tax must be collected.

[k] Under U.S. regulations, Grades B20 S5000 are required by 40 CFR part 80 to contain a sufficient amount of the dye solvent Red 164 so its presence is visually apparent. At or beyond terminal storage tanks, they are required by 26 CFR Part 48 to contain the dye Solvent Red 164 at a concentration spectrally equivalent to 3.9 lb per thousand barrels of the solid dye standard Solvent Red 26.

4.2 Low-Temperature Properties

Blending biodiesel with petroleum diesel moderates the low-temperature operability problems of B100 by dilution. Conventional low-temperature operability additives can be used with blends, as these are believed to be effective in the petroleum portion of the blend. Research is ongoing to develop additives that are more effective with biodiesel blends and for handling B100 in cold weather. When biodiesel is blended with diesel fuel, the key variables are the properties of the diesel fuel, the properties of the biodiesel, the blend level, and the effectiveness of cold flow additives.

There are some critical metrics for low-temperature operability. For blends, these include the following:

- **Cloud point**. The temperature at which small solid crystals are first visually observed as the fuel is cooled (ASTM D2500, D5771, D5772, or D5773). Below the cloud point, these crystals might plug filters or drop to the bottom of a storage tank. Cloud point is the most widely used and most conservative estimate of the low-temperature operability limit. However, fuels can usually be pumped at temperatures below the cloud point. A related test is for the wax appearance point, ASTM D3117.
- **Pour point**. The temperature at which the fuel contains so many agglomerated crystals that it is essentially a gel and will no longer flow (ASTM D97, D5949, or D5950). Distributors and blenders use the pour point as an indicator of whether the fuel can be pumped, even if it would not be suitable for use without heating or taking other steps.
- **Cold filter plugging point (CFPP)**. This is the temperature under a standard set of test conditions, as defined in ASTM D6371, at which a fuel filter plugs. The CFPP test employs rapid cooling conditions. CFPP results more than 10ºC below the cloud point should be viewed with suspicion, because they may not reflect the true low temperature operability limit. The test simulates the performance of an average or typical vehicle and is not protective of the most challenging fuel system designs from a low-temperature operability standpoint, which make up roughly one-third of heavy-duty vehicles or one-fifth of light-duty vehicles.
- **Low-temperature flow test (LTFT).** This test also reports a temperature under a standard set of conditions, defined in ASTM D4539, at which a fuel filter plugs. LTFT employs slow cooling at 1ºC/h and simulates the most severe (and common) fuel system designs in North American heavy-duty trucks from the standpoint of low-temperature operability.

It is strongly recommended that you consult Appendix X.4 of ASTM D975 or X.3 of ASTM D7467 to understand the history and relative utility of tests for cloud point, CFPP, and LTFT.

B100 cold flow properties depend on the composition, which affects the cold flow properties of blends (Figure 6 through Figure 11). Measurements of cloud point and pour point are not exact, but have ±2ºC (±3.5ºF) repeatability. The same is true of diesel fuel. In addition, different No. 2 diesel fuels may have cloud points of -35º to

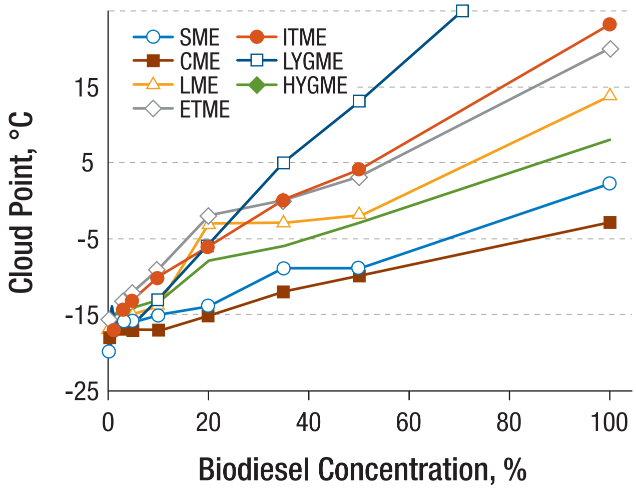


Figure 6. Biodiesel/Diesel Blend Cloud Point Test Results (abbreviations in graphs are defined in reference 18).

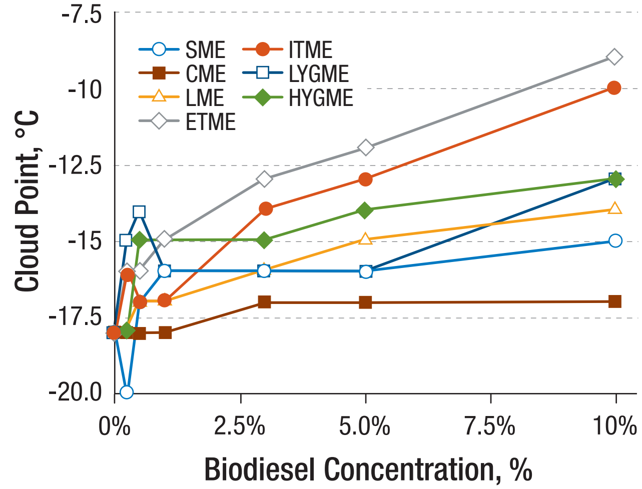


Figure 7. Biodiesel/Diesel Blend Cloud Point Test Results (0%–10% Biodiesel Blend Range)

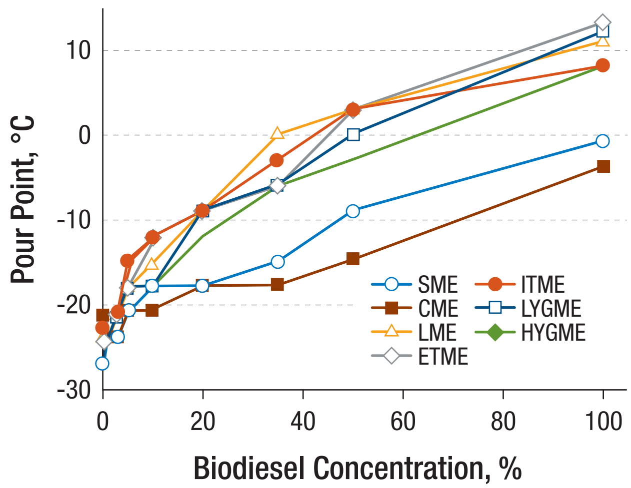


Figure 8. Biodiesel/Diesel Blend Pour Point Test Results

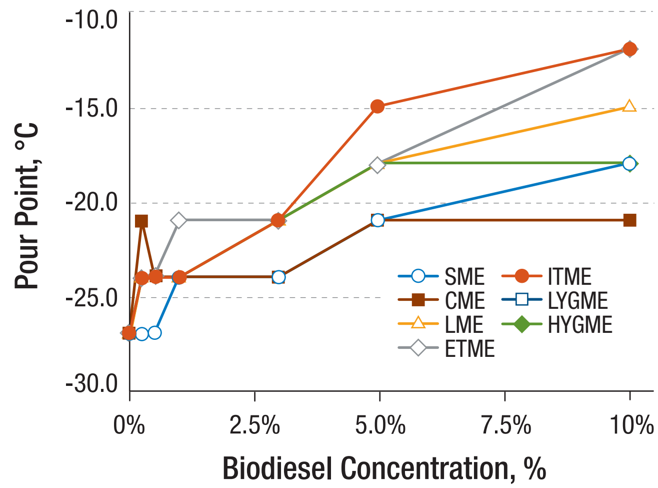


Figure 9. Biodiesel/Diesel Blend Pour Point Test Results (0%–10% Biodiesel Blend Range)

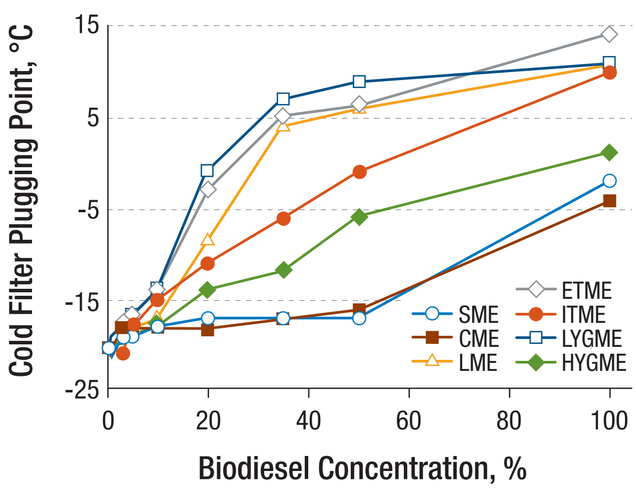


Figure 10. Biodiesel/Diesel Blend Cold Filter Plugging Point Test Results

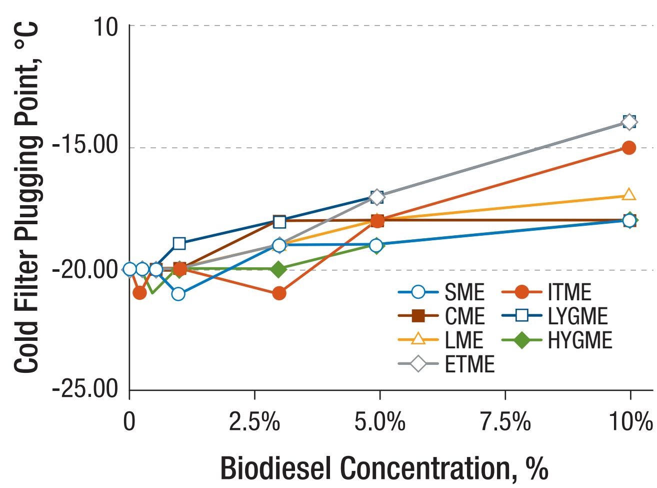


Figure 11. Biodiesel/Diesel Blend Cold Filter Plugging Point Test Results (0%–10% Biodiesel Blend Range)

-5ºC (-31º to 23ºF) (some fuels can be higher or lower than these figures). No. 1 diesel, jet A, or kerosene may have cloud points of -40º to -51ºC (-40º to -60ºF). Cloud point is the most widely used predictor of the low-temperature operability limit. A recent Coordinating Research Council study showed that biodiesel blends (B5 and B20) made from B100 meeting D6751-08a would provide operability down to the cloud point. Additives may allow operation at even lower temperatures.[17]

For biodiesel blends prepared from B100 meeting D6751-08a, the cloud point and LTFT will be nearly the same value, and CFPP will be 2º to 3ºC (3.5º to 5ºF) lower, if no low-temperature flow improver additives are used. Additives do not usually alter the cloud point, but they can lower LTFT. Thus, for additized fuels LTFT may be a better predictor of low-temperature operability.

Blends of No. 1 and No. 2 diesel fuel are frequently used to meet customer cold flow specifications (see Figure 12). Adjusting the blend of kerosene (or No. 1 diesel) in the diesel fuel alone or with additives can modify the cloud and pour point temperatures of B20. An accurate estimate of how B20 will perform in the winter months requires mixing the biodiesel with the winter diesel typically delivered in your area and testing the mixture.

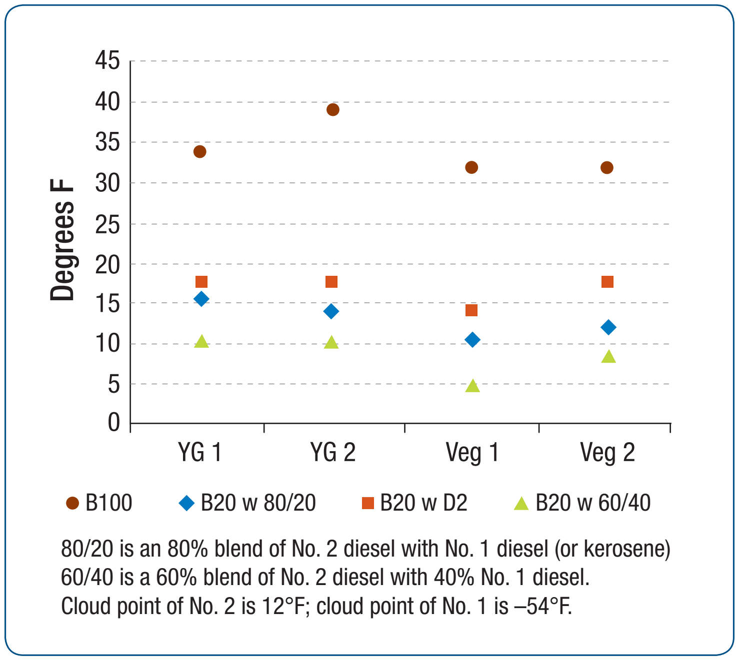


Figure 12. Adjusting Cloud Points of B20 Fuels with Blends of No. 1 and No. 2 Diesel (YG=yellow grease, Veg=vegetable oil)

Neither ASTM D975 nor ASTM D7467 has a specific requirement for the maximum cloud point, but the cloud point should be provided to the customer. This can be confusing to someone new to using diesel fuel or biodiesel. How can something be in the specification but not have an exact required value? The answer is that the cold flow properties needed for the fuel depend on where it is being used (for example, Michigan or Texas) and what time of year the fuel is being used (for example, January or July). A petroleum diesel or biodiesel fuel with a cloud point of 7ºC (20ºF) may be fine for a Texas summer, but not for a Michigan winter.

The appendices to the ASTM D975 and D7467 specifications contain maps of the 10th percentile minimum temperature for the central and northern tier states for various winter months. At the 10th percentile temperature, only 10% of the days were colder during that month on average, based on data from several decades. Some users and distributors use the 10th percentile as the target for their low-temperature operability requirement. Many diesel fuel users will specify a cloud point in their purchase contract—for example, that the fuel cloud point be no higher than the 10th percentile minimum temperature. Some users do not monitor cold flow properties at all, and they rely on their distributors to make sure the low-temperature operability is managed for their location.

The University of Minnesota Center for Diesel Research tested soy B20 made with various diesel fuels available in the region. The database of biodiesel blends (0%, 2%, 5%, 10%, 20%, 100%) shows how different diesel fuels and soy biodiesel blends alter cold flow properties (cloud point, pour point, and CFPP). CFPP is another measure of low-temperature operability that tends to predict an operability limit lower than the cloud point and may not protect the most challenging vehicles for low-temperature operability. Some of the data are shown in Figure 13.

No. 1 diesel fuel typically costs more than No. 2, so blenders may prefer to use additives. Many cold flow additives are available for diesel fuel. Most reduce the size of crystals or inhibit crystal formation in some way. Most have a limited effectiveness on B100 but work with varying degrees of effectiveness with B20.

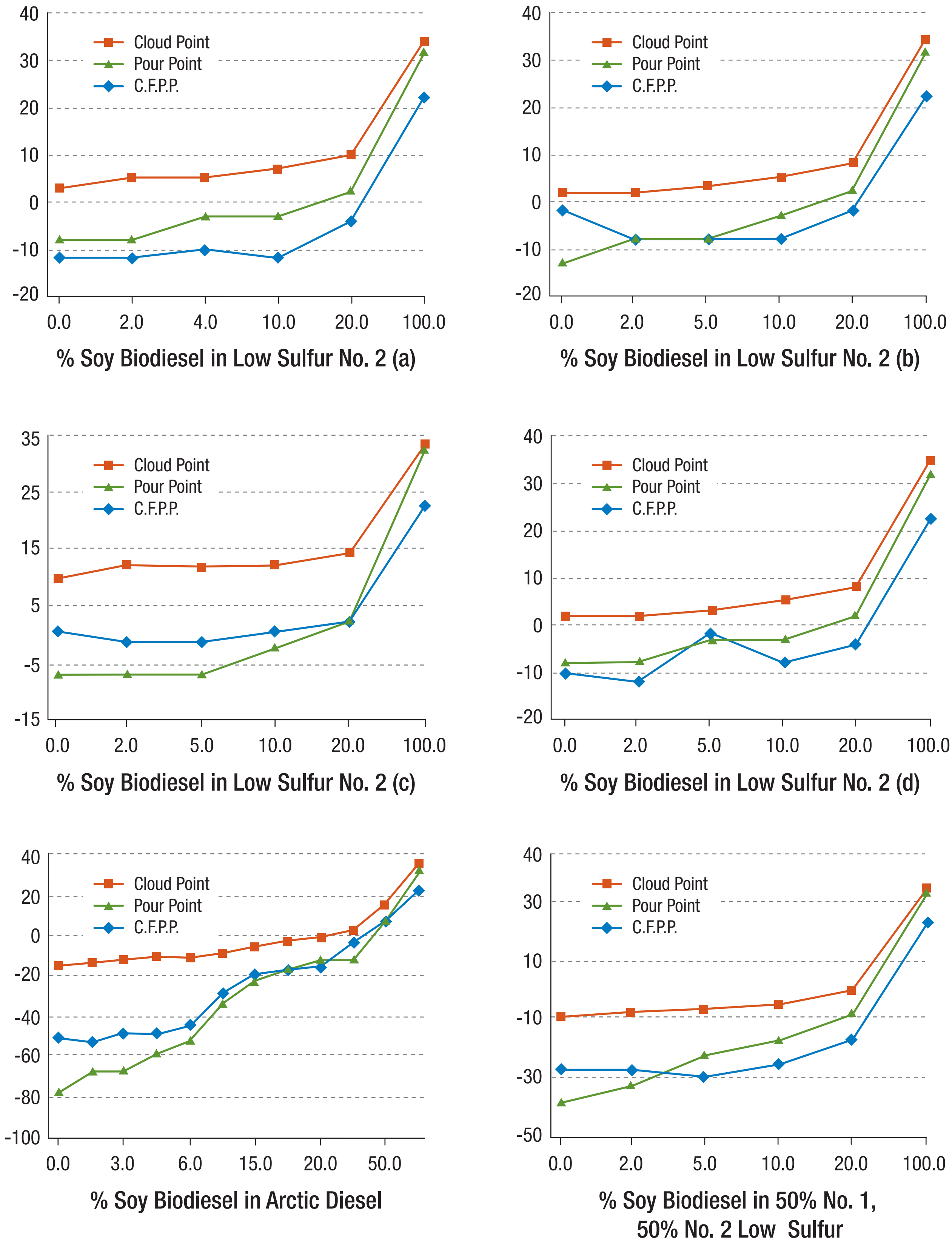


Figure 13. Cold Flow Properties of Some Soy Biodiesel Blends, ºF

Some blenders have specified feedstocks such as soy biodiesel in their purchasing contracts to obtain a biodiesel with a lower cloud point (relative to animal-fat-derived biodiesel). A more realistic approach may be to specify the cloud point of the B100. This may lock in a certain price range for biodiesel, but it can also ensure that the biodiesel has specific cold weather characteristics. It is important to consider the cost trade-offs of using less expensive biodiesel that might be higher in saturates, but require extra No. 1 diesel or additives for low-temperature operability, versus soy biodiesel and No. 2 diesel. A biodiesel supplier may be willing to switch from more highly saturated feedstocks in the summer to a more unsaturated feedstock in the winter. If low-temperature operability problems occur, a possible solution is to lower the biodiesel content in the blend during the coldest months. Most commonly, B20 users require their fuel supplier to ensure adequate low-temperature operability through contractual language. A purchase contract could specify that a fuel must remain crystal free at temperatures as low as -26ºC (-14ºF) (cloud point lower than -26ºC) for December, January, and February. Then the blender will work independently with the biodiesel and diesel suppliers and the additive firms to address these issues.

4.3 Lubricity

Blending biodiesel into petroleum diesel even at low levels can increase the lubricity of diesel fuel. As little as 0.25% biodiesel can significantly increase fuel lubricity.[14] Figure 14 shows the results of lubricity testing using the HFRR, the test used to determine if diesel fuels meet the ASTM lubricity requirement of a maximum 520 micron wear scar diameter. The exact blending level required to achieve adequate lubricity depends on the properties of the conventional diesel. Preliminary evidence suggests that 2% biodiesel almost always imparts adequate lubricity.

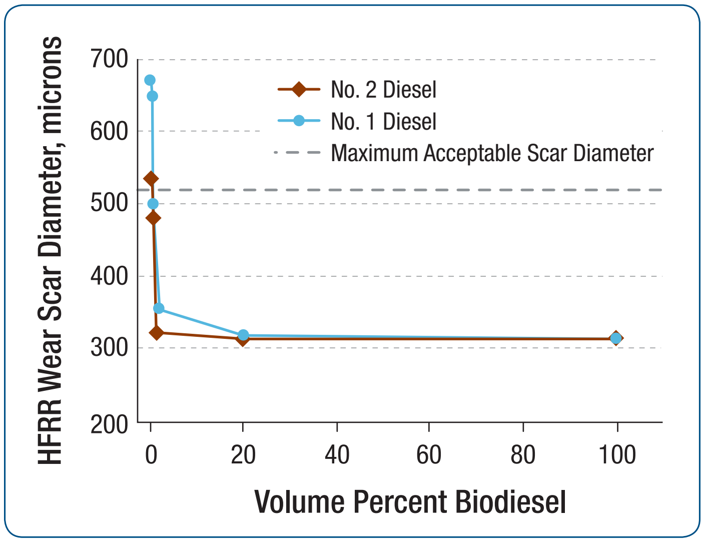


Figure 14. HFRR Lubricity as a Function of Biodiesel Content for a No. 1 and a No. 2 Diesel Fuel

4.4 Blending, Storage, and Transport

4.4.1 Blending

Most biodiesel users purchase finished B20 or lower blends from their petroleum distributors or biodiesel marketers. In this case, the distributor is responsible for ensuring that the biodiesel has been properly blended and that the cold flow properties of the finished blend will provide satisfactory performance for the area and time of year. Specify in your purchase contract or agreement that the fuel must meet certain low-temperature operability requirements.

Biodiesel blending procedures depend on a variety of factors, including the volume of B100 required to make the blend, the finished blend level, the volume of blended products being sold, tank and space availability, equipment and operational costs, and customer requirements for blends, both now and in the future. Biodiesel is a fuel for diesel applications only and is not to be blended with gasoline.

Generally, biodiesel is blended into diesel fuel via three primary methods:

- B100 is splash-blended with diesel fuel by the end user in a storage or transport truck.
- B100 is blended (via a variety of means) by a jobber or distribution company and offered for sale as a finished blend.
- B100 is blended at a petroleum terminal or rack by a pipeline or terminal company (usually through injection blending) and offered as a finished blend. This product is sold directly to customers or to a petroleum jobber or distribution company for further sale to customers. This is the preferred method because it ensures complete blending.

The chemical nature of biodiesel allows it to be blended with any kind of distillate or diesel fuel. This includes light fuels such as jet fuel, kerosene, No.1 diesel, and military fuels (JP8, JP5), as well as normal diesel fuel such as No. 2 diesel for diesel engines and gas turbines and heating oil for boilers and home heating. Once biodiesel is blended thoroughly with diesel fuel, it stays together as one fuel and does not separate over time provided it is maintained at temperatures above its cloud point.

In the early days of biodiesel blend use, volumes were too low for the conventional petroleum infrastructure to carry and handle the fuel economically. Most of the B20 used was splash-blended by the user after B100 arrived from a biodiesel supplier. As volumes increased, customers began to request B20 preblended from their petroleum diesel suppliers. These suppliers would then receive and store the B100, blend the biodiesel with petroleum diesel, and supply a finished blend to the customer. In some cases, the supplier might carry B100 and petroleum diesel in separate compartments in one truck and blend the two on the customer's site as the truck was unloaded.

The B100 should be stored as B20 or as another blend as soon as possible, regardless of the season. B100 is less stable than petroleum diesel blends, and cloud point considerations are less of a concern with blends during cold weather. If you have only a few B100 customers, you might consider setting aside a tote of B100 indoors or storing some underground or in heated tanks, depending on your climate, and blending the rest as soon as possible.

Always retain a one-quart sample of the diesel and B100 before blending the fuels. Once the customers have run through the current batch of fuel with no problems, you can mix them into the new batch of fuel. If any problems arise, these samples will help you determine whether they were caused by the fuel or by something else.

Recently, petroleum terminals and pipeline racks have been responding to increasing demand by installing a biodiesel blending capability. This is done so jobbers and distributors can receive a biodiesel blend directly from the rack and store and distribute only the blended biodiesel. This finished blend can then be sold to fleet or other applications that have some type of on-site storage. An increasing number of public pumps and key card pumps carry biodiesel blends for individual users or fleets that do not have their own on-site storage capability.

Many blending options are available, depending on your area. As the market matures and volumes continue to increase, the point of blending will likely occur further and further upstream in the distribution system, where it is most efficient and economical. This is likely to be especially true with lower blends of biodiesel, such as B2. Most users find blending their own fuel to be time-consuming and messy, so they increasingly request that their petroleum supplier make finished blends available.

The blending process is usually done by splash blending or in-line blending.

- **Splash blending.** Splash blending is appropriate for locations where the biodiesel and diesel fuel are loaded separately. In some cases, however, this is appropriate when the fuels are loaded at the same time through different incoming sources but at a high enough fill rate that the fuels are sufficiently mixed (several hundred gallons per minute for the diesel fuel). In some cases, the tank may need to be recirculated or further mixed to thoroughly blend the two fuels. Because biodiesel and diesel fuel mix easily and completely, splash blending can be sufficient to achieve a homogeneous blend, depending on the exact means of adding the fuel, the tank geometry, etc. If mixing is not complete, the slightly denser biodiesel will settle to the bottom. If the entire load is then pumped into a customer's tank, this action will usually be enough to cause complete mixing. But for loads split between customers, the load must be well mixed at the time of blending.

  B20 is frequently blended in bottom-loading tank trucks. The biodiesel is loaded into the tank truck first, followed by the diesel fuel. A homogeneous mixture should be obtained if the flow rate of the diesel fuel is adequate (several hundred gallons per minute). When the fuels are pumped from the truck into the B20 storage tank at the point of use, a final mixing occurs. This is generally enough mixing except in cold weather, when the ambient temperature is significantly below the B100 cloud point. Putting B100 into a cold, empty tank truck can cause the fuel to gel. Then the two fuels mix poorly or not at all. In cold weather, it is better to load half the diesel, then the biodiesel, and then the rest of the diesel fuel.

- **In-line blending.** In-line blending occurs when the biodiesel is added to a stream of diesel fuel as it travels through a pipe or hose in such a way that the biodiesel and diesel fuel become thoroughly mixed by the turbulent movement through the pipe. The biodiesel is added slowly and continuously into the moving stream of diesel fuel via a smaller line inserted in a larger pipe, or it can be added in small slug or pulsed quantities spread evenly throughout the time the petroleum diesel is being loaded. This is similar to the way most additives are blended into diesel fuel today, and it is most commonly used at pipeline terminals and racks. In some cases, distributors that carry B100 and petroleum diesel in separate compartments blend the two through in-line blending as they are loading fuel into a customer's tank.

  In-line blending uses two metered pumps and a dual-fuel injection system, and it requires an investment in equipment. This approach is the most accurate and reliable for guaranteeing a specific fuel blend. A variety of equipment is available for in-line blending. Systems have to be sized for a specific blend level (B2, B20) and generally cannot handle both types of blends.

In general, blending biodiesel is not difficult if you remember that biodiesel is slightly heavier and more viscous than diesel fuel, and the more it is mixed, the better.

Biodiesel has a specific gravity of 0.88 in comparison to No. 2 diesel at 0.85 and No. 1 diesel at 0.80. If biodiesel is put into an empty tank and diesel fuel is poured slowly on top, it may not blend properly, if at all. Or if you fill the tank with diesel and then slowly add biodiesel, it may go directly to the bottom of the tank (like slowly pouring honey into a glass of water). Biodiesel is heavier, so it may stay, unmixed, at the bottom of the tank. Most pumps draw from the bottom of a fuel tank, and if the fuel is not properly mixed, this bottom layer can contain high concentrations of biodiesel. The problems generally manifest themselves in cold months, as the high-concentration biodiesel fuel has a much higher cloud point, leading to plugging of filters and forming a gel layer at the bottom of aboveground tanks. Problems also can include leaks from hoses and gaskets that are compatible with B20 but not with higher blends. Because low-temperature operability problems may not occur in the summer, and any adverse effects on hoses and gaskets associated with higher blends may take some time to develop, users may go for many months without a problem. Another problem occurs when a concentrated layer of biodiesel starts to dissolve tank sediments. Filter clogging in warm months can be caused by this condition.

Two simple tests can be performed to determine if a tank has been thoroughly mixed.

- A top, middle, and bottom sample of the tank (see ASTM D4057 for the proper way to take a representative sample of a tank) can be taken and analyzed for the percent biodiesel using infrared spectroscopy or by measuring the specific gravity or density with any available means (e.g., digital density meter, hydrometer). If the values vary by no more than 0.006 specific gravity units from top to bottom, the mix is probably adequate. The test procedure for the percent biodiesel by infrared spectroscopy is ASTM D7371-07. Several instrument companies currently offer relatively inexpensive equipment to measure the percent biodiesel in the field, similar to that used for ethanol in gasoline.
- Put the samples from the three layers in a freezer with a thermometer and check every five minutes until the fuel in one sample begins to crystallize. Record that temperature. Then, check every few minutes until all three samples show crystallization. Compare the crystallization temperatures on all three samples; they should be within 3ºC (5ºF) of each other. Otherwise, the fuel will require agitation to mix thoroughly. Alternatively, the cloud point of the three samples could be measured, and values should be within 3ºC (5ºF) of each other.

Cold weather blending is a concern in situations in which the diesel fuel temperature falls below the cloud point of the B100 being blended. If the diesel fuel temperature is above the cloud point of the final blend, any crystals that form during blending should go back into solution. This process can be assisted by blending equipment that agitates the two fuels during blending. That agitation helps disperse the fuels and crystals more uniformly and can provide some energy to help the crystals dissolve.

Consider an example. Small-scale or hand blending shows the cloud point of the B20 blend will be -18ºC (0ºF), the cloud point of the diesel is -23ºC (-10ºF), and the biodiesel has a cloud point of 1ºC (34ºF) and is stored at a temperature above cloud point. The diesel fuel temperature is -6ºC (21ºF) on the day you decide to blend. The diesel fuel temperature is lower than the cloud point of your B100. This is an acceptable situation because the B20 cloud point is below the temperature of your diesel fuel, and the gap between the temperature of the diesel fuel and the target B20 cloud point is pretty generous, about 12ºC (21ºF). Any crystals that form during blending (because the diesel temperature is below the cloud point of the B100) will return to solution. If the gap were smaller, say 3ºC (5ºF), crystals may be slow to return to solution and have a chance to settle out.

Blends should be stored in tanks that can ensure that the fuel temperature will remain above the cloud point of the blend. Blended fuels can be stored below ground in most climates. B20 may be stored in aboveground tanks, depending on the cloud and pour points of the blended fuel and the local ambient weather conditions.

4.4.2 Stability

The storage stability of B5 and B20 blends has been examined recently using the D4625 test that simulates underground storage tank conditions. The test is accelerated by a factor of 4, such that one week of test time simulates one month of actual storage. Results for B5 blends are shown in Figure 15. Only one B100 shows increased peroxides, acids, or insolubles over the entire 12-week test, and this B100 did not meet the current stability requirement of a three-hour induction time. For B100 with a three-hour or longer induction time, the D4625 test shows no indication that oxidation is occurring in B5 blends under these test conditions. Based on these results, B5 blends

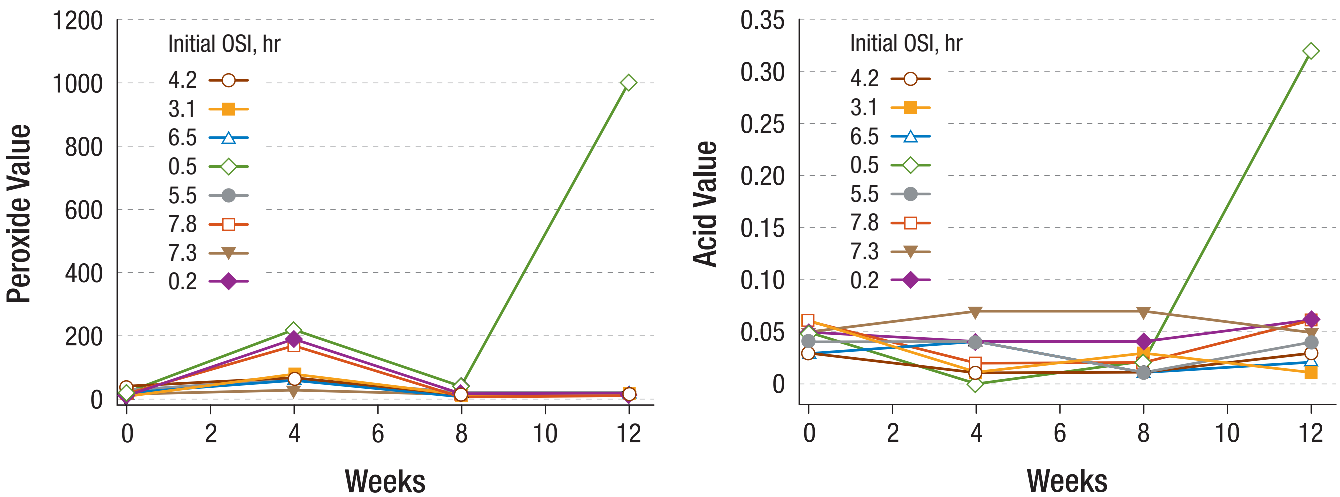
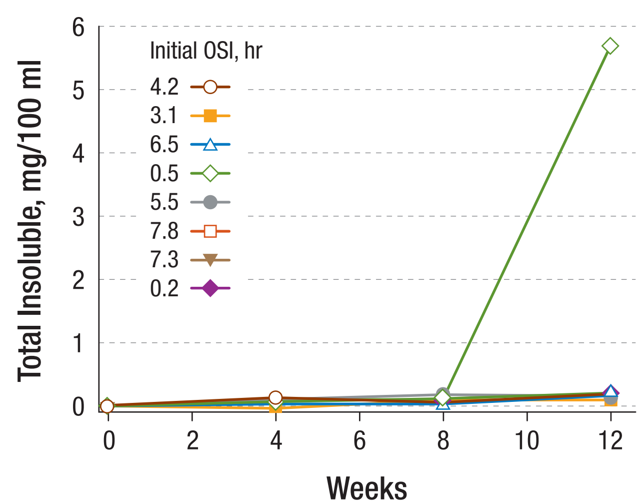


Figure 15. D4625 Storage Results for B5 Blends Made from B100 with Varying Levels of Oxidation Stability as Measured by the OSI Induction Time



made from in-specification B100 can be stored for up to one year. However, as biodiesel is still a relatively new fuel, we recommend that you consider adding a synthetic antioxidant or monitoring the condition of the fuel periodically if you store B5 for longer than a few months.

Figure 16 shows similar results for B20 blends. As for B5, only B100 with an oxidation stability level below the current specification shows indications of oxidation under these conditions. There may be some increase in acid value for one of the blends from an in-specification B100 after eight weeks, although this may be within the repeatability of the method. Thus, these results indicate storage of B20 for at least eight (and perhaps 12) months appears feasible under these conditions. Again, because biodiesel is still a relatively new fuel, and until more experience is gained in longer term storage, we recommend the use of a synthetic antioxidant or periodic monitoring until more data are available.

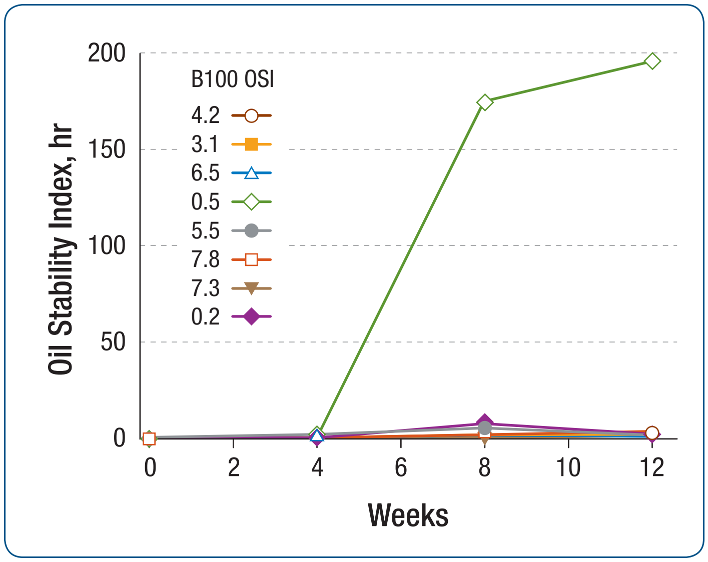


Figure 16. D4625 Storage Results for B20 Blends Made from B100 with Varying Levels of Oxidation Stability as Measured by OSI or Rancimat Induction Time

As biodiesel ages in storage, the induction period decreases, the acid number tends to increase and go out of specification, gums and varnish can form, and the viscosity can increase. Induction period, acid number, viscosity, and water and sediment tests can be used to ensure that your biodiesel blend meets ASTM specifications for either B6 to B20 or diesel fuel. Some data suggest that when oxidized or aged biodiesel is blended with diesel to make B20, some sediments and gums soluble in the B100 become insoluble and come out of solution, forming sediments. This information is presented as a warning only. You should never blend out-of-specification B100 into diesel to make B20. Make sure the induction period, water and sediment, acid number, and viscosity values are all in specification before blending.

Thermal stability is generally meant to indicate that the fuel is degrading when it is subjected to high temperatures for a short period, similar to what would be experienced in the fuel injector or fuel system of a modern diesel engine. If the fuel degrades in a hot engine, the primary concern is the potential for fuel pump and injector fouling or corrosion. Data suggest that thermal stability should not be a concern with biodiesel.

4.4.3 Cleaning Effect

Blends of 20% biodiesel or lower minimize any cleaning or solvent effect issues with accumulated sediments in tanks, although minor filter plugging may be observed during the initial weeks of B20 use. Blends higher than 20% should always be stored in clean, dry tanks as recommended for conventional diesel fuel. Using B20 for a year or more will probably not adequately clean your tanks and is not a substitute for a thorough tank cleaning when preparing for higher level blends or B100 storage.

Most people do not clean their tanks before B20 use, although it is still wise to keep some extra filters on hand and monitor potential filter clogging a little more closely than usual when first starting an engine on B20. The cleaning effect of the biodiesel in B20 is sufficiently diluted that most problems are insignificant, but a fuel filter may plug up when the fuel is first used. Drivers should be aware that sediments in the vehicle system might plug fuel filters during the first few weeks of using B20. Any filter clogging with B20, if it occurs at all, typically goes away after the first few times the tank is filled.

Some consumers who did not encounter problems with B20 assume they can switch to higher blends because the B20 has already cleaned their tanks. B20 is too dilute to clean tanks, so caution is still warranted with higher blends. The cleaning effect should not be an issue with B5 and lower blends.

4.4.4 Materials Compatibility

B20 or lower blends minimize most issues associated with materials compatibility. Experiences over the last 10 years indicate compatibility with all elastomers in diesel fuel systems, even those, such as nitrile rubber, that are sensitive to higher blends. Customers should thus continue to check for and fix leaks.

Improper or lengthy storage of biodiesel or biodiesel blends can result in oxidation and the formation of corrosive materials (including organic acids, water, and methanol) that can adversely affect vulnerable materials. Although only limited research has been done on this issue, tests indicate the degree of oxidation may be more important than the concentration of biodiesel. Unless they are used within a few months, biodiesel and biodiesel blends should be stabilized with antioxidants to reduce compatibility issues.

B20 may degrade faster than petroleum diesel if oxidizing metals such as copper, bronze, brass, or zinc are in the fueling systems. If filters clog more frequently with B20 than they do with petroleum diesel, the fueling system should be checked for these materials and they should be replaced with biodiesel-compatible parts. Typically, these metals are found in lead solders, zinc linings, copper pipes, and brass and copper fittings. Stainless steel, carbon steel, and aluminum are good replacements. Data on the materials compatibility of biodiesel blends are summarized in Appendix E.

5.0 BQ-9000 Program for Supply Chain Management

The biodiesel industry has developed a voluntary quality control program called BQ-9000 for producers and distributors to ensure biodiesel is produced according to ASTM specifications and ensure that consistent procedures are followed to prevent contamination and degradation during distribution, storage, and blending. It is managed by an independent organization, the National Biodiesel Accreditation Commission. Several engine manufacturers recommend the use of biodiesel from BQ-9000 certified sources. Consumers can avoid the need for independent testing by purchasing biodiesel fuels from certified distributors.

The BQ-9000 Program includes accredited producers and certified marketers, depending on which activity a firm specializes in. The firm—not the fuel—receives the accreditation, but the fuel supplied by either an accredited producer or a certified marketer must meet all applicable standards for sale and use in the United States. In July 2008, the NBB reported that 25 BQ-9000 accredited producers accounted for more than 70% of the biodiesel produced in the United States in 2008.

To become an accredited producer, a firm must develop a system for monitoring the production of biodiesel through proper sampling, testing, storage, sample retention, and shipping protocols, and these protocols must be rigorously followed. A certificate of analysis (COA) must be generated for each production lot with a unique identification code and analytical results from a sample (see a sample COA in Appendix F). Testing must include at least nine parameters of the current ASTM specification: visual appearance, free and total glycerin, flash point, acid number, water and sediment, oxidative stability, sulfur, and cloud point. The producer must also ensure the transport vehicles are clean and of appropriate construction for distributing biodiesel.

The certified marketer must either purchase B100 from an accredited producer, or conduct fuel quality testing on all biodiesel purchased from nonaccredited producers. The certified marketer must also maintain storage and distribution procedures that protect the biodiesel's quality.

Regular audits of accredited producers and certified marketers ensure that these standards are enforced.

More specific information on all aspects of the BQ-9000 Program can be found at *www.bq-9000.org*.

6.0 Engine Warranties

Among the variety of statements about biodiesel use from engine or vehicle manufacturers, some refer to warranty. Engine and vehicle manufacturers provide a materials and workmanship warranty on their products. Such warranties do not cover damage caused by some external condition. Thus, if an engine using biodiesel experiences a failure unrelated to the biodiesel use, it must be covered by the OEM's warranty. Federal law prohibits the voiding of a warranty just because biodiesel was used—it has to be the cause of the failure. If an engine experiences a failure caused by biodiesel use (or any other external condition, such as bad diesel fuel), the damage will not be covered by the OEM's warranty.

Many engine OEMs acknowledge biodiesel use by stating their observations about harmful effects (or lack thereof) with various blends in their equipment. Most OEMs declared a lack of harmful effects for B5 and lower blends, based on a statement by the leading fuel injection equipment suppliers, as long as the biodiesel meets ASTM D6751 or the European biodiesel specification. Some OEMs recognize higher blend levels. More evaluation is underway in the diesel engine industry related to biodiesel and its effects on diesel engines.

Damage directly attributable to biodiesel will not be covered by an engine OEM's warranty, but may be covered by the fuel supplier's general liability insurance. New biodiesel users should be sure their biodiesel suppliers provide liability coverage on the biodiesel and its blends. For an updated list of OEMs and their position statements, visit the NBB Web site at *www.biodiesel.org/resources/fuelfactsheets/standards_and_warranties.shtm*.

7.0 Taxes and Incentives

Biodiesel is not exempt from federal excise taxes, nor is it exempt from most state and local taxes. This means that biodiesel and biodiesel blends are taxed at the same rate as diesel fuel. Some states have passed legislation that either reduces fuel excise taxes or provides other incentives. For local exceptions to this statement, contact local tax authorities.

If you are using B100 or any blend of biodiesel in a vehicle that uses any public road, you are responsible for remitting federal, state, and local taxes on the fuel, including the biodiesel fraction, in a timely manner. This requirement applies to biodiesel that you make yourself and to B100 that you purchase and use in your own operations. If you are blending B100 that you purchased, and either using the B20 yourself, or selling it to others, you are responsible for remitting the federal, state, and local taxes in a timely way. To clarify, most B100 is sold on a pretax basis, so the blender or user is responsible for collecting and remitting taxes. For most commercial blend users, the blenders have already included the taxes owed in the sale price of the fuel. Check your invoice or talk to your supplier if you have questions. The customer is responsible for ensuring the taxes are paid.

The federal government currently offers some incentives related to biodiesel. Grant programs, tax credits for blending biodiesel, and investment opportunities in certain refueling infrastructures are available. The DOE Clean Cities Program maintains a Web site that summarizes state and local laws and incentives related to alternative fuels at *www.eere.energy.gov/cleancities/vbg/progs/laws.cgi*. Another good resource for information about federal incentives is the NBB Web site at *www.biodiesel.org*.

Since 2005, the federal government has offered a blender's tax credit of $1.00/gal for agri-biodiesel (derived from plant oil or animal fat) and $0.50/gal for recycled oil-derived biodiesel. These tax credits expire on December 31, 2008. The IRS has defined a blending event as adding 1 gallon of diesel fuel to 999 gallons of B100. Thus, it has become common to sell and ship B99.9 and B99. If you are blending B99.9 or B99 to make lower level blends, you probably cannot claim the blender's tax credit, since it was already claimed by the party who added the 0.1% or 1% diesel fuel.

7.1 Off-Road Diesel

Biodiesel or petroleum diesel intended for off-road use (agriculture, power, boiler fuels, construction, forestry, or mining) is not subject to federal excise taxes. However, if it is sold for one of these tax exempt purposes, and no tax is collected, the IRS (26 CFR 48.4082-1) requires that it be dyed with the dye solvent Red 164 at a concentration spectrally equivalent to at least 3.9 pounds of the solid dye standard solvent Red 26 per thousand barrels of diesel fuel or kerosene.

8.0 Safety, Health, and Environmental Issues

Biodiesel contains no hazardous materials and is generally regarded as safe. A number of studies have found that biodiesel biodegrades much more rapidly than conventional diesel. Users in environmentally sensitive areas such as wetlands, marine environments, and national parks have taken advantage of this property by replacing toxic petroleum diesel with biodiesel.

Like any fuel, biodiesel will burn; thus, certain fire safety precautions must be taken as described in this section. Of much greater concern are biodiesel blends that may contain kerosene or petroleum diesel. Kerosene is highly flammable with a flash point of 100° to 162°F (38° to 72°C). Diesel fuel is generally considered flammable; its flash point is 126° to 204°F (52° to 96°C). The flash point of biodiesel is higher than 212°F (100C°), so it is considerably less dangerous. However, biodiesel blends will have flash points intermediate to the two liquids. The U.S. Department of Transportation (DOT) considers a blend flammable and the Resource Conservation & Recovery Act of 1976 (RCRA) considers it to be ignitable if the flash point is lower than 140°F (60°C) or (DOT) combustible if the flash point is 140° to 200°F (60° to 93°C).

8.1 Signs, Labels, and Stickers

No placards or warning signs are required for the transport of pure biodiesel. However, biodiesel blends with diesel and kerosene are required to be transported in placarded trucks if the flash point of the blend is lower than 200°F (93°C), according to federal DOT regulations. If the flash point is lower than 140°F (60°C), the liquid is considered flammable and the Hazard Class 3 flammable placard is required (see Figure 17). Between 140° and 200°F (60° to 93°C), the liquid is generally considered to be Hazard Class 3 combustible, and the combustible placard shown in Figure 17 is required for transport.

Local fire regulations determine the requirements for signage on storage containers, but typically, tanks containing fuels (including B100) must be labeled with NFPA diamonds. The NFPA diamonds will indicate whether the fuel is flammable or combustible.

Figure 17. Placards for Transport of Combustible and Flammable Liquids

8.2 Fire Safety Considerations

Pure biodiesel can be extinguished with dry chemical, foam, halon, CO_2, or water spray, although the water stream may splash the burning liquid and spread fire. Oil-soaked rags can cause spontaneous combustion if they are not handled properly. Before disposal, wash rags with soap and water and dry them in well-ventilated areas. Because biodiesel will burn if ignited, keep it away from oxidizing agents, excessive heat, and ignition sources.

9.0 Frequently Asked Questions

What is biodiesel made from?

Biodiesel can be made from a variety of renewable sources such as plant oils (soybeans or other crops), recycled cooking grease, or animal fats. These feedstocks are used to manufacture a mixture of chemicals called fatty acid methyl esters (i.e., biodiesel).

Which feedstock is best?

Each feedstock can produce a high-quality B100 fuel but with slightly different properties, especially cloud point, cetane number, oxidative stability, and NOx emissions. Cost might also factor into the selection process. Most operational differences seen with B100 are reduced when B20 is produced. Most remaining differences can be managed with additives or diesel fuel blending strategies.

Does biodiesel affect how my engine operates?

Biodiesel blends of 20% or lower should not noticeably change engine performance. Some users of biodiesel blends notice significant reductions in soot, and CO and HC emissions are reduced. Higher blend levels can reduce fuel economy, torque, and power, but they will also produce lower PM, HC, and CO emissions. However, NOx may rise at higher blend levels.

Does using biodiesel void my warranty?

Original equipment manufacturers provide materials and workmanship warranties on their products. Such warranties do not cover damage caused by external conditions such as fuel. Thus, if an engine using biodiesel experiences a failure unrelated to the biodiesel use, it must be covered by the OEM's warranty. Federal law prohibits the voiding of a warranty just because biodiesel was used—it has to be the cause of the failure. If an engine experiences a failure caused by biodiesel (or any other external condition, such as bad diesel fuel), it will not be covered by the OEM's warranty. OEM positions on biodiesel blends and blend levels vary, and can be found on the NBB Web site (*www.biodiesel.org*).

Do I need to modify my vehicle to use biodiesel?

Users' experiences indicate that no vehicle modifications appear necessary for blends as high as 20% biodiesel mixed with diesel fuel. Higher blend levels may require minor modifications to seals, gaskets, and other parts. Tank and fuel line/fuel filter heaters (arctic packages) are recommended for blends higher than 20% biodiesel. Although a primary focus of NBB and NREL, detailed long-term engine durability data have not been established for B20 in the United States, so good maintenance practices are recommended.

Do I need to modify my dispensing equipment to use biodiesel?

Dispensing equipment does not need to be modified for blends of 20% biodiesel or lower, unless there is an issue with specific elastomers that are not compatible with B20. Occasional fuel filter plugging has been reported, and some people filter the biodiesel fuels entering or leaving the tank. Some exposed parts of the dispensing systems may need protection from freezing in cold climates. Tank cleaning is recommended before switching to B20 fuels.

How do biodiesel (B20 and B100) emissions compare with diesel emissions?

The EPA has conducted a comprehensive study of 80 biodiesel emission tests in CI engines (see Figure 2 in Section 2, which shows emission benefits for different biodiesel blend levels).

Does biodiesel use raise NOx emissions?

Blends lower than 5% do not have a measurable affect on NOx. For B20 blends, vehicle testing ongoing at NREL is finding no significant impact on NOx; however, engine test stand studies find B20 increases NOx emissions by about 2% over those of conventional diesel. Some B100 can raise NOx above the certification limits of CI engines. The impact of biodiesel on NOx is discussed in Section 2.4.

Biodiesel blends used in heating oil equipment will reduce NOx by 1% for every 1% of biodiesel used in the blend.

How much biodiesel is used and produced in the United States?

The NBB estimated U.S. production capacity for biodiesel at the beginning of 2008 to be 2.24 billion gallons per year. During the first four months of 2008, the Energy Information Agency (EIA) estimated that about 196 million gallons of biodiesel were produced (roughly on track to produce 600 million gallons in 2008). Much of the biodiesel production capacity has been built during the last five years.

Can I use biodiesel in a cold climate?

Users' experiences with cold weather vary. B20 blends are used in some very cold climates, such as northern Minnesota and Wyoming, where temperatures routinely fall below -30°F (1°C) in the winter. For example, B20 was used in an airport shuttle fleet for four years in Boston with no problems. Cold flow additives are applicable with biodiesel blends.

Some users have reported using B100 in extremely cold climates, such as in Yellowstone National Park. The vehicles were equipped with winterization packages, and no other precautions were noted. Widespread experience with B100 and higher blends in cold climates is lacking in the United States, so users should be alert to potential problems and take reasonable steps to prevent them.

10.0 Information Resources

A number of resources provide additional details and technical information in support of these guidelines. They include the following:

The National Biodiesel Board's online documents library and information number:
www.biodiesel.org/resources/reportsdatabase/
1-800-841-5849

The National Renewable Energy Laboratory's technical publications on biodiesel:
www.nrel.gov/vehiclesandfuels/npbf/pubs_biodiesel.html

The U.S. Department of Energy's Alternative Fuels and Advanced Vehicles Data Center:
http://www.eere.energy.gov/afdc/

The U.S. Department of Energy's technical publications:
www.eere.energy.gov/biomass/document_database.html

The U.S. Environmental Protection Agency's Renewable Fuel Program:
www.epa.gov/otaq/renewablefuels/index.html

Iowa State University also offers classes in biodiesel production, analytical test methods, and business management and provides an online tutorial on biodiesel:
www3.me.iastate.edu/biodiesel/Pages/biodiesel1.html.

You may also contact your Clean Cities representative (*www.eere.energy.gov/cleancities/*) and biodiesel suppliers for more information.

11.0 Glossary

Additive: Material added in small amounts to finished fuel products to improve certain properties or characteristics.

Antioxidant: Substance that inhibits reactions promoted by oxygen.

Biodiesel: Methyl esters of fatty acids meeting the requirements of ASTM specification D6751.

Biodegradable: Capable of being broken down by the action of microorganisms.

Boiling range: The spread of temperature over which a fuel, or other mixture of compounds, distills.

Cetane index: An approximation that correlates with a diesel fuels aromatic content based on an empirical relationship with density and volatility parameters such as the mid-boiling point; widely mistaken as an approximation of cetane number. This approximation is not valid for biodiesel or biodiesel blends.

Cetane number: A measure of the ignition quality of diesel fuel based on ignition delay in an engine. The higher the cetane number, the shorter the ignition delay and the better the ignition quality.

CI: Compression ignition, the ignition process used in a diesel engine.

Cloud point: The temperature at which a sample of a fuel just shows a cloud or haze of wax (or in the case of biodiesel, methyl ester) crystals when it is cooled under standard test conditions, as defined in ASTM D2500.

ECRA: Energy Conservation and Reauthorization Act of 1998, amended EPAct to allow qualified fleets to use B20 in existing vehicles to generate AFV purchase credits, with some limitations.

Elastomer: A rubber-type material frequently used in vehicle fuel systems (but not necessarily natural or synthetic rubber; may also apply to other polymers).

Energy content: The heat produced on combustion of a specified volume or mass of fuel; also known as heating value or heat of combustion.

EPAct: Energy Policy Act of 1992. Title III provides incentives to promote the use of alternative fuel vehicles in transportation.

FAME: Fatty acid methyl esters. A mono alkyl ester of long-chain fatty acids from naturally occurring plant oils, animal fats, and recycled greases.

Fatty acid: Any of the saturated or unsaturated monocarboxylic acids that occur naturally in the form of triglycerides (or mono or diglycerides) or as free fatty acids in fats and fatty oils.

Flash point: The lowest temperature at which vapors from a fuel will ignite when a small flame is applied under standard test conditions.

Free fatty acids: Any saturated or unsaturated monocarboxylic acids that occur naturally in fats, oils, or greases but are not attached to glycerol backbones. These can lead to high acid fuels and require special processes technology to convert into biodiesel.

HC: Hydrocarbon, a compound composed of hydrogen and carbon. Hydrocarbons can refer to fuel components and to unburned or poorly combusted components in vehicle exhaust.

Kerosene: A refined petroleum distillate, of which different grades are used as lamp oil, as heating oil, blended into diesel fuel, and as fuel for aviation turbine engines.

Lubricity: The ability of a fuel to lubricate.

Microbial contamination: Containing deposits or suspended matter formed by microbial degradation of the fuel.

OEM: Original equipment manufacturer.

Oxidation: Loosely, the chemical combination of oxygen to a molecule.

Oxidative stability: The ability of a fuel to resist oxidation during storage or use.

Oxygenate: A fuel component that contains oxygen, i.e., biodiesel or ethanol.

PM: Particulate matter, the solid or semi-solid compounds of unburned fuel that are emitted from engines.

Polyunsaturated fatty acids: Fatty acids with more than one double bond.

Pour point: The lowest temperature at which a fuel will just flow when tested under standard conditions, as defined in ASTM D97.

Saturation or saturated compound: A paraffinic hydrocarbon or fatty acid, i.e. one with only single bonds and no double or triple bonds.

Solvent: A liquid capable of dissolving another substance to form a solution, which is a homogeneous mixture composed of two or more substances.

Specific gravity: The ratio of the density of a substance to the density of water.

Splash blending: The fuels to be blended are delivered separately into a tank truck.

Stratification: To separate into layers.

Storage stability: The ability of a fuel to resist deterioration due to oxidation during storage.

Torque: A force that produces rotation.

Viscosity: A measure of the resistance to flow of a liquid.

Appendix A: Sample Biodiesel Material Safety Data Sheet

Chemical Product

General Product Name: **Biodiesel**
Synonyms: Methyl Soyate, Rapeseed Methyl Ester (RME), Methyl Tallowate
Product Description: Methyl esters from lipid sources
CAS Number: Methyl Soyate: 67784-80-9; RME: 73891-99-3; Methyl Tallowate: 61788-71-2

Composition/Information On Ingredients

This product contains no hazardous materials.

Hazards Identification

Potential Health Effects:

INHALATION: Negligible unless heated to produce vapors. Vapors or finely misted materials may irritate the mucous membranes and cause irritation, dizziness, and nausea. Remove to fresh air.

EYE CONTACT: May cause irritation. Irrigate eye with water for at least 15 to 20 minutes. Seek medical attention if symptoms persist.

SKIN CONTACT: Prolonged or repeated contact is not likely to cause significant skin irritation. Material is sometimes encountered at elevated temperatures. Thermal burns are possible.

INGESTION: No hazards anticipated from ingestion incidental to industrial exposure.

First Aid Measures

EYES: Irrigate eyes with a heavy stream of water for at least 15 to 20 minutes.

SKIN: Wash exposed areas of the body with soap and water.

INHALATION: Remove from area of exposure, seek medical attention if symptoms persist.

INGESTION: Give one or two glasses of water to drink. If gastrointestinal symptoms develop, consult medical personnel. (Never give anything by mouth to an unconscious person.)

Fire Fighting Measures

Flash Point (Method Used): 130.0° C min (ASTM 93)

Flammability Limits: None known

EXTINGUISHING MEDIA: Dry chemical, foam, halon, CO_2, water spray (fog). Water stream may splash the burning liquid and spread fire.

SPECIAL FIRE FIGHTING PROCEDURES: Use water spray to cool drums exposed to fire.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Oil soaked rags can cause spontaneous combustion if not handled properly. Before disposal, wash rags with soap and water and dry in well ventilated area. Firefighters should use self-contained breathing apparatus to avoid exposure to smoke and vapor.

Accidental Release Measures Spill Clean-Up Procedures

Remove sources of ignition, contain spill to smallest area possible. Stop leak if possible.

Pick up small spills with absorbent materials such as paper towels, “Oil Dry,” sand, or dirt.

Recover large spills for salvage or disposal. Wash hard surfaces with safety solvent or detergent to remove remaining oil film. Greasy nature will result in a slippery surface.

Appendix A: Sample Biodiesel Material Safety Data Sheet

Handling and Storage

Store in closed containers between 50°F and 120°F.

Keep away from oxidizing agents, excessive heat, and ignition sources.

Store and use in well-ventilated areas.

Do not store or use near heat, spark, or flame, store out of sun.

Do not puncture, drag, or slide this container.

Drum is not a pressure vessel; never use pressure to empty.

Exposure Control /Personal Protection

RESPIRATORY PROTECTION: If vapors or mists are generated, wear a NIOSH-approved organic vapor/mist respirator.

PROTECTIVE CLOTHING: Safety glasses, goggles, or face shield recommended to protect eyes from mists or splashing. PVC-coated gloves recommended to prevent skin contact.

OTHER PROTECTIVE MEASURES: Employees must practice good personal hygiene, washing exposed areas of skin several times daily and laundering contaminated clothing before re-use.

Physical and Chemical Properties

Boiling Point, 760 mm Hg:>200°C Volatiles, % by Volume: <2

Specific Gravity (H2O=1): 0.88 Solubility in H2O, % by Volume: insoluble

Vapor Pressure, mm Hg: <2 Evaporation Rate, Butyl Acetate=1: <1

Vapor Density, Air=1: >1

Appearance and Odor: pale yellow liquid, mild odor

Stability and Reactivity

GENERAL: This product is stable and hazardous polymerization will not occur.

INCOMPATIBLE MATERIALS AND CONDITIONS TO AVOID: Strong oxidizing agents

HAZARDOUS DECOMPOSITION PRODUCTS: Combustion produces carbon monoxide, carbon dioxide along with thick smoke.

Disposal Considerations

WASTE DISPOSAL: Waste may be disposed of by a licensed waste disposal company. Contaminated absorbent material may be disposed of in an approved landfill. Follow local, state, and federal disposal regulations.

Transport Information

UN HAZARD CLASS: N/A

NMFC (National Motor Freight Classification):

PROPER SHIPPING NAME: Fatty acid ester

IDENTIFICATION NUMBER: 144920

SHIPPING CLASSIFICATION: 65

Appendix A: Sample Biodiesel Material Safety Data Sheet

Regulatory Information

OSHA STATUS: This product is not hazardous under the criteria of the Federal OSHA Hazard Communication Standard 29 CFR 1910.1200. However, thermal processing and decomposition fumes from this product may be hazardous, as noted in Sections 2 and 3.

TSCA STATUS: This product is listed on TSCA.

CERCLA (Comprehensive Response Compensation and Liability Act): NOT reportable.

SARA TITLE III (Superfund Amendments and Reauthorization Act):
Section 312 Extremely Hazardous Substances: None
Section 311/312 Hazard Categories: Nonhazardous under Section 311/312
Section 313 Toxic Chemicals: None

RCRA STATUS: If discarded in its purchased form, this product would not be a hazardous waste either by listing or by characteristic. However, under RCRA, it is the responsibility of the product user to determine at the time of disposal, whether a material containing the product or derived from the product should be classified as a hazardous waste (40 CFR 261.20-24)

CALIFORNIA PROPOSITION 65: The following statement is made in order to comply with the California Safe Drinking Water and Toxic Enforcement Act of 1986. This product contains no chemicals known to the state of California to cause cancer.

Other Information

This information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any other process. Such information is to the best of the company's knowledge and believed accurate and reliable as of the date indicated. However, no representation, warranty or guarantee of any kind, express or implied, is made as to its accuracy, reliability or completeness and we assume no responsibility for any loss, damage or expense, direct or consequential, arising out of use. It is the user's responsibility to satisfy himself as to the suitableness and completeness of such information for his own particular use.

Appendix B: Renewable Identification Number

As part of the Energy Policy Act of 2005, Congress created a Renewable Fuel Standard (RFS) - a requirement that a certain amount of renewable fuel be used in the United States. The RFS was updated and increased in the Energy Independence and Security Act of 2007. A Renewable Identification Number is used to track compliance with the RFS in terms of volumes of renewable as well as credits, trading, and compliance by obligated parties. Additional information is available at EPA's Web site on the RFS: *www.epa.gov/otaq/renewablefuels/index.htm*.

Appendix C: Biodiesel Use as an EPAct Alternative Fuel

EPAct was passed by Congress to reduce the nation's dependence on imported petroleum by requiring certain fleets to acquire AFVs, which can operate on nonpetroleum fuels. Compliance with EPAct is met by credits awarded for acquisition of AFVs.

ECRA amended EPAct to allow credit for B20 use. DOE's Biodiesel Fuel Use Credit Interim Final Rule became effective in January 2001, allowing covered fleets to meet EPAct requirements by purchasing biodiesel fuel.

One biodiesel fuel use credit, which is counted as one AFV acquisition, is allocated to fleets for each purchase of 450 gallons of neat biodiesel fuel, for use in diesel vehicles heavier than 8,500 lb gross vehicle weight rating. The biodiesel must be neat (B100) or in blends that contain by volume at least 20% biodiesel (B20). Fleets are allowed to use these credits to fulfill up to 50% of their EPAct requirements. (Biodiesel fuel providers can meet up to 100% of their requirements by using biodiesel fuel use credits.) These credits can be claimed only in the year in which the fuel is purchased for use, and cannot be traded between fleets.

For further information, visit the EPAct Web page at
www.eere.energy.gov/vehiclesandfuels/deployment/fcvt_epact.shtml

Appendix D: Density and Viscosity as a Function of Temperature

Density as a Function of Temperature

Because the density of biodiesel varies with temperature, and biodiesel is typically sold by volume, the density of biodiesel as a function of temperature can be an important factor in biodiesel commerce. The density of biodiesel decreases linearly with temperature. Table D-1 shows soy biodiesel density by temperature. At the same temperature, biodiesels from different sources have different densities, so these values should not be used for any fuel other than soy biodiesel.

Appendix D: Density and Viscosity as a Function of Temperature

Table D-1. Density of Soy Biodiesel as a Function of Temperature[23]

Temperature		Density	
°F	°C	Specific Gravity	lb/gal
35	1.7	0.896	7.48
36	2.2	0.896	7.48
37	2.8	0.896	7.48
38	3.3	0.895	7.47
39	3.9	0.895	7.47
40	4.4	0.895	7.47
41	5.0	0.894	7.46
42	5.6	0.894	7.46
43	6.1	0.894	7.46
44	6.7	0.893	7.45
45	7.2	0.893	7.45
46	7.8	0.892	7.45
47	8.3	0.892	7.44
48	8.9	0.892	7.44
49	9.4	0.891	7.44
50	10.0	0.891	7.44
51	10.6	0.891	7.43
52	11.1	0.890	7.43
53	11.7	0.890	7.43
54	12.2	0.890	7.42
55	12.8	0.889	7.42
56	13.3	0.889	7.42
57	13.9	0.888	7.41
58	14.4	0.888	7.41
59	15.0	0.888	7.41
60	15.6	0.887	7.40
61	16.1	0.887	7.40
62	16.7	0.887	7.40
63	17.2	0.886	7.40
64	17.8	0.886	7.39
65	18.3	0.885	7.39
66	18.9	0.885	7.39
67	19.4	0.885	7.38

Table D-1. Density of Soy Biodiesel as a Function of Temperature *(cont.)*

Temperature		Density	
°F	°C	Specific Gravity	lb/gal
68	20.0	0.884	7.38
69	20.6	0.884	7.38
70	21.1	0.884	7.37
71	21.7	0.883	7.37
72	22.2	0.883	7.37
73	22.8	0.883	7.36
74	23.3	0.882	7.36
75	23.9	0.882	7.36
76	24.4	0.881	7.36
77	25.0	0.881	7.35
78	25.6	0.881	7.35
79	26.1	0.880	7.35
80	26.7	0.880	7.34
81	27.2	0.880	7.34
82	27.8	0.879	7.34
83	28.3	0.879	7.33
84	28.9	0.878	7.33
85	29.4	0.878	7.33
86	30.0	0.878	7.33
87	30.6	0.877	7.32
88	31.1	0.877	7.32
89	31.7	0.877	7.32
90	32.2	0.876	7.31
91	32.8	0.876	7.31
92	33.3	0.876	7.31
93	33.9	0.875	7.30
94	34.4	0.875	7.30
95	35.0	0.874	7.30
96	35.6	0.874	7.29
97	36.1	0.874	7.29
98	36.7	0.873	7.29
99	37.2	0.873	7.29
100	37.8	0.873	7.28

Appendix D: Density and Viscosity as a Function of Temperature

Viscosity as a Function of Temperature

Fuel viscosity has a significant impact on the operation of engine fuel injection and atomization systems and is known to affect engine wear and the rate of injector fouling. Additionally, viscosity can be a factor in the design of pumps for the transfer of stockpiled biodiesel.

Figure D-1 shows the kinematic viscosities predicted from the correlations of three biodiesel fuels over the temperature range of 68° to 572°F (20° to 300°C).

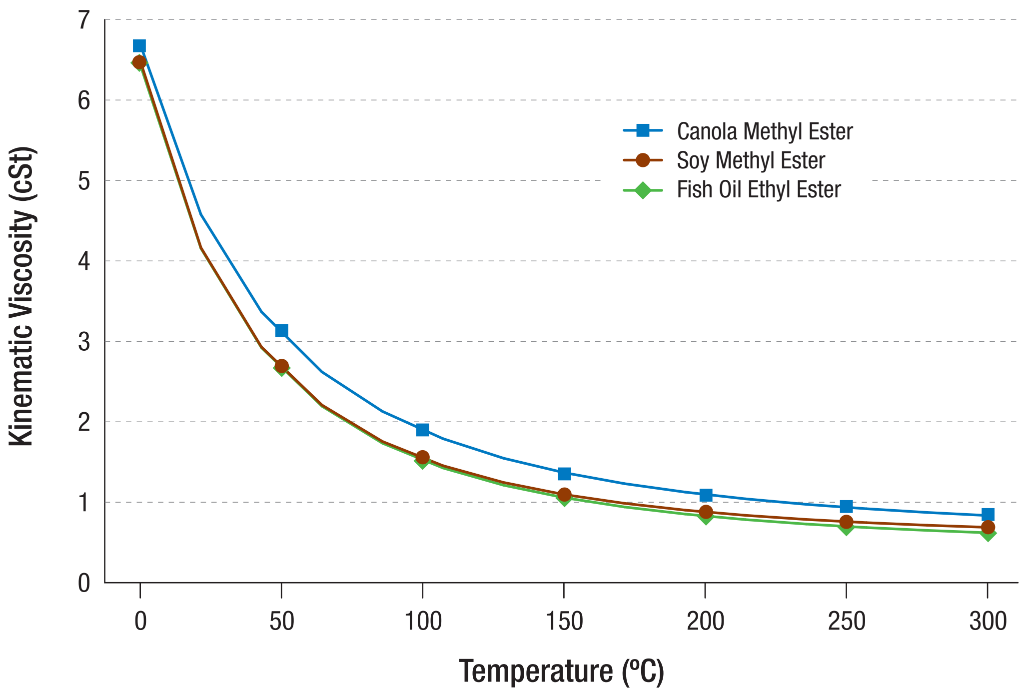


Figure D-1. Kinematic Viscosity of Three Biodiesel Blends

The relationship between temperature and viscosity typically follows the regression equation:

$\log\eta = A + B/T + C/T/T$, where

η = viscosity

T = absolute temperature (K).

For the biodiesels tested above, the constants for the best fit regression equation are shown in Table D-2:

Table D-2. Constants for Best Fit Regression Equation

Biodiesel Type	A	B	C
Canola Methyl Ester	-0.341	-498	338301
Soy Methyl Ester	0.076	-1078	469,741
Fish-Oil Ethyl Ester	-0.453	-739	415238

Viscosity of Various Biodiesel Blends as a Function of Temperature

Others have found good correlation with measured viscosity when predicting the viscosity of biodiesel blends using the standard method for calculating kinematic viscosities of mixtures:

$\log\eta_B = m_1 \log\eta_1 + m_2 \log\eta_2$, where

η_B = viscosity of the blend

η_1 and η_2 = viscosity of the components

m_1 and m_2 = mass fraction of the components.

The results of this equation for various blends of a commercial biodiesel are shown in Figure D-2.

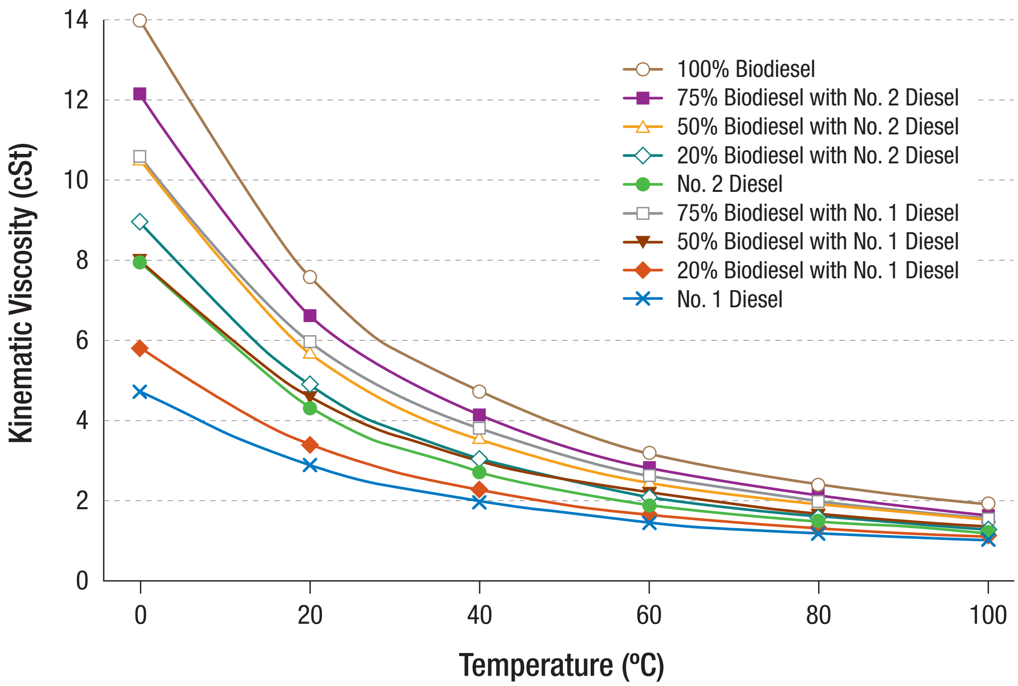


Figure D-2. Kinematic Viscosity for a Commercial Biodiesel in Various Blends

These results suggest that this equation could be used to estimate viscosities of other intermediate blends.

Appendix E: Biodiesel Materials Compatibility Summary Tables

Pure biodiesel is not compatible with certain elastomers, metals, and plastics that are commonly used with petroleum diesel. Generally, (but not always), biodiesel blends of 20% or lower have a much smaller effect on these materials; very small concentrations of biodiesel in B5 or B2 have no noticeable effect on materials compatibility. If in doubt, contact the manufacturer for more information about the compatibility of specific materials with biodiesel fuels or fatty methyl esters (see Table E-1).

Elastomers

Table E-1. Elastomer Compatibility with Biodiesel

Material	Compatibility with Fresh, Unoxidized Methyl Oleate Unless Noted	Reference
Buna-N	Not Recommended	3,4
Butadiene	Not Recommended	2
Butyl	Mild Effect	2,4
Chemraz	Satisfactory	4
Ethylene propylene (EPDM)	Moderate Effect	2,4
Fluorocarbon	Satisfactory	2,4,5
Fluorosilicon	Mild Effect; increase swelling	1
Fluorosilicone	Mild Effect	2,4
Hifluour	Satisfactory	2
Hypalon	Not Recommended	2,4
Natural Rubber	Not Recommended	2,4
Neoprene	Not Recommended	3,4
Neoprene/Chloroprene	Not Recommended	2
Nitrile	Not Recommended	1,2
Nitrile, high aceto-nitrile	Mild Effect with B20, swelling and break strength affected	5
Nitrile, hydrogenated	Not Recommended	2,4
Nitrile, peroxide-cured	Mild Effect with B20, swelling and break strength affected	5
Nordel	Moderate to Severe Effect	3
Nylon	Satisfactory	1
Perfluoroelastomer	Satisfactory	2
Polypropylene	Moderate Effect; increased swelling, hardness reduced	1
Polyurethane	Mild Effect; increased swelling	1
Styrene-butadiene	Not Recommended	2,4
Teflon	Satisfactory	1,3,4

Table E-1 continues on following page

Table E-1. Elastomer Compatibility with Biodiesel *(cont.)*		
Material	**Compatibility with Fresh, Unoxidized Methyl Oleate Unless Noted**	**Reference**
Viton	Satisfactory; type of cure affects compatibility with oxidized biodiesel see specific types of Viton below	1,3
Viton A-401C	Satisfactory with fresh RME; not recommended for oxidized blends B20 and above	6
Viton F-605C	Satisfactory with fresh RME; not recommended for oxidized blends B20 and above	6
Viton GBL-S	Satisfactory with RME and with all oxidized blends	6
Viton GF-S	Satisfactory with RME and with all oxidized blends	6
Wil-Flex	Moderate to Severe Effect	3

[1]Bessee, G.B. and J.P. Fey. Compatibility of Elastomers and Metals in Biodiesel Fuel Blends. SAE 971690. 1997.

[2]Parker O-Ring Handbook, Parker Hannilin Corporation, O-Ring Division, Lexington, KY, 2007.

[3]Chemical Resisitance Guide, Wilden Pump & Engineering Co., Grand Terrace, CA, 2005.

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[5]Terry, B., R.L. McCormick, M. Natarajan. Impact of Biodiesel Blends on Fuel System Component Durability. SAE 2006-01-3279, 2006.

[6]Thomas, E., R.E. Fuller, K. Terauchi. Fluoroelastomer Compatibility with Biodiesel Fuels, SAE 2007-01-4061, 2007.

Metals

Certain metals may affect the biodiesel by accelerating its oxidation process and creating fuel insolubles. Lead, tin, brass, bronze, and zinc significantly increase sediment formation in both B100 and B20. Galvanized metal and terne coated sheet metal are not compatible with biodiesel at any blend level.

CERTIFICATE FOR BIODIESEL

Certificate Identification Number: ______________________
(To support a claim related to biodiesel or a biodiesel mixture under the Internal Revenue Code)

The undersigned biodiesel producer ("Producer") hereby certifies the following under penalties of perjury:

1.____

Producer's name, address, and employer identification number

2.____

Name, address, and employer identification number of person buying the biodiesel from Producer

3.____

Date and location of sale to buyer

4. This certificate applies to _______ gallons of biodiesel.
5. Producer certifies that the biodiesel to which this certificate relates is:
_________% Agri-biodiesel (derived solely from virgin oils)
_________% Biodiesel other than agri-biodiesel

This certificate applies to the following sale:
___________ Invoice or delivery ticket number
__________Total number of gallons of biodiesel sold under that invoice or delivery Ticket number (including biodiesel not covered by this certificate)

______Total number of certificates issued for that invoice or delivery ticket number

6.____

Name, address, and employer identification number of reseller to whom certificate is issued (only in the case of certificates reissued to a reseller after the return of the original certificate)

7._________ Original Certificate Identification Number (only in the case of certificates reissued to a reseller after return of the original certificate)

Producer is registered as a biodiesel producer with registration number ______________ Producer's registration has not been suspended or revoked by the Internal Revenue Service.

Producer certifies that the biodiesel to which this certificate relates is monoalkyl esters of long chain fatty acids derived from plant or animal matter that meets the requirements of the American Society of Testing and Materials D6751 and the registration requirements for fuels and fuel additives established by EPA under section 211 of the Clean Air Act (42 U.S.C. 7545).

Producer understands that the fraudulent use of this certificate may subject Producer and all parties making any fraudulent use of this certificate to a fine or imprisonment, or both, together with the costs of prosecution.

Printed or typed name of person signing this certificate

Title of person signing

Signature and date signed ____

Appendix F: BQ-9000 Sample Certificate of Analysis

Motor Fuel Quality Report

Sample ID: | Product: BD - Biodiesel | Date Sampled:
Lab File No: | Grade: | Date Tested:
Storage (gal):

Establishment:

Supplier:
Not Available

No.	Test	Units	Method	Result	Min.	Max.	Compliance
1	Flash Point	deg.C	D-93	140.5	130		Y
2	Acid Number	mg	D-664	0.40		0.50	Y
3	Total Glycerin	Wt. %	D 6584	0.27		0.24	Y
4	Free Glycerin	Wt. %	D 6584	0.005		0.02	Y
5	Cetane Number		D-613	46.2	47		Y
6	Sulfated Ash	% mass	D-874	0.001		0.02	Y
7	Kinematic Viscosity, 40C	mm2/s	D-445	4.142	1.9	6.0	Y
8	Distillation, Atmos. Equi. 90%	Deg. C	D-1160	352		360	Y
9	Sediments and Water	Vol %	D-2709	0.05		0.05	Y
10	Carbon Residue	% mass	D-4530	0.1		0.05	Y
11	Sulfur	% mass	D-5453	0.0008		0.05	Y
12	Copper Corosion, 2h@100C		D-130	1A			Y
13	Phosphorous Content	% mass	D 4951	0.001		0.001	Y
14	Na+K	ppm	14538	0.4		5	Y
15	Ca + Mg	ppm	14538	0.1		5	Y
16	Oxidation Stability	hours	14112	16.0	3.0		Y
17	Cloud Point	Deg. C	D-2500	3.0			Y

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[1] The ASTM standard for B100 to be used as a blend stock is D6751. Diesel fuel is defined in ASTM D975. ASTM D396 defines heating oils. A-A-59693A defines B20 for military use.

[2] See *www.astm.org.*

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[15] Kinast, J.A. *Production of Biodiesels from Multiple Feedstocks and Properties of Biodiesels and Biodiesel/Diesel Blends: Final Report*, 2003.

[16] See *www.biodiesel.org/pdf _files/fuelfactsheets/Use_of _Biodiesel_Blends_above_%2020.pdf.*

[17] CRC. Biodiesel Blend Low-Temperature Performance Validation, 2008; *www.crcao.com/reports/recentstudies2008/DP-2a-07/CRC%20650.pdf*

[18] SME = soy methyl ester, CME = canola methyl ester, LME = lard methyl ester, ETME = edible tallow methyl ester, ITME = inedible tallow methyl ester, LYGME = low free fatty acid yellow grease, HYGME = high free fatty acid yellow grease. Since these tests, we have found that the free fatty acid content of the starting feedstock, whether it is yellow grease or some type of animal fat, has no effect on fuel properties. So LYGME and HYGME can be viewed as two different samples of yellow grease methyl esters.

[19] ASTM D4057. Standard Practice for Manual Sampling of Petroleum and Petroleum Products.

[20] NBB quality program, BQ-9000, *www.bq-9000.org/.*

[21] Table 10.4, *Biodiesel Overview*. *www.eia.doe.gov/mer/pdf/pages/sec10_8.pdf*

[22] NBB. "What's a RIN, and What Do I Do With It?" *www.biodiesel.org/news/RFS/20070919_BDMLetterRINS-Sept07.pdf.*

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