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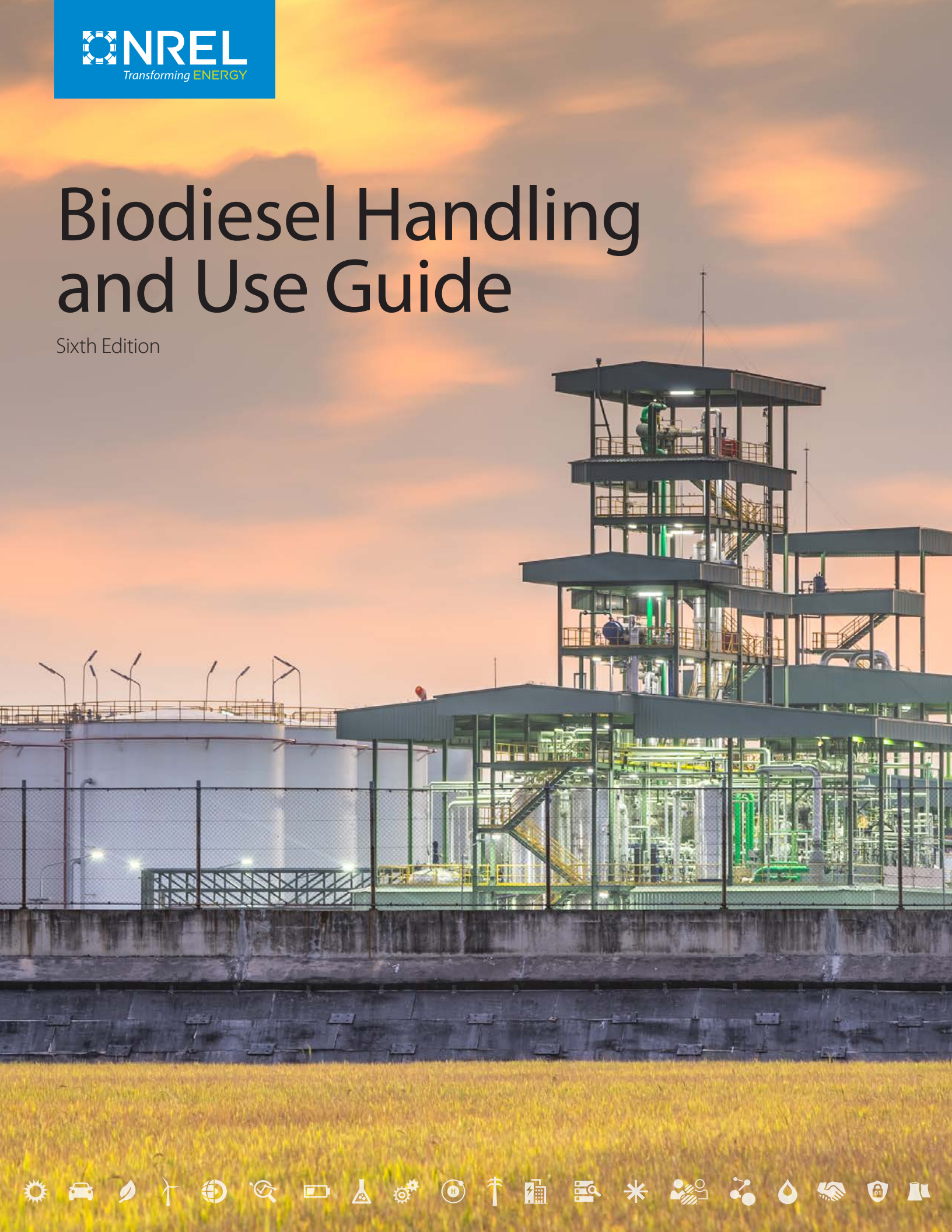
# Biodiesel Handling and Use Guide

Sixth Edition



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# List of Acronyms

| | |
|---|---|
| AST | aboveground storage tank |
| Bxx | biodiesel blend containing xx vol % biodiesel |
| CFPP | cold filter plugging point |
| EPA | U.S. Environmental Protection Agency |
| LM | low metals grade of biodiesel |
| LTFT | low-temperature flow test |
| OEM | original equipment manufacturer |
| UST | underground storage tank |



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# Table of Contents


**Introduction** ..... **1**
**Biodiesel Basics** ..... **3**
What Is Biodiesel? ..... 3
Biodiesel vs. Renewable Diesel ..... 4
Straight Vegetable Oil ..... 4
Benefits of Biodiesel Use ..... 4
**Properties and Handling of Biodiesel (B100)** ..... **6**
B100 Specification ..... 7
Energy Content ..... 12
Low-Temperature Properties ..... 13
Oxidation Stability ..... 14
Microbial Contamination ..... 18
Transport ..... 18
Biodiesel Quality ..... 19
**Biodiesel Blends** ..... **20**
Specifications ..... 20
B5 and Lower Blends ..... 20
B6 to B20 Blends ..... 20
Materials Compatibility ..... 22
Low-Temperature Properties ..... 23
Lubricity ..... 24
Stability of Biodiesel Blends ..... 25
Bulk Blending, Storage, and Transport ..... 29
Vehicle Refueling Infrastructure ..... 30
Codes and Regulations ..... 30
Retail and Fleet Station Equipment ..... 31
Checklist for Installing B20 Dispensing Equipment or Converting Underground Storage Tanks ..... 34
Use of Biodiesel Blends in Other Markets ..... 35
On-Road ..... 36
Off-Road ..... 36
Rail ..... 36
Marine ..... 36
Home Heating ..... 36
Power Generation ..... 37
Use of High Blends and B100 ..... 38
**Safety, Health, and Environmental Issues** ..... **39**
Signs, Labels, and Stickers ..... 39
Fire Safety Considerations ..... 39
**Frequently Asked Questions** ..... **40**
**Information Resources** ..... **41**
**Glossary** ..... **42**
**Appendix A. Sample Biodiesel Safety Data Sheet** ..... **44**
**Appendix B. Biodiesel Materials Compatibility Summary Tables** ..... **47**
**Appendix C. Pump Labeling** ..... **49**
**Appendix D. Refueling Equipment Compatibility** ..... **50**
**Appendix E. Engine and Vehicle Manufacturer Approvals** ..... **54**




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# List of Figures

Figure 1. Basic transesterification process ..... 3
Figure 2. Biofuels life cycle. ..... 5
Figure 3. ASTM D4625 long-term storage stability for B100 samples having a range of initial Rancimat induction periods. (a) Rancimat induction period (dashed line is 3-h minimum requirement), (b) peroxide content, and (c) acid number (dashed line is 0.5-mg KOH/g maximum requirement). ..... 17
Figure 4. Rancimat induction period for ASTM D4625 storage for B20 blends collected in the United States in 2016. Upper dashed line is 6-hour minimum stability required by ASTM D7647. Lower dashed line is 3-hour stability level below which the formation of acids and peroxides is observed ..... 26
Figure 5. Re-additization during storage of a biodiesel blend. (a) Induction period (dashed line is 6-h minimum requirement for B20 blends). (b) Peroxide content. (c) Acid number (dashed line is 0.3-mg KOH/g maximum allowable value) measured throughout storage ..... 28
Figure 6. Typical station fuel dispenser and underground storage piping. ..... 31
Figure 7. Placards for transport of combustible and flammable liquids ..... 39
Figure C-1. Federal Trade Commission-compliant B20 and B100 pump labels ..... 49

# List of Tables

Table 1. Requirements for Biodiesel (B100) Blendstock as Listed in ASTM D6751-23a ..... 8
Table 2. Typical Energy Density and Specific Energy of Diesel, Heating Oil, and Biodiesel ..... 13
Table 3. ASTM D7467-20a Specification for Diesel Blends B6 to B20 (reprinted with permission of ASTM) ..... 21
Table 4. ASTM D396-21 Specification for Heating Oil Blends B6 to B20 ..... 22
Table 5. Fuel Dispenser and Underground Storage Piping Components ..... 32
Table B-1. Elastomer Compatibility With Biodiesel ..... 47
Table D-1. UL Biodiesel Testing Standards for Refueling Equipment ..... 50
Table D-2. Tank Manufacturer Combability With Biodiesel Blends ..... 52
Table D-3. Dispensers, Hanging Hardware, Shear Valves, Submersible Turbine Pumps ..... 53



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# Introduction

This document serves as a background and guide for those who blend, distribute, and/or use biodiesel and biodiesel blends. It provides basic information on the proper and safe use of biodiesel in compression-ignition engines, home heating oil systems, boilers, and other applications. This guide is intended to help users, fleets, blenders, distributors, and others understand the handling and use of biodiesel and biodiesel blends. Information on the environmental benefits of biodiesel is also provided.

Biodiesel is produced from plant oils, animal fats, recycled cooking oils, and/or greases and has several advantages:

- Renewable, with a much lower carbon intensity/life cycle greenhouse gas emissions profile than petroleum diesel fuel, such that it reduces global warming emissions.
- Can be used at up to at least 20% blend level in most diesel equipment with zero or minor modifications.
- Compatible with all new on- and off-road diesel engines—often called "new technology diesel engines" (NTDEs)—and burners and backward-compatible with most equipment.
- Demonstrated to reduce tailpipe soot emissions and other criteria pollutants from older (e.g., legacy) engines without modern emission controls, as well as from industrial boiler and home heating systems.
- Nontoxic, biodegradable, and suitable for sensitive environments.

> NTDEs refers to on- and off-road diesel engines manufactured beginning in about 2010 in the United States that include state-of-the-art emissions control systems. The exact configurations of the systems may vary, but often include components like diesel oxidation catalysts, particulate filters, and selective catalytic $NO_x$ reduction systems.

In this report, biodiesel refers to the fuel (commonly called an ester, or fatty acid methyl esters [FAME]) produced from renewable fats, oils, and/or greases that meets the most current ASTM International Standard D6751 (D6751-23a at the time of this writing).[1] Biodiesel is most commonly used as a blend with petroleum diesel fuels, including ASTM International Standard D975 grades No. 1 and No. 2 diesel fuel or ASTM International Standard D396 heating oil, as well as other distillate and residual fuel oils. The number following the letter "B" in a biodiesel blend indicates the percent by volume (vol %) of biodiesel in 1 gallon of fuel (e.g., B20 is 20% biodiesel by volume); the remainder of the fuel can be No. 1 or No. 2 diesel, heating oil, or any other distillate or residual fuel. Pure (or neat) biodiesel is called B100. Appendix A shows a sample safety data sheet for biodiesel (B100).

[1] ASTM International. 2023. *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels*. West Conshohocken, PA. https://www.astm.org/d6751-20a.html.



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ASTM International (astm.org) is a consensus-based volunteer standards group that comprises experts across numerous industries. Committee D02—Petroleum Products, Liquid Fuels, and Lubricants—covers biodiesel, diesel, and heating oil specifications (in addition to many other products). Membership in D02 includes engine and fuel injection equipment companies, fuel producers, and fuel users (as well as other interested parties). ASTM standards are recognized in the United States by most government entities. Specifications are living documents and may be updated frequently to reflect the most current needs of the industry. Any ASTM method or specification will include a number and a year at the end, such as D6751-23a. This means the most current version of the method was published in 2023; a letter after the year indicates that more than one modification has been published in a given year. Users need to ensure they are using the most up-to-date version of a test method or specification.

At concentrations of up to 5 vol % (B5) in conventional diesel fuel or heating oil, the mixture falls under the ASTM D975 diesel fuel or ASTM D396 heating oil specifications, respectively, is considered diesel fuel or heating oil, and can be used in any application that uses diesel fuel or No. 1 or No. 2 grade heating oil.[2] At concentrations of 6–20 vol % (B6 to B20), the ASTM D7467 specification applies, and these biodiesel blends can be used in many applications that use diesel fuel or heating oil with minor or no modifications to the equipment.[3]

Higher blend levels between B20 and B100 may require special handling and equipment modifications. These issues can potentially be managed with heaters and/or changing engine seal and gasket materials. Consult your engine manufacturer and/or dealer for further information about procedures and/or precautions before using biodiesel blends higher than B20.

[2] The properties of fit-for-purpose diesel fuel is defined in ASTM D975 and for heating oils in ASTM D396.
[3] ASTM International. 2023. *Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20)*. West Conshohocken, PA. https://www.astm.org/d7467-20a.html



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# Biodiesel Basics

## What Is Biodiesel?

Biodiesel is a commercially available, lower-carbon-intensity fuel for use in diesel engines, boilers, and home heating oil systems. It can directly replace or be blended with distillate and residual fuel oils, like diesel fuel or heating oil. Biodiesel is manufactured from plant oils (e.g., soybean oil, cottonseed oil, canola oil, corn oil), recycled/used cooking greases (e.g., yellow grease), animal fats (e.g., beef tallow, pork lard, poultry fat), or various combinations of these feedstocks. In addition, other oilseed crops are being commercialized such as camelina, *Brassica carinata*, and CoverCress™.

The biodiesel production process is known as transesterification, which converts these oils, fats, and/or greases into long-chain mono-alkyl esters, or biodiesel. The esters are commonly referred to as fatty acid methyl esters (FAME) when methanol is used in the transesterification reaction. Virtually all biodiesel production today uses methanol. Roughly speaking, 100 pounds of oil, fat, and/or grease is reacted with 10 pounds of alcohol, usually methanol (although production from other alcohols is possible), in the presence of a catalyst (usually sodium methoxide)[4] to form 100 pounds of biodiesel and 10 pounds of glycerin (or glycerol). Crude glycerin is a coproduct of the biodiesel process and has economic value. Biodiesel is a legally registered fuel and fuel additive with the U.S. Environmental Protection Agency (EPA). The EPA registration is feedstock- and process-agnostic and includes all biodiesel that meets the most current ASTM biodiesel specification, D6751. Figure 1 provides a simplified diagram of the transesterification process.

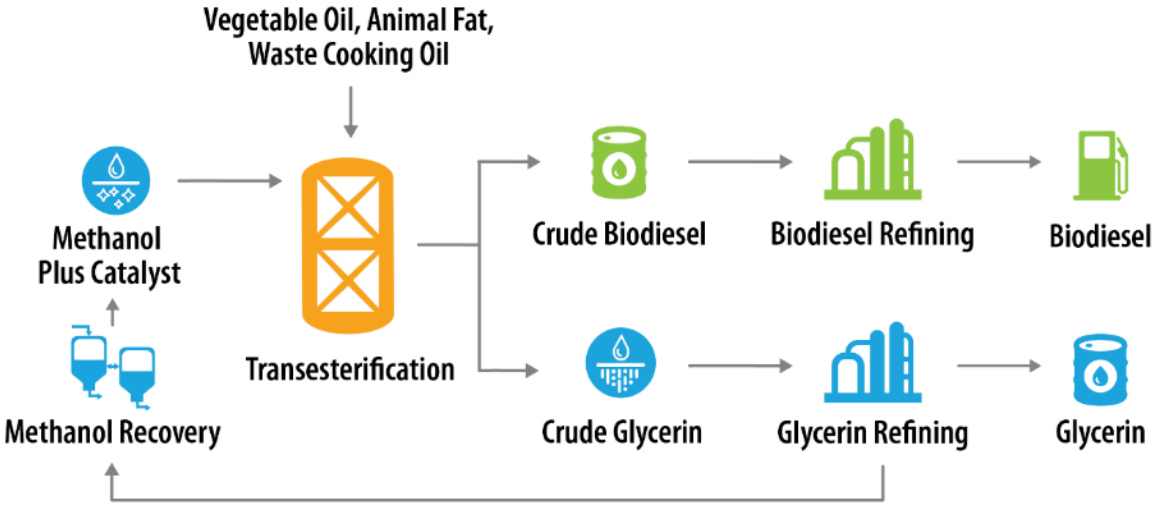


**Figure 1. Basic transesterification process**

[4] Most biodiesel producers use sodium or potassium methoxide, rather than methanol + sodium hydroxide or potassium hydroxide



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## Biodiesel vs. Renewable Diesel

Renewable diesel is another alternate fuel used in compression-ignition engines and is produced from some of the same renewable feedstocks as biodiesel. However, the way that these feedstocks are processed into renewable diesel is considerably different than biodiesel.

As discussed above, biodiesel is primarily made through transesterification to produce fatty acid methyl esters. Renewable diesel is produced by a process called hydroprocessing or hydrotreating—indicating a reaction with hydrogen. Hydroprocessing produces chemicals identical to some of the compounds found in conventional diesel fuel. Like biodiesel, renewable diesel has very low sulfur content, which is advantageous environmentally. Renewable diesel typically has a very high cetane number and can be made to meet a range of cloud point requirements.

## Straight Vegetable Oil

Raw or refined plant oils, fats, or recycled greases that have not been processed into biodiesel or renewable diesel should be avoided for use in compression-ignition engines. Research shows oils, fats, and/or greases, even at concentrations as low as 1%, can cause long-term engine deposits, ring sticking, lube oil gelling, and other maintenance problems and can reduce engine life.[5]

These problems are caused mostly by the much higher viscosity, or thickness, of the raw fats and/or oils compared to diesel fuel for which the engines and injectors were designed. The process of converting oils, fats, and greases to biodiesel by transesterification ensures the viscosity is reduced to values more similar to conventional diesel fuel.

## Benefits of Biodiesel Use

### Biodiesel Is a Low-Carbon-Intensity Fuel and Reduces Greenhouse Gas Emissions

Carbon intensity refers to the amount of greenhouse gases emitted per unit of energy consumed, usually stated in grams of $CO_2$ equivalent per megajoule ($CO_{2eq}$/MJ). The carbon intensity of petroleum-based diesel fuels is typically around 95 g $CO_{2eq}$/MJ. Biodiesel carbon intensity depends on feedstock used, but ranges from around 18 g $CO_{2eq}$/MJ for waste cooking oil to 21 g $CO_{2eq}$/MJ for soybean oil (or 30 g $CO_{2eq}$/MJ when including indirect land use change effects).[6] Because of biodiesel's lower carbon intensity, when biodiesel displaces petroleum in any application, it significantly reduces life cycle greenhouse gas emissions. These life cycle analysis results show greenhouse gas emissions for soy B100 are 67% to 77% lower than those from petroleum diesel. Figure 2 presents a basic overview of the life cycle of $CO_2$ emissions produced and recycled when biodiesel is generated from agricultural feedstocks and utilized in a vehicle.

[5] U.S. Department of Energy. 2021. "Straight Vegetable Oil as a Diesel Fuel?" https://afdc.energy.gov/files/u/publication/straight_vegetable_oil_as_diesel_fuel.pdf.

[6] H. Xu, L. Ou, Y. Li, T.R. Hawkins, and M. Wang. 2022. "Life Cycle Greenhouse Gas Emissions of Biodiesel and Renewable Diesel Production in the United States." *Environ. Sci. Technol.* 56: 7512–7521.



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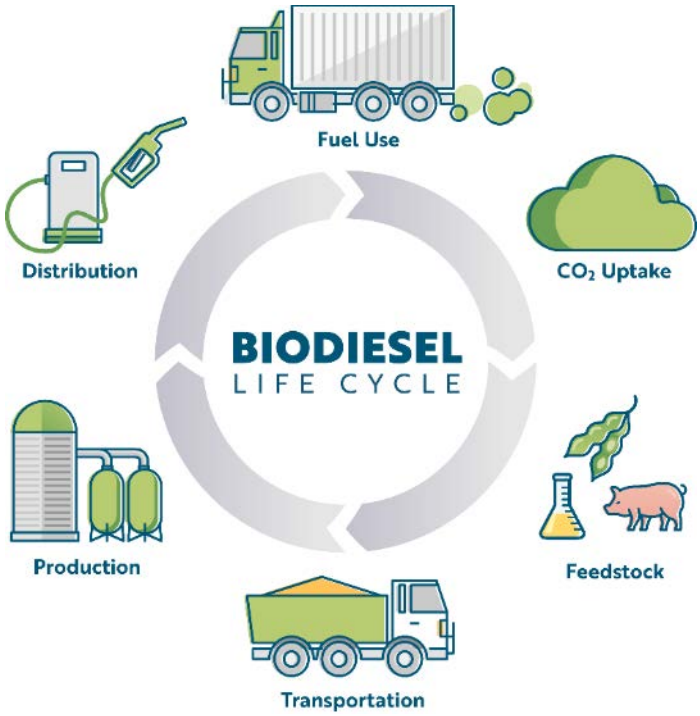


**Figure 2. Biofuels life cycle.**

Image copyright Clean Fuels Alliance America, used with permission.

### *Biodiesel Reduces Soot Emissions*

Because biodiesel contains approximately 11 wt% oxygen (i.e., an oxygenate), when it is blended into petroleum fuels it will dilute certain compounds that have a high soot (e.g., particulate matter) formation tendency and enhance combustion, thereby reducing particulate emissions. This is a major benefit for pre-2010 model year on-road engines and for many off-road engines not equipped with diesel particle filters. These reductions are greater for higher biodiesel blend levels, but also depend on engine design, calibration, and operating conditions. Biodiesel use in home heating oil systems and boilers can reduce soot by as much as 60% for B100 and roughly 10% for B20.[7,8]

[7] A. Macor and P. Pavanello. 2009. "Performance and emissions of biodiesel in a boiler for residential heating." *Energy* 34: 2025–2032.
[8] S. Win Lee, T. Herage, and B. Young. 2004. "Emission reduction potential from the combustion of soy methyl ester fuel blended with petroleum distillate fuel." *Fuel* 83: 1607–1613.



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# Properties and Handling of Biodiesel (B100)

This section describes the basic properties of B100 and considerations for its handling and blending. The storage and handling procedures for B100 are different than for B20 and lower biodiesel blends and vary from those for diesel fuel, especially in cold weather. Using B20 and lower blends significantly reduces or eliminates the effects of these property differences. However, because many distributors store and handle B100 before blending, a good understanding of B100 properties is valuable.

> In the United States, it is equally common to handle B99 and B99.9 blends. The considerations in this section also apply to B99 and B99.9, as these fuel blends may qualify for a tax credit for biodiesel blending.

Several significant attributes specific to B100 should be considered when handling, storing, and using B100:

- **B100 is a good solvent.** It may loosen or dissolve varnish and sediments in fuel tanks and fueling systems left by conventional diesel or other fuels over time. This may be especially true in systems that have never used biodiesel. If a system contains sediments, the tanks and fuel system should be cleaned before B100 is handled or used. A good indication that B100 is cleaning the tank is an initial increase in filter plugging. Over time, filter change intervals should return to normal. This should not be an issue for B20 or lower blends. Spills should be cleaned up immediately, as B100 may not be compatible with some types of paint.
- **B100 gels at higher temperatures than most diesel fuel and heating oil.** This must be considered if handling or using B100, especially in aboveground storage tanks (ASTs). The temperature where B100 starts to gel will vary with the feedstock and can range from −3°C to 15°C (27°F to 60°F) or higher,[9] so heated fuel lines and tanks may be needed in colder months, even in moderate climates. As B100 begins to gel, the viscosity increases quickly, which can increase stress on fuel pumps. The high cloud point of B100 may make its use challenging in colder climates.
- **B100 is not compatible with some hoses and gaskets.** B100 may degrade, soften, or seep through some hoses, gaskets, seals, elastomers, glues, and plastics with prolonged exposure. Polypropylene, polyvinyl, and Tygon materials are particularly vulnerable to B100, as are some nitrile rubber compounds. Before handling or using B100, ask the

[9] T. Alleman. 2020. *Assessment of BQ-9000 Biodiesel Properties for 2017*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-75795. https://www.nrel.gov/docs/fy20osti/75795.pdf; T. Alleman. 2020. *Assessment of BQ-9000 Biodiesel Properties for 2018*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-75796. https://www.nrel.gov/docs/fy20osti/75796.pdf; T. Alleman. 2020. *Assessment of BQ-9000 Biodiesel Properties for 2019*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-76840. https://www.nrel.gov/docs/fy20osti/76840.pdf; T. Alleman. 2021. *Assessment of BQ-9000 Biodiesel Properties for 2020*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-79815. https://www.nrel.gov/docs/fy21osti/79815.pdf; T. Alleman. 2022. *Assessment of BQ-9000 Biodiesel Properties for 2021*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-83108. https://www.nrel.gov/docs/fy22osti/83108.pdf.



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equipment vendor or original equipment manufacturer (OEM) if the equipment is suitable for B100 or biodiesel. If your equipment is not compatible with B100, the materials should be replaced with materials that are, such as Teflon, Viton, fluorinated plastics, or nylon. For bulk handling of B100, seals, gaskets, and hoses must be compatible with B100. (See Appendix B for information about material compatibility.) Using B100 in an engine or burner 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.

- **B100 is not compatible with some metals and plastics.** Biodiesel will degrade and form high sediment levels if contacted for long periods with lead, tin, or zinc (galvanized surfaces). Testing with biodiesel meeting today's ASTM D6751 specification with copper or copper-containing metals (e.g., brass, bronze) also shows the potential for long-term degradation or sediment formation, although values were similar to that of conventional petroleum-based fuel.[10] These high sediment levels may clog filters. B100 may also permeate some common plastics (e.g., polyethylene, polypropylene) over time, so these should not be used for storing B100.
- **B100 is compatible with most lubricants and filters.** No modifications are required in most cases for biodiesel.

## B100 Specification

The specification for B100 is frequently updated at ASTM, and as of this writing the most current version is D6751-23a, summarized in Table 1. Anyone buying or using B100 must be aware of the most current version of the specification—it is the user's responsibility to stay current. Specification updates may be significant (e.g., the addition of a new testing requirement) or may be more subtle, such as updated information in an appendix or a new test method. At the end of the specification, users can find a summary of changes that includes updates from the previous version. For the most up-to-date version of the specification, check the ASTM website (astm.org). Countries outside the United States may use other specifications, such as EN14214:2012+ A2:2019.[11]

[10] R. Kerr, T. Butcher, N. Islam, and M. Haverly. 2022. "Monitoring Biodiesel Blends in Heating Applications – Effects of Exposure Conditions." *IASH 2022 Proceedings of the 17th International Conference on Stability, Handling, and Use of Liquid Fuels*, Dresden, Germany, 11–15 Sept. 2022.

[11] DIN EN 14214 Liquid petroleum products - Fatty acid methyl esters (FAME) for use in diesel engines and heating applications - Requirements and test methods (includes Amendment :2019), https://www.en-standard.eu



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**Table 1. Requirements for Biodiesel (B100) Blendstock as Listed in ASTM D6751-23a**

| Property | Test Method | Grade No. 1-B S15, S15 LM | Grade No. 1-B S500 | Grade No. 2-B S15, S15 LM | Grade No. 2-B S500 |
|---|---|---|---|---|---|
| Sulfur,[a] % mass (ppm), max | D5453 | 0.0015 (15) | 0.05 (500) | 0.0015 (15) | 0.05 (500) |
| Cold soak filterability, seconds, max | D7501 | 200 | 200 | 360 | 360 |
| Monoglyceride content, % mass, max | D6584 | 0.40 | 0.40 | ... | ... |
| Metals, ppm (µg/g), max, Grades: | | | | | |
| No. 1-B S15, S500; No 2-B S15, S500 | | | | | |
| Calcium and magnesium, combined | EN 14538 | 5 | 5 | 5 | 5 |
| Sodium and potassium, combined | EN 14538 | 5 | 5 | 5 | 5 |
| No. 1-B S15 LM, No. 2-B S15 LM | | | | | |
| Sodium, potassium, calcium, and magnesium, combined | EN 14538 | 4 | | 4 | |
| **Requirements for All Grades** | | | | | |
| Flash point (closed cup), °C, min | D93 | 93 | 93 | 93 | 93 |
| Alcohol control; one of the following shall be met: | | | | | |
| 1. Methanol content, mass %, max | EN 14110 | 0.2 | 0.2 | 0.2 | 0.2 |
| 2. Flash point, °C, min | D93 | 130 | 130 | 130 | 130 |
| Water and sediment, % volume, max | D2709 | 0.050 | 0.050 | 0.050 | 0.050 |
| Kinematic viscosity,[b] $mm^2/s$, 40 °C | D445 | 1.9-6.0 | 1.9-6.0 | 1.9-6.0 | 1.9-6.0 |
| Sulfated ash, % mass, max | D874 | 0.020 | 0.020 | 0.020 | 0.020 |
| Copper strip corrosion, max | D130 | No. 3 | No. 3 | No. 3 | No. 3 |
| Cetane number, min | D613 | 45 | 45 | 45 | 45 |
| Cloud point,[c] °C | D2500 | Report | Report | Report | Report |
| Carbon residue,[d] % mass, max | D4530 | 0.050 | 0.050 | 0.050 | 0.050 |
| Acid number, mg KOH/g, max | D664 | 0.50 | 0.50 | 0.50 | 0.50 |
| Free glycerin, % mass, max | D6584 | 0.020 | 0.020 | 0.020 | 0.020 |
| Total glycerin, % mass, max | D6584 | 0.240 | 0.240 | 0.240 | 0.240 |
| Phosphorus content, % mass, max | D4951 | 0.001 | 0.001 | 0.001 | 0.001 |
| Distillation temperature, atmospheric equivalent temperature, 90% recovered, °C, max | D1160 | 360 | 360 | 360 | 360 |
| Oxidation stability, hours, min | EN 15751 | 3 | 3 | 3 | 3 |

[a] Other sulfur limits may apply in selected areas in the United States and in other countries.
[b] The 6.0-$mm^2/s$ upper viscosity limit is higher than petroleum-based diesel fuel and should be taken into consideration when blending.
[c] The cloud point of biodiesel is generally higher than petroleum-based diesel fuel and should be taken into consideration when blending.
[d] Carbon residue shall be run on the 100% sample.



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ASTM D6751 was originally developed to ensure the quality of biodiesel blended with diesel fuel and heating oil. Any biodiesel used in the United States should meet ASTM D6751 before blending. ASTM D6751 is based on the physical and chemical properties needed for safe and satisfactory diesel engine and boiler operations. It is not based on the specific feedstock or the manufacturing process used to produce the biodiesel. The finished blendstock must meet the properties specified in Table 1, as well as the following definition from ASTM D6751 and the workmanship clauses:

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

ASTM workmanship clauses:

> *"The biodiesel fuel shall be visually free of undissolved water, sediment, and suspended matter*."
>
> *"The diesel fuel shall also be free of any adulterant or contaminant that can render the fuel unacceptable for its commonly used applications."*

The No. 1-B grades meets more stringent purity requirements intended to provide better low-temperature performance for engines. Most biodiesel produced at the time of this publication is No. 1-B grade.[9] The 1-B grade is recommended if ambient temperatures for the end use application are below 0°C (32°F). The low metals (LM) grades are limited to 4 ppm total for sodium, potassium, magnesium, and calcium and are for applications using diesel engines with modern diesel particulate filters and selective catalytic reduction exhaust aftertreatment.

This specification was not originally intended to be applied to B100 used as a neat fuel for on-road applications, but ASTM D6751 does allow its use as a B100 neat fuel specification if desired. Buyers and sellers are encouraged to use ASTM D6751 for the commercial trading of biodiesel (B100). 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 (e.g., EPA sulfur limits, Occupational Safety and Health Administration safety limits on flash point).

Moreover, the B100 used in making biodiesel blends must meet the requirements of ASTM D6751 for blends to be legal on- and off-road fuels under the Clean Air Act fuel registration requirements and to be a legal blending component under many state regulations.[12]

The intent of each quality requirement in Table 1 is described here:

- **Group I and II metals.** Higher levels of sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg) can cause deposits to form, catalyze undesired side reactions, and adversely affect emissions control equipment. The Group I and II metals are limited as the combination of metals in each category, Na+K and Ca+Mg. The specification upper limit is 5 ppm, combined, for each pair of metals. The LM grade is intended for diesel engine applications using advanced emission controls, especially diesel particle filters

[12] Depending on point of blending, biodiesel may meet the EN14214 specification for quality in lieu of ASTM D6751.



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and selective catalytic reduction systems, and limits the total of all four of these metals combined to 4 ppm. These metals can accumulate on the filter, increasing filter pressure drop and reducing filter maintenance interval. Almost all biodiesel in the United States is routinely well below LM grade limit.[9]

- **Flash point.** A minimum flash point for diesel fuel is required for fire safety. The flash point of B100 is required to be at least 93°C (200°F) to ensure all the alcohol from production is removed; it is classified as nonhazardous under the National Fire Protection Association code.
- **Alcohol.** It is critical to ensure the manufacturer has removed excess alcohol (typically methanol) used in the production process. Residual methanol in the fuel is a safety issue, because even very small amounts dramatically reduce the flash point. Methanol can also negatively affect fuel pumps, seals, and elastomers, and can result in poor engine combustion properties. The intent of the alcohol control requirement is to limit volatile alcohols to less than 0.2 wt %. This can be accomplished by meeting a higher flash point requirement of 130°C (266°F) or by measuring methanol content by gas chromatography.
- **Water and sediment.** This refers to free water droplets and sediment particles suspended in the B100. The allowable level for B100 is set at the same level as for conventional diesel fuel. Poor 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, oxidation stability, and viscosity to determine if fuels have oxidized too much during storage.
- **Kinematic viscosity.** A minimum viscosity is required for some applications 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 No. 2 diesel fuel and No. 2 heating oil. 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 40°C (104°F). ASTM D6751 allows for slightly higher viscosity than ASTM D975 (up to 6.0 $mm^2/s$), primarily because the normal viscosity of B100 is slightly higher than that of diesel fuel and because this standard is for B100 to be used as a blendstock. Biodiesel blends of 20 vol % or lower with No. 2 diesel fuel should have viscosities between the 1.9 and 4.1 $mm^2/s$, within the range allowed by ASTM D975. Biodiesel blended with No. 1 diesel fuel can have viscosities as low as the 1.3-$mm^2/s$ lower limit for No. 1 in ASTM D975.
- **Sulfated ash.** 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 limit is by EPA regulations at 15 ppm to reduce sulfate and sulfuric acid pollutant emissions and to protect exhaust catalyst systems on newer diesel engines. Biodiesel generally contains less than 15 ppm sulfur. The ASTM D5453 test for sulfur in fuel should be used for accurate results for B100. Other test methods, like ASTM D1266,



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ASTM D2622, ASTM D3120, and ASTM D4294 may provide falsely high results caused by test interference with the oxygen in B100.

- **Copper strip corrosion.** 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 ASTM D6751 specifications always passes this test. Copper and bronze may not corrode in the presence of biodiesel, but prolonged contact with these catalysts can degrade the fuel and cause sediment to form with petroleum diesel or with biodiesel.
- **Cetane number.** An adequate cetane number is required for good engine performance. Cetane number is a measure of the ignition quality of the fuel and influences white smoke, cold starting, and combustion roughness. The cetane number requirements depend on engine design, size, and nature of speed and load variations, as well as starting and atmospheric conditions. The ASTM minimum limit for B100 cetane number is set at 45. There is no minimum cetane number for heating oil or marine fuels. The cetane index (ASTM D976 or ASTM D4737) 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 for petroleum diesel. The specific gravity and distillation curve for biodiesel are different and may provide falsely low cetane values using the cetane index calculation methods.
- **Cloud point.** This is the most used measure of low-temperature operability. There is no specification for cloud point for biodiesel, though reporting the value is required in the ASTM D6751 specification. Fuels are generally expected to operate at temperatures down to their cloud point. The cloud point of B100 is typically higher than the cloud point of conventional diesel fuel. 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 is a measure of the carbon-depositing tendency of a fuel and approximates the tendency for carbon deposits to form in an engine or boiler. 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% residue when distilling biodiesel. Therefore, biodiesel carbon residue specifies that the entire biodiesel sample be used rather than the 10% distilled residue.
- **Acid number.** For biodiesel, acid number is primarily an indicator of free fatty acids (natural degradation products of fats and oils or a component of some biodiesel feedstocks) and can be elevated if a fuel is not properly manufactured or has undergone oxidative degradation. Acid numbers higher than 0.50 mg KOH/g have been associated with fuel system deposits and reduced life of fuel pumps and filters.
- **Free and total glycerin.** A measure of the amount of unconverted or partially converted fats/oils and byproduct glycerin in B100. Incomplete conversion of the fats and oils into biodiesel can lead to high total glycerin from elevated mono-, di-, and triglycerides. Incomplete removal of glycerin can lead to high free and total glycerin. If the glycerides are too high, the storage tank, fuel system, and engine can be contaminated. Fuels that



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exceed these limits are highly likely to plug fuel filters and cause other problems. Controls for glycerides should be implemented at the B100 level before blending, as this test method (D6584) is highly sensitive to the presence of diesel fuel (some of which will be falsely counted as biodiesel in the method) and should not be used for biodiesel blends.

- **Phosphorus content.** Phosphorus is limited to 10 ppm maximum in biodiesel because high levels can adversely affect emissions control systems. Phosphorus above 10 ppm can be present in some plant oils and recycled greases before making it into biodiesel, but the biodiesel reaction and cleanup steps (i.e., water washing) essentially remove all phosphorous compounds in the finished biodiesel. At this time, biodiesel produced in the United States generally has phosphorus levels less 1 ppm.[9]
- **T90 distillation.** T90 is defined as the temperature at which 90% of the fuel has distilled. The specification was incorporated to ensure that fuels have not been contaminated with high-boiling materials such as used motor oil or raw fats and oils. B100 exhibits more of a single boiling point rather than a distillation curve. The fatty acids from which biodiesel are produced are mainly straight chains with 16 to 18 carbons that have similar boiling point temperatures. The atmospheric boiling point range of biodiesel is generally 330°C to 357°C (626°F to 675°F).
- **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 in clean tanks.
- **Cold soak filterability.** This specification was added in 2008 in response to data indicating that some B100 could, in blends up to B20, form precipitates at temperatures above the cloud point of the blend. B100 meeting the cold soak filterability requirements does not form these precipitates. This, along with cloud point, is needed to predict low-temperature operability.
- **No. 1-B grade.** The No. 1-B grade has year-round limits on cold soak filterability and monoglycerides. These limits ensure that trace components in biodiesel are minimized.

## Energy Content

With conventional diesel fuels, the inherent energy content of the fuel is the largest factor affecting the fuel economy, torque, and horsepower delivered by the fuel. The energy content of petroleum diesel fuel can vary up to 15% from supplier to supplier and from summer to winter. No. 2 diesel fuel usually has higher energy content than No. 1 diesel fuel. Neat biodiesel (B100) contains about 7.5% less energy per gallon than typical No. 2 diesel fuel. Due to the similar carbon chain length number of the fatty acid chains in the oils and fats used to produce biodiesel, the energy content of biodiesel is similar, regardless of the feedstock and the particular biodiesel process. The energy content of biodiesel and diesel fuel blend linearly, so the energy content of B50 would be midway between the energy content of the starting biodiesel and diesel fuel. However, these differences in energy content do not inherently translate into lower biodiesel fuel economy, especially with engines that employ modern diesel particulate filter/selective catalytic reduction technology that can be positively impacted by lower particulate emissions of biodiesel. Typical reference values for various fuels and biodiesel are shown in Table 2.



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**Table 2. Typical Energy Density and Specific Energy of Diesel, Heating Oil, and Biodiesel**

| | Specific Energy Btu/lb (MJ/kg) | Energy Density Btu/gal (MJ/L) |
|---|---|---|
| Typical diesel No. 2 [a] | 18,320 (42.6) | 128,488 (3881) |
| Typical heating oil [b] | 18,545 (43.2) | 139,000 (38.7) |
| Typical biodiesel (B100) [c] | 16,270 (37.8) | 119,550 (33.3) |

[a] https://afdc.energy.gov/fuels/properties

[b] https://noraweb.org/wp-content/uploads/2016/10/NORA-Silver-Chapter-2.pdf

[c] https://afdc.energy.gov/fuels/biodiesel_basics.html

The difference in energy content between diesel fuel and biodiesel can be noticeable when comparing diesel fuel with B100. For B20, historical field studies indicate the differences in power, torque, and fuel economy are less than 2%, depending on the diesel fuel (for an on-road vehicle that gets 5.5 miles per gallon, this is a difference of about 0.1 miles per gallon). Most users report little or no difference in fuel economy between B20 and diesel fuel. Any differences between B20 and diesel fuel are about the same as would be expected between summer and winter diesel fuel. As the amount of biodiesel in the blend is lowered, differences in energy content become proportionally less significant: Blends of B5 or lower cause no noticeable differences in performance compared to diesel fuel.

## Low-Temperature Properties

Understanding the low-temperature properties of fuels and how they impact utilization is extremely important to ensure a good user experience. Unlike gasoline, diesel fuels and biodiesel can freeze or gel as the temperature drops. 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 aboveground tanks for blending. Important low-temperature performance metrics for handling and blending of B100 are:

- Cloud point, defined as the temperature at which small solid crystals are first visually observed as the fuel is systematically cooled.[13] Below a fuel's cloud point, these crystals might plug filters or could drop to the bottom of a storage tank. This phenomenon may occur with diesel fuels or with B100.
- Pour point, defined as the temperature at which the fuel contains so many agglomerated crystals it is essentially a gel and will no longer flow.[14] 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 at this temperature for most diesel engine applications.

[13] Cloud point methods: ASTM D2500, D5771, D5772, or D5773.
[14] Pour point methods: ASTM D97, D5949, or D5950.



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

- The cloud point of B100 starts around −3°C (27°F) and may be up to 16°C, though in some rare cases can have a cloud point as high as 20°C (68°F). The pour point of B100 is usually only a few degrees lower than the cloud point, so once biodiesel begins to freeze, gelling can occur rapidly if the temperature drops only a few degrees further.
- B100 should be stored at temperatures at least 2.5°C to 5°C (5°F to 10°F) higher than the cloud point. Because the cloud point of the B100 varies, the storage temperature for trouble-free use will not be the same for all biodiesels.
- Aboveground B100 tanks and fuel lines should be designed for the cold flow properties of biodiesel and the local climate. Fuel pumps, lines, and dispensers must be protected from cold and wind chill with properly approved heating and insulating equipment.
- Most B100 can be stored underground in most cold climates without additional considerations because underground storage temperatures are normally above 7°C (45°F).

Most of the time, once crystals form in fuels, they will generally go back into solution as the fuel warms.[15] 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 drop to the bottom of the tank and begin to build up. Slow agitation can prevent crystals from building up on the tank bottom or, once present in the fuel, can help convert the crystals back into liquid.

The low-temperature performance of B100 cannot be effectively managed with current cold flow additives, as can diesel fuel and biodiesel blends. The level of saturated compounds in B100 is too high for most additives to be effective. Cold flow additives have been used much more successfully with biodiesel blends. Users should work directly with the additive manufacturers on this issue.

## Oxidation Stability

Biodiesel is thermally very stable but can be susceptible to oxidation in storage. Oxidation stability of fuels depends on initial fuel quality and additives but is also driven by storage conditions such as exposure to contaminants, heat, air, and light—oxidizing conditions that can accelerate degradation/aging. A high resistance to aging is necessary to ensure fuel retains quality throughout the supply chain. A fuel's resistance to oxidation, referred to as its oxidation reserve, is determined using accelerated aging tests, which can indicate if a fuel will be stable during typical storage and handling.

Fuel aging and oxidation can lead to the production of acids, increased viscosity, and the formation of gums and sediments that clog filters. Biodiesel with high oxidation stability will generally take longer than biodiesel with low oxidation stability to reach a condition that would

[15] G.M. Chupka, J. Yanowitz, G. Chiu, T.L. Alleman, and R.L. McCormick. 2011. "Effect of Saturated Monoglyceride Polymorphism on Low-Temperature Performance of Biodiesel." *Energy and Fuels* 25 (1): 398–405. doi: 10.1021/ef1013743.



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be problematic. Monitoring stability—measured as Rancimat induction period and the acid number of B100 over time—is recommended if it will be stored for longer time periods.

For B100, an oxidation stability measurement is carried out using the test method EN15751 (also referred to as the Rancimat test and listed in ASTM D6751, ASTM D7467, and ASTM D396 as oxidation stability). This analysis involves heating a small fuel sample to 110°C (230°F) while air is bubbled through the fuel at a controlled flow rate and recording the amount of time the fuel takes to degrade under these conditions (its induction period). These conditions are referred to as being accelerated because the temperature of the test is much higher than will occur in real-world storage and because the fuel is saturated with oxygen from the flowing air. This extreme aging does not mimic any condition the fuel might encounter in use, but is designed to force rapid oxidation, which differentiates stable and unstable fuels. Results from this test provide a relative stability index; longer times mean more stable fuel.

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, sediments are 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:

- Certain metals such as rust, copper, brass, bronze, lead, tin, and zinc will accelerate the degradation process and may form even higher levels of sediment. If possible, B100 (as well as petroleum diesel) should not be stored in systems that contain these metals. Copper fuel lines are common in home heating oil systems, however, and storage results indicate similar or lower sediment levels with B100 than with petroleum home heating oil.
- Antioxidants, whether natural or incorporated as additives, can significantly increase the storage life or stability of B100. The use of antioxidant additives is highly recommended with B100, especially with longer-term storage. Actual results and improvements may vary depending upon the chemistry of each additive.
- Limiting or preventing biodiesel contact with air 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 with minimal headspace.

Accelerated stability tests like EN15751 will show if a fuel has high or low stability, but this cannot exactly predict the amount of time a fuel can be stored. The stability requirement in D6751 is that B100 have a minimum three-hour oxidative reserve prior to being blended, so most biodiesel producers make B100 with higher oxidation reserve values. If the biodiesel will be stored for some time prior to blending, biodiesel with antioxidants or higher oxidation reserve should be considered or the induction time and acid number can be monitored at regular intervals to ensure the biodiesel meets D6751 prior to blending.

A very useful evaluation of diesel fuel stability during storage for research purposes is the ASTM D4625 storage stability test. This is used to simulate storage at ambient temperature,



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roughly 21°C (70°F), to gain a sense of how a fuel may behave over long periods of time. The test conditions are meant to accelerate aging by a factor of 4 for S500 diesel fuels—i.e., 1 week of storage at D4625 conditions (43°C or 110°F, slightly open to air) simulates 1 month of storage at 21°C (70°F). This acceleration factor has not been validated for B100 or other low-sulfur distillate fuels, but it is still a useful guide. ASTM D4625 data (see Figure 3)[16] indicate that B100 will lose oxidation stability gradually over time, eventually dropping below the specification minimum of 3 hours. Higher initial induction period values can provide longer storage time before biodiesel goes out of specification. Figure 3 also shows that as the oxidation stability is reduced to near zero, the material can oxidize due to complete loss of "oxidation reserve." This is evident in the increase in peroxide values, peroxides being the initial primary product of fuel oxidation. Acid numbers remain relatively constant until peroxide values become very high (>1,500 ppm), as acids are secondary products. Once sufficient peroxides have formed, the acid number increases rapidly via peroxide degradation.

Measurement of insoluble material in the B100 samples in Figure 3 was not statistically significant during ASTM D4625 storage for 13 weeks (simulating 1 year of storage); however, highly oxidized biodiesels—having acid numbers well above the ASTM D6751 limit of 0.5 mg KOH/g—have historically been shown to form insoluble materials.[17] Studies such as this show that B100 can lose its oxidation reserve to fall below the specification limit before the fuel forms acids and insoluble materials, which could become problematic. Tracking oxidation stability and acid number during storage therefore is recommended to determine when the fuel is beginning to lose stability and when chemical and physical changes are imminent so that mitigation strategies can be put into place to prevent operational issues.

High oxidation stability measured by EN15751indicates a B100 will remain stable in typical storage times. Non-oxidizing storage conditions in containers with little head space or under a nitrogen blanket will also be helpful. In fact, the recent industry quality data indicates most B100 being produced is far above the 3 hour oxidative reserve specification[9] and would be expected to be above 3 hours oxidation reserve after 4-6 months of clean dry storage. However, if B100 just meeting the 3 hour oxidative reserve specification is purchased and stored without the addition of anti-oxidant or new B100 with higher oxidative reserve, testing for oxidation reserve may be needed every 1-2 months to insure a 3 hour oxidative reserve prior to blending. Antioxidant additives can be used to improve stability in the field but are best used before peroxides reach high levels (>1,000 ppm), and before acid value goes out of specification and insoluble material has formed. Additives cannot eliminate acids or sediments in fuel once the fuel has degraded but can be added early on to prevent acids and gums from forming in the first place.

[16] E. Christensen and R.L. McCormick. 2014. "Long-Term Storage Stability of Biodiesel and Biodiesel Blends," *Fuel Processing Technology* 128: 339–348.
[17] R.L. McCormick and S.R. Westbrook. 2010. "Storage Stability of Biodiesel and Biodiesel Blends." *Energy & Fuels* 24 (1): 690–698.



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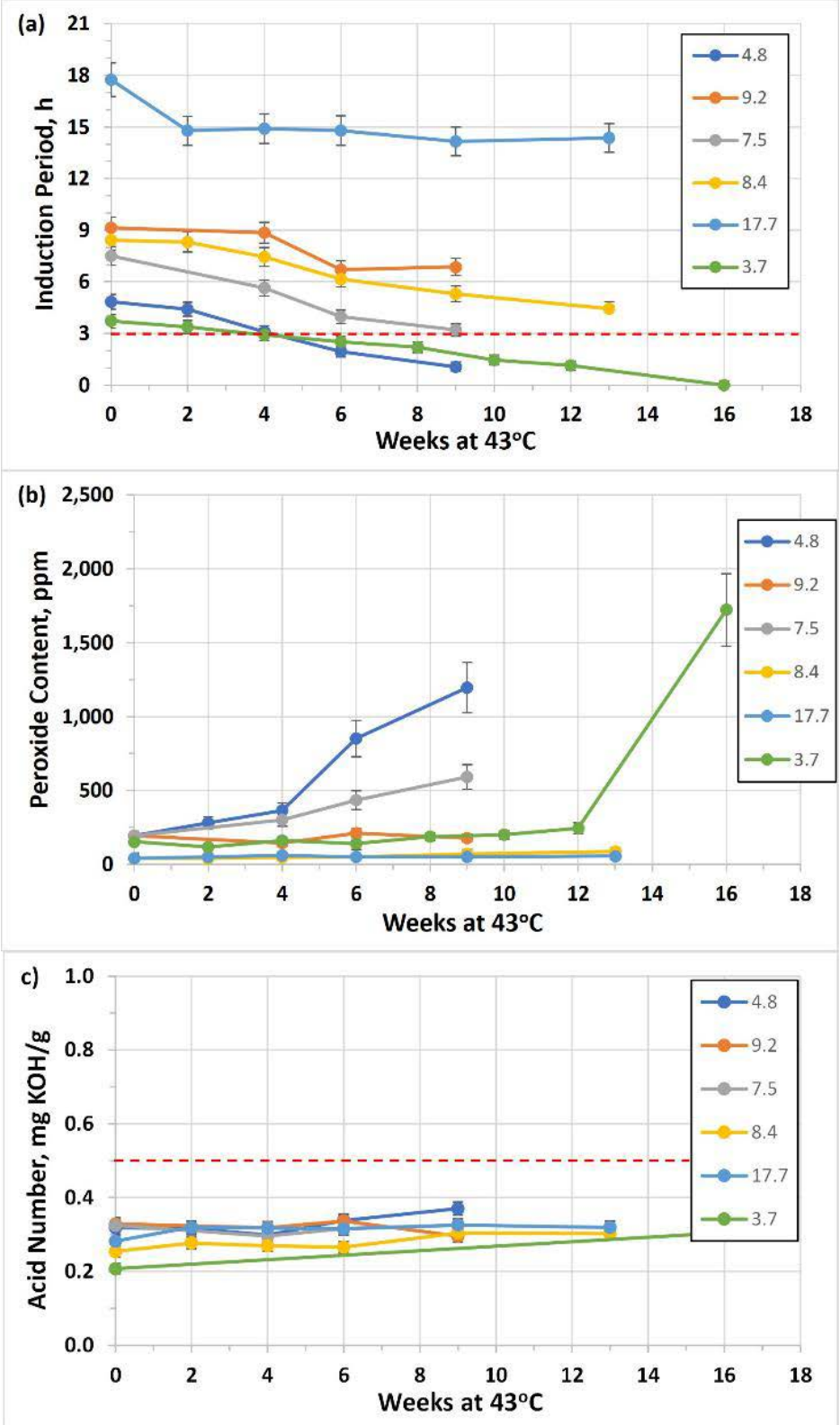


**Figure 3. ASTM D4625 long-term storage stability for B100 samples having a range of initial Rancimat induction periods. (a) Rancimat induction period (dashed line is 3-h minimum requirement), (b) peroxide content, and (c) acid number (dashed line is 0.5-mg KOH/g maximum requirement).[16]**



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## Microbial Contamination

Microbial contamination of fuel storage tanks can plug dispensers and fuel filters and cause operability issues. This requires a layer of free water at the bottom of the storage tank, and the best defense is to monitor the tank and keep it dry. Water bottoms must be removed from tanks as much as possible, and standing tanks should be sampled and tested for microbial contamination on a regular basis. Microbial contamination can occur for any fuel. Because biodiesel is more highly biodegradable than petroleum fuels, it may be more susceptible to microbial growth in tanks—particularly at higher blend levels—although the actual level of biodiesel vs. petroleum diesel in the field is not well documented.

Microbial contamination within fuels can also lead to microbial-induced corrosion. However, studies looking to identify the root causes of corrosion of metallic components in underground fuel tanks have found that corrosion ratings for samples containing biodiesel were statistically lower than the corrosion ratings for samples that were biodiesel-free.[18]

Biocides are recommended for fuels wherever biological growth in fuel tanks 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 hydrocarbon-utilizing microorganisms usually grow at the fuel–water interface. Anaerobic colonies 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.

## Transport

Like all fuels, 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 diesel fuel and/or biodiesel:

- Ensure trucks and railcars are constructed of aluminum, carbon steel, or stainless steel.
- Ensure proper inspection or washout (i.e., a washout certificate) before loading.
- Check for previous load carried and residual material. 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 or raw plant oils, gasoline, or lubricants—may not be acceptable.
- Ensure 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 B100 during cold weather. In the winter, most B100 is shipped in one of the following ways:
    - Hot (or at least warm) in trucks for delivery at 27°C to 54°C (80°F to 130°F).

[18] Coordinating Research Council. 2021. *Identification of Potential Parameters Causing Corrosion of Metallic Components in Diesel Fuel Underground Storage Tanks*. CRC Report No. DP-07-16-1.



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- Frozen after several days in cold weather in railcars equipped with external steam coils (the fuel in the tank cars is melted at the final destination with low-pressure steam).

Regardless of how the biodiesel arrives, procedures that prevent the temperature of B100 from being delivered below its cloud point must be in place. The cloud point of the biodiesel, biodiesel temperature, ambient temperatures, and time the fuel is in transport should all be considered when transporting B100.

## Biodiesel Quality

The biodiesel industry has developed a voluntary quality control program called BQ-9000 to ensure biodiesel meets the most current ASTM specifications and consistent procedures are followed to prevent contamination and degradation during production, distribution, storage, and blending. The BQ-9000 program includes accredited producers, marketers, and laboratories. The BQ-9000 program is managed by an independent organization, the National Biodiesel Accreditation Commission. Numerous engine manufacturers recommend use of biodiesel from BQ-9000-accredited producers, and retailers or end users can avoid the need for independent testing by purchasing biodiesel fuels from accredited marketers.

The company, whether a producer, marketer, or laboratory—not the fuel—receives the accreditation, but the fuel supplied by either an accredited producer or marketer must meet all applicable standards for sale and use in the United States. As of June 2023, there are 43 accredited producers, 14 accredited marketers, and 11 accredited laboratories.

To become an accredited producer, a company must develop a system for monitoring the production of biodiesel through proper sampling, testing, storage, sample retention, and shipping protocols. These protocols must be rigorously followed and meet all appropriate program requirements. A certificate of analysis must be generated for each production lot with a unique identification code and analytical results from a sample. Testing must include at least the following parameters of the current ASTM specification: visual appearance, free and total glycerin, monoglycerides, water and sediment, cloud point, acid number, sulfur, oxidative stability, cold soak filterability, and alcohol control (by either methanol content or flash point). The producer must also ensure transport vehicles are clean and of appropriate construction for distributing biodiesel.

The accredited marketer must either purchase B100 from an accredited producer or conduct full fuel quality testing on all biodiesel purchased from non-accredited producers. The accredited marketer must also maintain storage and distribution procedures that protect the biodiesel's quality, while monitoring the accuracy of any biodiesel blend ratios. A BQ-9000-accredited laboratory must have an established quality system procedure and demonstrated competency for testing biodiesel samples to the most current ASTM specifications.

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

Recent reports on biodiesel quality from producers that participate in BQ-9000 show the specifications are routinely met.[9]



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# Biodiesel Blends

This section focuses on blending B100 with diesel fuel to make B6 to B20 blends, but the approach is similar for lower 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 fuel. Blending biodiesel into diesel fuel can minimize these property differences and retain many of the benefits. B20 is popular because it represents a good balance of cost, lubricity, emissions, cold weather performance, and compatibility with existing engines and fueling infrastructure.[19]

## Specifications

### *B5 and Lower Blends*

The specification for conventional diesel fuel, ASTM D975, allows for up to 5 vol % biodiesel to be blended into No. 1 and No. 2 grade diesel fuels, and the resultant blends up to B5 are considered conventional diesel fuel. The biodiesel used in the blend must meet ASTM D6751. Blends up to B5 must meet all the specification requirements for No. 1 or No. 2 grade diesel fuel properties listed in ASTM D975. None of the properties were changed or relaxed to accommodate biodiesel. There is no requirement that ASTM D975 fuels list the percent of biodiesel in the blend. ASTM D396 also allows up to 5 vol % biodiesel in No. 1 and No. 2 grade oils for use in domestic (home heating) and industrial burners. Blends up to B5 are considered conventional heating oil.

### *B6 to B20 Blends*

The specification for B6 to B20 blends also requires that the biodiesel meet the ASTM D6751 specification prior to blending with diesel fuel or heating oil. The general requirements of B6–B20 for diesel engines, ASTM D7467-20a (most current version at this publication), are shown in Table 3, and the B6–B20 requirements for heating oil, ASTM D396-21 (current version), are shown in Table 4. To produce B6–B20, biodiesel can be blended with No. 1, No. 2, or mixtures of No. 1 and No. 2 petroleum fuel as is common in cold weather. The properties of the B6–B20 blend are based generally on the widest values from either the No. 1 or No. 2 petroleum grades. The T90 is allowed to be slightly higher for B20, however, due to the inherently high boiling range of B100. Additional parameters for oxidation reserve and acid number were added for B6–B20 to help ensure adequate long-term storage properties. Beyond the properties in these tables, there are many other requirements within the specification that are important for users (for example, see sections entitled “Requirements” and “Workmanship”). Consult the full specifications for additional details. The additional requirements ensure the fuel is fit for purpose. Requirements for pump labeling are in Appendix C.

[19] B20 is also the minimum blend level that can be used for Energy Policy Act (EPAct) compliance for covered fleets. See epact.energy.gov for more information.



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**Table 3. ASTM D7467-20a Specification for Diesel Blends B6 to B20 (reprinted with permission of ASTM)**

| Property | Test Method (ASTM) | Grade | | |
|---|---|---|---|---|
| | | B6 to B20 S15 | B6 to B20 S500 | B6 to B20 S5000 |
| Acid number, mg KOH/g, max | D664 | 0.3 | 0.3 | 0.3 |
| Viscosity, $mm^2/s$ at 40°C | D445 | 1.9–4.1 [a] | 1.9–4.1 [a] | 1.9–4.1 [a] |
| Flash point, °C, min | D93 | 52 [b] | 52 [b] | 52 [b] |
| Cloud point, °C, max or low-temperature flow test (LTFT)/cold filter plugging point (CFPP), °C, max | D2500 | [c] | [c] | [c] |
| Sulfur content, (µg/g or ppm) [d] | D5453 | 15 | – | – |
| mass %, max | D2622 | – | 0.05 | – |
| mass %, max | D129 | – | – | 0.50 |
| Distillation temperature, °C, 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 | 40 [e] | 40 [e] | 40 [e] |
| One of the following must be met: | | | | |
| Cetane index, min | D976-80 | 40 | 40 | 40 |
| Aromaticity, vol %, max | D1319-03 | 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 at 50°C, max | D130 | No. 3 | No. 3 | No. 3 |
| Biodiesel content, % (V/V) | D7371 | 6.– 20. | 6.– 20. | 6.– 20. |
| Oxidation stability, hours, min | EN15751 | 6 | 6 | 6 |
| Lubricity, high-frequency reciprocating rig (HFRR) at 60°C, (µm), max | D6079 | 520 [f] | 520 [f] | 520 [f] |
| Conductivity (pS/m) or conductivity units (C.U.), min | D2624/D4308 | 25 [g] | 25 [g] | 25 [g] |

[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 −12°C is specified, the minimum flash point shall be 38°C.
[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. Appropriate low-temperature operability properties should be agreed upon between the fuel supplier and purchaser for the intended use and expected ambient temperatures.
[d] Other sulfur limits can apply in selected areas in the United States and in other countries.
[e] 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 ASTM D975 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.
[f] If the diesel fuel is qualified under Table 1 of ASTM D975 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 less than 520 µm, so the resulting blend will also be less than 520 µm.
[g] The electrical conductivity of the fuel oil is measured at the time and temperature of the fuel at delivery. The 25-pS/m minimum conductivity requirement applies at all instances of high velocity transfer (7 m/s), but sometimes lower velocities into mobile transport (e.g., tanker trucks, rail cars, and barges).



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**Table 4. ASTM D396-21 Specification for Heating Oil Blends B6 to B20**

| Property | Test Method (ASTM) | B6-B20, S15, S500, or S5000 |
|---|---|---|
| Distillation temperature, °C | D86 | |
| 10% volume recovered, max | | - |
| 90% volume recovered, min | | 282 |
| 90% volume recovered, max | | 343 |
| Kinematic viscosity at 40°C, $mm^2/s$ | | |
| Min | | 1.3 |
| Max | | 4.1 |
| Sulfur, percent by mass, max [a] | | |
| Grade S15 | D5453 | 0.0015 |
| Grade S500 | D2622 | 0.05 |
| Grade S5000 | D2622 | 0.5 |
| Pour point, °C, max [b] | D97 | −6 |
| Ramsbottom carbon residue on 10% distillation residue percent by mass, max | D524 | 0.35 |
| Density at 15°C, $kg/m^3$, max | D1298 | |
| Oxidation stability, hours, min | EN15751 | 6 |
| Acid number, mg KOH/g, max | D664 | 0.3 |
| Biodiesel content, percent (V/V) | D7371 | 6–20 |
| Flash point, °C, min | D93 – Proc A | 38 |
| Water and sediment, percent by volume, max | D2709 | 0.05 |
| Lubricity, high-frequency reciprocating rig (HFRR) at 60°C, µm, max | D6079/D7688 | 520 [c] |
| Copper strip corrosion rating, max, 3 h at a minimum control temperature of 50°C | D130 | No. 3 |
| Conductivity (pS/m) or conductivity units (C.U.), min | D2624/D4306 | 25 [d] |

[a] Other sulfur limits may apply in selected areas in the United States and in other countries.
[b] Lower or higher pour points can be specified whenever required by conditions of storage or use. When a pour point less than −18°C is specified, the minimum viscosity at 40°C for Grade No. 2 shall be 1.7 $mm^2/s$, and the minimum 90% recovered temperature shall be waived.
[c] If the fuel oil is qualified under Table 1 of ASTM D396 for lubricity, it is not necessary to measure the lubricity of the blend because the lubricity of the individual blend components will be less than 520 µm, so the resulting blend will also be less than 520 µm.
[d] The electrical conductivity of the fuel oil is measured at the time and temperature of the fuel at delivery. The 25-pS/m minimum conductivity requirement applies at all instances of high velocity transfer (7 m/s), but sometimes lower velocities into mobile transport (e.g., tanker trucks, rail cars, and barges).

## Materials Compatibility

B20 or lower blends made with today's ASTM D6751-grade biodiesel minimize most issues associated with materials compatibility. Experience over the last 15 years indicates B20 compatibility with all elastomers in diesel ground vehicle fuel systems, even those such as nitrile rubber, which can be sensitive to higher blends or higher acid numbers. While today's biodiesel specifications have largely been successful in minimizing fuel system leaks or issues, fuel systems can and do degrade over time, so customers should continue to check for and fix leaks should they occur.



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## Low-Temperature Properties

Blending biodiesel with petroleum diesel may reduce some of the low-temperature operability challenges of B100, although the effects are not necessarily linear. Conventional low-temperature operability additives can be used with blends, though these additives are believed to be effective only on the diesel portion of the blend. When biodiesel is blended with diesel fuel, the key variables are the cold flow properties of the diesel fuel, properties of the biodiesel, blend level, and effectiveness of cold flow additives.

B100 cold flow properties depend on feedstock composition, which also affects the cold flow properties of blends. The same is true of diesel fuel. Diesel fuels have a cloud point range of −35°C to −5°C (−31°F to 23°F). Some fuels can have cloud points higher or lower. No. 1 diesel (i.e., kerosene) or Jet A may have cloud points of −40°C to −51°C (−40°F to −60°F).

Cloud point and pour point are addressed earlier in the B100 section of this report. Cloud point is the most commonly used low-temperature operability metric for diesel fuels and biodiesel blends. However, especially for fuels treated with low-temperature operability additives, there are other important metrics:

- **Cold filter plugging point test.** This test measures the temperature at which a standard volume of fuel can be pulled by vacuum through a filter in a given time. The CFPP test employs rapid cooling and simulates light-duty diesel truck fuel system designs in Europe.
- **Low-temperature flow test.** 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 (1°C per hour) 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 users consult Appendix X.5 of ASTM D975 or Appendix X.3 of ASTM D7467 to understand the history and relative utility of tests for cloud point, CFPP, and LTFT. Note that CFPP and LTFT are particularly useful for evaluating the effectiveness of additives.

When handling biodiesel blends in cold climates, such as during fueling of vehicles, the same guidelines given above for handling B100 should be followed:

- The biodiesel blend should be stored at temperatures at least 2.5°C to 5°C (5°F to 10°F) higher than the cloud point. Because the cloud point of the fuel varies, the storage temperature for trouble-free use will not be the same for all biodiesel blends.
- Aboveground fuel storage tanks and fuel lines should be designed for the cold flow properties of biodiesel blends and the local climate. Fuel pumps, lines, and dispensers must be protected from cold and wind chill with properly approved heating and insulating equipment.
- Most B20 can be stored underground in most cold climates without additional considerations because underground storage temperatures are normally above 7°C (45°F).



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A Coordinating Research Council study showed that biodiesel blends (B5 and B20), made from B100 meeting the ASTM specification, would provide operability down to cloud point. Additives may allow operation at even lower temperatures.[20] From this same study, it was found for biodiesel blends prepared from B100 meeting the ASTM D6751 specification, the cloud point and LTFT will be nearly the same, and CFPP will be 2°C to 3°C (3.5°F to 5°F) lower if no low-temperature flow improver additives are used. Additives do not usually alter cloud point but can lower CFPP and LTFT. Thus, for additized fuels, CFPP or 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 requirements. Adjusting the blend of kerosene/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 will require mixing the biodiesel with the winter diesel typically delivered in your area and testing the mixture. Cold flow properties needed for the fuel depend on where it is being used (e.g., Minnesota or Texas) and what time of year the fuel is being used (e.g., January or July). A petroleum diesel or biodiesel fuel with a cloud point of −7°C (20°F) may be fine for a Texas summer, but not for a Minnesota winter.

At the 10th percentile minimum temperature, only 10% of the days were colder during that month on average, based on data from several decades. The 10th percentile minimum temperature information is contained in Table 3 in ASTM D396 and in the appendixes to ASTM D975 and ASTM D7467. 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 rely on their distributors to make sure low-temperature operability is managed for their location.

## Lubricity

In some diesel engines and/or diesel fuel systems, the fuel used acts as a lubricant for the moving components in the system. Prior to the implementation of ultra-low-sulfur diesel (ULSD) fuel (i.e., <15 ppm sulfur), petroleum diesel or heating oil had adequate lubricating properties to fulfill the equipment needs. With the advent of ULSD in 2006, fuel standards needed to be added to ASTM D975 to eliminate fuel pump issues. New fuel lubricity additives were implemented to address these needs. Blending biodiesel into diesel fuel even at low levels can improve the lubricity of ULSD fuel without the use of other lubricity additives. The exact blending level required to achieve adequate lubricity of a maximum 520-µm high-frequency reciprocating rig (HFRR) wear scar depends on the properties of the diesel fuel, but 2% biodiesel almost always imparts adequate lubricity to biodiesel blends.[21] If the biodiesel blend being used contains at least 2% biodiesel, this can eliminate the need for and cost of other lubricity additives.

[20] Coordinating Research Council. 2008. *Biodiesel Blend Low-Temperature Performance Validation*. CRC Report No. 650. https://crcao.org/wp-content/uploads/2019/05/CRC-650.pdf#new_tab.
[21] G. Knothe and K.R. Steidley. 2005. "Lubricity of Components of Biodiesel and Petrodiesel. The Origin of Biodiesel Lubricity." *Energy & Fuels* 19: 1192–1200. https://doi.org/10.1021/ef049684c.



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## Stability of Biodiesel Blends

Stability of B6 to B20 blends, as with B100, refers to potential for changes over time as the fuel ages during storage. Oxidation being the primary mechanism for biodiesel aging, this is included in the ASTM D7467 blend specification as an oxidation stability requirement. Blends are evaluated for oxidation stability using the EN15751 test procedure (also known as the induction period or Rancimat test), which provides a relative indication of a fuel's ability to resist oxidation and changes in properties during storage and handling. ASTM D975 does not include a stability test for No. 1 or No. 2 diesel fuels, but the same analysis can be applied for fuels containing up to 5% biodiesel if desired. Biodiesel blends are typically more stable than B100, with the stability of the biodiesel component playing a key role in the final blend.

During storage of a biodiesel blend, the induction period can decrease over time. This is indicative of the fuel's resistance to oxidation (or oxidation reserve) slowly being depleted prior to the fuel itself oxidizing. This expected decrease in induction period is caused by the depletion of antioxidants, and normally occurs prior to measurable changes in fuel quality. Once the oxidation stability has declined to a low value, the fuel itself will begin to oxidize, which can be detected by measuring peroxides, the primary product of fuel oxidation. As peroxides form, they will eventually break down into acids, which are secondary products. Acid value is therefore a useful analysis for tracking evidence of oxidation. If the fuel degrades even further, this will then lead to the formation of gums and insoluble deposits, which can be problematic for fuel system performance.

As with any fuel, the storge life of biodiesel blends is a function of fuel quality but is also strongly driven by storage conditions. Bad storage conditions will accelerate the deterioration of even the most stable fuels. Oxidizing conditions such as exposure to air, heat, contaminants, oxidizing metals, and light can reduce storage life. Oxidizing metals such as rust, copper, bronze, brass, or zinc can be found in some fuel storage and handling systems. If filters clog more frequently with B20 than with petroleum diesel, the fueling system should be checked for materials such lead solders, zinc linings, copper pipes, and brass and copper fittings, and they should be replaced with carbon steel, aluminum, or stainless steel parts. Alternatively, use of fuel antioxidants and/or metal chelators can also help reduce filter issues in systems with these components.

A fuel meeting the ASTM D7467 specification will remain stable in typical storage conditions and use. For longer-term storage, higher initial stability can be beneficial. Figure 4 provides the results of a study of B20 blends collected from retail sites and fleets across the United States in 2016.[22] The fuels in this study were subjected to mildly accelerated aging following the ASTM D4625 storage stability test described above. Nearly all showed a steady decrease in induction period over time as expected. By 12 weeks of this exposure, simulating approximately 12 months, the fuels retained sufficient oxidation stability for use, and fuel quality remained high during this time frame.

After 12 weeks, Fuel G—the fuel beginning just above 6 hours in Figure 4—produced a detectable change in acid number (going from an initial 0.15 mg KOH/g to 0.20 mg KOH/g) and

[22] E.D. Christensen, T. Alleman, and R.L. McCormick. 2020. *Re-Additization of Commercial Biodiesel Blends During Long-Term Storage*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5100-75895.



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finally became out of specification for acid number at 16 weeks of storage. A fuel meeting the specification minimum is expected to retain quality for up to 1 year in clean, dry storage conditions. Fuels having higher initial stability retained their induction period for much longer, with some fuels showing little to no change in induction period for as long as 36 weeks—simulating 3 years of storage with no changes in fuel quality.

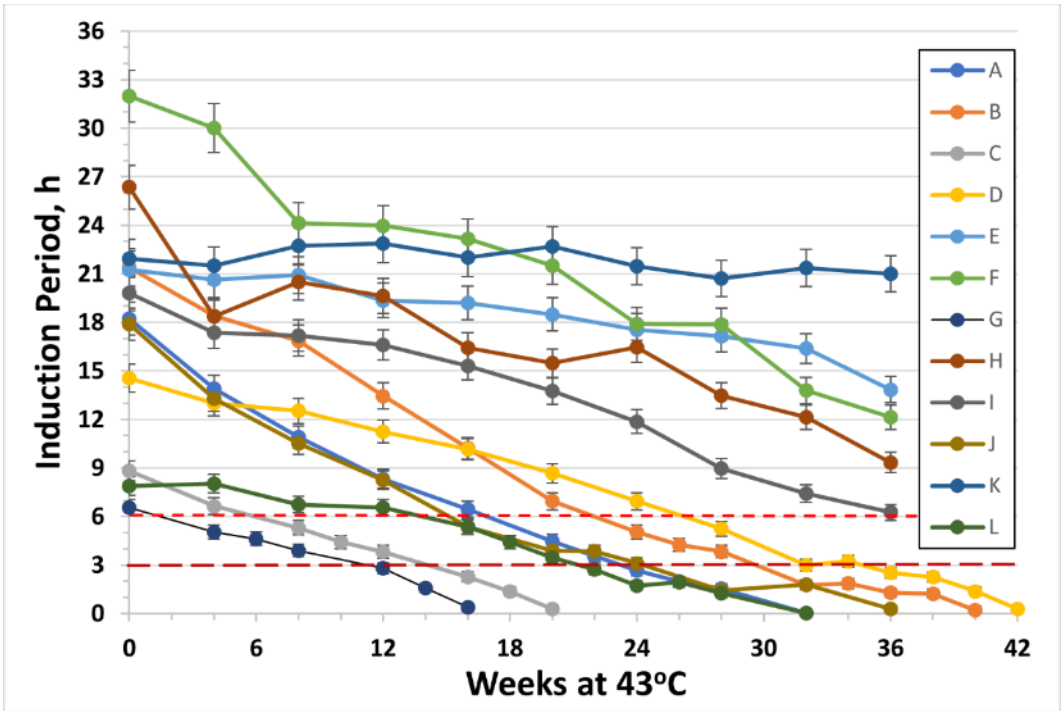


**Figure 4. Rancimat induction period for ASTM D4625 storage for B20 blends collected in the United States in 2016. Upper dashed line is 6-hour minimum stability required by ASTM D7647. Lower dashed line is 3-hour stability level below which the formation of acids and peroxides is observed.[22]**

**Preventing degradation from occurring is paramount for maintaining fuel quality in storage.** An antioxidant additive package can also be beneficial for fuels stored for longer periods, increasing induction period and thus oxidation reserve of the fuel. Addition of an antioxidant should be done as close to production as possible to maximize benefits and prevent any changes to initial fuel quality. It is important to note stabilizing additives are preventative measures only, as further described below.

If fuel is to be stored for long periods of time, it is recommended that both the oxidation stability and acid number be monitored at regular intervals to look for indicators of oxidation. With regular monitoring it is possible to observe changes in induction period prior to an increase in acid number, and prior to the onset of fuel degradation.

Additization further down the supply chain, such as inside a storage tank, can be referred to as re-additization, indicating antioxidant treatment in addition to any included at the point of manufacturing. Re-additization can only slow the oxidation process from proceeding further if applied correctly. These additives cannot correct fuel degradation once it has occurred; therefore,



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re-additization should be used in combination with fuel monitoring to prevent loss of fuel quality.

Figure 5 illustrates this situation.[22] Fuel G from Figure 4 had a beginning induction period of just over 6 hours, meeting the specification. This fuel had an approximate storge life of just over 1 year as it was received, indicated by acid number increase. After the addition of an antioxidant, the induction period was increased (Figure 5a) back to a minimum of 6 hours. The induction period continued to decline, but this re-additized fuel was now able to be stored for 36 weeks (approximately 3 years) without going out of specification for acid number, while the fuel without re-additization took 16 weeks (slightly over a year).

In this case, re-additization extended the life of this fuel considerably when used in combination with monitoring. Figures 5b and 5c provide a picture of the impacts on fuel quality from aging and re-additization. After several weeks the fuel produced low concentrations of peroxides, while the acid number remained constant. Once the rate of peroxide production became exponential the acid value increased above specification. With re-additization the production of peroxides was slowed dramatically (Figure 5b). The acid value did increase (peroxides had formed and were degrading) but remained on specification for a much longer time (Figure 5c).

These figures highlight the fact that additives can be very beneficial for longer-term storage, but they will not correct any degradation that occurred prior to additization. For instance, once the acid number has gone out of specification, enough additive could possibly restore induction period, but the acids would remain as an indicator the fuel had aged. It must be stressed that antioxidant addition is much more effective early on.

Because biodiesel and biodiesel blends can oxidize in storage if not property handled, there has been concern that oxidation could occur in the fuel tanks of vehicles that are used infrequently. A study was conducted to investigate the potential for onboard vehicle oxidation in cars equipped with high-pressure common rail (HPCR) fuel systems.[23] A light-duty passenger vehicle was outfitted with temperature and pressure sensors to monitor the stress on fuel as it passed through the HPCR and was returned to the fuel tank. In addition, the engine was outfitted such that fuel could be sampled between the HPCR and tank, differentiating the fuel in the tank from that which had immediately experienced the high temperature/high pressure of the rail.

Experiments were conducted on a dynamometer inside a temperature-controlled chamber with underbody heating simulating driving on a hot day (95°F ambient temperature and 120°F underbody). A drive cycle was developed to maximize heat and pressure on the fuel and replicate driving under high load in a hot climate. The intention of these experiments was to stress fuel as much as possible in the fuel system. The tank was filled with a minimum amount of fuel to conduct the experiment, providing as much headspace for air exposure as possible.

After a 1-hour drive cycle under these conditions, the vehicle was then taken to a driving track in Phoenix, Arizona, and parked in the sun. Every 2 weeks the vehicle was operated briefly such

[23] E. Christensen, R. McCormick, J. Sigelko, S. Johnson, S. Zickmannn, S. Lopes, R. Gault, and D. Slade. 2016. "Impact of a Diesel High Pressure Common Rail Fuel System and Onboard Vehicle Storage on B20 Biodiesel Blend Stability." *SAE Int. J. Fuels Lubr.* 9 (1): 203–214. https://doi.org/10.4271/2016-01-0885.



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that the fuel in the system was circulated and heated, returning aged fuel from the rail to the tank and agitating fuel in the tank in an attempt to maximize aging (exposure to heat and air).

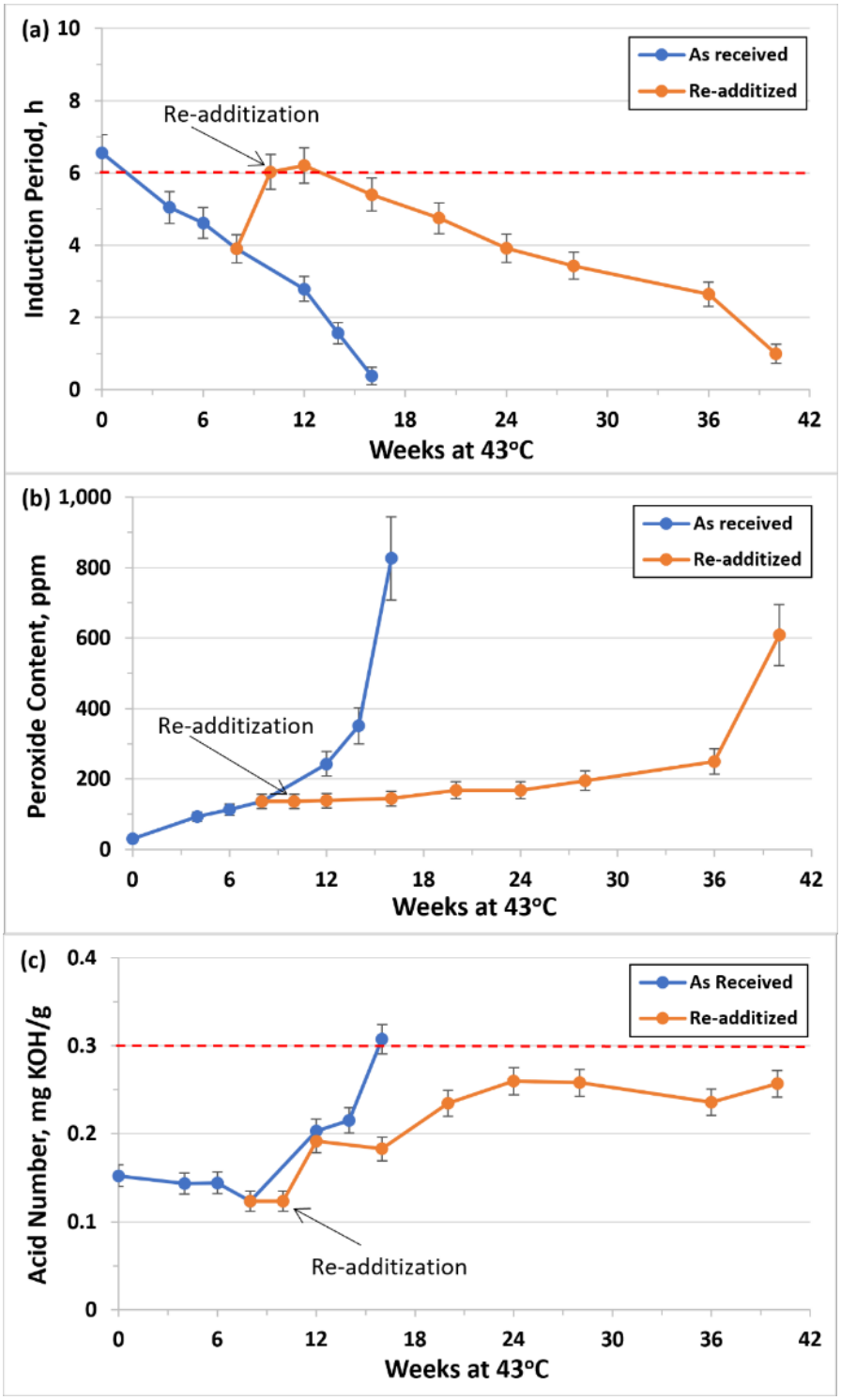


**Figure 5. Re-additization during storage of a biodiesel blend. (a) Induction period (dashed line is 6-h minimum requirement for B20 blends). (b) Peroxide content. (c) Acid number (dashed line is 0.3-mg KOH/g maximum allowable value) measured throughout storage.[22]**



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After 2 months the vehicle was once again subjected to the 1-hour drive cycle, again stressing the fuel after storage. The fuel taken after 8 weeks of storage in the fuel tank with periodic driving and one final hot driving cycle showed some decrease in induction period, as would be expected with time, but did not appear greatly impacted by this experiment relative to what would be expected after 2 months of storage tank aging. The acid number, which would indicate oxidation of the fuel itself, remained constant for each sampling. These results indicate thermal stability of biodiesel blends are not likely impacted by the environment of the fuel system, so long-term storage in a vehicle is expected to be similar to that in a bulk storage tank under similar conditions.

Thermal stability is generally meant to indicate a fuel's resistance to quality changes when subjected to high temperatures for a short period, as may 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. Like cooking oils, biodiesel has high thermal stability.

## Bulk Blending, Storage, and Transport

Most biodiesel users purchase finished biodiesel 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. You may also want to specify in your purchase contract or agreement that the fuel meet certain low-temperature operability requirements.

The chemical nature of biodiesel allows it to be blended with any kind of distillate or diesel fuel. This includes light distillate fuels such as kerosene, No.1 diesel, and military fuels, as well as middle distillate fuels such as No. 2 diesel for diesel engines and locomotives, distillate and residual marine fuel grades, and heating oil for boilers and home heating. Once biodiesel is blended thoroughly with diesel fuel, the blends do not separate over time if the blend is maintained at temperatures above its cloud point. **Biodiesel is a fuel for diesel applications only and is not to be blended with gasoline**.

Petroleum terminals and pipeline racks responded to increasing demand by installing biodiesel blending capability so jobbers and distributors can receive a biodiesel blend directly at 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.

Biodiesel blending procedures depend on a variety of factors, including the volume of B100 required to make the blend, finished blend level, 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.

Generally, biodiesel is blended into diesel fuel via two methods:



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- B100 may be splash blended with diesel fuel in a storage tank or a vehicle fuel tank. The action of the incoming biodiesel is sufficient to ensure mixing, which can be augmented by tank recirculation or movement of the vehicle.
- B100 may be blended at a petroleum terminal or rack by a pipeline or terminal operator (usually through ratio or in-line blending, though sequential blending may be used) 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 highly preferred method because it ensures complete 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 is most commonly used at pipeline terminals and racks. In some cases, distributors who carry B100 and petroleum diesel in separate compartments and blend the two as they are loading into a customer's tank also use this method.
>
> In-line blending uses two metered pumps and a dual-fuel injection system, requiring 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 (e.g., B2, B20) and generally cannot handle both types of blends.

Most users find blending their own fuel to be time-consuming and costly, so they increasingly request that their petroleum supplier make finished blends available.

## Vehicle Refueling Infrastructure

### *Codes and Regulations*

Biodiesel blends are subject to the same regulations and codes as diesel fuels. Blends up to B5 are considered regular diesel fuel and approved for use in existing diesel infrastructure. Blends above B5 are sometimes subject to additional requirements. Stations considering blends above B5 should first contact their state and local authorities to identify other regulations and requirements.

Sufficient positive experience exists with B20 and lower blends such that EPA allows B20 and lower blends to be stored in existing underground storage tanks (USTs) approved for petroleum diesel. UST are regulated by the EPA's Office of Underground Storage Tanks and blends above B20 must meet demonstrate compatibility with the biodiesel blend being stored. In addition, the Occupational Safety and Health Administration is involved in regulating fuel dispensing equipment, but they do not specifically mention biofuels. UL is also involved with testing and



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developing standards for fuels, and a summary of applicable UL standards for refueling equipment is available in Appendix D. More detailed information on these three entities and their involvement can be found at https://afdc.energy.gov/fuels/biodiesel_codes.html.

### *Retail and Fleet Station Equipment*

A service station consists of approximately 60 interconnected pieces of refueling equipment necessary to deliver fuels to vehicles and handle vapor. This can include tanks, pipes, pumps, dispensers, and hanging hardware. The remainder and majority of equipment prevent, detect, and contain releases with overfill protection, leak detection, and all associated fittings and accessories of these equipment types. Figure 6 provides a diagram and Table 5 a corresponding equipment list.

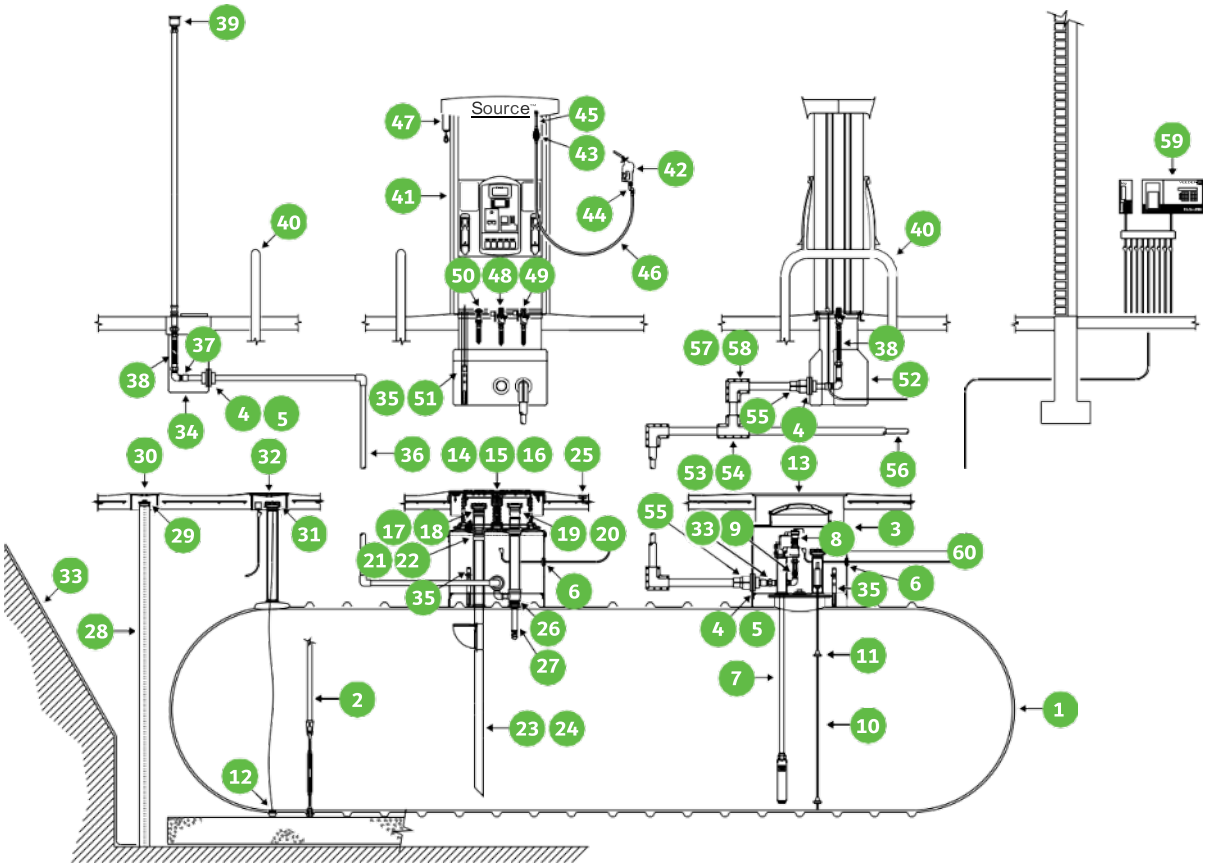


**Figure 6. Typical station fuel dispenser and underground storage piping.**

Figure from Source Fueling Equipment Solutions.



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**Table 5. Fuel Dispenser and Underground Storage Piping Components**

| # | Equipment | # | Equipment | # | Equipment |
|---|---|---|---|---|---|
| 1 | Tank | 21 | Face seal adaptor | 41 | Dispenser |
| 2 | Tank straps | 22 | Jack screw kit | 42 | Nozzle |
| 3 | Sump and cover (tank) | 23 | Overfill prevention valve | 43 | Breakaway |
| 4 | Sump entry fitting (boot) | 24 | Drop tube (often a part of #23) | 44 | Swivel |
| 5 | Sump penetration fittings | 25 | Fuel grade ID # | 45 | Whip hose |
| 6 | Flexible entry boots | 26 | Extractor tee | 46 | Hose |
| 7 | Submersible turbine pump | 27 | Ball float vent valve | 47 | Hose retractor |
| 8 | Mechanical line leak detector | 28 | Monitoring well screen (pipe) | 48 | Stabilizer bar kit |
| 9 | Ball valve | 29 | Well cap-monitoring | 49 | Shear valve |
| 10 | Magnetostrictive probe | 30 | Manhole-monitoring | 50 | Shear valve-vapor (stage II only) |
| 11 | Float kit | 31 | Interstitial cap | 51 | Sensor tube |
| 12 | Interstitial sensor | 32 | Manhole | 52 | Dispenser sump |
| 13 | Manhole-composite | 33 | Roll filter fabric | 53 | Pipe-secondary containment tee |
| 14 | Manhole-multi-port spill containment | 34 | Transition sump-vent | 54 | Pipe-product tee |
| 15 | Spill bucket | 35 | Sump sensor | 55 | Concentric reducer |
| 16 | Fuel grade ID tag | 36 | Pipe | 56 | Pipe-secondary containment |
| 17 | Fill adaptor (top or side) | 37 | Pipe adaptor | 58 | Pipe-product elbow |
| 18 | Fill cap (top or side) | 38 | Flexible connector | 57 | Pipe-secondary containment elbow |
| 19 | Vapor adaptor | 39 | Vent | 59 | Console |
| 20 | Vapor cap | 40 | Steel bumper | 60 | Probe cap adaptor |

## *Tanks*

Most existing tanks are compatible with biodiesel blends up to B100. Appendix D lists tank manufacturers and their compatibility with biodiesel blends. All existing fuel storage tank manufacturers have issued signed letters stating compatibility with up to B100 per federal requirements. Steel tanks are listed under UL 58 for flammable fuels and do not test with specific fuels. Fiberglass tanks listed under UL 1316 now allow biodiesel test fluids. For existing equipment, both existing fiberglass tank manufacturers have tested with biodiesel fuels and meet federal codes with compatibility letters. Owens Corning manufactured underground fiberglass tanks between 1965 and 1994 using similar manufacturing processes and procedures as other fiberglass tank manufacturers, but the company is no longer in the fiberglass tank business and has therefore not tested with biodiesel, so they are not able to issue a letter stating compatibility.

### Aboveground Tanks

Aboveground tanks are uncommon at retail stations. ASTs are typically constructed of stainless steel or carbon steel. The use of galvanized metal tanks or plastic tanks is not recommended. It is



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important to check with local and national fire codes to determine appropriate tank construction. Many jurisdictions will require 2-hour fire-rated tank technology to dispense fuels from ASTs into motor vehicles. The construction of the tank may determine where the dispenser can be mounted and how close the tank can be to nearby buildings and property lines.

**Cleaning and Maintaining Tanks**

During fuel storage, debris and moisture can build up over time to form sludge, known as "water bottoms," in a tank. Biodiesel blends, particularly B100, have a solvent effect and will remove any sludge buildup and contaminate the fuel. A thorough tank cleaning is recommended when switching to B20 or higher blends, although many users simply change to biodiesel blends and monitor their system fuel filters and change them if needed. Proper housekeeping procedures should be instituted to limit debris and water contamination with either petroleum diesel or biodiesel fuels. Microbial contamination of diesel tanks is being investigated nationwide. UST owners should routinely clean tanks and remove water bottoms to reduce the risk of corrosion and microbial contamination.

There are several methods for cleaning sludge from storage tanks, listed below. It is possible to inspect a tank prior to cleaning using a camera with a remote that is inserted into a tank. It is important to note that all of the methods should be completed by a qualified company familiar with cleaning petroleum storage tanks.

- **Optic sweep:** This patented system uses a fiber-optic camera and controllable probe with an extraction device that can visually inspect and clean fuel storage tank bottoms at any fuel level with no tank downtime. The optic sweep can locate and remove water, sludge, bacteria, rust particles, and sediment while customers continue to pump.
- **Steam cleaning:** A person physically enters the tank, steam cleans it, and removes sludge. Care must be taken to properly dry the tank.
- **Filter agitator:** An agitating device is lowered into the tank. The fuel and any debris are agitated and circulated. A filtration system removes the suspended debris.
- **Chemical solvents:** Chemical solvents are used to remove scale and debris. Liquid and debris are then pumped from the tank and disposed of.

Choosing the appropriate cleaning technique will depend upon the type of fuel that has been stored in the tank, availability of the cleaning service, and state and local environmental regulations.

### *Other Underground Equipment*

Stations have a significant amount of equipment underground and in the tank to receive fuel deliveries and to prevent, detect, and contain leaks. This equipment includes but is not limited to sumps and accessories, manholes, flexible connectors, fill caps and adaptors, entry fittings, overfill prevention, leak detection, sensors, drop tubes, and vents. Those wanting to store blends above B20 should contact their equipment distributor or manufacturer to determine compatibility with biodiesel blends for specific models. The following manufacturers provide B100 compatible products: Bravo Systems (fiberglass fittings, spill buckets, tank sumps and covers, transition sumps, and under dispenser containment sumps); Cimtek (filters); Franklin Fueling (multiple products); Husky (pressure vacuum vents); Morrison Bros. (multiple products); National



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Environmental Fiberglass (sumps and accessories); OPW (multiple products); Veeder-Root (continuous interstitial tank system, electric line leak detector, interstitial and secondary containment monitoring, magnetostrictive probe, submersible turbine pump, tall tank probe, vapor monitoring); Western Fiberglass (all co-flow hydrostatic monitoring systems, cuff fittings, and sumps).

### *Pipes*

Approximately 99% of installed pipes are either fiberglass or flexible, and many products are compatible with biodiesel blends. The following manufacturers have issued letters stating compatibility with B100 to meet federal code: Brugg Pipesystems, NOV Fiberglass Systems (includes Ameron brand), Nupi Americas, and OmegaFlex (requires stainless steel fittings). Other manufacturers, including Advantage Earth Products, Franklin Fueling, and OPW, should be contacted directly for biodiesel compatibility. Typical warranties for fiberglass and flexible pipes are 30 and 10 years, respectively.

### *Aboveground Equipment*

Aboveground equipment includes the dispenser and hanging hardware. The hanging hardware consists of the nozzle, swivel, hose, whip hose, and breakaway. UL listed equipment compatible with B20 is available and should be used to meet federal and local regulations. Appendix D provides a list of UL listed B20 aboveground equipment.

All Gilbarco Atlas[24] and Encore dispensers sold since January 1, 2014, are UL listed for B20. B20 is standard on all Wayne (Dover Fueling Solutions) Ovation, Ovation HS, Helix, Select and Reliance models. Husky and OPW offer UL B20 listed breakaways, nozzles, and swivels. Continental ContiTech's Flexsteel Futura is UL listed for B20.

Shear valves are an important piece of safety equipment that cut off the flow of fuel from the UST to the dispenser to prevent a release in the event of an accident dislodging the dispenser or fire. UL listed B20 shear valves are available from Franklin Fueling and OPW. Submersible turbine pumps draw fuel from the tank and into piping that delivers the fuel to the dispenser. Both Franklin Fueling and Veeder-Root have UL B20 and B100 listed submersible turbine pumps. Appendix D lists compatible equipment.

## *Checklist for Installing B20 Dispensing Equipment or Converting Underground Storage Tanks*

- Notify your installer to review the applicable codes (generally NFPA 30A or IFC 2012), then contact the local authority having jurisdiction, usually the building code office or local fire marshal, to determine whether there are any local code issues that should be addressed.
- Notify the nearest fire department (and/or local first responders) that the site will soon be dispensing B20.
- Install UL listed B20 dispenser, hanging hardware, and shear valve.

[24] Atlas was approved by Gilbarco for use with B20 as of 2005



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- Calibrate the dispenser meter at the time of conversion or new installation and 2 weeks later to verify meter accuracy with B20.
- Label the dispenser with all B20 Federal Trade Commission-required labels, cautionary labels, and logos. Consider using hangtags, pump toppers, and other signage to educate your customers. Price sign inserts, curbside signs, and decals are available from industry associations.
- Notify first responders biodiesel is being used, and train site operators on fuel safety and the differences relative to diesel.

### *Underground Tanks*

- Notify your UST insurance carrier to determine whether it has additional requirements for B20 fuels.
- If using an existing tank, clean the tank of all water and sediment. Ensure no water is present. To protect the quality of your B20 fuel and your customers' vehicles see the American Petroleum Institute's 2015 publication *Cleaning Petroleum Storage Tanks* and the National Fire Protection Association's *NFPA 326: Standard for the Safeguarding of Tanks and Containers for Entry, Cleaning, or Repair, 2020 Edition*.
- Ensure all visible fittings and connections at the top of the tank are tight (no vapors escape and no water enters).
- Ensure the sump and spill containment covers will prevent water from entering the system. Identify the B20 fill port and paint the access cover according to API RP1637. Make certain transport drivers cannot make fuel deliveries to the wrong fill pipe.
- Conduct a precision test of the tank system (0.1-gallon/hour leak rate) with an automatic tank gauging system within 7 days after the tank is filled, to confirm the integrity of the system and that the leak detection equipment is operating properly. Report any fail results as required by the authority having jurisdiction.

### *Maintenance*

- Check for water regularly for both petroleum diesel and biodiesel. Ensure that no water is contaminating your fueling system. If water is suspected or detected, track down its source and fix the problem immediately. The best way to guard against contamination is to property clean and maintain the fueling system. Confirm no leaks exist in the tank fill cap and containment reservoir before beginning your B20 operation.
- If the product seems to pump slowly, check and replace filters. Persistently clogged filters could indicate moisture or another source of contamination.

## Use of Biodiesel Blends in Other Markets

While biodiesel blends were originally studied for use in on-road cars and trucks, recent years have seen their application in a wide range of other situations. This is because low-carbon liquid fuels are one of the lowest-cost options for decarbonization (with zero or few modifications to either the equipment or fueling infrastructure) of applications that currently rely on liquid fossil



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fuels. This section briefly describes the use of biodiesel blends in major end use categories, including any special precautions or concerns.

### On-Road

The ASTM standards for B100 biodiesel blendstock (ASTM D6751) and biodiesel blends (ASTM D7467) were originally developed primarily for use of the fuel in on-road cars and trucks. Fuel distribution supply chains, OEM approval, and user familiarity are in place.

### Off-Road

Off-road applications such as construction and agriculture have long used biodiesel. The engines in this equipment are not very different from on-road truck engines and thus are well suited to biodiesel blends meeting the ASTM D7467 standard. Challenges may occur in equipment that is parked during winter months, such as some farming equipment, with low-temperature operability and gelling of the fuel. A strategy for dealing with this is to fill the vehicle tank with a wintertime cloud point diesel fuel before parking for the season.

### Rail

Rail applications are characterized by the very long lifetime of locomotives, which can be in service for many decades. However, these engines are periodically rebuilt and updated with more modern components by the locomotive manufacturer, which includes elastomeric components. Because B20 is compatible with seals and gaskets used today, we anticipate that all locomotives in use will also be compatible. While the larger railroad companies (Class I) continue to investigate use and performance of higher biodiesel blends, not all locomotive manufacturers currently warranty the use of at least B20 blends

### Marine

Marine fuel use can be divided into two major classifications. The first is within inland waterways (navigable lakes and rivers). The engines in most tug/tow operations are similar to the same engine technologies that power locomotives. B20 and higher blends have been used successfully so long as the fuel is kept clean and dry in these applications.

Oceangoing vessels typically rely on the fuel specifications found in ISO 8217. Within this standard, numerous grades of both distillate and residual fuels, along with the appropriate parameters and limits, can be found. In order to handle and pump residual fuels, these fuel systems are heated so they are already capable of handling the cold flow properties of B100. ISO and the global shipping community are currently in the process of revising ISO 8217 to allow for the use of up to B100 in each grade so long as the biodiesel can first be demonstrated to meet either the current ASTM D6751 or EN14214 specifications. Over the last several years, shipping companies and large-vessel engine manufacturers have demonstrated the performance and confidence needed with higher biodiesel blends and B100 for use on board their vessels.

### Home Heating

Use of biodiesel blends in heating applications, including residential and commercial boilers, furnaces, and water heaters, has been increasing steadily. As of 2023 it is estimated that more than 400,000 homes are using B20 blends, 10,000 are using B50 blends, and 100–200 are exploring the use of B100. In this market sector, burners are tested for safety listing against the



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UL296 standard. This standard has changed recently to include protocols for testing new burner products with biodiesel blend levels up to B100. Burners tested and approved for B100 and low blends are approved for all blend levels. Several burner manufacturers have already gone through the testing-for-listing process. Increasingly, other high-blend system components including filters and safety valves are becoming available for use in this market.[25]

In homes, 275-gallon steel tanks are commonly used for heating oil. Newer, plastic tanks with steel outer enclosures are also being installed. After years of service, older steel tanks typically have a layer of products of oxidative degradation and possibly water on the bottom. The steel in these tanks is not subject to corrosion by biodiesel blends. However, corrosion on the bottom of these tanks where there is water present will occur with any fuel.

Replacing or cleaning an existing tank prior to conversion to biodiesel is desirable and might be necessary if the tank is in poor condition. However, in most conversions to a biodiesel blend, the tank is not replaced or cleaned. It is most common to simply begin biodiesel blend delivery into an existing tank that already contains petroleum heating oil.

While testing has shown that most legacy equipment is not damaged by use of biodiesel, it is of course recommended that manufacturer-approved equipment be used with biodiesel blends.

Some concerns have been raised about the use of biodiesel in heating systems that contain yellow metals (e.g., brass, copper). Under the ASTM standards D396 and D6751, both B100 and blends used for heating purposes must pass the ASTM D130 copper strip corrosion test and show no significant corrosion under the conditions of the test. With near-zero sulfur and low acid values, on-spec B100 does not show corrosion using ASTM D130. When exposed to yellow metals with a high surface-to-volume ratio, a very small amount of copper or other metals can dissolve into biodiesel. This can strongly affect the performance in Rancimat oxidative stability tests but may not impact fuel performance in the field.[26] This can happen, for example, in the copper fuel line where the fuel is typically burned quickly after exposure to copper. This same effect occurs with petroleum fuels, which have been used in this application with copper fuel lines for decades, and therefore replacing copper lines with other materials such as carbon steel or stainless steel during a conversion to higher biodiesel blends is not seen as a requirement.[10]

### *Power Generation*

With industry and regulatory pressure toward increasing electrification, there has been additional interest in utilizing low-carbon liquid fuels such as biodiesel to help generate electricity. Some turbine manufacturers have recently completed successful studies on the performance of B20 and B50 blends and are testing B100. ASTM D2880 is the standard specification covering the fuels for ground-based gas turbines. It is largely based on the use of either ASTM D975 or ASTM D396, which both allow up to B5 in the No. 1 and No. 2 grades, but ASTM D2880 has not yet been formally changed to include biodiesel blends. Similar to efforts in other areas, we expect to see higher biodiesel blends incorporated into the ASTM specification over time as customer demands increase.

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[25] T.A. Butcher. 2023. "Decarbonization of Liquid Heating Fuels." *ASHRAE Transactions* 129 (1): 644–650.
[26] Z. Yang, B.P. Hollebone, Z. Wang, C. Yang, and M. Landriault. 2013. "Factors affecting oxidation stability of commercially available biodiesel products." *Fuel Processing Technology* 106: 366–375.



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### *Use of High Blends and B100*

Most biodiesel is currently used in blends of B20 or lower in on- and off-road vehicles and locomotives. Historical factors, like the price and lack of regulatory incentives, have limited higher blend levels in this market sector. High-level biodiesel blends are used successfully in underground mining equipment, other off-road applications, and marine applications. Thus, most of the information in this guide is intended for biodiesel use as a blending component. If you want to use high blend levels or even B100 as a fuel, these recommendations should help:

- Contact other users of higher-level blends and B100. Clean Fuels Alliance America (formerly the National Biodiesel Board) has names of individuals and businesses as well as reference materials about storage, handling, and use of higher-level blends and B100.
- If you manage a fleet, contact your fleet management association to find out if anyone near you has experience with B100 or blends above B20. Ask your biodiesel supplier for 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 higher-level blends or B100, and what kinds of engines and equipment use higher-level blends and B100 at their sites.
- Discuss your needs with your OEM and dealer and ask for advice, including any recommendations from other customers.
- Replace materials you know will be problematic and institute a monitoring program based on the information presented in the Materials Compatibility section.
- Plan and budget for the time and potential expense of increased fuel filter changes or cleaning your fuel system when first starting to use higher-level blends and B100, depending on the cleanliness of your existing fuel system.

At the time of this writing, there is no specification in place for blends above 20%, but work is ongoing in this area.



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# Safety, Health, and Environmental Issues

Neat 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. Of much greater concern are biodiesel blends that may contain kerosene or petroleum diesel. Kerosene is highly flammable with a flash point of 38°C to 72°C (100°F to 162°F). Diesel fuel is generally considered flammable—its flash point is 52°C to 96°C (126°F to 204°F). The flash point of biodiesel is required to be greater than 93°C (200°F), so is considerably less dangerous. However, biodiesel blends will have flash points in between diesel and biodiesel. The U.S. Department of Transportation considers biodiesel blends flammable, and the Resource Conservation and Recovery Act of 1976 considers it to be ignitable if the flash point is lower than 60°C (140°F) or combustible if the flash point is 60°C to 93°C (140°F to 200°F).

## Signs, Labels, and Stickers

No placards or warning signs are required for the transport of neat 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 93°C (200°F), according to federal Department of Transportation regulations. If the flash point is lower than 60°C (140°F), the liquid is considered flammable, and the Hazard Class 3 flammable placard is required (see Figure 7, right). Between 60°C and 93°C (140°F and 200°F), the liquid is generally considered Hazard Class 3 combustible, and the combustible placard shown in Figure 7 (left) 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 National Fire Protection Association diamonds. These will indicate whether the fuel is flammable or combustible.

**Figure 7. Placards for transport of combustible and flammable liquids**

## Fire Safety Considerations

As with petroleum diesel, neat biodiesel or biodiesel blends can be extinguished with dry chemical, foam, Halon, $CO_2$, or water spray, although the water stream may splash the burning liquid and spread the fire. Biodiesel-soaked rags can cause spontaneous combustion if not handled properly. Before disposal, wash rags with soap and water and dry in a well-ventilated area. Because biodiesel will burn if ignited, keep it away from oxidizing agents, excessive heat, and ignition sources.



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# Frequently Asked Questions

**Is biodiesel the same as renewable diesel?**

No. While biodiesel and renewable diesel are both processed from fats, oils, and greases, the production process between the two differs greatly. The biodiesel production process produces fatty acid methyl esters, while renewable diesel is generally alkanes (hydrocarbons) produced through hydroprocessing.

**Are there tax incentives for using biodiesel?**

Tax credits and incentives change frequently. Some resources to see if a tax incentive is available can be found at afdc.energy.gov/laws and cleanfuels.org.

**Where can I find information about renewable identification numbers?**

Renewable identification numbers (RINs) are used to track compliance with the renewable fuel standard (RFS) volumes and credits, trading, and compliance by obligated parties.[27] Additional information is available on EPA's website: epa.gov/renewable-fuel-standard-program.

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

UST equipment does not need to be modified for blends of 20% biodiesel or lower. Aboveground equipment including the dispenser (pump) and hanging hardware should be UL listed for B20. It is a best practice to clean a tank prior to storing a different fuel.

**Do I need to modify my heating oil system to use biodiesel?**

Previous research on the use and performance of B20 blends was performed on legacy equipment that was not yet UL certified or manufacturer approved. No issues at the time were reported. However, certified equipment now exists, and is manufacturer approved for up to B100. Consult your equipment manufacturer or heating oil fuel supplier for additional information and recommendations.

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

With new technology diesel engines (NTDEs), vehicle emissions show very little change regardless of the fuel burned in the engine. The emissions control devices are equally efficient with biodiesel and diesel fuel and their blends. In older engines not equipped with these advanced emissions controls, there may be differences in emissions. For these older engines (pre-2007), carbon monoxide, hydrocarbons, and particulate matter will be reduced with increasing biodiesel blend level. There is still considerable debate about the effect of biodiesel on $NO_x$ emissions from these older technology engines.

[27] U.S. Environmental Protection Agency. 2023. "Overview for Renewable Fuel Standard." Last updated Feb. 10, 2023. epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard.



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# Information Resources

Clean Fuels Alliance America, formerly the National Biodiesel Board, has many resources available for biodiesel users. Their website is cleanfuels.org, or call 1-800-841-5849 to obtain general information on biodiesel, cold flow, renewable diesel, and carbon reductions. Information concerning the use of biodiesel as a home heating oil can be located at mybioheat.com.

The U.S. Department of Energy's Office of Scientific and Technical Information is a great resource for biodiesel research conducted by the national laboratories and their contractors: osti.gov/search/semantic:biodiesel.

The U.S. Department of Energy's Alternative Fuels Data Center provides data, information, and tools for biodiesel: https://afdc.energy.gov.

The National Renewable Energy Laboratory also has technical documents at nrel.gov/research/publications.html.

The EPA has information about its Renewable Fuel Standard Program at epa.gov/renewable-fuel-standard-program.

The U.S. Department of Defense cites ASTM in its fuel specifications. For more information, consult MIL-STD-3004D.



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# Glossary

| Term | Definition |
|---|---|
| Additive | Material added up to 1 vol % to finished fuel products to improve certain properties or characteristics. |
| Antioxidant | Substance that inhibits chemical reactions promoted by oxygen. |
| ASTM International | A consensus standards-setting organization. |
| Biodegradable | Capable of being broken down by microorganisms. |
| Biodiesel | Fatty acid methyl esters meeting the current requirements of ASTM D6751. |
| Biodiesel blend | Blend of biodiesel in diesel fuel, denoted as Bxx, where xx is the volume percent biodiesel in the blend. |
| Bioheat | A blend of biodiesel and low-sulfur fuel used in home heating fuel systems. |
| Boiling range | The spread of temperature over which a fuel or other mixture of compounds distills. |
| BQ-9000 | A voluntary quality control program developed by the biodiesel industry. |
| Cetane index | An approximation that correlates with a diesel fuel's 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 compared to reference fuels. The higher the cetane number, the shorter the ignition delay and the better the ignition quality. |
| Cloud point | The temperature at which a sample of a fuel just shows observable crystals when it is cooled under standard test conditions, as defined in ASTM D2500. |
| Elastomer | A polymeric material frequently used in vehicle fuel systems. |
| 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. |



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| Term | Definition |
|---|---|
| Fatty acid | Any of the saturated or unsaturated monocarboxylic acids. Fatty acids occur naturally in triglycerides (or mono- or diglycerides) or as free fatty acids. High-free-fatty-acid feedstocks need special processing to be converted into biodiesel. |
| Flash point | The lowest temperature at which vapors from a fuel will ignite when a small flame is applied under standard test conditions. |
| Hydrocarbon | A compound composed of hydrogen and carbon. |
| Induction period | The period of time before oxidation products form as biodiesel begins to age and degrade. |
| Kerosene | A light, refined distillate that can be used as heating oil, blended into diesel fuel, or used as fuel for aviation turbine engines. |
| Lubricity | The ability of a fuel to mitigate wear on metal–metal contact surfaces. |
| Microbial contamination | Containing deposits or suspended matter formed by microbial degradation of the fuel. |
| Oxidation | Loosely, the chemical addition of oxygen to a molecule. |
| Oxidative stability | The ability of a fuel to resist oxidation during storage or use. |
| Particulate matter (PM) | The solid or semi-solid compounds of unburned fuel emitted from engines. |
| Pour point | The lowest temperature at which a fuel will just flow when tested under standard conditions as defined in ASTM D97. |
| Renewable diesel fuel | A diesel fuel produced by hydroprocessing renewable feedstocks, like fats and oils. |
| Solvent | A liquid capable of dissolving another substance to form a solution. A solution 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. |
| Storage stability | The ability of a fuel to resist deterioration in storage due to oxidation. |
| Unsaturated | Molecule with double bonds. |
| Viscosity | A measure of the resistance to flow of a liquid. |



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# Appendix A. Sample Biodiesel Safety Data Sheet

**SAMPLE MATERIAL SAFETY DATA SHEET**

## 1. CHEMICAL PRODUCT

| | |
|---|---|
| General Product Name: | **Biodiesel (B100)** |
| Synonyms: | Methyl Soyate, Rapeseed Methyl Ester (RME) |
| Product Description: | Methyl esters from lipid sources |
| CAS Number: | Methyl Soyate: 67784-80-9; Methyl Tallowate: 61788-61-2; and RME: 73891-99-3 |

## 2. COMPOSITION/INFORMATION ON INGREDIENTS

This product contains no hazardous materials.

## 3. 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.

## 4. 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 gastro-intestinal symptoms develop, consult medical personnel. (Never give anything by mouth to an unconscious person.)

## 5. FIRE FIGHTING MEASURES

Flash Point (Method Used): 130.0 C or 266.0 F min (ASTM 93)

Flammability Limits: None known

EXTINGUISHING MEDIA:

Dry chemical, foam, halon (may not be permissible in some countries), $CO_2$, 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:

Biodiesel soaked rags or spill absorbents (i.e. oil dry, polypropylene socks, sand, etc.) can cause spontaneous combustion if stored near combustibles and not handled properly. Store biodiesel soaked rags or spill absorbents in approved safety containers and dispose of properly. Oil soaked rags may be washed with soap and water and allowed to dry in



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well ventilated area. Firefighters should use self-contained breathing apparatus to avoid exposure to smoke and vapor.

## 6. 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 and dispose of properly to avoid spontaneous combustion (see unusual fire and explosion hazards above).

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.

## 7. 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.

## 8. 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.

## 9. PHYSICAL AND CHEMICAL PROPERTIES

| | |
|---|---|
| Boiling Point, 760 mm Hg:>200°C | Volatiles, % by Volume: <2 |
| Specific Gravity ($H_2O$=1): 0.88 | Solubility in $H_2O$, % 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

## 10. 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.



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## 11. 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.

## 12. TRANSPORT INFORMATION

UN HAZARD CLASS: N/A

NMFC (National Motor Freight Classification):

PROPER SHIPPING NAME: Fatty acid ester
IDENTIFICATION NUMBER: 144920
SHIPPING CLASSIFICATION: 65

## 13. 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:

Non-hazardous 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.

## 14. 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.



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# Appendix B. Biodiesel Materials Compatibility Summary Tables

Neat 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; the 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 B-1).

## Elastomers

**Table B-1. Elastomer Compatibility With Biodiesel**

| Material | Compatibility With Fresh, Unoxidized Methyl Oleate Unless Noted | Reference |
|---|---|---|
| Buna-N | Not recommended | c,d |
| Butadiene | Not recommended | b |
| Butyl | Mild effect | b,d |
| Chemraz | Satisfactory | d |
| Ethylene propylene (EPDM) | Moderate effect | b,d |
| Fluorocarbon | Satisfactory | b,d,e |
| Fluorosilicon | Mild effect; increase swelling | a |
| Fluorosilicone | Mild effect | b,d |
| Hifluor | Satisfactory | b |
| Hypalon | Not recommended | b,d |
| Natural rubber | Not recommended | b,d |
| Neoprene | Not recommended | c,d |
| Neoprene/chloroprene | Not recommended | b |
| Nitrile | Not recommended | a,b |
| Nitrile, high aceto-nitrile | Mild effect with B20, swelling and break strength affected | e |
| Nitrile, hydrogenated | Not recommended | b,d |
| Nitrile, peroxide-cured | Mild effect with B20, swelling and break strength affected | e |
| Nordel | Moderate to severe effect | c |
| Nylon | Satisfactory | a |
| Perfluoroelastomer | Satisfactory | b |
| Polypropylene | Moderate effect; increased swelling, hardness reduced | a |
| Polyurethane | Mild effect; increased swelling | a |



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| Material | Compatibility With Fresh, Unoxidized Methyl Oleate Unless Noted | Reference |
|---|---|---|
| Styrene-butadiene | Not recommended | b,d |
| Teflon | Satisfactory | a,c,d |
| Viton | Satisfactory; type of cure affects compatibility with oxidized biodiesel. See specific types of Viton below. | a,c |
| Viton A-401C | Satisfactory with fresh rapeseed methyl ester (RME); not recommended for oxidized blends B20 and above | f |
| Viton F-605C | Satisfactory with fresh RME; not recommended for oxidized blends B20 and above | f |
| Viton GBL-S | Satisfactory with RME and with all oxidized blends | f |
| Viton GF-S | Satisfactory with RME and with all oxidized blends | f |
| Wil-Flex | Moderate to severe effect | c |

[a] G.B. Bessee and J.P. Fey. 1997. *Compatibility of Elastomers and Metals in Biodiesel Fuel Blends*. SAE 971690.
[b] Parker Hannifin Corporation. 2007. *Parker O-Ring Handbook*. O-Ring Division, Lexington, KY.
[c] Wilden Pump & Engineering Co. 2005. *Chemical Resistance Guide*, Grand Terrace, CA.
[d] Custom Rubber O-Ring Mfg. "O-Ring Chemical Compatibility Guide." Accessed Nov. 2, 2015. efunda.com/designstandards/oring/oring_chemical.cfm.
[e] B. Terry, R.L. McCormick, and M. Natarajan. 2006. "Impact of Biodiesel Blends on Fuel System Component Durability." SAE 2006-01-3279.
[f] E. Thomas, R.E. Fuller, and K. Terauchi. 2007. "Fluoroelastomer Compatibility with Biodiesel Fuels." SAE 2007-01-4061.

## 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.



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# Appendix C. Pump Labeling

Federal code requires dispenser (pump) labels to inform consumers about the percentage of biodiesel being offered for sale. Pups selling up to B5 require no separate labeling. Figure C-1 shows the label for blends between B5 and B20.[28] Although the label indicates the blend is "B-20," the regulations allow this label to be used for any blend inclusively between B6 and B20. Blends higher than B20 are required to be labeled with the exact blend percentage, within +/-1%; for example, a B30 blend will have a pump label stating the blend is B30.

The requirements for labeling renewable diesel are the same, except that those fuel blends have an orange/black label with identical language. Fuels containing greater than 5% of both biodiesel and renewable diesel would be expected to have both stickers.

It should be noted that these federal requirements are the minimum necessary at pumps to inform consumers about the blends they are purchasing. Individual states may have requirements that exceed the federal requirements.

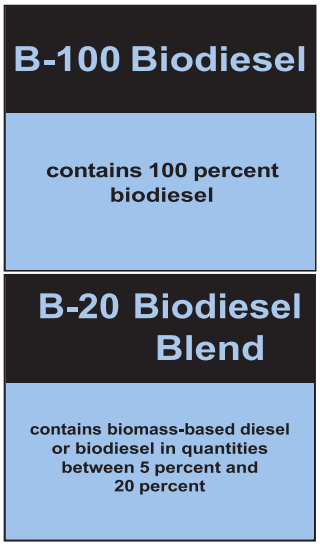


**Figure C-1. Federal Trade Commission-compliant B20 and B100 pump labels**

[28] "Automotive Fuel Ratings, Certification and Posting." 16 CFR 306.10. https://www.ecfr.gov/current/title-16/chapter-I/subchapter-C/part-306.



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# Appendix D. Refueling Equipment Compatibility

## UL Standards

**Table D-1. UL Biodiesel Testing Standards for Refueling Equipment**

| UL Testing Standard | Equipment Covered | Biodiesel Test Fuel Blends in UL Standard |
|---|---|---|
| UL 58 and UL 1746 | USTs and external corrosion protection systems for steel USTs | UL58 – No test fuels<br>UL 1746 – No biodiesel test fuels |
| UL 1316 (expires Feb. 2023)<br>UL/ULC 1316 (new Oct. 2018) | Underground fiberglass tanks | UL1316 – No biodiesel test fuels<br>UL/ULC 1316 – B25a and B100a test fuels |
| UL 80 | Aboveground steel combustible liquid fuel tanks – heating oils, diesel, and other Class II fuels | No test fuels |
| UL/ULC 2258 | Aboveground plastic combustible liquid fuel tanks – heating oils, diesel, and other Class II fuels | B25a and B100a test fuels |
| UL142 and UL142A | Aboveground general-purpose and special-purpose steel tanks | No test fuels |
| UL2080 and UL2085 | Aboveground fire-resistant and fire-protected steel tanks | No test fuels |
| UL 971 and UL 971A | Underground pipes and pipe fittings | No biodiesel test fuels |
| UL 2039 and future UL/ULC 2039 (est Q3 2023?) | Flexible connector pipes – underground, sump, and/or aboveground rating options | UL 2039 – B25a test fuel<br>UL/ULC 2039 – B25a and has optional B100a test fuels |
| UL 971 and UL 971A | Underground fuel pipes and pipe fittings | No biodiesel test fuels |
| UL/ULC 1386 | Aboveground fuel pipes and pipe fittings | B25a and has optional B100a test fuels |
| UL 2447 and future UL/ULC 2447 (est Q3 2023) | *Containment sumps, fittings, and accessories*<br>*Sumps:* tank, dispenser, transition, fill/vent (spill buckets)<br>*Sump fittings:* penetration, termination, internal, test and monitoring types<br>*Sump accessories:* covers/lids, frames, brackets, chase pipes | UL 2447 – B25a test fluid.<br>UL/ULC 2447 – B25a and has optional B100a test fuels |
| UL 2583 (expires April 2025)<br>UL/ULC 2583 (new Dec. 2021) | Flammable liquid tank accessories<br>Part I vapor control products: emergency vents, pressure vacuum vents, fill and vapor adaptors, and monitor well caps<br>Part II liquid control products: overfill prevention devices (for fill pipes); flow restriction devices (for | UL 2583 – B25a test fluid.<br>UL/ULC 2447 – B25a and has optional B100a test fuels |



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| UL Testing Standard | Equipment Covered | Biodiesel Test Fuel Blends in UL Standard |
|---|---|---|
| | vent pipes), and overfill containment devices (direct and remote) | |
| UL 180 (expires May 2023)<br>UL/ULC 180 (New March 2019) | *Combustible liquid tank accessories*<br>*Pipes:* fill/vent, supply, flex connectors<br>*Gauges:* liquid level, fill signal, leak detection | UL 180 – B25a test fuel.<br>UL/ULC 180 – B25a and has optional B100a test fuels |
| UL 87B | Diesel, biodiesel, and diesel/biodiesel blend dispensers | B25a test fuel required with B100a test fuel option |
| UL 25B | Diesel, biodiesel, and diesel/biodiesel blend meters | B25a test fuel required with B100a test fuel option |
| UL 79B | Diesel, biodiesel, and diesel/biodiesel blend pumps | B25a test fuel required with B100a test fuel option |
| UL 330B | Diesel, biodiesel, and diesel/biodiesel blend hoses and hose assemblies | B25a test fuel required with B100a test fuel option |
| UL 331B | Diesel, biodiesel, and diesel/biodiesel blend filters and strainers | B25a test fuel required with B100a test fuel option |
| UL 428B | Diesel, biodiesel, and diesel/biodiesel blend submersible turbine pumps | B25a test fuel required with B100a test fuel option |
| UL 567B | Diesel, biodiesel, and diesel/biodiesel blend break-aways, swivels, pipe connection fittings | B25a test fuel required with B100a test fuel option |
| UL 842B | Diesel, biodiesel, and diesel/biodiesel blend shear valve (emergency shut-off valve) | B25a test fuel required with B100a test fuel option |
| UL 2586B | Diesel, biodiesel, and diesel/biodiesel blend nozzles | B25a test fuel required with B100a test fuel option |



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## Tank Manufacturer Compatibility

**Table D-2. Tank Manufacturer Combability With Biodiesel Blends**

| Manufacturer | B100 |
|---|---|
| **Fiberglass [a]** | |
| Containment Solutions | ✓ |
| Owens Corning | ✗ |
| Xerxes | ✓ |
| **Steel [b]** | |
| Acterra Group Inc. | ✓ |
| Caribbean Tank Technologies Inc. | ✓ |
| Eaton Sales & Service LLC | ✓ |
| General Industries | ✓ |
| Greer Steel, Inc. | ✓ |
| Hall Tank Co. | ✓ |
| Hamilton Tanks | ✓ |
| Highland Tank | ✓ |
| J.L. Houston Co. | ✓ |
| Kennedy Tank and Manufacturing Co., Inc. | ✓ |
| Lancaster Tanks and Steel Products | ✓ |
| Lannon Tank Corporation | ✓ |
| Mass Tank Sales Corp. | ✓ |
| Metal Products Company | ✓ |
| Mid-South Steel Products, Inc. | ✓ |
| Modern Welding Company | ✓ |
| Newberry Tanks & Equipment, LLC | ✓ |
| Plasteela | ✓ |
| Service Welding & Machine Company | ✓ |
| Southern Tank & Manufacturing Co., Inc. | ✓ |
| Stanwade Metal Products | ✓ |
| Talleres Industriales Potosinos, S.A. de C.V. | ✓ |
| Tanques Antillanos C. x A. | ✓ |
| Watco Tanks, Inc. | ✓ |
| We-Mac Manufacturing Company | ✓ |

Letters stating compatibility:
[a] PEI: pei.org/ust-component-compatibility-library
[b] STI: https://stispfa.org/alternative-fuels/



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## Aboveground Equipment (Dispensers, Hanging Hardware, etc.)

**Table D-3. Dispensers, Hanging Hardware, Shear Valves, Submersible Turbine Pumps**

| Company | Product | Model | Biodiesel Compatibility |
|---|---|---|---|
| UL B20 Listed Equipment | | | |
| Manufacturers introduce and discontinue models over time. If you do not see your equipment on this list, please contact the manufacturer. Note, X in these lists can be substituted for any value. | | | |
| Continental | Hose | ContiTech Flexsteel Futura | B20 |
| Franklin Fueling | Shear valve | Franklin has third-party certified equipment compatible with biodiesel blends. Contact manufacturer for specific part numbers. | |
| Franklin Fueling | Submersible turbine pump | Franklin has third-party certified equipment compatible with biodiesel blends. Contact manufacturer for specific part numbers. | |
| Gilbarco | Dispenser | Standard on Atlas and Encore models | B20 |
| Husky | Breakaway | 5812 Safe-T-Brake | B20 |
| Husky | Nozzle | X, XS, XFS, VIII, VIIIS, rebuilt VIII/VIIIS | B20 |
| Husky | Swivel | 4860 | B20 |
| OPW | Breakaway | 66V-030RF, 66V-130RF, 66V-135RF, 66RB-20RF | B20 |
| OPW | Nozzle | 7H and 7HB models ending in -B20; 11A and 11B models ending in -B20; 14C | B20 |
| OPW | Swivel | 241TPS-75RF, 241TPS-10RF | B20 |
| OPW | Shear valve | 10P-0152 | B20 |
| Wayne (DFS) | Dispenser | Standard on Ovation, Ovation HS, Helix, Select, and Reliance Models. Contact Wayne for specific model information. | B20 |
| | | | |



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# Appendix E. Engine and Vehicle Manufacturer Approvals

There are a variety of statements about biodiesel use from engine and/or vehicle manufacturers, some of which refer to the warranty. Engine and vehicle manufacturers provide warranties covering materials and workmanship on their products. Such warranties do not necessarily cover damage caused by external conditions. Fuels are not covered under these terms. Federal law prohibits the voiding of a warranty just because biodiesel was used. The biodiesel would need to be shown as 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 necessarily be covered by the OEM warranty.

All known engine on-road and off-road vehicle OEMs have approved the use of biodiesel blends up to B5 as long as the biodiesel meets the ASTM D6751 specification (or the European biodiesel specification, EN14214). More OEMs are recognizing higher blend levels, and several approve up to B100. Approval levels for biodiesel-blended fuels are separate from the warranties.

Damage directly attributable to biodiesel, or any other fuel, would 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 https://cleanfuels.org/wp-content/uploads/2023/07/oem-support-summary.pdf or check the current owner's manual for the equipment being operated.



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