Biomass

BIODIESEL Handling and Use Guidelines

DOE/GO-102006-2288
Second Edition
March 2006

U.S. Department of Energy
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Abbreviations and Acronyms

AFV	alternative fuel vehicle
ASTM	American Society for Testing and Materials
B100	100% biodiesel
B20	20% biodiesel, 80% petroleum diesel
BTU	British Thermal Unit
CFPP	cold filter plug point
CI	compression ignition
CO	carbon monoxide
CO_2	carbon dioxide
DOE	U.S. Department of Energy
ECRA	Energy Conservation Reauthorization Act of 1998
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 1992
FAME	fatty acid methyl esters
GVWR	gross vehicle weight rating
HC	hydrocarbon
HUMBUGS	hydrocarbon utilizing microorganisms
MSDA	material safety data sheet
MSHA	Department of Labor's Mining Safety Health Administration
NBB	National Biodiesel Board
NO_x	nitrogen oxide
NPAH	nitrated polyaromatic hydrocarbons
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer
OSHA	Occupational Safety and Health Administration
PAH	polyaromatic hydrocarbons
PM	particulate matter
ppm	parts per million
SO_2	sulfur dioxide
ULSD	ultra low sulfur diesel
VOC	volatile organic compound

1. INTRODUCTION

This document is a guide for those who blend, distribute, and use biodiesel and biodiesel blends. It is intended to help fleets and individual users, blenders, distributors, and those involved in related activities understand procedures for handling and using biodiesel fuels. We hope it will be a useful tool, both when planning biodiesel use and as an ongoing resource.

Biodiesel is a renewable fuel manufactured from vegetable oils, animal fats, and recycled cooking oils. Biodiesel offers many advantages:

- It is renewable.
- It is energy efficient.
- It displaces petroleum derived diesel fuel.
- It can be used in most diesel equipment with no or only minor modifications.
- It can reduce global warming gas emissions.
- It can reduce tailpipe emissions, including air toxics.
- It is nontoxic, biodegradable, and suitable for sensitive environments.
- It is made in the United States from either agricultural or recycled resources.
- It can be easy to use if you follow these guidelines.

Biodiesel can be used in several different ways. You can use 1% to 2% biodiesel as a lubricity additive, which could be especially important for ultra low sulfur diesel fuels (ULSD, less than 15 ppm sulfur), which may have poor lubricating properties. You can blend 20% biodiesel with 80% diesel fuel (B20) for use in most applications that use diesel fuel. You can even use it in its pure form (B100) if you take proper precautions. The word *biodiesel* in this report refers to the pure fuel—B100—that meets the specific biodiesel definition and standards approved by ASTM International. A number following the "B" indicates the percentage of biodiesel in a gallon of fuel, where the remainder of the gallon can be No. 1 or No. 2 diesel, kerosene, jet A, JP8, heating oil, or any other distillate fuel.[1]

Today, B20 is the most common biodiesel blend in the United States because it balances property differences with conventional diesel, performance, emission benefits, and costs. B20 is also the minimum blend level allowed for Energy Policy Act of 1992 (EPAct) compliance. B20 can be used in equipment designed to use diesel fuel. Equipment that can use B20 includes compression-ignition (CI) engines, fuel oil and heating oil boilers, and turbines.

Higher blend levels, such as B50 or B100, require special handling and fuel management and may require equipment modifications such as the use of heaters or changing seals and gaskets that come in contact with the fuel to those compatible with high blends of biodiesel. The level of special care needed largely depends on the engine and vehicle manufacturer. High blend levels are not recommended for the first-time biodiesel consumer.

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

2. BIODIESEL BASICS

This section provides a basic overview of biodiesel. This section, in addition to the Frequently Asked Questions (Chapter 9) will help you answer general questions from your management, customers, or reporters. Technical details are provided in Chapters 3-8.

2.1 What is Biodiesel?

Biodiesel is a diesel replacement fuel that is manufactured from vegetable oils, recycled cooking greases or oils, or animal fats. Because plants produce oils from sunlight and air, and can do so year after year on cropland, these oils are renewable. Animal fats are produced when the animal consumes plant oils and other fats, and they too are renewable. Used cooking oils are mostly made from vegetable oils, but may also contain animal fats. Used cooking oils are both recycled and renewable.

The biodiesel manufacturing process converts oils and fats into chemicals called long chain mono alkyl esters, or biodiesel. These chemicals are also referred to as fatty acid methyl esters or FAME. In the manufacturing process, 100 pounds of oils or fats are reacted with 10 pounds of a short chain alcohol (usually methanol) in the presence of a catalyst (usually sodium or potassium hydroxide) to form 100 pounds of biodiesel and 10 pounds of glycerine. Glycerine is a sugar, and is a co-product of the biodiesel process.

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

2.2 Registration and Regulation

ASTM International is a consensus based standards group comprised of engine and fuel injection equipment companies, fuel producers, and fuel users whose standards are recognized in the United States by most government entities, including states with the responsibility of insuring fuel quality. The specification for biodiesel (B100) is ASTM D6751-03. This specification is intended to insure the quality of biodiesel to be used as a blend stock at 20% and lower blend levels. Any biodiesel used in the United States for blending should meet ASTM D6751 standards.

The definition of biodiesel within ASTM D6751 describes long chain fatty acid esters from vegetable or animal fats that contain only one alcohol molecule on one ester linkage. Raw or refined vegetable oils contain three ester linkages and are therefore not legally biodiesel. Biodiesel can be made from methyl, ethyl, isopropyl, and other alcohols, but most biodiesel research focuses on methyl esters and virtually all commercial-production in the United States today uses methyl esters. Some research has occurred on ethyl esters (biodiesel produced with ethanol as the alcohol rather than methanol), however higher ethanol prices relative to methanol, lower ethyl ester conversions, and the difficulty of recycling excess ethanol internally in the process, have hampered ethyl ester production in the commercial marketplace. Therefore, in this document we will only consider methyl esters.

Biodiesel is a legally registered fuel and fuel additive with the U.S. Environmental Protection Agency (EPA). The EPA registration includes all biodiesel meeting the ASTM International biodiesel specification, ASTM D 6751, and is not dependent upon the oil or fat used to produce the biodiesel or the specific process employed.

Do not be fooled by other so-called "biofuel" products, many of which are being offered to consumers without the benefit of EPA registration or extensive testing and demonstrations. In fact, if you purchase methyl ester that does not meet ASTM biodiesel standards, it is not legally biodiesel and should not be used in diesel engines or other equipment designed to operate on diesel fuel. Methyl esters are used as an industrial lubricant and solvent in some applications so be sure to purchase only ASTM grade methyl esters (i.e. biodiesel).

Biodiesel is a recognized alternative fuel under the Energy Policy Act of 1992 (EPAct) as amended in 1996. EPAct requires that over 75% of new vehicle purchases by certain federal, state, and alternative fuel provider fleets be alternative fueled vehicles. As a recognized alternative fuel, any vehicle certified to run on B100 could qualify under the alternative fuel vehicle purchase provisions of EPAct, but it does not appear that any vehicles meeting this requirement are available today. B100 is more expensive than other alternative fuel options, and the original equipment manufacturer (OEM) community has had little interest in certifying vehicles on B100, so this vehicle credit has not created a market for biodiesel.

EPAct was amended in 1998 by the Energy Conservation and Reauthorization Act (ECRA). The amendment allowed qualified fleets to use B20 in existing vehicles to generate alternative fuel vehicle purchase credits, with some limitations. This has created significant B20 use by government and alternative fuel provider fleets. For more information on using biodiesel to fulfill EPAct requirements, see Chapter 8, Using Biodiesel Under the Energy Policy Act.

As biodiesel grows in popularity, some states are beginning to develop biodiesel incentive policies to promote biodiesel use and production. State policies can change rapidly, so please contact your state agencies or the National Biodiesel Board for more information.

2.3 Benefits of Biodiesel Use

Biodiesel Displaces Imported Petroleum

The fossil fuel energy required to produce biodiesel from soybean oil is only a fraction (31%) of the energy contained in one gallon of the fuel.[2] You get 3.2 units of fuel energy from biodiesel for every unit of fossil energy used to produce the fuel. That estimate includes the energy used in diesel farm equipment and transportation equipment (trucks, locomotives), fossil fuels used to produce fertilizers and pesticides, fossil fuels used to produce steam and electricity, and methanol used in the manufacturing process. Because biodiesel is an energy-efficient fuel, it can extend petroleum supplies and makes for sound state or federal energy policy.

Biodiesel Reduces Emissions

When biodiesel displaces petroleum, it reduces global warming gas emissions such as carbon dioxide (CO_2). When plants like soybeans grow they take CO_2 from the air to make the stems, roots, leaves, and seeds (soybeans). After the oil is extracted from the soybeans, it is converted into biodiesel and when burned produces CO_2 and other emissions, which return to the atmosphere. This cycle does not add to the net CO_2 concentration in the air because the next soybean crop will reuse the CO_2 in order to grow.

When fossil fuels are burned, however, 100% of the CO_2 released adds to the CO_2 concentration levels in the air. Because fossil fuels are used to produce biodiesel, the recycling of CO_2 with biodiesel is not 100%, but substituting biodiesel for petroleum diesel reduces life-cycle CO_2 emissions by 78%. B20 reduces CO_2 by 15.66%.[3]

Biodiesel reduces tailpipe particulate matter (PM), hydrocarbon (HC), and carbon monoxide (CO) emissions from most modern four-stroke CI engines. These benefits occur because the fuel (B100) contains 11% oxygen by weight. The presence of fuel oxygen allows the fuel to burn more completely, so fewer unburned fuel emissions result. This same phenomenon reduces air toxics, because the air toxics are associated with the unburned or partially burned HC and PM emissions. Testing has shown that PM, HC, and CO reductions are independent of the feedstock used to make biodiesel. The EPA reviewed 80 biodiesel emission tests on CI engines and has concluded that the benefits are real and predictable over a wide range of biodiesel blends (Figure 1, page 5).[4]

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[2] Sheehan et al. May 1998. *A Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus.* NREL/SR-580-24089.

[3] Some other life cycle studies show negative emission benefits for biodiesel. Those studies assume that oilseed crops are planted on native prairie. In the United States, oilseed crops such as soybean, sunflower and canola are planted on cropland that has been used to produce crops for more than 150 years. None of the life cycle studies take credit for the ability of soybean crops to sequester nitrogen in their root systems. This sequestering benefit reduces nitrogen fertilizer requirements for crops planted in the following year and saves emissions that result from the production of nitrogen fertilizer from natural gas.

[4] 39 studies were ultimately used in the EPA analysis in Figure 1.

In older two-stroke engines, B20 can reduce CO, HC, and PM if the engines do not consume excessive amounts of lube oil. If lube oil consumption is high, PM benefits from B20 use may be less than shown in Figure 1.

In addition, one of the first benefits that people notice when using biodiesel or biodiesel blends is the smell. Using biodiesel can make diesel exhaust smell better; more like cooking odors.

Biodiesel and Human Health

Some PM and HC emissions from diesel fuel combustion are toxic or are suspected of causing cancer and other life threatening illnesses. Using B100 can eliminate as much as 90% of these "air toxics." B20 reduces air toxics by 20% to 40%. The effects of biodiesel on air toxics are supported by numerous studies, starting with the former Bureau of Mines Center for Diesel Research at the University of Minnesota. The Department of Energy (DOE) conducted similar research through the University of Idaho, Southwest Research Institute, and the Montana Department of Environmental Quality. The National Biodiesel Board conducted Tier I and Tier II Health Effects Studies that also support these claims.

Recently, the Department of Labor's Mining Safety Health Administration (MSHA) tested and approved the use of biodiesel in underground mining equipment where workers are exposed to high levels of diesel exhaust.[5] Switching to biodiesel blends is believed to reduce the risk of illness and life-threatening diseases in miners.

Biodiesel Improves Lubricity

By 2006, all U.S. highway diesel will contain less than 15 ppm sulfur—ultra low sulfur diesel fuel (ULSD). Currently highway diesel contains 500 ppm sulfur (or less). Biodiesel typically contains less than 15 parts per million (ppm) sulfur (sometimes as low as zero). Some biodiesel produced today may exceed 15 ppm sulfur, and those producers will be required to reduce those levels by 2006 if the biodiesel is sold into on-road markets.

In the on-road market, low-level blends of biodiesel such as 1% or 2% can improve lubricity of diesel fuels and this may be particularly important for ULSD as these fuels can have poor lubricating properties. Engine manufacturers depend on lubricity to keep moving parts, especially fuel pumps, from wearing prematurely. Even 2% biodiesel can restore adequate lubricity to dry fuels such as kerosene or Fischer-Tropsch diesel.

Biodiesel is Easy to Use

And last, but maybe not least, the biggest benefit to using biodiesel is that it is easy. In blends of B20 or less, it is literally a "drop in" technology. No new equipment and no equipment modifications are necessary. B20 can be stored in diesel fuel tanks and pumped with diesel equipment. You can find many users to ask questions of and compare notes with. There are some caveats and precautions that must be followed to ensure a trouble free B20 experience and some mistakes to be avoided, as discussed in this guide.

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[5] Schultz, Mark and David Atchison. 2003. *Environmental Diesel Particulate Matter Investigation* PS&HTC-DD-03-808.

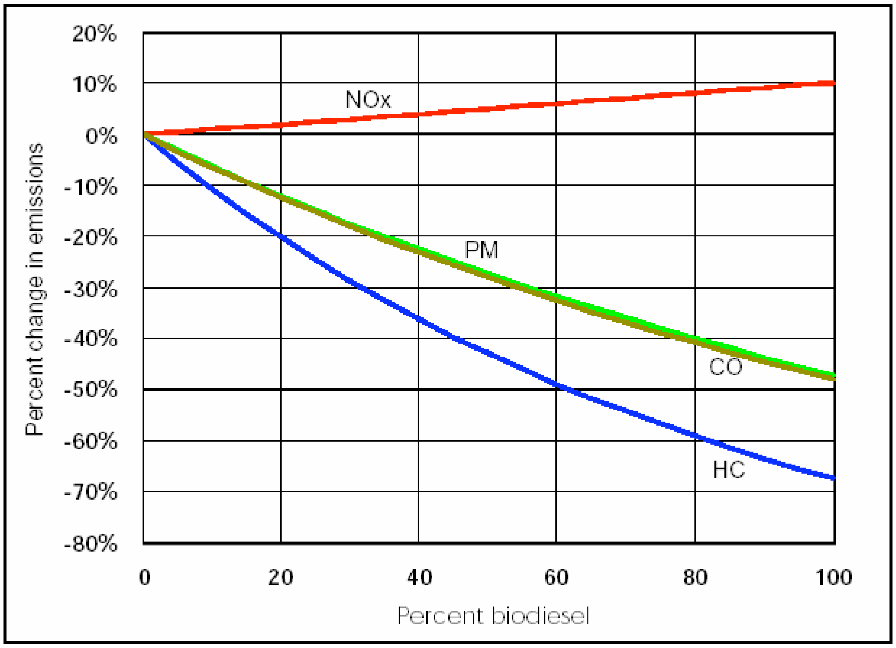

Figure 1. Average emission impacts of biodiesel fuels in CI engines[6]

2.4 Drawbacks of Biodiesel Use

Biodiesel contains 8% less energy per gallon than typical No. 2 diesel in the United States; 12.5% less energy per pound. The difference between these two measurements is caused by the fact that biodiesel is slightly more dense than diesel fuel, so there are slightly more pounds in a gallon of fuel. All biodiesel, regardless of its feedstock, provides about the same amount of energy.

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

The difference in energy content can be noticeable if you are using B100. If you are using B20, the difference in power, torque, and fuel economy should be between 1% and 2%, depending on the diesel with which you are blending. Most users report little difference between B20 and No. 2 diesel fuel. As the biodiesel blend level is lowered, any differences in energy content become diminished and blends of B5 or less do not cause noticeable differences in performance compared to diesel No. 2.

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[6] Environmental Protection Agency. October 2002 Draft Technical Report, *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions*, (EPA420-P-02-001) (www.epa.gov/OMS/models/biodsl.htm).

A further drawback to biodiesel use is its less favorable cold flow properties compared to conventional diesel. The cold flow properties of biodiesel and conventional petrodiesel are extremely important. Unlike gasoline, petrodiesel and biodiesel can both start to freeze or gel as the temperature gets colder. If the fuel begins to gel, it can clog filters or eventually it can become thick enough that it cannot even be pumped from the fuel tank to the engine.

Biodiesel has also been shown to increase nitrogen oxide (NO_x) emissions in many engines. Biodiesel does not contain nitrogen so the increasing NO_x phenomenon is not related to fuel nitrogen content. NO_x is created in the engine as the nitrogen in the intake air reacts at the high in-cylinder combustion temperatures. As with petroleum based diesel fuel, the exact composition of the biodiesel can also influence NO_x emissions. Data shows NO_x variability between the various biodiesel meeting ASTM D6751 of around 15%, with soybean oil based biodiesel producing the highest NO_x increase. This is similar to the variability observed for conventional diesel fuels spanning the range of the ASTM diesel fuel specifications (ASTM D975).

2.5 Biodiesel in Non-Transportation Applications

When biodiesel is used in CI engines, nitrogen oxide (NO_x) emissions tend to increase as shown above. But when biodiesel is used in boilers or home heating oil applications, NO_x tends to decrease. The fuel is burned in very different ways in these dramatically different applications (open flame for boilers, enclosed cylinder with high pressure spray combustion for engines) and results in different effects.

Heating oil boilers have been tested with blends as high as 20% biodiesel. At 20% biodiesel, NO_x emissions appear to be reduced 20% over the entire range of air settings, based on studies of several different boiler systems conducted by Brookhaven National Laboratory,[7] the New England Fuel Institute, the Massachusetts Oil Heat Council, and the Northeast Oil Research Organization.[8] Sulfur dioxide (SO_2) emissions were reduced when the two fuels were blended because biodiesel contains much less sulfur than typical heating oil. So a 20% blend of biodiesel in heating oil will reduce SO_2 by about 20%.

Heating oil and diesel fuel that is dyed red for off-road use (agriculture, power, boiler fuels, construction, forestry, mining, etc.) can contain as much as 5,000 ppm sulfur today. By blending biodiesel into off-road diesel fuel, large SO_2 reduction benefits can be generated. Even if off-road diesel sulfur content is reduced to 500 ppm in the future (under EPA consideration), biodiesel will still provide significant SO_2 benefits in these markets for a long time to come.

[7] Krishna, C.R. October 2003. *Biodiesel Blends in Space Heating Equipment*, NREL/SR-510-33579.
[8] Batey, John E. December 2002. Interim report of test results, Massachusetts Oilheat Council Biodiesel Project.

3. BIODIESEL (B100)

This section will describe the basic properties and blending considerations for B100 fuels. The considerations for storing, handling, blending and using B100 are *very different* than for B20 or lower biodiesel blends, but for some readers the B100 information may help you further understand B20 use. If you are only interested in using or handling finished B20 or lower biodiesel blends, you may want to skip the B100 section and go directly to the B20 section.

B100 has physical and chemical properties similar to petroleum based diesel (see Table 1) and can in some cases be used in existing diesel applications with little or no modification to the engine or fueling system. While B100 can be used as a pure fuel in diesel applications, there are important differences between B100 and conventional diesel fuels that must be taken into consideration when handling or using B100. Using B20 and lower blends significantly reduces or eliminates the issues described here (see the following section on using B20).

1. B100 is a good solvent. It may loosen and/or dissolve sediments in fuel tanks and fueling systems left by conventional diesel over time. If your system contains sediments, you should clean your existing tanks and fuel system before handling or using B100.

2. B100 freezes at higher temperatures than most conventional diesel fuel and this must be taken into account if handling or using B100. Most B100 starts to cloud at between 35°F and 60°F, so heated fuel lines and tanks may be needed even in moderate climates. As B100 begins to gel, the viscosity also begins to rise, and it rises to levels much higher than most diesel fuel, which can cause increased stress on fuel pumps and fuel injection systems. Cold weather properties are the biggest reason many people use biodiesel blends.

3. B100 is not compatible with some hoses and gaskets. B100 may soften and degrade certain types of rubber compounds found in hoses and gaskets (i.e. buna N, nitrile, natural rubber) and may cause them to leak and become degraded to the point they crumble and become useless. This could cause a fuel spill on a hot engine, could ruin a fuel pump, or could result in filter clogging as the hose material gradually wears away. If using B100, extreme care should be taken to ensure that any part of the fuel system that touches the fuel is compatible with B100. Some systems already have biodiesel resistant materials (i.e. Viton™) but many do not because these materials are usually slightly more expensive.

4. B100 is not compatible with some metals and plastics. Biodiesel will form high sediment levels if contacted for long periods of time with copper or copper containing metals (brass, bronze) or with lead, tin, or zinc (i.e. galvanized surfaces). These high sediment levels may cause filter clogging. Diesel systems are not supposed to contain these metals, but sometimes they can occur anyway. In addition, B100 may permeate

some typical types of plastics (polyethylene, polypropylene) over time and they should not be used for storing B100.

There are other physical or chemical properties where biodiesel is substantially different from petroleum diesel and where these differences provide significant benefits. Biodiesel has significantly lower sulfur than today's diesel fuel, while providing a significant increase in lubricity. Most B100 already meets the EPA's new rule requiring all on-road diesel fuel to contain less than 15 ppm sulfur in 2006. The future 15 ppm diesel—Ultra low sulfur diesel or ULSD—can create lubricity problems as the new refining processes tends to reduce the natural lubricity of diesel. Pure biodiesel, or biodiesel blended with ULSD restores fuel lubricity in levels as low as 1% or 2% biodiesel. Biodiesel also contains 11% oxygen by weight, as well as a slightly higher cetane number, which provides for more complete combustion and a reduction in most emissions.

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

Fuel Property	Diesel	Biodiesel
Fuel Standard	ASTM D975	ASTM D6751
Lower Heating Value, Btu/gal	~129,050	~118,170
Kinematic Viscosity, @ 40°C	1.3-4.1	4.0-6.0
Specific Gravity kg/l @ 60°F	0.85	0.88
Density, lb/gal @ 15°C	7.079	7.328
Water and Sediment, vol%	0.05 max	0.05 max
Carbon, wt %	87	77
Hydrogen, wt %	13	12
Oxygen, by dif. Wt %	0	11
Sulfur, wt %*	0.05 max	0.0 to 0.0024
Boiling Point, °C	180 to 340	315 to 350
Flash Point, °C	60 to 80	100 to 170
Cloud Point, °C	-15 to 5	-3 to 12
Pour Point, °C	-35 to -15	-15 to 10
Cetane Number	40-55	48-65
Lubricity SLBOCLE, grams	2000-5000	>7,000
Lubricity HFRR, microns	300-600	<300

*Sulfur content for on-road fuel will be lowered to 15 ppm maximum in 2006.

3.1 Quality Specifications

The American Society for Testing and Materials International (ASTM) specification for biodiesel (B100) is ASTM D6751-03. It is summarized in Table 2 below. This specification is intended to insure the quality of biodiesel to be used as a blend stock at 20% and lower blend levels. Any biodiesel used in the United States for blending, should meet ASTM D6751 prior to blending. ASTM is a consensus based standards group comprised of engine and fuel injection equipment companies, fuel producers, and fuel users whose standards are recognized in the United States by EPA and most government entities, including states with the responsibility of insuring fuel quality.

As with other ASTM fuel standards, ASTM D6751 is based on the physical and chemical properties needed for safe and satisfactory diesel engine operation. It is not based on the specific raw materials or the manufacturing process used to produce the biodiesel. The finished blend stock must meet the properties specified in Table 2 below as well as the following definition:

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

Table 2. Requirements for Biodiesel (B100) Blend Stock as Listed in ASTM D6751-03

Property	ASTM Method	Limits	Units
Flash Point	D93	130.0 min.	°C
Water and Sediment	D2709	0.050 max.	% vol.
Kinematic Viscosity, 40°C	D445	1.9 - 6.0	mm^2/s
Sulfated Ash	D874	0.020 max.	% mass
Sulfur*	D5453	0.0015 max. (S15) 0.05 max. (S500)	% mass
Copper Strip Corrosion	D130	No. 3 max.	
Cetane Number	D613	47 min.	
Cloud Point	D2500	Report to Customer	°C
Carbon Residue**	D4530	0.050 max.	% mass
Acid Number	D664	0.80 max.	mg KOH/g
Free Glycerin	D6584	0.020 max.	% mass
Total Glycerin	D6584	0.240 max.	% mass
Phosphorus Content	D4951	0.001 max.	% max.
Distillation Temperature, 90% Recovered (T90)***	D1160	360 max.	°C

*Sulfur content of on-road diesel fuel to be lowered to 15 ppm in 2006
**Carbon residue shall be run on the 100% sample
***Atmospheric equivalent temperature

The definition of biodiesel contained in ASTM D 6751, along with the physical and chemical property limits, eliminates certain "biofuels" that have been incorrectly called biodiesel in the past. The raw vegetable oil or animal fat feedstock, partially reacted oils or fats, coal slurries, or any other “biologically derived” fuels not meeting the definition and table above are not biodiesel and should not be confused with biodiesel.

The ASTM biodiesel standard began as a standard for B100 as a stand alone motor fuel. During the ASTM ballot process, lack of experience with blends over B20 did not allow ASTM to come to consensus on the properties needed for satisfactory B100 operation. The standard was re-named to reflect its formal approval by ASTM as applying to a blend stock but not to a neat motor fuel. While D6751 can be used as the standard for B100 as a neat motor fuel upon consultation with the equipment manufacturer, and is being used successfully for that purpose in the United States today, users and suppliers should recognize that D6751 does not have full ASTM consensus as a stand alone fuel specification and that B100 is only recognized by a select few equipment manufacturers (see warranty section).

Buyers and sellers are encouraged to use ASTM D6751 for the commercial trading of biodiesel (B100) whether the fuel is planned for B100 use or for blending. Other arrangements or specifications can be legally used provided both the buyer and seller agree upon them and so long as they meet pertinent local, state, and federal regulations (i.e. EPA sulfur limits, OSHA safety limits on flash point, etc.).

Some of the test methods listed in Table 2 perform more than one role to ensure that the fuel performs as intended in CI engines and as tests to ensure that the manufacturer produced a high-quality B100. The intent of each quality requirement in Table 2 is described below:

- A minimum **flash point** for diesel fuel is required for fire safety. B100’s flash point is typically much higher than diesel fuel’s (150^{o} C compared to 70^{o} C) to ensure that the manufacturer has removed excess methanol used in the manufacturing process. Residual methanol in the fuel is a safety issue because even very small amounts reduce the flash point. Residual methanol, which can be found in biodiesel with low, out-of-specification flash point, can also affect fuel pumps, seals and elastomers, and can result in poor combustion properties.
- **Water and sediment** refers to the presence of free water droplets and sediment particles. The allowable level for B100 is set at the same level allowed for conventional diesel fuel. Poor drying techniques during manufacturing or contact with excessive water during transport or storage can cause B100 to be out of specification for water content. Excess water can lead to corrosion and provides an environment for microorganisms. Fuel oxidation can also raise sediment levels, so this test can be used in conjunction with acid number and viscosity to determine if fuels have oxidized too much during storage.
- A minimum **viscosity** is required for some engines because of the potential for power loss caused by injection pump and injector leakage. This is not an issue for B100 and the minimum is set at the same level as for petroleum diesel. The maximum viscosity is limited by the design of engine fuel injection systems. Higher viscosity fuels can cause poor fuel combustion that leads to deposit formation as well as higher in-cylinder penetration of the fuel spray which can result in elevated engine oil dilution

with fuel. The maximum allowable viscosity in ASTM D975 for No. 2 diesel is 4.1 mm^2/s at 40°C although most engines are designed to operate on fuels of higher viscosity than 4.1 mm^2/s. ASTM D6751 allows for slightly higher viscosity than D975 primarily because that is where the normal viscosity of B100 lies. Consult your operational manual or your engine manufacturer if you intend to use a B100 in your engine that has a higher viscosity than what the engine or fuel system was designed for.

- The **sulfated ash** test measures the amount of residual alkali catalyst present in the biodiesel as well as any other ash forming compounds that could contribute to injector deposits or fuel system fouling.
- **Sulfur** is limited to reduce sulfate and sulfuric acid pollutant emissions and to protect exhaust catalyst systems when they are deployed on diesel engines in the future. Biodiesel generally contains less than 15 ppm sulfur. The test for low-sulfur fuel (ASTM D5453) should be used for accurate results instead of D2622, which will provide falsely high results due to test interference with the oxygen in the biodiesel.
- The **copper strip corrosion** test is used to indicate potential difficulties with copper and bronze fuel system components. The requirements for B100 and conventional diesel are identical, and biodiesel meeting other D6751 specifications always passes this test. While copper and bronze may not corrode in the presence of biodiesel fuel, prolonged contact with these catalysts can cause fuel degradation and sediment formation.
- An adequate **cetane number** is required for good engine performance. Conventional diesel must have a cetane number of at least 40 in the United States. Higher cetane numbers help ensure good cold start properties and minimize the formation of white smoke. The ASTM limit for B100 cetane number is set at 47 as this is the level identified for "Premium Diesel Fuel" by the National Conference of Weights and Measures, as well as the fact that 47 has been the lowest cetane number found in U.S. biodiesel fuels. The cetane index (ASTM D976) is not an accurate predictor of cetane number for biodiesel or biodiesel blends since it is based on a calculation using specific gravity and distillation curve, both of which are different for biodiesel than for petrodiesel.
- **Cloud point** is important for ensuring good performance in cold temperatures. B100 cloud point is typically higher than the cloud point of conventional diesel. Low temperature properties and strategies for ensuring good low-temperature performance of biodiesel blends are discussed in more detail in the following chapters.
- **Carbon residue** gives a measure of the carbon-depositing tendency of a fuel and is an approximation of the tendency for carbon deposits to form in an engine. For conventional diesel fuel the carbon residue is measured on the 10% distillation residue. Because B100 boils entirely in the high end of the diesel fuel range and at approximately the same temperature it is difficult to leave only a 10% residual when distilling biodiesel. So biodiesel carbon residue specifies that the entire biodiesel sample be used rather than the 10% distilled residue.
- **Acid number** for biodiesel is primarily an indicator of free fatty acids (natural degradation products of fats and oils) and can be elevated if a fuel is not properly manufactured or has undergone oxidative degradation. Acid numbers higher than 0.80

have been associated with fuel system deposits and reduced life of fuel pumps and filters.

- **Free and total glycerin** numbers measure the amount of unconverted or partially converted fats and by-product glycerin present in the fuel. Incomplete conversion of the fats and oils into biodiesel can lead to high total glycerin. Incomplete removal of glycerin can lead to high free glycerin and total glycerin. If these numbers are too high, storage tank, fuel system, and engine fouling can occur. Fuels that exceed these limits are highly likely to cause filter plugging and other problems.
- **Phosphorus** content is limited to 10 ppm maximum in biodiesel because phosphorus can damage catalytic converters and phosphorus above 10 ppm can be present in some vegetable oils. Biodiesel produced in the United States generally has low phosphorus levels, on the order of 1 ppm.
- The **T90 distillation** specification was incorporated to ensure that fuels have not been contaminated with high boiling materials such as used motor oil. B100 exhibits a boiling point rather than a distillation curve. The fatty acids from which biodiesel is produced are mainly straight chain hydrocarbons with 16 to 18 carbons that have close boiling temperatures. The atmospheric boiling point of biodiesel generally ranges from 330°C to 357°C.

The D6751 specification also includes the following workmanship statement: "The biodiesel fuel shall be visually free of undissolved water, sediment, and suspended matter." B100 should be clear, although it may come in a variety of colors. Biodiesel color does not predict fuel quality.

Currently there are ASTM specifications for B100 (D6751) and for petrodiesel (D975), but there is not a separate approved specification for biodiesel blends. Current practice to insure the quality of biodiesel blends is to use petrodiesel (No. 1 or No. 2) meeting D975 and biodiesel meeting D6751 prior to blending. Once blended, it is very difficult to determine the quality of the B100 used to make the blend. ASTM specifications for finished biodiesel blends up to B20 are under development, so please check with ASTM or the National Biodiesel Board (NBB) for updated information.

B5 and lower blends generally meet the properties listed in ASTM D975, which defines the properties of conventional diesel fuel. B20 or higher blends can also meet the properties listed in ASTM D975 with the possible exception of viscosity and distillation, depending mostly on the diesel fuel with which it is blended. The engine community has generally agreed that a slightly higher distillation with biodiesel blends will not cause the technical problems associated with high boiling petrodiesel fuel—provided the increase is due to biodiesel meeting D6751. They have also stated that a higher viscosity than allowed by D975 may cause added stress on the fuel system and inadequate fuel atomization that can result in poor engine performance and injector coking. Biodiesel blends that meet ASTM D975 can generally be used interchangeably with diesel fuel for normal usage, as long as the biodiesel meets the requirements of ASTM D6751 and the cold flow properties of the blend are adequate for the geography and time of year the fuel will be used.

3.2 Variation in Biodiesel Properties

As with petroleum-based fuels, the ASTM specifications for biodiesel allow for a variety of feedstocks and processes to be used to produce biodiesel. The specifications prescribe the amount of acceptable variability in the finished product. This variability is a compromise between maximizing the amount of fuel available for use and minimizing cost, while providing a minimum satisfactory level of engine performance.

Since biodiesel is produced mainly as a whole cut fuel, where the goal is to take all of the vegetable oil or animal fat and turn it into biodiesel, some of the properties of finished biodiesel depend heavily on the feedstock. These properties can include cetane, cold flow, bulk modulus (compressibility), and stability. In addition, testing has shown that differing biodiesel properties can also lead to different levels of NO_x emissions from compression ignition (diesel) engines, although this does not appear to be the case with other regulated emissions (HC, CO, PM) or unregulated emissions (PAH, NPAH) or with open flame combustion in boilers or home heating applications.

Biodiesel can be produced commercially from a variety of oils and fats:

- Animal fats: edible tallow, inedible tallow, and all the other variations of tallow, lard, choice white grease, yellow grease, poultry fats and fish oils.
- Vegetable oils: soy, corn, canola, sunflower, rapeseed, cottonseed
- Recycled greases: used cooking oils and restaurant frying oils.

It is also possible to make biodiesel from other oils, fats and recycled oils such as mustard, palm, coconut, peanut, olive, sesame, and safflower oils, trap greases, and even oils produced from algae, fungi, bacteria, molds, and yeast.

Compared to the chemistry of diesel fuel, which contains hundreds of compounds, the chemistry of different fats and oils typically used for biodiesel are very similar. Each fat or oil molecule is made up of a glycerine backbone of three carbons, and on each of these carbons is attached a long chain fatty acid. These long chain fatty acids are what react with methanol to make the methyl ester, or biodiesel. The glycerin backbone is turned into glycerin and sold as a byproduct of biodiesel manufacturing. The fats and oils listed above contain 10 common types of fatty acids which have between 12 and 22 carbons, with over 90% of them being between 16 and 18 carbons. Some of these fatty acid chains are saturated, while others are monounsaturated and others are polyunsaturated. Within the limits of the specifications, the differing levels of saturation can affect some of the biodiesel fuel properties. This can be important when selecting the biodiesel for your application.

What makes each of these feedstocks different from the others is that they are made of different proportions of saturated, monounsaturated, and polyunsaturated fatty acids (Figure 2). A “perfect” biodiesel would be made only from monounsaturated fatty acids.

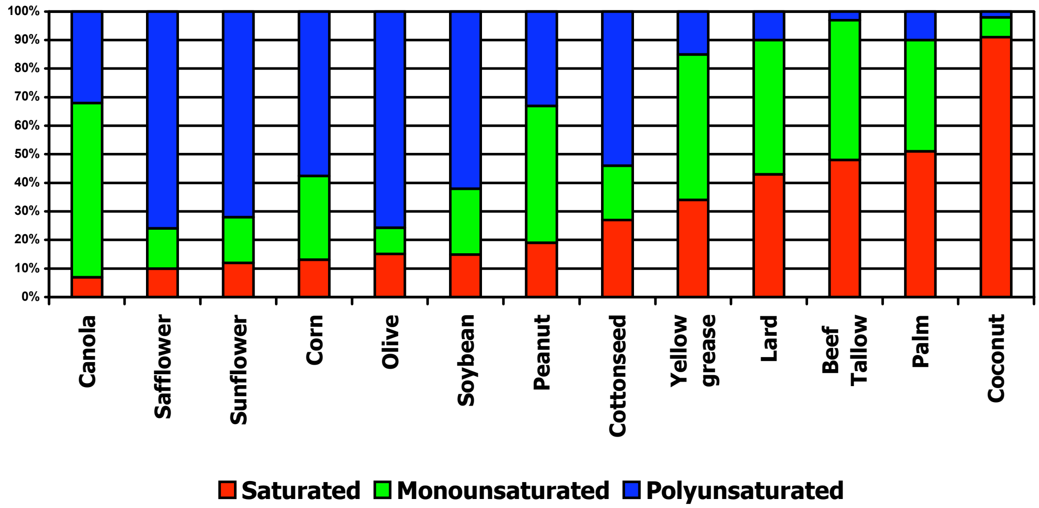


Figure 2. Composition of various biodiesel feedstocks

Under each category heading in Table 3 we show what types of fatty acids are considered saturated, monounsaturated, or polyunsaturated and their general impact on the fuel properties and emissions. The first number of the combination shows the number of carbons in the fatty acid chain; the second number is the level of saturation or unsaturation—0 for saturated, 1 for monounsaturated, and 2 or 3 for polyunsaturated. For example, 18:1 is a fatty acid containing 18 carbons and one point of unsaturation (monounsaturated). It should be noted that these are general trends only and that other factors such as the use of additives may modify the effects shown below.

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

	Saturated	Monounsaturated	Polyunsaturated
Fatty acid	12:0, 14:0, 16:0, 18:0, 20:0, 22:0	16:1, 18:1, 20:1, 22:1	18:2, 18:3
Cetane Number	High	Medium	Low
Cloud Point	High	Medium	Low
Stability	High	Medium	Low
NO_x Emissions	Reduction	Slight increase	Large increase

As with conventional diesel fuel, the best type of biodiesel for your applications will be based on several factors. A No. 2 petrodiesel fuel with a cetane of 50 but that starts to freeze at 20°F may be perfectly suitable for December in Texas, while a No. 1 petrodiesel with a cetane of 42 and that starts to freeze at –40°F may be best for a December in Minnesota. The considerations and trade-offs made every day with petrodiesel fuel will also apply to the choice of biodiesel. The data below provides more detail about B100 properties and considerations.

3.3 B100 Energy Content

With conventional diesel fuels, the inherent energy content of the fuel, measured typically in BTUs per gallon, is the largest factor in the fuel economy, torque, and horsepower delivered by the fuel. The energy content of conventional diesel can vary up to 15% from supplier to supplier or from summer to winter. This variability in conventional diesel is due to changes in its composition, and these changes are determined by the refining and blending practices. Number 2 diesel fuel usually has a higher energy content than number 1 diesel fuel, with blend values somewhere in between.

With biodiesel, or B100, the refining and blending methods have no significant effect on energy content (Figure 3). The reason B100 does not vary much is because the energy content of the fats and oils used to make biodiesel do not vary nearly as much as the components used to make diesel fuel. Therefore, B100 made from most of the common feedstocks will have the same impact on fuel economy, power, and torque. Compared to most No. 2 diesel fuel in the United States, B100 has a slightly lower (12.5% per pound or 8% per gallon) energy content (Figure 3). Typically losses in power, torque, and fuel economy are similar to the difference seen in energy content.

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

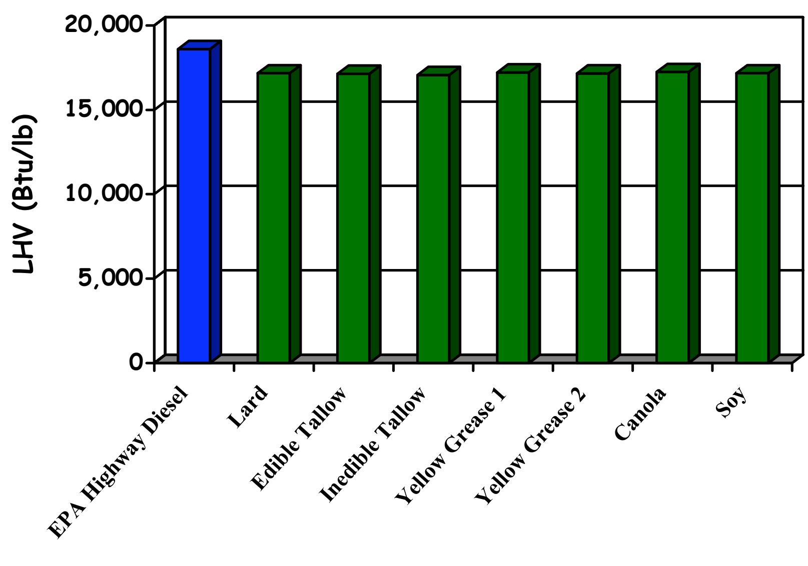


Figure 3. Heating value of diesel and biodiesel (B100) fuels

3.4 B100 Cold Flow Properties

The cold flow properties of biodiesel and conventional petrodiesel are extremely important. Unlike gasoline, petrodiesel and biodiesel can both start to freeze or gel as the temperature gets colder. If the fuel begins to gel, it can clog filters or can eventually become too thick to pump from the fuel tank to the engine. There are three tests used to measure the cold flow properties of fuels for diesel engines: cloud point, cold filter plug point, and pour point. They are described in more detail below.

Cloud Point: The temperature at which small solid crystals are first visually observed as the fuel is cooled. This is the most conservative measurement of cold flow properties, and most fuel can be used without problems below the cloud point but above the cold filter plug point.

Cold Filter Plug Point (CFPP): The temperature at which fuel crystals have agglomerated in sufficient amounts to cause a test filter to plug. The CFPP is less conservative than the cloud point, and is considered by some to be a better indication of low temperature operability.

Pour Point: The temperature at which the fuel contains so many agglomerated crystals it is essentially a gel and will no longer flow. This measurement is of little practical value to users, since the fuel has clogged the filter long before reaching its pour point. Distributors and blenders, however, use pour point as an indicator of whether the fuel can be pumped, even if it would not be suitable for use without heating or taking other steps.

Neither ASTM D975 nor ASTM D6751 has a specific requirement for the maximum cloud point, but the cloud point should be provided to the customer. This can be confusing to someone new to using diesel fuel or biodiesel. How can something be in the specification but not have an exact required value? The answer is that the cold flow properties needed for the fuel depend on where it is being used (i.e. Michigan or Texas) and what time of year the fuel is being used (i.e. January or July). A petrodiesel or biodiesel fuel with a cloud point of 20°F may be just fine for a Texas summer, but would not be fine for a North Dakota winter.

There is a set of maps in the back of ASTM D975 that identify the 10^{th} percentile minimum temperature for the central and northern tier states for the various months of the winter. These maps can be used as a guide for the user or distributor. The 10^{th} percentile temperature is that temperature at which only 10% of the days got colder during that month on average over the last 50 years or so. Some users and distributors use the 10^{th} percentile as the target for their cold flow properties, some use 10 degrees higher than that as their target, while some use cloud point as their measurement and some use CFPP. Still other users do not monitor cold flow properties at all, and rely on their distributor to make sure the cold flow properties are managed.

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

- B100 should be stored at temperatures at least 5°F to 10°F higher than the cloud point of the fuel. A storage temperature of 40°F to 45°F is fine for most B100, although some B100 fuels may require higher storage temperatures.

- B100 can be stored underground in most cold climates without additional considerations because underground storage temperatures are normally above 45°F. Above ground fuel systems should be protected with insulation, agitation, heating systems, or other measures if temperatures regularly fall below the cloud point of the fuel. This precaution includes piping, tanks, pumping equipment, and the vehicles. Many small-scale B2 blenders store B100 in drums or totes indoors during winter months.

The cloud point of B100 starts at 30°F to 32°F for most of the vegetable oils that are made up primarily of mono- or poly-unsaturated fatty acid chains and can go as high as 80°F or higher for animal fats or frying oils that are highly saturated. Some examples of the cloud, pour, and cold filter plug point of B100 made from various sources can be found in Table 4. It should be noted that the pour point of B100 is usually only a few degrees lower than the cloud point, so once biodiesel "begins to freeze," gelling can proceed rapidly if the temperature drops only a few degrees further.

Table 4. Cold Flow Data for Various B100 Fuels

Test Method	**Cloud Point ASTM D2500**		**Pour Point ASTM D97**		**Cold Filter Plug Point IP 309**	
B100 Fuel	**°F**	**°C**	**°F**	**°C**	**°F**	**°C**
Soy Methyl Ester	38	3	25	-4	28	-2
Canola Methyl Ester	26	-3	25	-4	24	-4
Lard Methyl Ester	56	13	55	13	52	11
Edible Tallow Methyl Ester	66	19	60	16	58	14
Inedible Tallow Methyl Ester	61	16	59	15	50	10
Yellow Grease 1 Methyl Ester	--	--	48	9	52	11
Yellow Grease 2 Methyl Ester	46	8	43	6	34	1

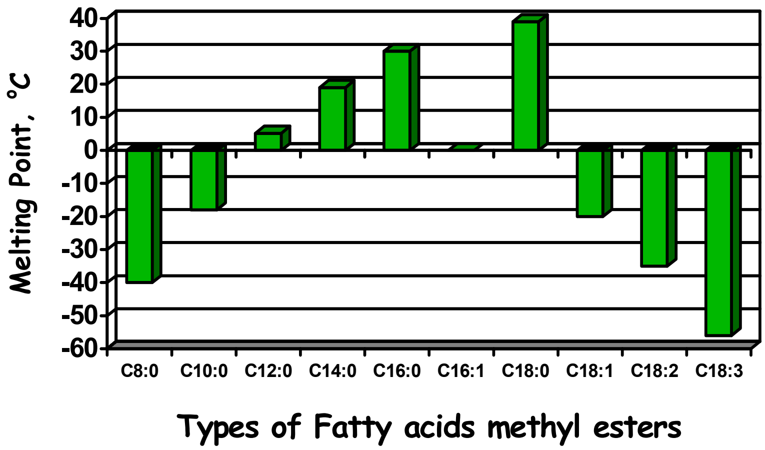


Figure 4. Melting points of biodiesel components.

B100 tanks and fuel lines should be designed for the cold flow properties of the biodiesel being used and the climate they will see. Make sure that fuel pumps, lines, and dispensers are protected from cold and wind chill with properly approved heating and/or insulating equipment. Fuel in above ground tanks should be heated in a range that fluctuates between 5°F to 10°F above the fuel cloud point.

Once crystals begin to form, they should go back into solution as the fuel warms up. However, that process could be slow if the fuel warms only marginally or very slowly. Crystals formed in biodiesel or diesel fuel can drift to the bottom of the tank and begin to build up a gel layer. Slow agitation can prevent crystals from building up on the tank bottom or, once present in the fuel, agitation can help to dissolve crystals back into solution. If B100 has gelled completely, it may be wise to bring the B100 temperature up to 100°F to 110°F to melt the most highly saturated biodiesel components if the fuel needs to be used right away. Lower temperatures can be used if enough time is provided for the mixture to come to its equilibrium cloud point. Further work is occurring in this arena.

Some additive manufacturers have data that show their cold flow additives can reduce the pour point of a B100 by as much as 12°C (30°F), but the treat rate is in excess of 10,000 ppm. At more typical treat rates (1000 ppm), benefits were about 3°C, which are within the variation in the test method.

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

There are efforts underway to design new additives specific for U.S.-based B100, and there are processes which serve to winterize biodiesel by removing some of the saturated compounds. At present the cost of these approaches makes them undesirable. As time goes on, and biodiesel volumes increase, expect to see more progress in this area.

3.5 B100 Cetane Number

Most of the B100 made today that meets D6751 has a cetane number higher than 47. This is compared to the minimum of 40 for highway diesel fuel, whose national average is between 42 and 44. Therefore, biodiesel has a higher cetane number than most U.S. diesel fuel, which is believed to provide easier starting and quieter operation. Highly saturated B100, such as animal fats and used cooking oils, can have a cetane number of 70 or higher. Common polyunsaturated fuels that contain high levels of C18:2 and C18:3 fatty acids include soy, sunflower, corn, and canola (rapeseed) oils. These will be at the lower end of the scale, at 47 or slightly higher. Figure 5 shows the cetane number of various pure fatty acid methyl esters. Figure 6 shows the cetane number of various biodiesel samples.

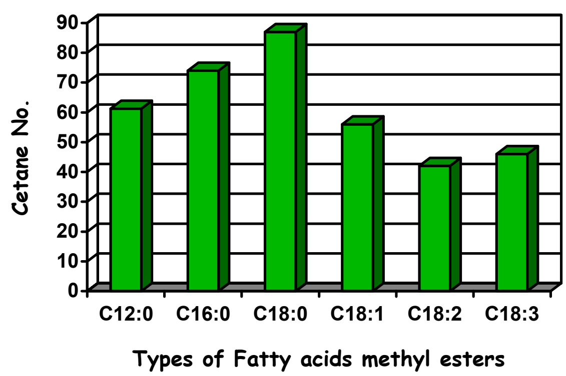


Figure 5. Cetane number of fuels made from pure fatty acids

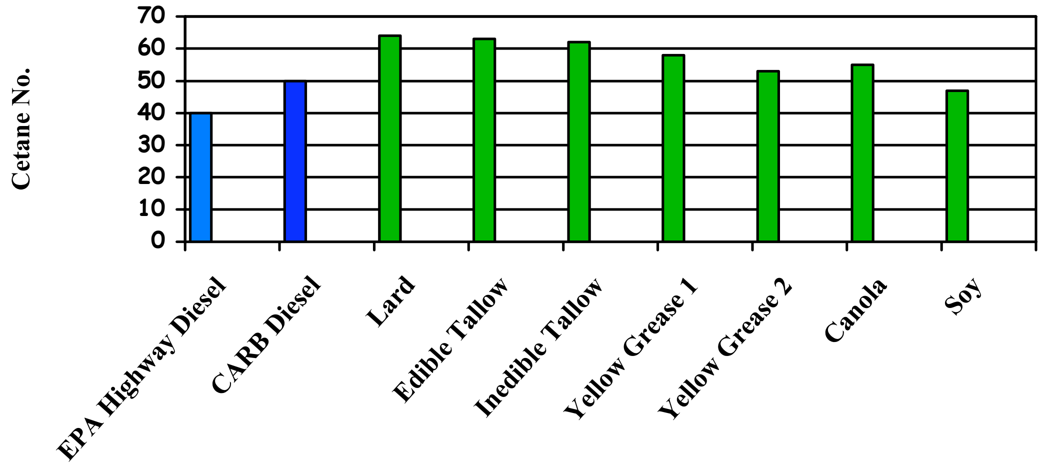


Figure 6. Cetane number of fatty acid methyl esters, petroleum diesel and various biodiesel fuels

3.6 B100 Stability

Few users have reported stability problems with B20 or B100 in the United States, but stability is a major issue for engine and fuel system manufacturers. Stability is a broad term, but really refers to two issues for fuels: long-term storage stability or aging and stability at elevated temperatures and/or pressures as the fuel is recirculated through an engine's fuel system. In the diesel fuel arena, long-term storage stability is commonly referred to as oxidative stability, and thermal stability is the common term for the stability of fuels at elevated fuel system temperatures. At this time there are no ASTM specifications for the stability of either diesel or biodiesel.

In biodiesel, fuel aging and oxidation can lead to high acid numbers, high viscosity, and the formation of gums and sediments that clog filters. If the acid number, viscosity, or sediment measurements exceed the limits in ASTM D6751, the B100 is degraded to the point where it is out of specification and should not be used. Biodiesel with high oxidation stability will take longer to reach an out of specification condition, while biodiesel with low oxidation stability will take less time in storage to reach an out of specification condition. Monitoring the acid number and viscosity of B100 over time can provide some idea about whether the fuel is oxidizing, with sampling at the receipt of the B100 and periodically during storage providing the most useful data.

In some cases, deposits from the cleaning effect or solvency of B100 have been confused with gums and sediments that could form over time in storage as the fuel ages. While 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 the acid number of the fuel is within specification, then sediment formation is most likely due to the cleaning affect and not to fuel aging or oxidation.

Even though there is no ASTM specification for the stability of either biodiesel or diesel fuel at this time, several organizations have experimented with diesel test methods (ASTM D4625 or ASTM D2274), modifying them to work with biodiesel and trying to determine how well they might predict fuel stability. So far, none of the modifications are good enough for an ASTM round robin, but these experiments have provided data to better understand B100 stability. Tests can measure fuel degradation over time, but few are good at predicting what actually happens in the field, and even fewer test methods can be correlated to field performance problems such as filter plugging, deposit formation, or fuel injector failure. Most test methods can identify the worst and the best of fuels, but differentiating between the average or borderline fuels has yielded mixed results.

There are some guidelines that help identify fuels and conditions that will provide the highest levels of stability.

- The higher the level of unsaturation the more likely it is that the fuel will oxidize. As a rule, saturated fatty acids (such as 16:0 or 18:0) are stable. And each time the level of unsaturation increases (for example from 18:1 to 18:2 to 18:3) the stability of the fuel goes down by a factor of 10. So a fuel composed primarily of C18:3 is 100 times more unstable than a fuel made of C18:1. The points of unsaturation on the biodiesel molecule can react with oxygen, forming peroxides that break down into acids, sediments, and gums.
- Heat and sunlight will accelerate this process, so it is best not to store B100 outside in clear totes in the summer.
- Certain metals such as copper, brass, bronze, lead, tin, and zinc will accelerate the degradation process and form even higher levels of sediment than would be formed otherwise. B100 should not be stored for long periods of time in systems that contain these metals. Metal chelating additives, which serve to de-activate these metals, may reduce or eliminate the negative impact of the presence of these metals.
- Some types of feedstock processing and biodiesel processing can remove natural anti-oxidants, potentially lessening fuel stability. Vegetable oils and fats are produced with natural antioxidants—nature's way of protecting the oil from degradation over time. Bleaching, deodorizing, or distilling oils and fats, either before or as part of the biodiesel process, can remove these natural antioxidants while other processes leave the antioxidants in the finished biodiesel.
- Keeping oxygen from the fuel reduces or eliminates fuel oxidation and increases storage life. Commercially, this is done using a nitrogen blanket on fuel tanks or storing biodiesel in sealed drums or totes for smaller amounts of fuel.
- Antioxidants, whether natural or incorporated as an additive, can significantly increase the storage life or stability of B100.

In many commercial systems, the fuel turn over is in a range (two to four months) where fuel stability with B100 has not been problematic. The ASTM D4625 data (Figure 7) suggests that the least stable B100 could be stored for up to 8 months,[9] while the most stable could be stored for a year or more. The National Biodiesel Board recommends a six month storage life for B100.

There is not a lot of experience with B100 storage for periods greater than six months, so if the fuel is kept longer than six months, anti-oxidants should be used and/or periodic tests for acid number and sediments, and perhaps viscosity, should be performed to insure that the fuel remains within the boundaries of ASTM D6751.

Thermal stability is generally meant to be an indicator of fuel degradation when subjected to high temperatures for a short period of time, similar to what would be experienced in the fuel injector or fuel system of a modern diesel engine. If the fuel degrades here, the primary concern is the potential for injector coking. The data available regarding thermal stability generally show that B100 has good thermal stability. This makes some sense, as saturated vegetable oils and animal fats are used as frying oils and are subjected to extremely hot temperatures for relatively long periods of time. In addition, most reports from the field have indicated that biodiesel produces less injector coking that conventional diesel fuel, but much of this information is anecdotal.

The most common thermal stability test method is ASTM D6468. It measures the black residue formed as the fuel is subjected to very high temperatures for 90 or 180 minutes through a reflectance measurement on the filtered material. B100 forms very little black residue upon extreme heating and performs well in this test. There is some question about whether the biodiesel sediment could be brown or gray and not be measured in this reflectance test, as well as some questions about whether the biodiesel residue is completely washed from the aging apparatus with the current solvents and these questions are being further investigated.

[9] Appendix X.1, Section x.1.4 of ASTM D4625 states: "For most practical purposes, it has been shown that aging fuel at 43°C results in an approximately fourfold acceleration of the degradation for an ambient temperature of 21°C, that is, a week of 43°C storage is roughly equivalent to a month of storage at normal (environmental) ambient temperatures. Depending on fuel composition and actual storage conditions, this correlation may vary substantially in either direction."

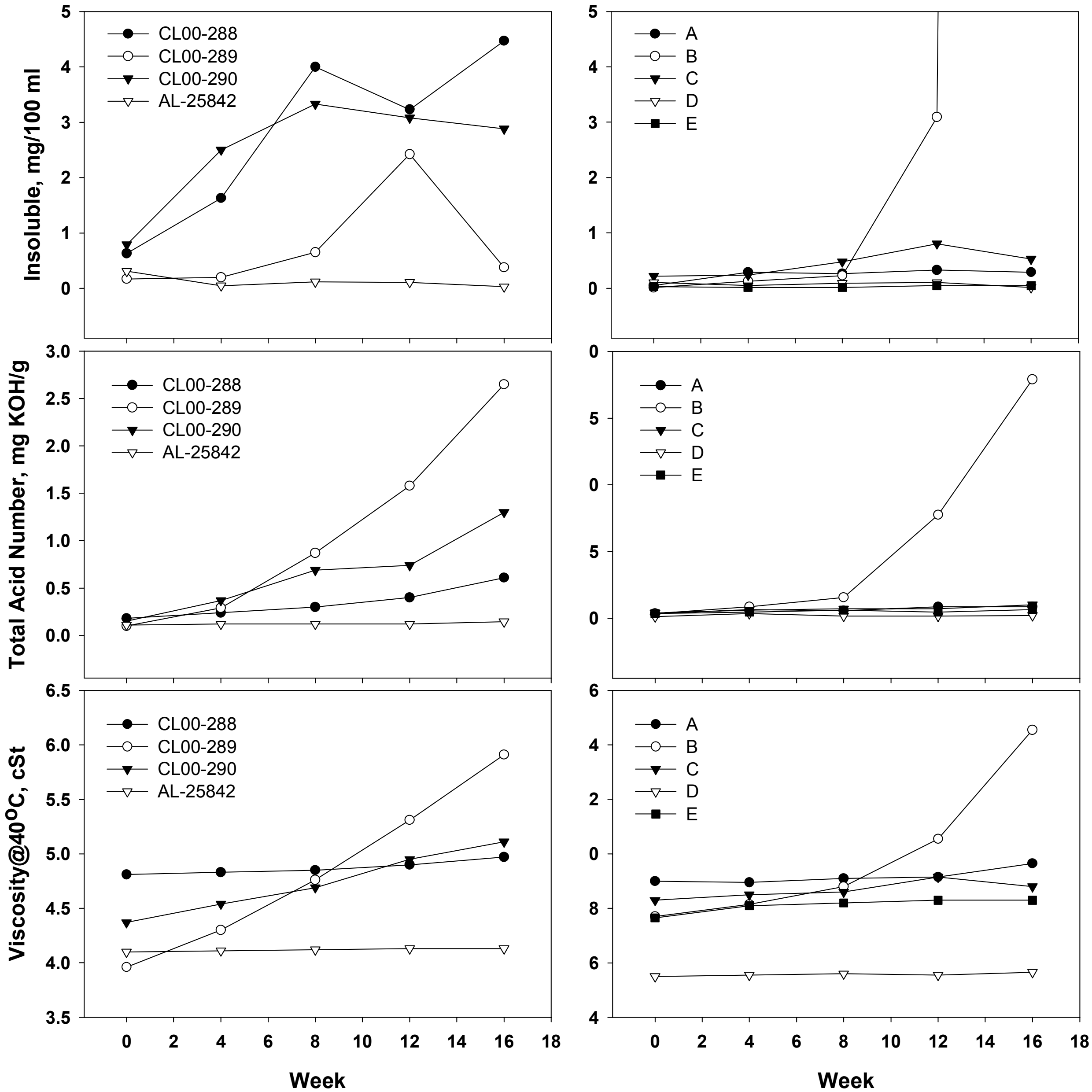


Figure 7. ASTM D4625 (43°C) Long-term storage stability. B100 on left. B20 on right. Some fuels contain natural antioxidants, some contain additions, some B100 distillated, some natural.

While B100 thermal stability does not appear to be an issue, additional investigation is under way with both existing diesel engines and, more importantly, newer and future diesel engines. The newest engines, and future engines, will be operating at higher temperatures and pressures than most engines in operation today. These engines may recirculate more fuel that ever before and there is not much information about operating these engines on B100. If any problems do occur, they are more likely with B100 than with lower blends.

3.7 B100 Microbial Contamination

Biocides are recommended for conventional and biodiesel fuels wherever biological growth in the fuel has been a problem. If biological contamination is a problem, water contamination needs to be controlled since the aerobic fungus, bacteria, and yeast hydrocarbon utilizing microorganisms (HUMBUGS) usually grow at the fuel-water interface. Anaerobic colonies, usually sulfur reducing, can be active in sediments on tank surfaces and cause corrosion. Since the biocides work where the HUMBUGS live (in the water), products that are used with diesel fuels will work equally well with biodiesel.

3.8 B100 Cleaning Effect

Methyl esters have been used as low VOC (volatile organic compound) cleaners and solvents for decades. Methyl esters make an excellent parts cleaner, and several companies are offering methyl esters as a low VOC, non-toxic replacement for the volatile solvents used in parts washers. B100, being comprised of methyl esters meeting ASTM D6751, has a tendency to dissolve the accumulated sediments in diesel storage and engine fuel tanks. These dissolved sediments can plug fuel filters and in some cases cause the fuel filters to burst, sending all the sediment through the fuel injection system. If this happens, it can cause injector deposits and even fuel injector failure. If you plan to use or store B100 for the first time, clean the tanks and anywhere in the fuel system where sediments or deposits may occur before filling with B100.

The level of 'cleaning' depends on the amount of sediment in the system (i.e. if the system is sediment free there should be no effect) as well as the blend level of biodiesel being used. The cleaning effect is much greater with B100 and blends with 35% or more biodiesel, compared to B20 and lower blends. Most people do not clean their tanks before B20 use, although it is still wise to keep some extra filters on hand and monitor potential filter clogging a little closer than normal when first starting up with B20. The cleaning effect of the biodiesel in B20 is sufficiently diluted so that most problems encountered are insignificant, but an occasional plugged fuel filter may occur upon initial use. Drivers should be aware that sediments in the vehicle system might plug fuel filters during the first few weeks of using B20. Any filter clogging with B20, if it occurs at all, typically goes away after the first few tanks of fuel.

Some consumers who did not encounter problems with B20 assume they can switch to higher blends because the B20 has already cleaned their tanks. B20 is too dilute to "clean" tanks and therefore caution is still warranted with blends over B20.

You should keep biodiesel spills wiped up because it can remove some types of body and engine paint if the fuel is not wiped up immediately. It can also remove decals that are stuck on tanks or vehicles near the fueling areas. All materials that are used to wipe up biodiesel spills should be considered combustible and should be stored in a safety can.

3.9 B100 Material Compatibility

B100 will degrade, soften, or seep through some hoses, gaskets, seals, elastomers, glues, and plastics with prolonged exposure. Some testing has been done with materials common to diesel systems but more data is needed on the wide variety of grades and variations of compounds that can be found in these systems, particularly with B100 in U.S. applications. Nitrile rubber compounds, polypropylene, polyvinyl, and Tygon materials are particularly vulnerable to B100. Before handling or using B100, contact the equipment vendor or OEM and ask if the equipment is suitable for B100 or Biodiesel. In some cases, the vendor may need the chemical family name for biodiesel (i.e. the methyl esters of fats and oils) to look up the information or even the exact chemical name of some of the biodiesel components such as methyl oleate, methyl linoleate, methyl palmitate, or methyl stearate. There have not been significant material compatibility issues with B20.

If your existing equipment or engine components are not compatible with B100, they should be replaced with those that are. Materials such as Teflon, Viton, fluorinated plastics, and Nylon are compatible with B100. B100 suppliers and equipment vendors should be consulted to determine material compatibility. Also consult other B100 vendors in other regions of the country to see what problems they may have experienced and what kind of replacement materials they are using. It is advisable to set up a monitoring program to visually inspect the equipment once a month for leaks, seeps, and seal decomposition. It would be wise to continue these inspections even after one year, as the experience is still relatively limited with B100.

Older vehicles, manufactured before approximately 1993, are more likely to contain seals, gaskets, etc., that will be affected by B100 over long periods of time. Modern rebuild kits or engines after 1993 may contain biodiesel compatible materials, but not always. Ask your dealership for recommendations.

Most tanks designed to store diesel fuel will store B100 with no problem. Acceptable storage tank materials include aluminum, steel, fluorinated polyethylene, fluorinated polypropylene, Teflon®, and most fiberglass. If in doubt, contact the tank vendor or check the National Biodiesel Board web site.

Brass, bronze, copper, lead, tin, and zinc may accelerate the oxidation of diesel and biodiesel fuels and potentially create fuel insolubles (sediments) or gels and salts when reacted with some fuel components. Lead solders and zinc linings should be avoided, as should copper pipes, brass regulators, and copper fittings. The fuel or the fittings will tend to change color and insolubles may plug fuel filters. Affected equipment should be replaced with stainless steel, carbon steel, or aluminum.

3.10 Suggestions for Transporting B100

As with petrodiesel, it is important that B100 be transported in a way that does not lead to contamination. The following procedures are recommended and are also used by distributors and transporters of petroleum derived diesel.

- Trucks and Railcars: Aluminum, carbon steel, or stainless steel
  1. Proper inspection and/or washout (washout certificate)
  2. Check for previous load carried and residual. Generally only diesel fuel is acceptable as a residual. If the vessel has not gone through a washout, some residuals may not be acceptable like:
     a. food products or raw vegetable oils
     b. gasoline
     c. lubricants
  3. No residual water
  4. Hoses and seals clean, compatible with B100
  5. Determine need for insulation or method to heat truck or rail car contents if shipping during cold weather.

B100 is challenging to ship in cold weather. In the winter, most B100 is shipped one of the following ways:

- Hot (or at least warm) in trucks for immediate delivery (130^{o}F to 80^{o}F)
- Hot (120^{o}F to 130^{o}F) in railcars for delivery within 7-8 days (arrives warm if only 1 week has passed since loading)
- Frozen in railcars equipped with external steam coils (the fuel in the tank cars is melted at the final destination with steam),
- In a blend with winter diesel, kerosene, or other low cloud point fuel in either railcars or trucks.

Regardless of how the biodiesel arrives, it must be stored and handled using procedures that do not allow the temperature of B100 or blend to drop below its cloud point. The cloud point of the biodiesel, the biodiesel temperature, the ambient temperature, and the time the fuel is in transport are all factors that should be taken into consideration when transporting B100 to insure that the fuel does not freeze in transport.

3.11 Suggestions for Using B100

If you want to use B100, these recommendations should help:

- Contact other B100 users. If you manage a fleet, contact your Fleet Management Association or Clean Cities Coalition to find out if anyone near you has experience with B100. Contact the National Biodiesel Board and look through its news and other outreach material for references to B100 users. Ask your B100 vendor for some recommendations.

- Ask other users what they did, how they did it, how long it took, how much it cost, what problems (if any) they encountered, how long have they been using B100, and what kind of engines and equipment have they been using it in.
- Contact your dealership and discuss your needs and ask for advice, including any recommendations from their European distributors or other U.S. fleet customers. You are probably not alone.
- Replace materials you know will be problematic and institute a monitoring program.
- Plan and budget for the time and expense of increased fuel filter changes or cleaning your fuel system when first starting to use B100.

3.12 B100 and NO_x Emissions

The composition of the biodiesel will affect how much NO_x a biodiesel will produce from a CI engine. Figure 8 and Figure 9 below show the percentage increase in NO_x from B100 compared to diesel fuel with engines representative of what is on the road today. Some kinds of B100, such as those high in polyunsaturated fatty acids, produce more NO_x than B100 high in saturated fatty acids. Of course, highly saturated biodiesel starts to freeze at a higher temperature.

Beginning in 2007, new diesel engine and after-treatment technologies that use fuel with less than 15 ppm sulfur content will be required in an effort to *reduce NO_x emissions by over 90%* compared to today's level. Biodiesel has not been thoroughly tested in these new types of engines, so we don't know how much benefit these new technologies may provide. The NREL and NBB web sites will provide updated test data as it becomes available.

While new diesel technology appears to be the long-term solution for reducing NO_x with biodiesel, further study is occurring to find ways to reduce NO_x with B100, and to further understand the biodiesel NO_x phenomenon with existing engines. A slight engine timing retard (1 to 5 degrees) can bring B100 NO_x to diesel baselines or provide NO_x reductions. Retarding engine timing with EPA certified diesel engines, however, without re-certification with EPA is considered tampering and re-timing modern diesel engines is generally not a user serviceable item. It is best to check with your engine manufacturer about this option for their equipment, but most manufacturers have not looked into this option for B100 due to the low volumes used in the United States.

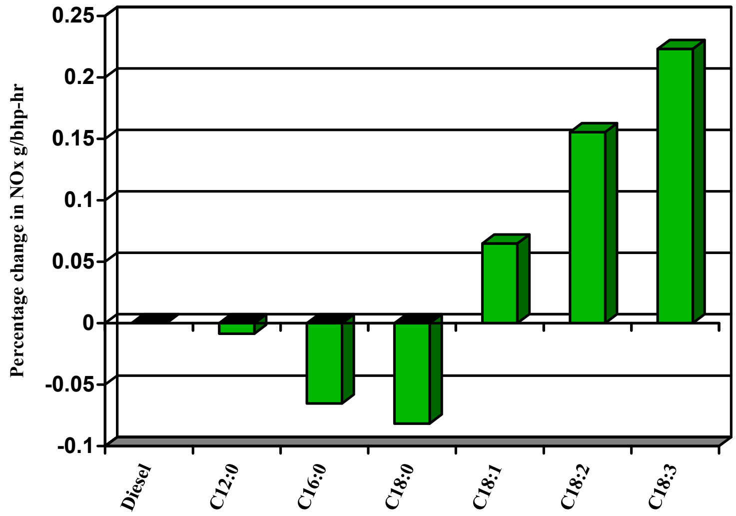


Figure 8. NOx emissions of B100 made from single types of fatty acids[10]

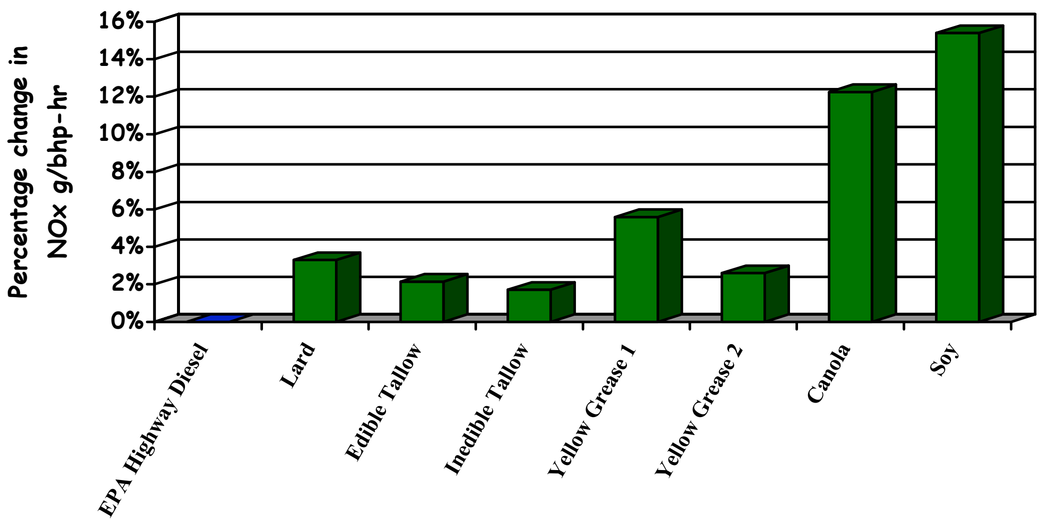


Figure 9. Increase in NOx emissions from CI engines using various B100 fuels

Additive manufacturers are working on additives that can improve NO_x, but testing done by NREL with B100 has shown that they provide little benefit while adding significant costs. Most commercial additive tests to date have not been validated with EPA heavy-duty transit emission testing that shows a direct comparison between the B100 fuel with and without the additive and a No. 2 diesel baseline. If you are shopping for an additive, you should ask for data from comparative testing of all three fuels. If you only have steady state mode data, make sure NO_x reductions occur at the high load, high RPM

[10] Graboski et al. February 2003. *The Effect of Biodiesel Composition on Engine Emissions from a DDC Series 60 Engine.* NREL-SR/510-31461.

ranges. NO_x emissions are generally not a problem at low load, low RPM ranges. Make sure that the data show emissions of B100 with and without the additive and a diesel No. 2 baseline.

The NO_x reduction seen with biodiesel blends used in boilers appears to be independent of the type of biodiesel used. NO_x is reduced 1% for every 1% biodiesel used in heating oil.

4. USING 20% BIODIESEL BLENDS

This section is focused on blending B100 with petrodiesel to make a B20 blend, but the approach is similar for other blend levels such as B2 or B5. As discussed in the previous chapters, the performance properties of B100 can be significantly different from conventional diesel. Blending biodiesel into petroleum diesel is a way to minimize these property differences while still retaining some of the benefits of B100. We are not going to repeat the information provided in the B100 section, just elaborate where it specifically applies to blends.

B20 is popular because it represents a good balance of cost, emissions, cold weather performance, materials compatibility, and solvency. B20 is also the minimum blend level that can be used for EPAct compliance for covered fleets (see Chapter 8).

A blending level above 20% can provide higher emission reduction benefits for CO, PM, and HC; with the impact on NO_x depending on the application (increases in most diesel engines, decreases in boiler or home heating applications). Higher blend levels of biodiesel significantly reduce polycyclic aromatic hydrocarbons and other toxic or carcinogenic compounds found in diesel exhaust. High blend levels also promote faster biodegradation should a spill occur. However, at biodiesel levels above 20%, cold flow management is a more significant issue, the cleaning effect is more severe, and hoses and gaskets will be more affected.

4.1 B20 Cold flow

This is probably the largest concern for blenders and users alike. Blending biodiesel with petroleum diesel moderates cold flow problems by dilution. The blend also makes the use of cold flow additives practical, since these are effective in the petroleum portion of the blend. When biodiesel is blended with diesel fuel, the key variables are the cold flow properties of the diesel fuel you blend with, the properties of the biodiesel, the blend level, and the effectiveness of cold flow additives.

B100 cold flow properties depend on composition, which affects the cold flow properties of blends (Figure 10 through Figure 15). The same is true of diesel fuel. No. 2 diesel fuel may have cloud points that range from -10^{o}F to 10^{o}F on average (some fuels can be higher or lower than these figures). No 1 diesel, jet A, or kerosene may have cloud points that range between -40^{o}F to -60^{o}F.

Blends of No. 1 and No. 2 diesel fuel are frequently used to meet customer cold flow specifications (Figure 16). Adjusting the blend of kerosene (or No. 1 diesel) in the diesel fuel alone or with additives can modify the cloud and pour point temperatures of B20. An accurate estimate of how B20 will perform in the winter months will require mixing the biodiesel with the winter diesel typically delivered in your area and testing the mixture. Your petroleum distributor or refinery may already be blending No. 1 and No. 2 diesels in the winter, using cold flow additives, or both. So ask your diesel distributor to provide some samples of winter diesel.

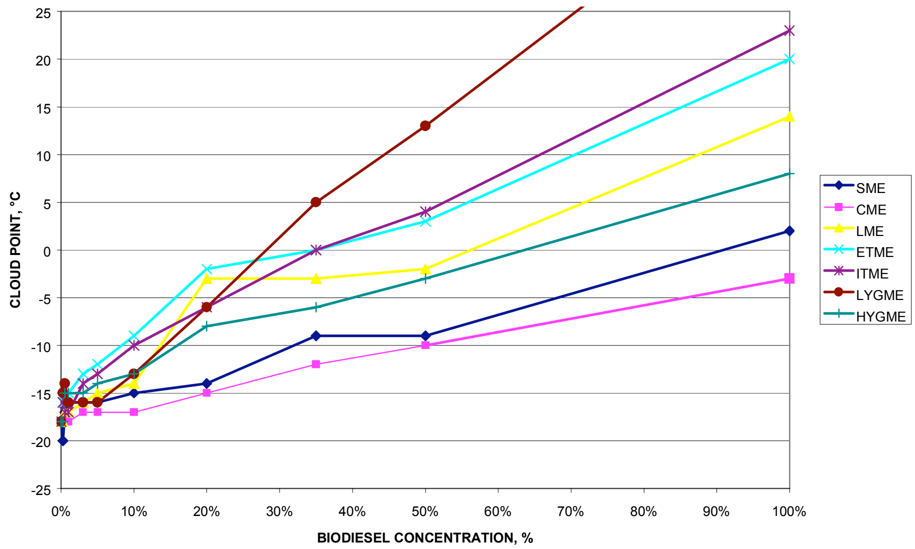


Figure 10. Biodiesel/diesel blend cloud point test results[11]

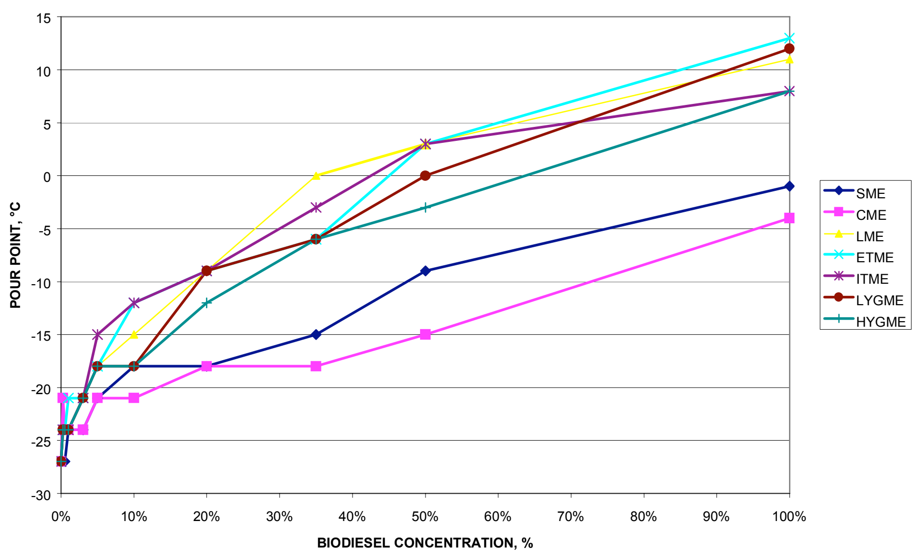


Figure 11. Biodiesel/diesel blend pour point test results

[11] SME= soy methyl ester, CME=canola methyl ester, LME=lard methyl ester, ETME=edible tallow methyl ester, ITME=inedible tallow methyl ester, LYGME=low free fatty acid yellow grease, HYGME=high free fatty acid yellow grease. As a note, since these tests, we have found that the free fatty acid content of the starting feedstock, whether it is yellow grease or some type of animal fats, does not have any effect on fuel properties. So LYGME and HYGME can be viewed as two different samples of yellow grease methyl esters.

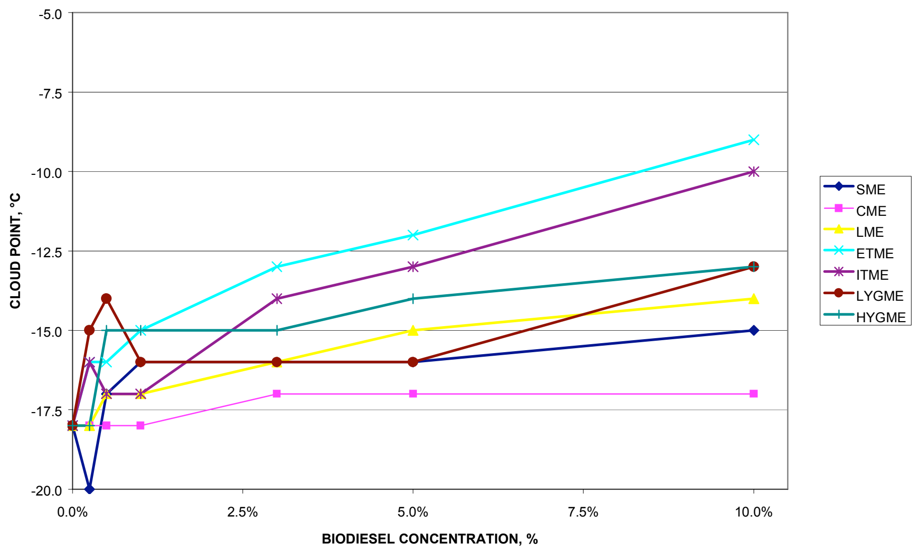


Figure 12. Biodiesel/diesel blend cloud point test results (0–10% biodiesel blend range)

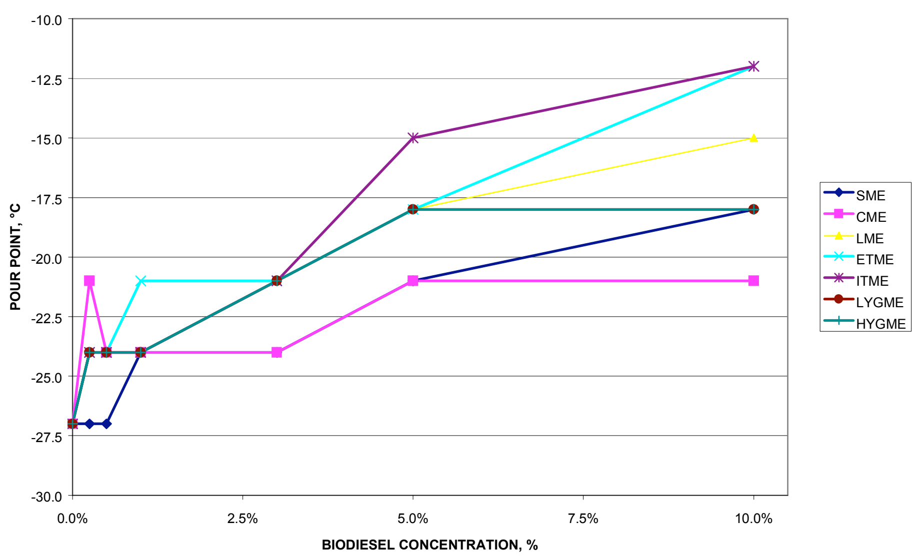


Figure 13. Biodiesel/diesel blend pour point test results (0–10% biodiesel blend range)

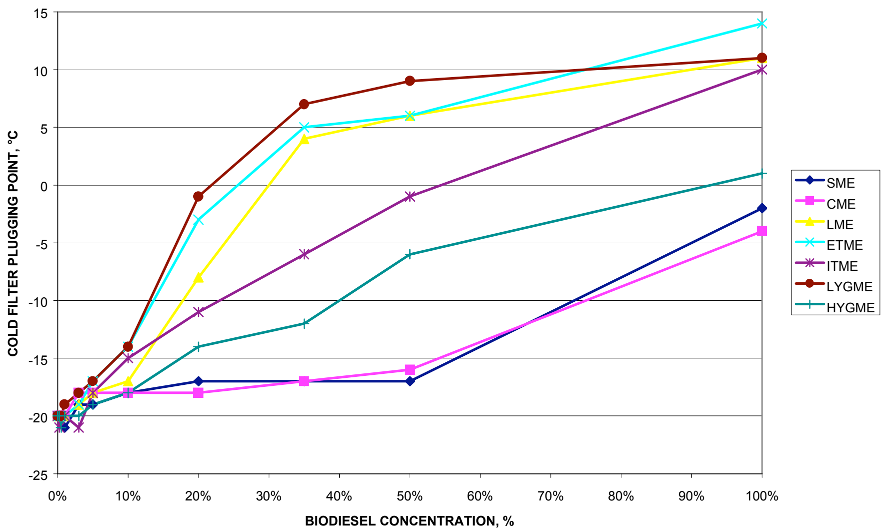


Figure 14. Biodiesel/diesel blend cold filter plugging point test results

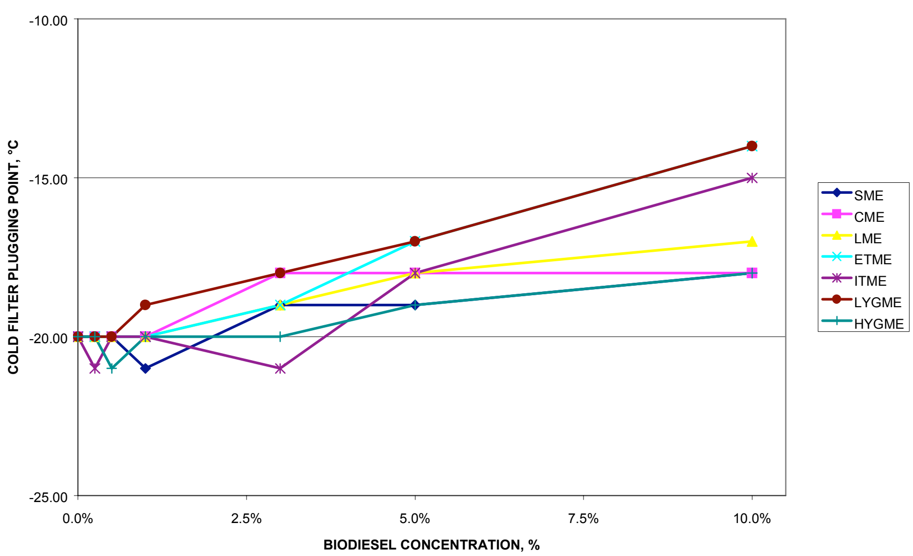


Figure 15. Biodiesel/diesel blend cold filter plugging point test results (0–10% biodiesel blend range)

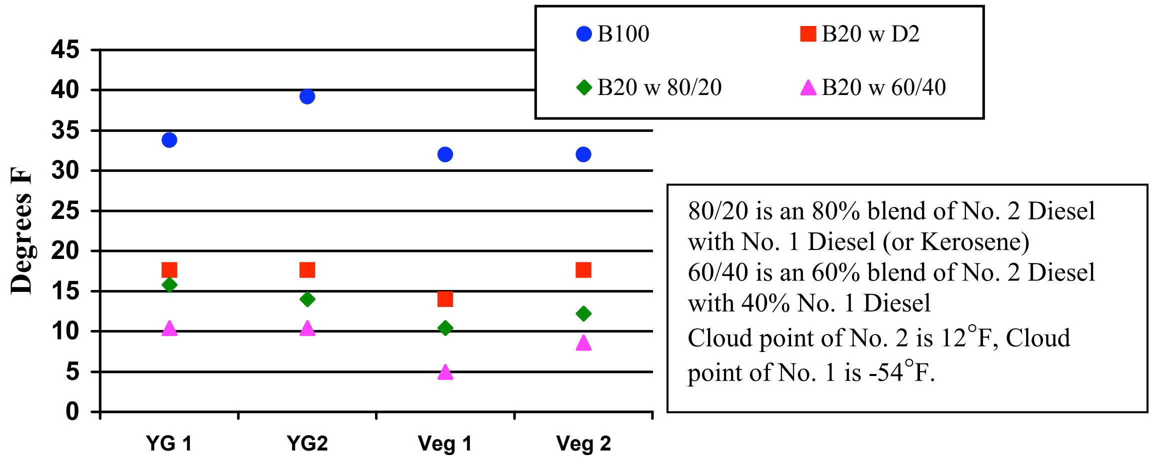


Figure 16. Adjusting cloud points of B20 fuels with blends of No. 1 and No. 2 diesel

The University of Minnesota Center for Diesel Research tested soy B20 made with various diesel fuels available in their region. The database of biodiesel blends (0%, 2%, 5%, 10%, 20%, 100%) shows how different diesel fuels and soy biodiesel blends alter cold flow properties (cloud, pour, and CFPP). Some of the data are shown on the following page (Figure 17, all in °F)

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

Additive manufacturers have struggled to develop cold flow additives for biodiesel. They have observed that some additives may work quite well with European rapeseed biodiesel but not with soy biodiesel. They have also observed that some additives have performed differently among the same kinds of biodiesel (from one type of rapeseed biodiesel to another). They theorize that the way some oils are produced can change how the additives perform. Oils are typically either crude or have undergone some kind of pretreatment before they are converted into biodiesel. Pretreating oils removes minor compounds that may affect the performance of cold flow additives. Because of these factors, there is no better way to test additive packages than to use your B100, your winter diesel, and a selection of possible additives.

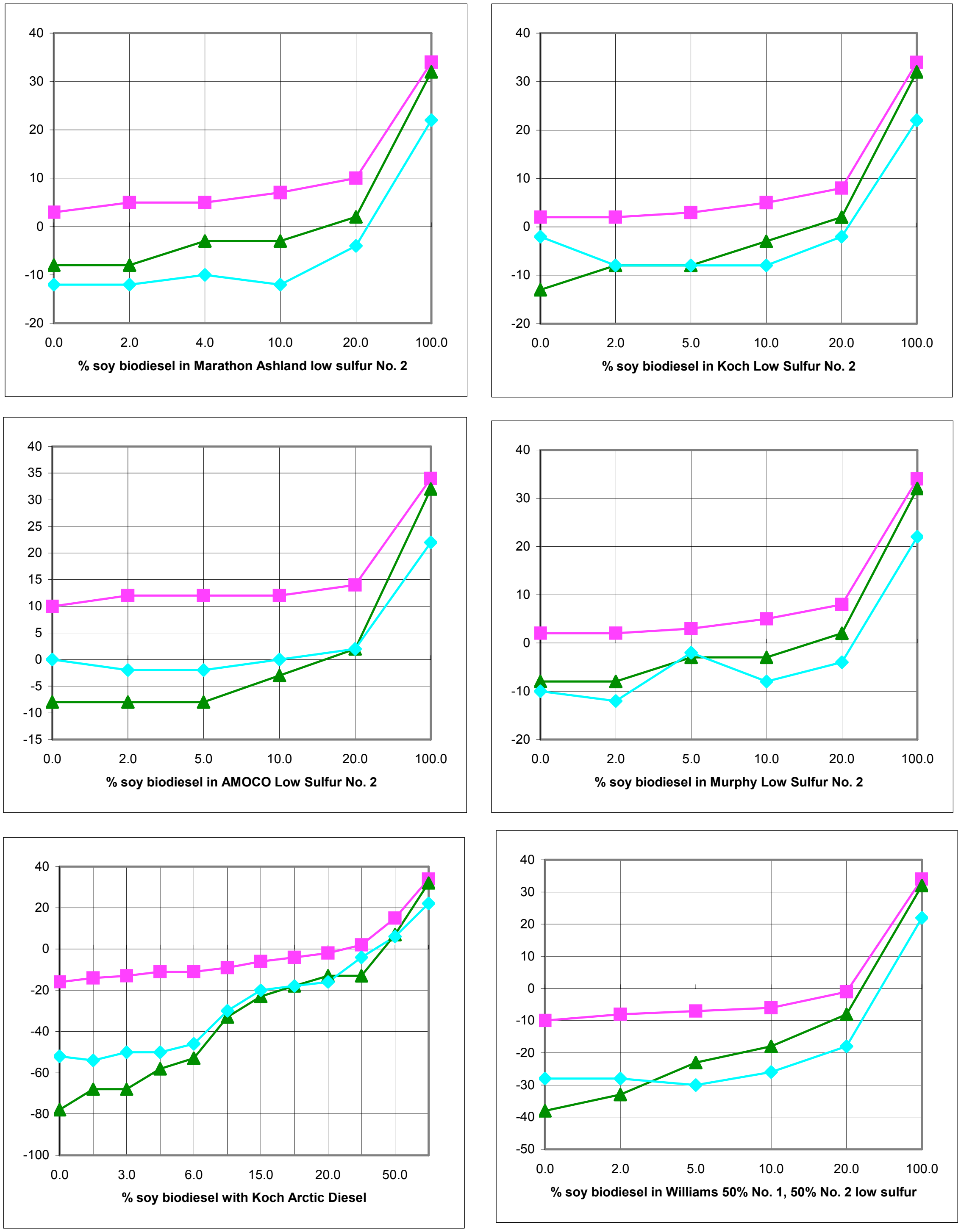
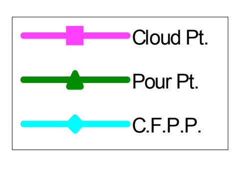


Figure 17. Cold flow properties of some soy biodiesel blends, °F



Laboratory testing should be done on the winter fuel, biodiesel, and the additive at realistic temperatures before starting a fleet wide program with biodiesel and additives. In other words, experiment with the additive with *cold* diesel fuel (in the range you would expect diesel to be on a cold winter day), biodiesel, and the additive. Remember, even the truck or tank you mix the fuels in may be cold. We've seen additives freeze in fuel tanks before the fuels could be blended in. We've also seen biodiesel gel in very cold truck tanks if it goes in first.

Some people have specified feedstocks in their purchasing contracts, such as soy biodiesel. This may lock you into a certain price range for your biodiesel but can also assure biodiesel with specific cold weather characteristics. You might consider the cost trade-offs of using less expensive biodiesel that might be higher in saturates with extra No. 1 diesel or additives versus soy biodiesel and No. 2 diesel.

Your current supplier may be willing to switch from higher saturated feedstocks in the summer (lower NO_x) to a more unsaturated feedstock in the winter. If cold flow problems occur, you could use 10% biodiesel in the winter and 30% biodiesel in the summer. If you are using biodiesel to meet EPAct requirements, this approach may not work because EPAct requires users to use B20 or higher blend levels. Examine your reporting requirements to see if this might work for you. As a last resort, you could limit your biodiesel use to the warmer months.

B20 users are generally pushing all these issues onto the fuel distributor and blender's shoulders with contractual language. Users may simply specify that they need a fuel to remain crystal free at temperatures down to -14°F for December, January, and February. Then the blender will work with the biodiesel and diesel suppliers and the additive firms to address these issues independently of the user.

4.2 Blending Biodiesel to Make B20 or Lower Blends

Many biodiesel users are now purchasing finished B20 or lower blends from their petroleum distributor or outlet. If this is the case, the petroleum distributor takes care of ensuring the biodiesel has been properly blended and that the cold flow properties of the finished blend will provide satisfactory performance for the area of the country and time of the year. You may wish to specify that the fuel meet certain cold flow requirements in your purchase contract or agreement.

This is exactly the way that conventional No. 2 petrodiesel is handled, and this is also the optimum way for users to purchase and use B20 and lower blends. As with No. 2 diesel fuel, if you are buying biodiesel blends in the summer and plan to use the fuel in the winter or drive to colder conditions, you should check with your supplier to make sure the cold flow properties of the fuel you are buying are acceptable for those climates.

If you are planning to blend your own fuel, if you are a distributor planning to blend fuels for your customers, or if you are just interested in more details, the section below will go over the options and considerations for blending biodiesel into petrodiesel.

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

At the time of the writing of this document, biodiesel is blended into diesel fuel via three primary means:

1. B100 splash blended with diesel fuel by the end user.
2. Blended (via a variety of means) by a jobber or distribution company and offered for sale as a finished blend, usually B20 or B2.
3. Blended at a petroleum terminal or rack by a pipeline or terminal company 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.

The chemical nature of biodiesel allows it to be blended with any kind of distillate, or diesel fuel. This includes light fuels such as jet fuel, kerosene, No.1 diesel, or military fuels (JP8, JP5), as well as normal diesel fuel like No. 2 diesel for diesel engines or gas turbines, and heating oil for boilers or home heating. Once biodiesel is blended thoroughly with diesel fuel, it stays together as one fuel and does not separate over time (assuming the fuel is maintained at temperatures above its cloud point). Once blended, B20 and lower blends should be treated exactly like conventional petrodiesel.

In the early days of biodiesel blend use, volumes were not high enough for the conventional petroleum infrastructure to carry and handle the fuel economically. Most of the B20 used in these early days was splash blended by the user after receiving B100 from a biodiesel supplier. As volumes increased, customers began to request B20 pre-blended from their existing supplier of petrodiesel. These petrodiesel suppliers would then receive and store the B100 and would blend the biodiesel with petrodiesel and supply a finished blend to the customer. In some cases, the petrodiesel supplier might carry B100 and petrodiesel in separate compartments in one truck and blend the two on the customer's site as the truck is unloaded.

More recently, as demand increases, petroleum terminals and pipeline racks are installing biodiesel blending capability so that 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. Even more recently, there are an increasing number of public pumps and key card pumps that are carrying biodiesel blends for individual users or fleets who do not have their own on-site storage capability.

There are many blending options available to the user or distributor depending on your area. As the market matures and volumes continue to increase, it is highly likely that the actual point of blending will occur further and further upstream in the distribution system where it is most efficient and economical. This is likely to be especially true with lower blends of biodiesel, such as B2. Most users find blending their own fuel to be time consuming and sometimes messy, so there are an increasing number of user who are requesting that their petroleum supplier make finished blends available.

As noted, in the marketplace today, there are three avenues to blend biodiesel into petrodiesel. They are described in general terms below. Any of these options can be used to blend biodiesel into diesel fuel. Indeed, all three options are commonly used in practice today.

<u>Splash Blending.</u> Splash blending is an operation where the biodiesel and diesel fuel are loaded into a vessel separately with relatively little mixing occurring as the fuels are placed in the vessel. The vessel is usually an individual vehicle fuel tank or a fuel delivery truck, although in come cases it could be a drum or a tote. Once the fuels are in the vessel, driving down the road is regarded as sufficient agitation to allow the biodiesel and diesel fuel to become thoroughly mixed. Usually this approach is successful, but on occasion difficulties in mixing can be encountered if the biodiesel is loaded into the vessel first under very cold temperature conditions .

<u>In-Tank Blending.</u> In-tank blending is where the biodiesel and diesel fuel are loaded separately, or, in some cases at the same time through different incoming sources, but at a high enough fill rate that the fuels are sufficiently mixed without the need for additional mixing, recirculation, or agitation. In some cases this is similar to splash blending but without the need to drive up and down the road. In other cases, the tank may need to be recirculated or further mixed in order to get the two fuels thoroughly blended. Since biodiesel and diesel fuel mix easily and completely, in tank blending is sufficient to get a homogeneous blend in many cases, depending on the exact means of adding the fuel, the tank geometry, etc.

<u>In-Line Blending.</u> In-line blending is where 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—or by the mixing that occurs once the fuel is loaded into its receiving vessel. The biodiesel is added slowly and continuously into the moving stream of diesel fuel via a smaller line inserted or ‘Y’ in a larger pipe, or the biodiesel can be added in small slug or pulsed quantities spread evenly throughout the time the petrodiesel 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 petrodiesel in separate compartments and blend the two as they are loading into a customer’s tank also use this method.

In general, blending biodiesel is not difficult if you keep a couple of basic facts in mind:

- The more mixing the better
- Biodiesel is slightly heavier than diesel fuel.

Biodiesel has a specific gravity of 0.88 compared to No. 2 diesel at 0.85 and No. 1 diesel at 0.80. So if you put the biodiesel in an empty tank and then pour diesel fuel slowly on top, it may not blend properly, if at all. Since the biodiesel is heavier, it may stay in the bottom of the tank in a layer of mostly biodiesel. Most pumps draw from the bottom of a fuel tank, and if not properly mixed this bottom layer can contain high concentrations of biodiesel. The problems generally manifest themselves in cold months, as the high concentration biodiesel fuel starts to freeze, plugging filters and forming a gel layer at the bottom of above ground tanks or with leaks from hoses and gaskets that are compatible with B20 but not with higher blends. Because the freezing problems may not manifest themselves in the summer and any adverse affects on hoses and gaskets associated with higher blends may take some time to develop, users may go for many months without a problem. But over a long enough period of time, or during cold weather, improperly mixed fuels are guaranteed to cause problems. One additional issue this can create is that a concentrated layer of biodiesel could also start to dissolve tank sediments if they are present. Filter clogging in warm months can be caused by this property.

There are two simple tests that can be performed to see if a tank has been thoroughly mixed.

1. A top, middle, and bottom sample of the tank (see ASTM D4057[12] for the proper way to take a representative sample of a tank) can be taken and analyzed for the percent biodiesel using infra-red spectroscopy or by measuring the specific gravity or density. This can be done with any of the conventional means of measuring density or specific gravity that are readily available (i.e. digital density meter, hydrometer). If the values do not vary by more than 0.006 specific gravity units from top to bottom, the mix is probably adequate. See the NBB quality program, BQ-9000, for more details. The test procedure for the percent biodiesel by infrared spectroscopy is from Europe, EN 14078, and ASTM is developing an official ASTM number for this test method. There are several instrument companies who are currently offering relatively inexpensive equipment to measure the percent biodiesel in the field, similar to that used for ethanol in gasoline. See the National Biodiesel Board at www.biodiesel.org for further details.
2. Put the samples from the three layers in a freezer with a thermometer and check every 5 minutes until the fuel in one of the samples begins to crystallize. Record that temperature. Then, check every couple of minutes or so until all three samples show crystallization. Compare the crystallization temperatures on all three samples, they should be within 5-6°F (3°C). If not, the fuel will require agitation to mix thoroughly.

So what is the best option for blending biodiesel and diesel fuel? It depends on your volume, your investment, and your needs.

- Drums and totes are typically mixed by splash or in-tank blending or by adding B100 on top of diesel fuel in a storage tank. Disperse the biodiesel as much as possible with this approach by spreading it evenly over the diesel fuel surface. If

[12] ASTM D4057, Standard Practice for Manual Sampling of Petroleum and Petroleum Products

an even distribution of the biodiesel over the surface of the diesel fuel cannot be obtained, or the addition of the biodiesel is not sufficient to get it thoroughly mixed, further agitation or recirculation may be needed.

- B20 is frequently blended in bottom-loading tank trucks. The biodiesel is loaded into the tank truck first, followed by the diesel fuel and some mixing occurs. The fuels continue mixing as the truck moves to the delivery point, so long as the roads are not straight and level and the route is not too short. When the fuels are pumped from the truck into the B20 storage tank at the point of use, a final mixing occurs. This is generally enough mixing except in cold weather. Putting B100 into a cold empty tank truck can cause the B100 to gel. Then the two fuels mix poorly or not at all. In cold weather, it is better to load half of the diesel, then the biodiesel is loaded, followed by the rest of the diesel fuel. This will help prevent the biodiesel from freezing to the internal parts of the tank truck. The gel point of the B100 and the ambient temperatures will tell you if this practice is necessary and there is additional research planned to further understand this phenomenon.

- In-line blending uses two metered pumps and a dual fuel injection system, but requires an investment in equipment. This approach is the most accurate and reliable for guaranteeing a specific fuel blend. It can also be complicated for small users. A variety of different types of equipment are available for in-line blending. Systems have to be sized for a specific blend level (B2, B20) and are generally not able to handle both types of blends. When two blend levels are needed, a B20 tank is generally created and B2 is blended from that.

Regardless of your blend technology, blenders need to answer the following questions to figure out their blending strategy:

- How is the B100 arriving, particularly in the winter months (B100, B50 or B20)? Can your supplier handle all or just some of those options? Are summer deliveries different, and if so, how? How does that affect your blending and storage system?
- What products are you making, B20 only or B20, B2, and B100?
- How much tankage do you have or can you afford? How much space? Is it worth the space or tankage for small volume blends?
- How much do you want to spend on equipment, heat, pumping, labor, training, problem solving?
- Do your customers have requirements? Customers will test to determine whether or not the specified blend level is being delivered. Can your blending strategy meet that standard time after time, with personnel turnover?

Cold weather blending is a concern in climates where the diesel fuel temperature falls below the cloud point of the B100 you are blending with. The first thing to keep in mind is that there should not be a problem if the diesel fuel temperature is above the cloud point of the final blend. If crystals do form during blending, they should go back into solution so long as the temperature of the blended fuel is above the cloud point of the blend. This process can be assisted by blending equipment that agitates the two fuels during blending. That agitation helps disperse the fuels and crystals more uniformly and can provide some energy to help the crystals dissolve. Additional work in this area is planned also.

It is best to store the B100 as B20 or some kind of blend as soon as possible regardless of the season. B100 does not store as long as blends and there are always cold weather factors to consider. If you have just a few B100 customers, you might consider setting aside a tote of B100 indoors or storing some underground or in heated tanks, depending on your climate.

It is always a good idea to retain a sample (one gallon) of the diesel and the B100 before blending the fuels (see BQ-9000). Once the customers have run through the current batch of fuel with no problems, you can dispose of these samples by mixing them into the new batch of fuel. If any problems arise, these samples will help you determine whether they were caused by the fuel or by something else.

Consider an example. Your target cloud point for B20 using winter diesel is 0°F, the cloud point of your diesel is -10°F and you are using biodiesel with a cloud point of 34°F. Your diesel fuel temperature is about 21°F on the day you decide to blend. Your diesel fuel temperature is less than the cloud point of your B100. This is an acceptable situation because the B20 cloud point is below the temperature of your diesel fuel and the gap between the temperature of the diesel fuel and the target B20 cloud point is pretty generous, about 21°F. Any crystals that form will go back into solution. If the gap was narrow, like 5°F, crystals might be slow going back into solution and may settle out.

Consider another example. Your target B2 cloud point is -8°F, your B100 cloud is 34°F and your diesel cloud is -10°F. It's a really cold day and your diesel fuel temperature is 10°F. Since the target cloud for your blend is lower than the temperature of your fuel, any crystals formed should go back into solution. In addition, since biodiesel is such a small fraction of the blend for B2, the diesel fuel should act like a solvent and help that process along. Once again, any agitation used to blend the fuels will also help. You do not need to heat the biodiesel, since that will not heat up the 98% of the gallon that is diesel fuel any perceptible amount.

Some distributors in northern climates follow a protocol of filtering biodiesel blends before delivery to customer tanks. This is thought to prevent clogging of the refueling pump filter caused by crystallized saturated fatty acid methyl esters that can form if the petroleum diesel is too cold during blending. This protocol was developed, in part, because the consumers were testing B20 made from biodiesel with a high cloud point. Researchers recommend using a filter that is at least as fine as the vehicle fuel filters.

Some biodiesel is transported as a 50:50 blend with kerosene to prevent it from freezing during transportation. When you blend that down to B20, recognize that the kerosene fraction will provide some cloud point benefit for your final B20 blend. It is important to adjust the blending formula so that you have the desired blend level of biodiesel in the final fuel (for example: 60% No. 2, 40% 50:50 mixture of biodiesel and kerosene results in a B20 blend).

Blends should be stored in tanks that can ensure the fuel temperature will remain above the cloud point of the blend.

- Blends of biodiesel and diesel should be stored at temperatures at least 5°F to 10°F above the cloud point of the blended fuel.
- Blended fuels can be stored below ground in most climates. B20 may be stored in aboveground tanks, depending on the cloud and pour points of the blended fuel and the local ambient weather conditions.

4.3 B20 and Emissions

The impact of B20 on emissions is less than that of higher blends. Research has shown that NO_x emissions vary in a straight-line fashion (see Figure 1) with biodiesel blending level. B20 reduces CO, PM, HC, and air toxic compounds. Emissions trends for CO, HC, and PM are slightly curved with the lower blends having slightly more impact per unit of biodiesel burned than the higher blends. The NO_x emissions may vary depending on the source of the biodiesel and some B20 blends may be NO_x neutral, while HC, PM, and CO reductions do not appear to change with biodiesel composition.

In blends with heating oil up to 20%, NO_x is also linear but biodiesel provides reductions rather than increases. For every 1% biodiesel added, NO_x decreases by 1%. A B20 heating oil fuel will reduce NO_x by about 20%.

4.4 B20 Cleaning Effect

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

4.5 B20 Material Compatibility

B20 or lower blends minimize most issues associated with material compatibility. Experience over the last 10 years with B20 indicates compatibility with all existing elastomers in diesel fuel systems, even those that are sensitive to higher blends, such as nitrile rubber. Customers should continue to check for leaks, however, and fix them if they occur. B20 may degrade faster than petrodiesel if oxidizing metals such as copper, bronze, brass, or zinc are in fueling systems. If filter clogging occurs more frequently with B20 than with petrodiesel, the fueling system should be checked for these materials and they should be replaced with biodiesel compatible parts. There is a growing body of long-term experience with B20 in the United States that will ultimately allow a better assessment of the long-term effects of biodiesel and biodiesel blends on engines and fueling systems, but B20 experience has been positive so far.

4.6 Lubricity

Blending biodiesel into petroleum diesel at even low levels can increase the lubricity of diesel fuel. As little as 0.25% biodiesel can significantly increase fuel lubricity (Figure 18). Some fleets choose to use B2 for its lubricity properties instead of using other additives. The exact blending level required to achieve adequate lubricity will depend on the properties of the conventional diesel. Preliminary evidence suggests that 2% biodiesel imparts adequate lubricity in almost all cases.

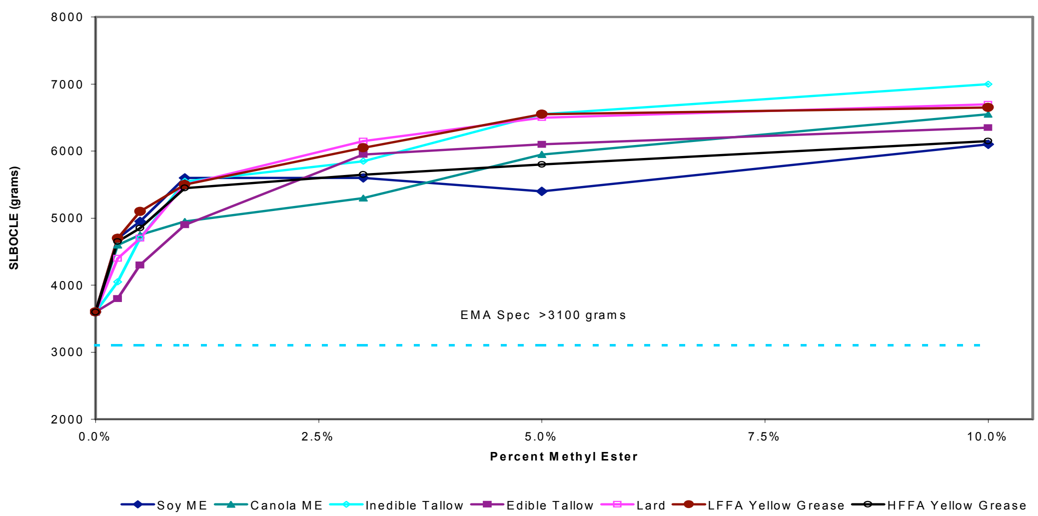


Figure 18. Scuffing Load Ball on Cylinder (SCBOCLE) lubricity data for various biodiesel fuels

4.7 B20 Stability

As of this date there is a growing database available on B20 but more data is needed to accurately predict the impact of biodiesel on blend oxidative and thermal stability. Data in the previous chapter (see Figure 9) includes results of the ASTM D4625 stability test for several B20 fuels. Compared to the B100 data on the same fuels, it appears that B20 may have a longer storage life than B100. Those data also show that some B20 can have good stability and others do not depending on the B100 used for blending. The D4625 data suggests that most B20 can be stored for 8 to 12 months. The National Biodiesel Board recommends that B20 be used within 6 months. This is comparable to the recommendations of petrodiesel suppliers, some of whom recommend petrodiesel be used within 3-4 months. Adding antioxidants and/or stability additives is recommended for storage over longer periods.

We recommend using stability additives when long-term stability is a concern. For example, during one demonstration of heating oil blends with 20% biodiesel, stability additives were only added in the summer months when the fuel turnover rate was low. Good fuel management and frequent turnover should minimize stability concerns for most applications.

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

5. WARRANTY ISSUES

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

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

Damage directly attributable to biodiesel will not be covered by an engine OEM's warranty, but should be covered by the fuel supplier's general liability insurance. New biodiesel users should be sure that their biodiesel suppliers provide liability coverage on the biodiesel and its blends. For an updated list of OEMs and their positional statements, visit the National Biodiesel Board Web page at URL http://www.biodiesel.org/.

6. TAXES AND INCENTIVES

Biodiesel is not exempt from federal excise taxes, and it is not exempt from most state or local taxes. That means that biodiesel and biodiesel blends are taxed at the same rate as diesel fuel. Some states have passed legislation that either reduces fuel excise taxes or provides other incentives. For local exceptions to this statement, please contact local tax authorities.

The federal government currently offers some incentives related to biodiesel. There are a number of grant programs available, as well as tax credits for blending biodiesel, and investment opportunities in certain refueling infrastructure. DOE's Clean Cities Program maintains a Web site that summarizes state and local laws and incentives related to alternative fuels. This can be accessed at www.eere.energy.gov/cleancities/vbg/progs/laws.cgi. Another good resource for information on federal incentives is the National Biodiesel Board's Web site at www.biodiesel.org.

If you are using biodiesel in a vehicle that uses any public road (B100 or any blend of biodiesel), then you are responsible for remitting federal, state, and local taxes on the fuel, **including the biodiesel fraction,** to the appropriate agencies in a timely manner. This requirement applies to biodiesel you make yourself and to B100 that you purchase and use in your own operations. If you are blending B100 that you purchased, and either using the B20 yourself, or selling it to others, you are responsible for remitting the federal, state, and local taxes in a timely way to the appropriate agencies. Most B100 is sold on a pre-tax basis, which leaves the blender responsible for collecting and remitting taxes. For most commercial blend users, the blenders have already included the taxes owed in the sale price of the fuel. Check your invoice or with your supplier if you have questions. The customer has the responsibility to ensure that the appropriate taxes have been paid.

7. SAFETY, HEALTH, AND ENVIRONMENTAL ISSUES

Biodiesel contains no hazardous materials and is generally regarded as safe to use. Like any fuel, certain fire safety precautions must be taken. Appendix III contains a Material Safety Data Sheet (MSDS) with details on concerns in these areas.

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.

8. USING BIODIESEL UNDER THE ENERGY POLICY ACT

The Energy Policy Act of 1992 (EPAct) was passed by Congress to reduce the nation's dependence on imported petroleum by requiring certain fleets to acquire alternative fuel vehicles (AFVs), which are capable of operating on non-petroleum fuels. Compliance with EPAct is met by credits awarded for acquisition of AFVs.

The Energy Conservation Reauthorization Act of 1998 (ECRA) amended EPAct to allow credit for B20 use. DOE's Biodiesel Fuel Use Credit Interim Final Rule became effective in January 2001, allowing covered fleets to meet EPAct requirements through the purchase of biodiesel fuel.

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

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

For specific information about biodiesel use in federal fleets, contact:
Shabnam Fardanesh
202 586-7011
shabnam.fardanesh@ee.doe.gov

For specific information about biodiesel use in state and fuel provider fleets, contact:
Linda Bluestein
202 586-6116
Linda.Bluestein@ee.doe.gov

9. FREQUENTLY ASKED QUESTIONS ABOUT USING BIODIESEL

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

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

Does biodiesel affect how my engine operates?
Biodiesel blends of 20% or less should not change the engine performance in a noticeable way. Some users of biodiesel blends notice significant reductions in soot, and CO and HC emissions are reduced. Higher blend levels can reduce fuel economy, torque, and power but will also produce lower PM, HC, and CO emissions. NO_x may also rise with higher blend levels. Less noise and a better exhaust smell have also been noticed with biodiesel fuels.

Does using biodiesel void my warranty?
OEMs provide a material and workmanship warranty on their products. Such warranties do not cover damage caused by external conditions, such as fuel. Thus, if an engine using biodiesel experiences a failure unrelated to the biodiesel use, it must be covered by the OEM's warranty. Federal law prohibits the voiding of a warranty just because biodiesel was used—it has to be the cause of the failure. If an engine experiences a failure caused by biodiesel (or any other external condition, such as bad diesel fuel), it will not be covered by the OEM's warranty.

Who is using biodiesel?
The largest user of B20 is the U.S. Department of Defense, who planned to purchase more than 5.2 million gallons of biodiesel during the 2003-2004 contracting year. Many other federal, state, and alternative fuel provider fleets are also using B20, because it allows them to comply with EPAct regulation. B20 is even sold at retail pumps throughout the country.[13]

B2 is sold in many outlets throughout the Midwest. Several states are considering legislation that requires the use of low-level biodiesel blends (B2-B5), and many operators in agricultural areas use biodiesel blends to support their local economies. Some fleets and many private consumers use B100.

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[13] Producers, distributors, and retail stations can be found at http://www.biodiesel.org/buyingbiodiesel/guide/.

Equipment that has been successfully used with biodiesel blends includes on-road vehicles of all types; construction, logging, farming equipment, power generators, boats and barges, heating oil boilers and industrial boilers, and even locomotives.

How much does biodiesel cost?
The wholesale cost of biodiesel is typically higher than diesel fuel by $1 to $2 per gallon. The size of the cost difference depends on the size of the biodiesel producer, their feedstock cost, transportation costs, production incentives, tax incentives, and other local variables. Historically, the cost of B20 has been about 20 cents per gallon higher than diesel fuel. B2 is only a few cents higher than diesel fuel.

How can I tell if the biodiesel I receive is good quality?
The biodiesel industry has developed a voluntary quality control program for producers and distributors to ensure that biodiesel is produced according to ASTM specifications and contamination or degradation does not occur during distribution, storage, or blending. That program is called the BQ9000. It is managed by an independent organization—the National Biodiesel Accreditation Commission. There are "Accredited Producers" and "Certified Distributors" depending on which activity a firm specializes in. The firm receives the accreditation, not the fuel, but the fuel supplied by either an accredited producer or a certified distributor meets all applicable standards for sale and use in the United States. There is no logo for an accredited producer. The logo for a certified distributor is shown below.

Figure 19. Logo for a Certified B100 Distributor

The certified distributor must:

- Purchase its B100 from an accredited producer, or
- Conduct fuel quality testing on all biodiesel purchased from non accredited producers

Testing each batch of biodiesel is the only way to ensure good quality—just like with conventional fuels. The simple tests that consumers may perform such as looking at clarity by filling a clear glass container and doing a visual inspection, cannot determine the quality of the fuel. Other fleets conduct more extensive tests either in-house or by sending the fuel to independent testing laboratories for more specialized testing of fuel properties. The consumer saves money on testing by purchasing biodiesel fuels through certified marketers.

Are there standards or specifications for biodiesel?
ASTM has a biodiesel blend stock standard (ASTM D6751) that describes minimum standards for biodiesel properties. The Department of Defense has specification for B20 blends (http://assist.daps.dla.mil/docimages/0004/29/73/AA59693.PD0).

Do I need to modify my vehicle to use biodiesel?
Based on user experience, no vehicle modifications appear to be necessary for blends of biodiesel as high as 20% biodiesel mixed with diesel fuel. Higher blend levels may require minor modification to seals, gaskets, and other parts. Tank and fuel line/fuel filter heaters (arctic packages) are recommended for blends of more than 20% biodiesel. Detailed long-term engine durability data have not been established for B20 in the United States so good maintenance practices are recommended.

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

How do biodiesel (B20 and B100) emissions compare to diesel emissions?
The EPA has conducted a comprehensive study of 80 biodiesel emission tests in CI engines that are presented in an easy to read chart in Chapter 2: Biodiesel Basics. The chart shows emission benefits for different biodiesel blend levels.

Does biodiesel use raise NO_x emissions?
The use of biodiesel will raise NO_x emissions of most CI engines. Blends of less than 5% do not have a significant increase in NO_x, with B20 blends raising NO_x emissions by about 2% over conventional diesel. Some B20 does not increase NO_x in B20 blends. Some B100 can raise NO_x above the certification limits of CI engines.

Biodiesel blends used in heating oil equipment will reduce NO_x by 1% for every 1% of biodiesel used in the blend. A B20 with heating oil will reduce NO_x by 20%.

How much biodiesel is used and produced in the United States?
Current production capacity for biodiesel is estimated at 60 - 80 million gallons per year, and in 2004, the Energy Information Agency (EIA) estimated that over 26 million gallons were used in transportation applications.[14]

Can I use biodiesel in a cold climate?
User experience with cold weather varies. B20 blends are used in some very cold climates such as northern Minnesota and Wyoming, where temperatures routinely fall

[14] http://www.eia.doe.gov/cneaf/alternate/page/datatables/afvtable10_03.xls

below -30°F in the winter. B20 was used in an airport shuttle fleet for four years in Boston with no problems.

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

10. INFORMATION RESOURCES

The National Biodiesel Board has compiled an impressive library of online documents located at http://www.biodiesel.org/resources/reportsdatabase/. It can add detail to these guidelines. The search engine is set up by market segment. You have to be creative and use a variety of key words to search on specific non-market topics or call 1-800-841-5849 for information.

The U.S. Department of Energy has some technical documents located at http://www.eere.energy.gov/biomass/document_database.html.

The EPA has reviewed many emission reports and has summarized them at http://www.epa.gov/OMS/models/biodsl.htm.

Iowa State University has an online tutorial on biodiesel at http://www.me.iastate.edu/biodiesel/Pages/biodiesel1.html. They also offer classes in biodiesel production, analytical test methods, and business management for producers and marketing firms.

Department of Defense A-A-59693A Biodiesel Commercial Item Description (CID) is located at http://assist.daps.dla.mil/docimages/0004/29/73/AA59693.PD0 in PDF format.

Also contact your Clean Cities representative, biodiesel suppliers, and others for information.

11. GLOSSARY/DEFINITIONS

additive: material added in small amounts to finished fuel products to improve certain properties or characteristics.

antioxidant: substance that inhibits reactions promoted by oxygen

aromatic compound: a hydrocarbon based on a six-carbon benzenoid ring

biodiesel: methyl esters of fatty acids meeting the requirements of ASTM specification D6751.

biodegradable: capable of being broken down by the action of microorganisms

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

cetane index: an approximation of cetane number based on an empirical relationship with density and volatility parameters such as the mid-boiling point. This approximation is not valid for biodiesel or biodiesel blends.

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

chelating compound: a fuel additive that deactivates the catalytic oxidizing action of dissolved metals, notably copper, on fuels during storage.

CI: compression ignition, i.e. a diesel engine

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

detergent: a fuel detergent is an oil-soluble surfactant additive that maintains the cleanliness of engine parts by solubilizing deposits or materials likely to deposit in the engine fuel system.

dispersant: a surfactant additive designed to hold particulate matter dispersed in a liquid.

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

energy content: the heat produced on combustion of a specified volume or mass of fuel, also known as heating value or heat of combustion.

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

fatty acid methyl esters (FAME): Mono alkyl ester of long-chain fatty acids from naturally occurring vegetable oil, animal fats, and recycled greases.

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

flash point: the lowest temperature at which vapors from a fuel will ignite on application of a small flame under standard test conditions.

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

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

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

lubricity: the ability of a fuel to lubricate.

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

multifunctional additive: an additive or blend of additives with more than one function.

OEM: original engine manufacturer.

oxidation: loosely, the chemical combination of oxygen to a molecule.

oxidative stability: the ability of a fuel to resist oxidation during storage or use.

oxygenate: a fuel component that contains oxygen; i.e., biodiesel or ethanol.

particulate matter (PM): the solid or semi-solid compounds of unburned fuel that are emitted from engines.

polycyclic aromatic hydrocarbons (PAH): aromatic compounds with more than one benzenoid ring (PAH). Also, NPAH for nitro-polyaromatic compounds.

polyunsaturated fatty acids: fatty acids with more than one double bond.

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

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

solvency: the quality or state of being a solvent.

specific gravity: the ratio of the density of a substance to the density of water.

splash blending: the fuels to be blended are delivered separately into a tank truck

stratification: to separate into layers.

storage stability: the ability of a fuel to resist deterioration on storage due to oxidation.

torque: a force that produces rotation.

viscosity: a measure of the resistance to flow of a liquid.

12. SAMPLE BIODIESEL MATERIAL SAFETY DATA SHEET

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

Composition/Information On Ingredients
This product contains no hazardous materials.

Hazards Identification
Potential Health Effects:
INHALATION:
Negligible unless heated to produce vapors. Vapors or finely misted materials may irritate the mucous membranes and cause irritation, dizziness, and nausea. Remove to fresh air.
EYE CONTACT:
May cause irritation. Irrigate eye with water for at least 15 to 20 minutes. Seek medical attention if symptoms persist.
SKIN CONTACT:
Prolonged or repeated contact is not likely to cause significant skin irritation. Material is sometimes encountered at elevated temperatures. Thermal burns are possible.
INGESTION:
No hazards anticipated from ingestion incidental to industrial exposure.

First Aid Measures
EYES:
Irrigate eyes with a heavy stream of water for at least 15 to 20 minutes.
SKIN:
Wash exposed areas of the body with soap and water.
INHALATION:
Remove from area of exposure, seek medical attention if symptoms persist.
INGESTION:
Give one or two glasses of water to drink. If gastro-intestinal symptoms develop, consult medical personnel. (Never give anything by mouth to an unconscious person.)
–

Fire Fighting Measures
Flash Point (Method Used): 130.0° C min (ASTM 93)
Flammability Limits: None known
EXTINGUISHING MEDIA:
Dry chemical, foam, halon, CO_2, water spray (fog). Water stream may splash the burning liquid and spread fire.

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

Accidental Release Measures Spill Clean-Up Procedures
Remove sources of ignition, contain spill to smallest area possible. Stop leak if possible. Pick up small spills with absorbent materials such as paper towels, “Oil Dry”, sand or dirt.
Recover large spills for salvage or disposal. Wash hard surfaces with safety solvent or detergent to remove remaining oil film. Greasy nature will result in a slippery surface.

Handling And Storage
Store in closed containers between 50°F and 120°F.
Keep away from oxidizing agents, excessive heat, and ignition sources.
Store and use in well ventilated areas.
Do not store or use near heat, spark, or flame, store out of sun.
Do not puncture, drag, or slide this container.
Drum is not a pressure vessel; never use pressure to empty.

Exposure Control /Personal Protection
RESPIRATORY PROTECTION:
If vapors or mists are generated, wear a NIOSH approved organic vapor/mist respirator.
PROTECTIVE CLOTHING:
Safety glasses, goggles, or face shield recommended to protect eyes from mists or splashing. PVC coated gloves recommended to prevent skin contact.
OTHER PROTECTIVE MEASURES:
Employees must practice good personal hygiene, washing exposed areas of skin several times daily and laundering contaminated clothing before re-use.

Physical And Chemical Properties
Boiling Point, 760 mm Hg:>200°C Volatiles, % by Volume: <2
Specific Gravity (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

Stability And Reactivity
GENERAL:
This product is stable and hazardous polymerization will not occur.
INCOMPATIBLE MATERIALS AND CONDITIONS TO AVOID:
Strong oxidizing agents
HAZARDOUS DECOMPOSITION PRODUCTS:
Combustion produces carbon monoxide, carbon dioxide along with thick smoke.

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

Transport Information
UN HAZARD CLASS: N/A
NMFC (National Motor Freight Classification):
PROPER SHIPPING NAME: Fatty acid ester
IDENTIFICATION NUMBER: 144920
SHIPPING CLASSIFICATION: 65

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.

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.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
March 2006	Technical Report	

4. TITLE AND SUBTITLE 2006 Biodiesel Handling and Use Guidelines Second Edition	**5a. CONTRACT NUMBER** DE-AC36-99-GO10337
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) K.S. Tyson and R.L. McCormick	**5d. PROJECT NUMBER** NREL/TP-540-39451
	5e. TASK NUMBER FC06.9400
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393	**8. PERFORMING ORGANIZATION REPORT NUMBER** NREL/TP-540-38836
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)** NREL
	11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
A guide for handling, blending, distributing, and using biodiesel fuels and biodiesel fuel blends.

15. SUBJECT TERMS
biodiesel, biodiesel fuel, fuel blends, biodiesel blends, biodiesel handling, biodiesel

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			
Unclassified	Unclassified	Unclassified	UL		**19b. TELEPHONE NUMBER** (*Include area code*)

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

F1147-E(12/2004)

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