Draft Final Report

Biodiesel Fleet Durability Study

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Abstract

California currently has several legislative initiatives that promote increased alternative fuels use to reduce oil dependency, greenhouse gases, and air pollution. CARB is conducting a comprehensive study to evaluate the impacts of biodiesel use on vehicle durability and engine performance. This study included the impacts of biodiesel, biodiesel blend level, and feedstocks on engine durability, fuel systems, material compatibility, exhaust and aftertreatment systems, cold weather problems, and storage and handling. This biodiesel fleet durability study consisted of a thorough literature review and a comprehensive survey of biodiesel fleet users.

The use of biodiesel has increased considerably in the United States and in Europe over the past decade. Biodiesel is also extensively used throughout Europe, where governmental initiatives have promoted the use of up to B5 in the marketplace. This program has been largely successful in terms of impacts to the vehicle fleet, and indicates that biodiesel can be implemented successfully into the larger marketplace. In the United States, biodiesel has been promoted in a number of states that either have active mandates (Minnesota and Washington), have special tax incentives (Illinois), or are in the process of putting mandates in place. A total of 40 fleets using biodiesel were surveyed for this project. These included fleets throughout the US, such as national park sites, transit agencies, county and municipal fleets, school districts, private companies, and others. B20 was the predominant fuel used by the fleets that were surveyed.

Characterizing the impacts of biodiesel on the durability of the engine, fuel system, and associated components was one of the most important elements of this study. There are some important differences in the properties of biodiesel compared with diesel fuel. It is also worth noting that while B5 is acceptable by all engine manufacturers from a warranty standpoint, the use of biodiesel at blend levels higher than B5 depends on the specific engine manufacturer and engine being used. Biodiesel provides improved lubricity compared to petroleum diesel but also higher viscosity that can impact injection quality and fuel atomization. Laboratory or bench-scale tests have shown that biodiesel meeting specifications is generally acceptable from a durability standpoint, although there were a number of failures on tests where oxidized or otherwise off-spec biodiesel was used. Most surveyed users found no adverse effects of biodiesel on engine wear, exhaust system and aftertreatment devices. Some fleets experienced less engine wear, which may be due to biodiesel's enhanced lubricity. More than 50% of the biodiesel fleet users surveyed reported biodiesel did not have a negative impact on the durability of fuel pumps and injectors, however, six users recorded more frequent fuel pump and injector failures attributed to biodiesel use. Biodiesel has a greater tendency to stay on the cylinder walls and bypass the rings into the crankcase, causing oil dilution, but most of the surveyed fleets did not observe this problem or change their oil change interval to accommodate the biodiesel.

Biodiesel exposure can cause degradation, softening, or seeping through some hoses, gaskets, seals, elastomers, glues, and plastics. Nitrile rubber compounds, polypropylene, polyvinyl, and Tygon are particularly vulnerable to B100. Biodiesel can cause degradation of system components made of nitrile rubber compounds, Teflon, Biton, fluorinated Plastics, and Nylon. Studies by the National Renewable Energy Laboratory suggest that material compatibility problems have been minimal over the last 10 years, even for elastomers made of materials that are not compatible with higher biodiesel blends. More than 50% of the biodiesel fleet users

responded to the survey question relating to elastomer seal problems, with nearly all responders indicating they observed no elastomer seal problems in the engines and fuel systems. Only one incidence of engine elastomer seal failure was reported in associated with B100 use.

The impact on vehicle performance is another important element of in-use operation with biodiesel. Biodiesel does have a lower energy content than regular No. 2 diesel, although this difference is relatively small at B20 or lower blend levels. About seventy five percent of the biodiesel users surveyed reported no noticeable engine power difference while running biodiesel. Four fleet users reported less power on biodiesel compared to conventional diesel, while another four users reported more power. Biodiesel use also did not appear to have a noticeable impact on fuel economy. Twenty-seven biodiesel fleet users reported no change in fuel economy when using biodiesel fuel. A smaller subset of four biodiesel users found that fleet fuel mileage was reduced as much as 1.5 mile/gallon with B20 use, while two agencies reported fuel economy increased by 0.2 and 0.6 mile/gallon, respectively. It should be noted that these comparisons are more qualitative, as they are not necessarily based on systematic studies and the results were not analyzed statistically.

Biodiesel also has solvent properties that will dissolve the deposits accumulated in vehicles and storage tanks previously used with diesel. Over half of the surveyed fleets reported some level of filter plugging. Filter plugging appeared to be mostly at levels of B20 or higher, and most of the agencies reporting fuel filter plugging indicated that the problems were encountered only during the initial period when biodiesel fuel was introduced to tanks previously storing diesel fuel. Persistent filter plugging was reported by four agencies, however.

Fuel quality is an important issue with the use of biodiesel. Fuel quality surveys have shown issues with biodiesel fuel quality in the recent past. Fuel quality appears to be improving in the more recent surveys, although there still appears to be issues with biodiesel produced by smaller production volume facilities. Fuel quality issues were also seen with the initial implementation of the biodiesel program in Minnesota. Biodiesel fleet experience from the surveyed users suggested all biodiesel users should use B100 and B20 or lower blends that meet ASTM D6751 and ASTM D7461 specifications, respectively. Some biodiesel users strongly recommended procuring biodiesel form BQ-9000 certified producers and distributors to ensure successful implementation of biodiesel program. It is suggested that the appropriate California agency should evaluate the possibility of developing fuel quality monitoring and enforcement programs for biodiesel that are comparable to those used for other motor vehicle fuels.

Biodiesel has a higher cloud point and pour point compared to petroleum diesel, which can lead to operational issues in cold climates, such as filter plugging. Biodiesel blend fuels have been operated year round in many of the states by developing cold weather management plans. Fuel gelling and filter plugging in cold winters were observed by some biodiesel users, so winter flow additives are recommended for blending into biodiesel fuel under cold conditions. Nine surveyed biodiesel fleet users observed fuel gelling and filter plugging in cold winter conditions and Glacier National Park indicated they only operate biodiesel in the summer. NREL suggests users specify to the blend supplier that the fuel remains crystal free at temperatures down to -14°F for regions that experience more severe winter seasons.

Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
ARB	Air Resources Board
CARB	California Air Resources Board
CEC	California Energy Commission
CE-CERT	College of Engineering-Center for Environmental Research and Technology (University of California, Riverside)
CFR	Code of Federal Regulations
CRC	Coordinating Research Council
DPF	diesel particle filter
DOD	Department of Defense
DOT	Department of Transportation
EBB	European Biodiesel Board
EPA	Environmental Protection Agency
EMA	Engine Manufacturers Association
FAAE	Fatty Acid Alkyl Ester
FAME	Fatty Acid Methyl Ester
FIE	Fuel Injection Equipment
HDDT	Heavy-Duty Diesel Truck
HDV	heavy-duty vehicle
LDV	light-duty vehicle
LCFS	Low Carbon Fuels Standard
NBB	National Biodiesel Board
NAC	NO_x adsorber catalyst
OEM	Original Equipment Manufacturer
PM	particulate matter
QA	quality assurance
QC	quality control
RME	Rapeseed Methyl Ester
SCR	selective-catalytic reduction catalyst
SME	Soybean Methyl Ester
ULSD	ultralow sulfur diesel
US	United States

Executive Summary

California is making a concerted effort to increase the use of alternative fuels in transportation and other areas, along with other states and federal government. In California, the legislature passed AB1007 that requires the California Air Resources Board (CARB) and California Energy Commission (CEC) to develop a plan to increase alternative fuels use in California to reduce oil dependency and air pollution. The California Governor has also established aggressive greenhouse emission reduction targets for which CARB has identified potential strategies such as biodiesel. Biodiesel is an alternative diesel fuel that has the potential to reduce greenhouse gas emissions, other pollutants, and can partially offset our use of petroleum-based fuels. In order to support the Low Carbon Fuels Standard (LCFS), CARB is conducting a comprehensive program to evaluate the potential impacts of biodiesel implementation on engine/vehicle durability and emissions. As part of this evaluation process, a biodiesel fleet durability study was conducted to understand the impacts of biodiesel on engine durability, fuel system durability, material compatibility, and the life of exhaust and aftertreatment systems. Cold weather problems, storage and handling, blend level, feedstocks, as well as biodiesel fuel cost, are also incorporated in this study.

This biodiesel fleet durability study was performed in the following major areas: (1) A thorough literature review of potential durability issues associated with biodiesel use. The literature review also included cold weather issues, fuel stability, storage and handling, and engine manufacturer's warranty. (2) A literature review of biodiesel fleet use experiences. (3) A comprehensive biodiesel fleet user experience survey. The survey focused on the biodiesel fleet repair and maintenance records. Other biodiesel use experiences, such as year round operability, storage and handling, fuel feedstocks, blend level, fuel price, fleet engine performance and fuel economy etc., were also included in the survey. A total of 40 agencies responded to the survey, including national park sites, airports, county and municipal fleets, school districts, private companies, state Department of Transportation agencies, various city transit agencies, as well as a few other users of biodiesel, such as the US Postal Service.

A summary of the conclusions of this study for the primary topic areas is provided as follows:

Biodiesel Production and Use

The use of biodiesel has increased considerably in the United States from a production level of 2 million gallons per year in 2000 to 700 million gallons per year in 2008. Biodiesel is also extensively used throughout Europe, where governmental initiatives have promoted the use of up to B5 in the marketplace. This program has been largely successful in terms of impacts to the vehicle fleet, and indicates that biodiesel can be implemented successfully into the larger marketplace. It is suggested that the fuel specifications and monitoring and enforcement programs in Europe be used as a guide for the implementation of biofuels in California. Several states have either implemented or are in the process of implementing programs to increase the use of biodiesel and other biofuels. These programs should be monitored as they are being implemented, especially as higher levels of biodiesel become required. It is important to note that issues with fuel quality were identified during the initial implementation of the biodiesel program in Minnesota, reinforcing the important of monitoring and enforcement programs.

In our survey, some national parks and cities have been using biodiesel blends dating back to 1995. The amount of biodiesel fuel used by the surveyed fleet users varied significantly, ranging from 80 to 220,000 gallons/week. The most common biodiesel blend fuel used by the surveyed fleets is B20. The biodiesel fuel blend level varies significantly among the biodiesel fleet users, ranging from B5 to B100. Soy methyl ester is the major feedstock for biodiesel fuel. Biodiesel fuels made from other feedstocks, such as rape methyl ester, yellow grease and tallow, are also used by some users.

Fuel Quality and Warranty Issues

ASTM fuel quality standards are in place for the addition of up to 5% biodiesel in traditional petroleum diesel (ASTM D975), for biodiesel blends between 6 and 20% (ASTM D7467), and for the pure biodiesel (B100) use to produce these blends (ASTM D6751). These specifications are comparable to those used in Europe for blends of B7 (EN 590) and for the B100 (EN 14214), although the European specifications include a stability requirement in EN 590 for the low level blends.

All engine manufacturers provide certain warranties on the engines powered by biodiesel. While B5 is accepted by all engine manufactures, the use of biodiesel at blend levels higher than B5 depends on the specific engine manufacturer and engine being used. The potential impact of regulations requiring blend levels higher than 5% should be examined by CARB as part of their regulation implementation. A consortium of diesel fuel injection equipment manufacturers ("FIE Manufacturers") has also expressed concern that ASTM D975 does not include a stability requirement and that the stability induction period of 6 hours for ASTM D7467 for B6 to B20 blends is considerably less than the induction period of 20 hours required in EN 590 for blends up to B7.

Fuel quality surveys have shown issues with fuel quality in the recent past. Fuel quality appears to be improving in the more recent surveys, although there still appears to be issues with biodiesel produced by smaller production volume facilities. The biodiesel industry has developed a BQ-9000 program that is a quality control and monitoring program for biodiesel producers and distributors. This program includes requirements for the testing and monitoring of fuel quality for all participants who receive accreditation. It is suggested that the appropriate California agency should evaluate the possibility of developing fuel quality monitoring and enforcement programs for biodiesel that are comparable to those used for other motor vehicle fuels. This could include provisions such as more aggressive enforcement during the initial implementation to ensure no off-spec fuel enters the marketplace and specifications for a subset of fuel parameters that will be tested on each batch of biodiesel produced, similar to the BQ-9000 requirements. Biodiesel fleet surveys strongly suggested that all biodiesel users obtain B100 and B20 or lower blends complying to ASTM D6751 and ASTM D7461 standards, respectively. Procuring biodiesel fuel from BQ 9000 certified producers and distributors was considered to be a critical step by those surveyed to ensuring successful implementation of a biodiesel program at a fleet level.

Fuel Storage

Biodiesel fuel has solvent properties and will dissolve the deposits accumulated in vehicles run on petroleum diesel before and fuel storage tanks used to store petroleum diesel previously. The dissolved sediments will cause filter plugging at the initial stage of biodiesel use. Once the filters have been changed and fuel storage tanks are thoroughly cleaned, as filter plugging problems should be resolved. It is suggested that extra fuel filters be maintained on hand during initial use, as filter plugging is more likely in the initial weeks of B20 (or below) use. It is recommended blends higher than B20 should always be stored in clean, dry tanks. Other potential issues associated with biodiesel storage include microbial growth, water contamination, and gelling in cold climates (discussed below). These problems can be mitigated with the cleaning of fuel tanks, the use of biocides, and the use of filters on the fuel dispensers (e.g., 10 micron) that can prevent water from entering a vehicle's fuel system.

Most biodiesel users in the survey did not make any changes in fuel storage routine to accommodate biodiesel fuel. Nine of the surveyed biodiesel users increased biodiesel fuel tank storage tank maintenance procedures, including more rigid storage tank, increasing fuel dispensing filter change, and adding winter flow additives and biocides. Several biodiesel users that were surveyed found microbial growth in the biodiesel fuel storage tanks. Biocides can be used to prevent microbial growth in the biodiesel fuel storage tank.

Of the 40 agencies surveyed, 22 recorded fuel filter plugging issues, while 18 reported no fuel filter plugging issues. Filter plugging appeared to be mostly at levels of B20 or higher, and 18 of the agencies reporting fuel filter plugging indicated that the problems were encountered only during the initial period when biodiesel fuel was introduced to tanks previously storing diesel fuel. Persistent filter plugging was reported by four agencies.

The oxidation stability of biodiesel is generally worse than that for petroleum diesel fuel. Studies have shown that B100 that does not contain a synthetic antioxidant will begin to oxidize immediately during storage, and that B100 should not be stored for more than several months unless additized. Studies have shown that phenolic–based antioxidants are effective in preventing acid and insoluble formation during storage. The National Biodiesel Board recommends a six-month storage life for B100 meeting ASTM specifications.

Given the likelihood that large numbers of fuel distributors and storage facilities will not make changes to accommodate the biodiesel fuel, it is suggested that precautions be taken or advisements be provided on potential issues, at least during the initial stages of widespread implementation.

Material Compatibility and Engine Durability Issues

Prolonged exposure to biodiesel can cause degradation, softening, or seeping through some hoses, gaskets, seals, elastomers, glues, and plastics. Concern about elastomer degradation is more critical for applications where B100 is used, as opposed to B20. Nitrile rubber compounds, polypropylene, polyvinyl, and Tygon are particularly vulnerable to B100. Materials such as

Teflon, Viton, fluorinated plastics, and Nylon, on the other hand, are compatible with biodiesel. Older vehicles manufactured before approximately 1993 are more likely to contain materials that could be affected by B100 over longer periods of time. For use at more standard B20 and lower blend levels, NREL (2009) indicates that fleet experience over the last 10 year has shown that material compatibility issues are minimal, even for elastomers made of materials such as nitrile rubber that are not compatible with higher biodiesel blends.

Studies where elastomers are soaked in biodiesel have shown fluorocarbon elastomers with good compatibility to biodiesel. A range of other candidate materials have also shown good compatibility with biodiesel, although some studies have shown an exceedance of acceptable levels of degradation for some properties or higher levels of degradation when the elastomers are tested with off-spec biodiesel. For the survey, nearly all fleets reported no elastomer seal problems associated with biodiesel use, with more than 50% of the biodiesel fleet users answering the question. While one user noticed early elastomer failure when an engine was operated by B100, two other users recorded no elastomer failure problems with B100 use. Some users did not respond to the materials compatibility question.

Biodiesel provides improved lubricity compared to petroleum diesel but also higher viscosity that can impact injection quality and fuel atomization. Laboratory or bench-scale tests have shown that biodiesel meeting specifications is generally acceptable from a durability standpoint, although there were a number of failures on tests where oxidized or otherwise off-spec biodiesel was used.

The surveys showed no adverse effects of biodiesel on the vehicles or engine wear. Some biodiesel fleet users observed less engine wear after implementing biodiesel, which could be due to biodiesel's enhanced lubricity. More than 50% biodiesel fleet survey respondents reported that fuel pumps or injector systems were routinely monitored and no difference in the fleet fuel pump or injector durability was showed when biodiesel fuel was compared to petroleum diesel. Six biodiesel fleet users recorded more frequent fuel injector or fuel pumps failures, however, the St. Louis Airport observed longer fuel pump and injector life after biodiesel was adopted. Biodiesel fleet repair and maintenance survey results indicated that biodiesel has minimal impact on fleet exhaust and aftertreatment systems. Two biodiesel fleet users documented a slightly vehicle maintenance cost reduction attributed to biodiesel, but this was not a finding from a systematic study.

Since biodiesel has a higher and narrower boiling range, it tends to form larger droplets exiting the fuel injectors, which can lead to greater amounts of biodiesel remaining on the cylinder wall, and to bypass the rings into the crankcase, causing oil dilution. In some limited studies, NREL found increased oil dilution for light-duty vehicles with aftertreatment operated from 50-150 hours, but this did not have an impact on engine or emissions performance. Most the surveyed fleets indicated they did not change the engine oil change interval after biodiesel fuel was adopted.

Biodiesel Impacts of Vehicle Performance

Biodiesel contains on average 11% oxygen by weight, which accounts for its lower heating value and lower volumetric energy content. The energy content difference between petroleum diesel and biodiesel depends on a variety of factors including the feedstock and refining processing and blend level. NREL (2009) gives the energy of biodiesel (B100) as roughly 8% less than diesel No. 2. The EMA suggests that B100 may lower engine power approximately 5-7% lower compared to petroleum diesel fuel. Biodiesel blends of B20 and lower typically do not result in observable power loss or reduction in fuel economy.

Biodiesel did not have negative impact on engine power for the fleet users surveyed. Thirty-one biodiesel users reported no engine power difference was noticed when biodiesel fuel was used. Four fleet users reported less power on biodiesel compared with conventional diesel. On the contrary, more engine power was observed with biodiesel use by other four biodiesel users. Biodiesel use also did not appear to have a noticeable impact on fuel economy. Twenty-seven biodiesel fleet users reported that no change in fuel economy was noted while using biodiesel fuel. A smaller subset of four biodiesel users found that fleet fuel mileage was reduced as much as 1.5 mile/gallon with B20 use. Two agencies reported fuel economy increased by 0.2 and 0.6 mile/gallon, respectively. These two users did not indicate biodiesel blend level. Other users did not track the fuel mileage. It should be noted that these comparisons are more qualitative, as they are not necessarily based on systematic studies and the results were not analyzed statistically

Cold Weather Issues

Biodiesel has a higher cloud point and pour point compared to petroleum diesel, which can lead to operational issues in cold climates, such as filter plugging due to wax buildup or reduced fuel flow. Biodiesel blend fuel can be operated year round in most of the states by developing a cold weather management plan, such as using lower percentages of biodiesel, adding cold flow additives, and blending in a certain percentage of No.1 diesel with the biodiesel fuel in winter to improve the fuel cold flow property. NREL (2009) suggests that users specify to the blend supplier that the fuel remains crystal free at temperatures down to -14°F for regions that experience more severe winter seasons. Nine surveyed biodiesel fleet users observed fuel gelling and filter plugging in cold winter conditions and Glacier National Park indicated they only operate biodiesel in the summer.

1 Introduction

California, as well as the United States as a whole, is making a concerted effort to increase the use of alternative fuels in transportation and other areas. The California legislature passed AB1007 that requires the California Air Resources Board (CARB) and California Energy Commission (CEC) to develop a plan to increase alternative fuels use in California to reduce oil dependency and air pollution. Also, the California Governor has established aggressive greenhouse emission reduction targets for which CARB has identified potential strategies such as biodiesel.

The use of biodiesel as an alternative transportation fuel can provide many benefits. Biodiesel is a fuel composed of mono-alkyl esters made from plant oils (soybean, rapeseed, cotton seed, canola, and other vegetable oils), animal fats, or used cooking greases. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel blend. Biodiesel blends with petroleum-based diesel fuel can be used with the current fueling infrastructure and in all diesel engines with little or no engine modification. The use of biodiesel is also driven in part by federal and state incentives or initiatives and state credits in some states.

Biodiesel blends are becoming more available in US markets, and the number of biodiesel users and the amount biodiesel used has grown significantly in recent years (National Biodiesel Board, 2010). Many state and federal agencies, such as, the Department of Transportation (DOT), the Department of Defense (DOD), school districts, airports, etc, utilize biodiesel. Some states have mandates or executive orders to require state fleets to use certain percentages of biodiesel fuels. For example, a minimum 2% biodiesel blend is mandatory in the state of Minnesota. In California, although the number of fleets using biodiesel is still small, there is a growing use of biodiesel in fleets, including the Department of Defense and several municipalities.

While biodiesel use and operational experience is growing rapidly, it is still a relatively new fuel and there is only limited experience and information on the long term effects biodiesel can have on engines and fuel systems. Also, due to biodiesel's relative infancy as a commercial fuel, the production and distribution infrastructure are presently not as developed as for petroleum fuels in ensuring a consistent and quality fuel. American Society of Testing and Materials (ASTM) specifications on finished biodiesel blends ranging up to 20% have only recently been adopted, and many engine manufacturers do not provide warranty coverage on the use of biodiesel above 5%. Problems have also been reported with the use of biodiesel. The State of Minnesota, which adopted a low blend requirement of biodiesel in its diesel regulations, initially experienced widespread problems with clogged fuel filters that were attributed to poor biodiesel quality (Howell, 2006b). Studies have also shown that poor quality fuel can also lead to deterioration of elastomers and other durability issues (Thomas et al., 2007; Terry et al., 2005). Other information indicates that biodiesel can also contaminate engine crankcase oil (Thornton et al., 2009).

As part of California’s Low Carbon Fuels Standard (LCFS), CARB is currently examining the possibility of the introduction of a larger percent of renewable fuels into use in the statewide diesel fuel marketplace. This would represent the largest implementation of biodiesel to date into a non-centralized fleet application in the United States (US). CARB is conducting one of the

most comprehensive studies of biodiesel and renewable fuels to date to examine any possible negative impacts on emissions, the vehicle fleet, and associated fueling infrastructure. This study represents one component of the larger CARB program that is focused on biodiesel fuel effects on engines and fuel system components. The main elements of this biodiesel durability study are a literature review and a fleet survey. The literature survey covered a variety of topics including potential impacts of biodiesel fuel use, fuel quality, cold weather problems, storage and handling, fleet experiences with biodiesel use, and studies of material compatibility and durability. A maintenance and repair survey was also conducted with various fleets that utilize biodiesel throughout the country, with an emphasis on California fleets. The survey evaluated the impacts of biodiesel fuels on the durability of engine and fuel system components, material compatibility, and the life of exhaust and aftertreatment systems, and other biodiesel use experiences, such as performance and fuel economy, biodiesel fuel operability, storage and handling, biodiesel fuel feedstocks, blend level, and price.

2 Biodiesel Use in Use in Compression Ignition Engines

2.1 Biodiesel Basics

2.1.1 What is Biodiesel?

Biodiesel can be produced from a variety of renewable resources such as vegetable oils, (for example; soybean oil), recycled restaurant grease, and animal fats. The raw feedstocks are processed to produce a fatty acid methyl ester (FAME), such as rapeseed methyl ester (RME) and soybean methyl ester (SME). The National Biodiesel Board suggests that organizations seeking to adopt a definition of biodiesel for purposes such as federal or state statute, state or national divisions of weights and measures, or for any other purpose, use the following definition to be consistent with other federal and state laws and original equipment manufacturer (OEM) guidelines as follows:

Biodiesel is defined as a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751. Biodiesel refers to the pure fuel before blending with diesel fuel. ASTM D 6751-09 standard specification is the latest standard specification for B100 blend stock for middle distillate fuels used to control B100 quality prior to blending with conventional diesel.

Biodiesel is a legally registered fuel and fuel additive with the U.S. Environmental Protection Agency (EPA) for sale and distribution (Biodiesel Use and Handling guide, 2009). The EPA registration includes all biodiesel that meets the ASTM biodiesel specification, ASTM D 6751, and does not depend on the oil or fat used to produce the biodiesel or the specific production process employed. Raw vegetable oil does not meet biodiesel fuel specifications, is not registered with the EPA, and is not a legal motor fuel. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel blend. Biodiesel is usually blended with petroleum diesel and biodiesel blends. Biodiesel blends are denoted BXX, which refers to a fuel that is composed of XX volume percent biodiesel and diesel fuel. For example, B100 is neat or pure biodiesel and B20 is a blend of 20 volume percent biodiesel and 80 volume percent diesel fuel. The petroleum diesel fuel can be either a No. 1 or No. 2 meeting ASTM D 975, the standard for petroleum-based diesel fuel, or JP-8. Biodiesel and Biodiesel blends can be used in compression-ignition (diesel) engines with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics.

2.1.2 Properties of Commercial #2 Diesel and Biodiesel Fuels

Biodiesel differs from petroleum-based diesel fuel in a number of physical and chemical properties. Biodiesel has a specific gravity of 0.88 kg/l compared to 0.85 kg/l for diesel fuel, contains no nitrogen or aromatics, and typically contains less than 15 ppmw sulfur. Biodiesel contains 11% oxygen by weight, which accounts for its lower heating value and lower volumetric energy content. The energy content difference between petroleum diesel and biodiesel depends on a variety of factors, including the feedstock and refining processing. The National Renewable Energy Laboratory (NREL) gives the energy of biodiesel as roughly 8% less than diesel No. 2 (NREL, 2009). This differential is probably less for a typical CARB diesel or a diesel No.1, due to their generally lower energy contents. Other comparative properties are shown in Table 2-1, where the diesel for comparison is a Federal No. 2 diesel fuel.

Table 2-1 Selected Properties of Typical Diesel and Soy-Derived Biodiesel Fuels.

Fuel Property	Diesel	Biodiesel
Fuel Standard	ASTM D975	ASTM D6751
Fuel composition	C10-C21 HC	C12-C22 FAME
Lower Heating Value, Btu/gal	~131,300	~117,000
Kin. Viscosity, @ 40°C	1.3-4.1	1.9-6.0
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 - 0.0024
Boiling Point, °C	180-340	315-350
Flash Point, °C*	60-80	100-170
Cloud Point, °C	-15 to 5	-3 to 12
Pour Point, °C	-35 to -15	-15 to 10
Cetane Number	40-55	48-65
Stoichiometric Air/Fuel Ratio wt./wt.	15	13.8
Lubricity SLBOCLE, grams	2000-5000	>7,000
Lubricity HFRR, microns	300-600	<300

The cetane number for biodiesel is comparable to that typically used in California, but it is generally higher than that found in Federal diesel #2. The cetane number for biodiesel depends on the feedstock used to produce the biodiesel. Cetane number increases for more highly saturated esters and for esters with longer chain lengths. Cetane number decreases with unsaturated content and the number of double bonds, and as the double bonds and carbonyl groups move toward the center of the chain. Generally, higher cetane numbers are found for esters produced from tallow or yellow grease sources. Graboski and McCormick (1998) found that cetane numbers for soy-based biodiesels ranged from 45.8 to 56.9, with an average of 50.9.

Biodiesel has favorable properties for lubricity. Fuel lubricity is an important parameter since fuel pumps heavily rely on the fuel itself for lubricating many moving parts. The lubricity of biodiesel is higher than that of base diesel fuel. Even low levels blends of 1-2% biodiesel in petroleum diesel can provide significant improvements in lubricity for a diesel fuel. There was some discussion that low level biodiesel blends could be utilized in conjunction with the introduction of ultra-low sulfur diesel (ULSD) to improve lubricity, but these lubricity issues were largely being addressed by the petroleum industry through the use of additives. Two factors contribute to biodiesel's high lubricity. One is the ester group within the FAME molecules. The other factor is the trace impurities in the biodiesel (Hasimoglu, 2008; Knothe, 2005)

Biodiesel has higher viscosity than conventional diesel. A higher viscosity is indicative of a higher resistance to flow for the liquid due to internal friction. Higher viscosity can lead to poor fuel atomization and have an impact on the quality of fuel injection (Hasimoglu, 2008). The viscosity of blends with levels of B20 or less should be acceptable for typical use, and the ASTM D7467 viscosity specification for B6-B20 blends is the same as the D975 specification for regular diesel fuel. Viscosity effects could have a more important impact at cooler temperatures, since viscosity increases nearly exponentially with reductions in temperature (Knothe, 2008).

The flash point of biodiesel is also higher than that of typical diesel fuels. The flash point is a measure of the temperature to which the fuel must be heated to create a vapor/air mixture that can be ignited. This means that most safety precautions for handling diesel fuel would be more than adequate for handling biodiesel blends.

2.1.3 Biodiesel Fuel Standards

Fuel quality is very important to owners of diesel engines. Consumers expect all fuels to meet certain minimum quality, safety, and performance standards and engine manufacturers expect a fuel quality that does not affect engine performance and durability. Biodiesel fuel is no different, and the minimum fuel quality specifications are defined in ASTM specification D6751, the standard specification for biodiesel fuel (B100) blend stock for distillate fuels. The standard is independent of manufacturing process or feedstock and is designed to ensure that biodiesel has adequate quality for safe and satisfactory operation in a compression ignition engine. Similar to the petroleum-based diesel specification (ASTM D975), the ASTM D6751 specification starts with a workmanship statement: "The biodiesel fuel shall be visually free of undissolved water, sediment, and suspended matter." Biodiesel should be clear and bright, although it may come in a variety of colors, as color cannot be used as an indicator of predicting fuel quality. Specifications of ASTM D6751-09 are shown in Table 2-2.

Issuance of the original ASTM D 6751 standards for biodiesel brought a level of credibility for this fledgling fuel, but it was only the beginning of what was needed. There were still a number of issues and requirements for biodiesel to address to provide similar credibility and acceptance as a fuel when compared with petroleum diesel fuel. For example, how to handle different potential blend levels and other factors with the use of biodiesel fuel (Howell, 2006a). Fuel stability and storage was an issue that was addressed in 2006. The ASTM members agreed to incorporate the same test used for oxidation stability for the biodiesel standard in Europe, namely the Rancimat standard method for oxidation stability (EN 14112). Cold flow properties were another area of concern, and in June 2008 the ASTM committee adopted new standards and limits to deal with this issue for B100. The ASTM committee also modified the petroleum diesel specification ASTM D 975 to include blends of up to 5 volume percent of biodiesel at the June 2008 meeting. ASTM members are continuing to examine new and improved methods, including different chromatographic methods (Porter, 2006, Cecil and Sidisky, 2006, Foglia, et al. 2006; Alleman and Cecil, 2009; Alleman et al., 2009).

Prior to 2008, there was no specification for biodiesel blends from B0 to B20. In developing a biodiesel blend specification, a number of practical and technical issues relating specifically to biodiesel properties arose; such as low temperature properties, oxidative stability impacts on storage and, at high temperatures, microbial contamination effects on handling and distribution. For example, the cloud point of biodiesel is generally higher than petroleum diesel and should be taken into consideration when blending. These issues are well covered in an older report from NREL (Tyson et al., 2004). Leading up to the June 2008 ASTM meeting, however, a number of challenging issues were resolved, and ASTM released ASTM D7467 in October, 2008. It was revised in 2009 to establish standards for finished diesel fuel blends containing 6 percent to 20

Table 2-2 ASTM D-6751-09 Standard Specification for Biodiesel Fuels (B100) Blend Stock for Distillate Fuels

Property	ASTM Method	Limits	Units
Calcium & Magnesium, combined	EN 14538	5 maximum	ppm (ug/g)
Flash Point (closed cup)	**D 93**	**93 minimum**	**degrees C**
Alcohol Control (One of the following must be met)			
1. Methanol Content	EN14110	0.2 maximum	% volume
2. Flash Point	D93	130 minimum	Degrees C
Water & Sediment	**D 2709**	**0.05 maximum**	**% vol.**
Kinematic Viscosity, 40 C	D 445	1.9 - 6.0	$mm^2/sec.$
Sulfated Ash	D 874	0.02 maximum	% mass
Sulfur			
S 15 Grade	**D 5453**	**0.0015 max. (15)**	**% mass (ppm)**
S 500 Grade	**D 5453**	**0.05 max. (500)**	**% mass (ppm)**
Copper Strip Corrosion	D 130	No. 3 maximum	
Cetane	D 613	47 minimum	
Cloud Point	**D 2500**	**report**	**degrees C**
Carbon Residue 100% sample	D 4530*	0.05 maximum	% mass
Acid Number	**D 664**	**0.50 maximum**	**mg KOH/g**
Free Glycerin	**D 6584**	**0.020 maximum**	**% mass**
Total Glycerin	**D 6584**	**0.240 maximum**	**% mass**
Phosphorus Content	D 4951	0.001 maximum	% mass
Distillation, T90 AET	D 1160	360 maximum	degrees C
Sodium/Potassium, combined	EN 14538	5 maximum	ppm
Oxidation Stability	**EN 14112**	**3 minimum**	**hours**
Cold Soak Filtration	**Annex to D6751**	**360 maximum**	**seconds**
For use in temperatures below -12 C	**Annex to D6751**	**200 maximum**	**seconds**

BOLD = BQ-9000 Critical Specification Testing Once Production Process Under Control

* The carbon residue shall be run on the 100% sample.

\# A considerable amount of experience exists in the US with a 20% blend of biodiesel with 80% diesel fuel (B20). Although biodiesel (B100) can be used, blends of over 20% biodiesel with diesel fuel should be evaluated on a case-by-case basis until further experience is available.

percent biodiesel for on-road and off-road diesel engine use. Table 2-3 provides the detailed specifications of ASTM D7467-09A. Biodiesel fuels that meet ASTM D7467 and are legally registered with the Environmental Protection Agency are legal motor fuels for sale and distribution.

Similar to the US, the European biodiesel standard, EN 14214:2009, provides minimum quality requirements for biodiesel (B100). The European specification EN 14214 includes more stringent limits for water and sediments, limits for mono-, di-, and tri-glycerides, and an Iodine value that are not included in the US ASTM D6751 specification. The European diesel fuel standard EN 590:2009 includes biodiesel fuel blends up to 7% (B7), as opposed to the US diesel fuel standard ASTM D975-09, which includes biodiesel blends up to only 5% (B5). EN 590:2009 also specifies an induction period of at least 20 hours, whereas the D975-09 does not

specify an oxidation stability limit. Only the U.S. has established a separate standard for biodiesel blends (ASTM D7467).

Table 2-3. ASTM D7467-09A Standard Specification for Biodiesel Blends B6-B20

Property	ASTM Method	Limits	Units
Flash Point (closed cup)	D 93	52 minimum	degrees C
Water & Sediment	D 2709	0.05 maximum	% vol.
Kinematic Viscosity, 40 C			
Ash Content	D 482	0.01 maximum	% mass
Sulfur			
S 15 Grade	D 5453	0.0015 max. (15)	% mass (ppm)
S 500 Grade	D 5453	0.05 max. (500)	% mass (ppm)
Copper Strip Corrosion	D 130	No. 3 maximum	
Cetane	D 613	40 minimum	
Cloud Point	D 2500	report	degrees C
Carbon Residue, 10% bottom	D 524*	0.35 maximum	% mass
Acid Number	D 664	0.3 maximum	mg KOH/g
Distillation, T90 AET	D 86	343 maximum	degrees C
Oxidation Stability	EN 14112	6 minimum	hours
Lubricity, HFRR at 60°C	D 6079	520 maximum	microns
Biodiesel Content, % (V/V)	D 7371	6. – 20.	% volume

* Ramsbottom Carbon Residue on 10% bottoms, mass %, max.

\# A considerable amount of experience exists in the US with a 20% blend of biodiesel with 80% diesel fuel (B20). Although biodiesel (B100) can be used, blends of over 20% biodiesel with diesel fuel should be evaluated on a case-by-case basis until further experience is available.

2.2 Engine and Fuel System with Biodiesel Use

2.2.1 Biodiesel Use in Compression Ignition Engines

The number of biodiesel users has grown with greater interest in low-carbon, renewable fuels, and initiatives and tax credits. A number of discussions on the use of biodiesel and biodiesel blends in compression ignition engines can be found in Society of American Engineers (SAE) meeting papers or the web pages of either the National Biodiesel Board (2009) or the Engine Manufacturers Association (2009a). In 2001, NBB prepared a report, *Biodiesel: On the Road to Fueling the Future,* which outlined the properties of biodiesel and the many applications where biodiesel was being successfully used. The NBB webpage contains both testimonial and as technical reports about biodiesel.

Perhaps more salient to consumers of biodiesel fuels are the views of the EMA, an international membership organization representing the interests of manufacturers of internal combustion

engines. In 2003, EMA (2003) published a "Technical Statement on the Use of Biodiesel Fuels for Mobile Applications." Their report was updated in October 2009, based on the increasing worldwide interest in reducing reliance on petroleum-based fuels and the potential to improve air quality with alternative fuels (EMA, 2009b). The new technical statement takes into consideration data collected since the publication of the 2003 Statement, and sets forth EMA's position on the use of biodiesel blend stock. The new EMA report states that available data are limited regarding the use of biodiesel with those technologies that have been, or are about to be, introduced to meet the (US) Environmental Protection Agency's ("EPA's") 2010 heavy-duty on highway or Tier 4 nonroad emission standards. Their technical position statement provides an assessment of biodiesel fuels and the potential effects of their use with current technology engines. The statement was prepared as a resource for potential biodiesel fuel users, the government, and the public. In its Technical Statement, the Association concludes:

- Regardless of the biomass feedstock and the process used to produce the fuel, B100 blendstock should meet the requirements of ASTM D6751, EN 14214, or individual engine manufacturer specifications/recommendations.
- Biodiesel blends up to a maximum of B5 should not cause engine or fuel system problems, provided the B100 used in the blend meets the requirements of ASTM D6751 or EN 14214.
- Biodiesel blends ranging from B6 up to B20 should meet the requirements of ASTM D7467. Engine manufacturers should be consulted prior to using B6-B20 blends because acceptability varies by engine model. Biodiesel blends greater than twenty percent (B20) are not typically recommended and should be used only after consulting the engine manufacturer.
- Biodiesel blends may require additives to improve storage stability and allow use in a wider range of temperatures. In addition, the conditions of seals, hoses, gaskets, and wire coatings should be monitored regularly when biodiesel blends are used. When converting from a petroleum-based diesel to a biodiesel blend, fuel tanks should be cleaned and more frequent filter service may be required until fuel system deposits are stabilized.
- Although the actual power loss will vary depending on the percentage of biodiesel blended in the fuel, B100 fuel's energy content is approximately 5-7% lower than that of petroleum diesel fuel. Biodiesel blends of B20 and lower typically do not result in observable power loss or reduction in fuel economy.
- Biodiesel blends reduce particulate, HC and CO emissions. Depending on the engine type and duty cycle, they may produce increased NO_x emissions compared with those of petroleum-based diesel fuel used in an unmodified diesel engine. Engines designed with aftertreatment to meet stringent emission regulations have not demonstrated additional reductions in particulate, HC, and CO emissions or increases in NO_x emissions when using biodiesel blends, but more testing is required to confirm the interaction between the emission reduction strategies and biodiesel blends.
- Biodiesel blend stocks have generally been found to be nontoxic and biodegradable, which may promote their use in applications where biodegradability is desired.
- Individual engine manufacturers determine what implications, if any, the use of biodiesel blends has on the manufacturer's commercial warranties.
- Although several factors affect the cost of biodiesel blend stock, its average cost exceeds that of petroleum-based diesel fuel. The relative cost of converting an existing

fleet to biodiesel blends, however, is likely lower than the cost of converting to other alternative fuels.

The EMA statements should be used as a checklist and guide for any fleet making a change from petroleum diesel to biodiesel. The EMA also points out that information is limited on the effect of neat biodiesel and biodiesel blends on engine durability during various environmental conditions.

2.2.2 Statement of the Diesel Fuel Injector Manufacturers

A consortium of diesel fuel injection equipment manufacturers ("FIE Manufacturers") has also investigated the potential impacts of biodiesel and recently updated their position statement (FIE Manufacturers, 2009). The position statement expresses concern that there is no specification for a B5 induction period under ASTM D975-09 and that the induction period of 6 hours for the ASTM D7467-09 for B6-B20 blends is considerably lower than the induction period of 20 hours used in the EN 590:2009 (for blends up to B7). Based on this information, the FIE manufacturers stated that "The use of B5 according to ASTM D975-09 is tolerated by the FIE manufacturers, although the absence of a stability requirement is seen as a large risk that should be reduced as soon as possible. Blends containing in excess of 5% (V/V) FAAE (Fatty Acid Alkyl Ester) (ASTM D6751-09) require positive validation of specific issues associated with higher concentrations of low stability FAME (also in view of the fact that ASTM D6751-09 allows the use of fatty acid alkyl esters [other than methyl esters], which are not yet successfully evaluated)." The FIE Manufacturers also accept the use of biodiesel blends up to B7 meeting EN 590:2009, provided the biodiesel meets EN14214:2009. As a result, the FIE Manufacturers disclaimed responsibility for any failures attributable to operating their products with fuels for which the products were not designed.

2.2.3 Warranties

Warranty repair is a key decision element when purchasing a vehicle or engine, and customers expect the fuel used in a truck will not affect repairs under warranty provision. While the EMA stated that manufacturers accept B5 for all engines, it also pointed out that individual engine manufacturers determine what implications, if any, the use of any fuel, including biodiesel, has on the manufacturers' commercial warranties. Some manufacturers indicate that proper fueling does not affect OEM's materials and workmanship warranties. In general, while the biodiesel supplier should warrant fuel quality, the use and effect on the customer's engine warranty needs to be understood by all parties: the biodiesel manufacturer/supplier, the engine manufacturer, and the consumer/customer. Table 2-4 provides information on the position statements for some of the automakers' and engine manufacturers' relating to biodiesel and biodiesel blends.

Table 2-4. Automakers and Engine Manufacturers' Position of Support Biodiesel Blends.

	Biodiesel Blend Approval	Notes
Caterpillar	B30 / B20 / B5	Tiered biodiesel blend approval structure based on equipment type and model. Further information is provided at www.cat.com.
Cummins	B20	B20 Approval is for 2002 and later emissions-compliant On-Highway ISX, ISM, ISL, ISC and ISB engines. B20 is also approved for Off-Highway engines including: QSX, QSM, QSL, QSC, QSB6.7, QSB4.5, QSM Marine, QSM G-Drive. All 2010 Cummins engines will be B20 compliant.
Detroit Diesel	B5	Biodiesel must meet ASTM D6751 and petroleum diesel must meet ASTM D975. Biodiesel should be sourced from a BQ-9000 Accredited Producer. Detroit Diesel is currently conducting research that may allow future B20 acceptance.
Ford Motor Co.	B5	Any recent-model Ford truck with a diesel engine can run on a mixture including up to 5 percent biodiesel (B5), but higher amounts are not recommended at this time. Ford is currently conducting research that may enable future B20 acceptance.
Freightliner	B5	Freightliner is a division of Daimler Trucks North America. NBB is working with Freightliner to have a formal biodiesel statement posted on their website.
General Motors	B20 / B5	B20 SEO available to fleets on the 6.6L Duramax diesel engine in the 2009 Chevy Silverado Heavy Duty and GM Sierra Heavy Duty One Ton Pickup, as well as on the Chevy Express and GM Savana Commercial Cutaway Vans with Duramax diesel engines
International / Navistar	B5 / B20	Navistar unconditionally warrants use of biodiesel blends up to and including B5 blends meeting the ASTM D975-08a standard. Use of B6-B20 blends in International® MaxxForce™ Diesel Engines 2007-up is at the discretion of the customer/operator and will not automatically void an engine warranty. However, if engine component failure can be directly attributable to use of a B6-B20 blend not provided by a BQ9000 certified fuel supplier, not meeting the ASTM D7467-08 standard or not used per Navistar recommendations, Navistar may, at its option, deny warranty on the affected engine or engine component.
Isuzu	B5	Isuzu currently approves B5 but is in the process of completing research with B20 that may allow for future B20 support. Isuzu recommends using fuel that meets ASTM D6751.
John Deere	B20	John Deere places a B2 factory fill in all its U.S. diesel equipment. While 5 percent blends (B5) are preferred, biodiesel concentrations up to a 20 percent blend (B20) in petroleum diesel fuel can be used in John Deere engines through Tier 3/Stage III A. Biodiesel must meet ASTM

		D6751, and John Deere strongly recommends sourcing the fuel from a BQ-9000 Producer or Marketer.
Mac	B5 produced from Soy Methyl Ester (SME or SOME)	Ester (SME or SOME) Biodiesel use is approved at B5 in all Mack engines including MP, ASET and E-Tech. The biodiesel must be supplied by a BQ-9000 Accredited Producer and Certified Marketer.
Mercedes Benz	B5	Mercedes-Benz USA now approves the use of B5 in all Common Rail Injection Diesel "CDI-engines" – including BLUETEC engines. The only approved biodiesel content is one that meets the ASTM D6751 specification.
Perkins	B5 / B20	Currently, all Perkins diesel engines are capable of using up to 5% RME without affecting the standard warranty terms. Many models, such as the 400 Series and 1100 Series engines, are also approved for up to B20 meeting ASTM D6751 and EN 14214.
Thomas Built Buses	B5	NBB is working with Thomas Built to post a formal statement on biodiesel on their website.
Volkswagen	B5	B5 is approved for use in all Volkswagen of America TDI diesel vehicles. Biodiesel blend must meet all current petroleum industry specifications (ASTM D6751 and ASTM D975) and be purchased from a reputable commercial retail pump. Volkswagen of America is using biodiesel blends to power its entire 2009 Volkswagen Jetta TDI Cup race series, from the VW Jetta TDI racecars running on B5, to the generators and transport trucks running on blends up to B20.
Volvo	B5	Volvo Truck Corporation does not accept more than 5% biodiesel (SME) in diesel, ready mixed from the oil company. http://www.volvo.com/NR/rdonlyres/6D4EEEFA-EEC4-495E-B6C2-4E4AF1B18D0B/0/PV77620120920_biodiesel.pdf

The EMA has a prepared statement on the quality of fuels required to ensure optimal operation of the different vehicle and engine types they manufacturer. The draft Worldwide Fuel Charter (of August 2005) allowed the addition of biodiesel at up to 5% by volume to fuel categories 1-3, provided the biodiesel meets either ASTM D6751 or the European standard EN14214. Where biodiesel is used, it is recommended that pumps using biodiesel fuels should be marked.

Engine manufacturers must provide a warranty for repair of the emissions control system for the lifetime specified in the Code of Federal regulations (40CFR85). A separate section, 40CFR86, specifies the test protocols, including petroleum diesel fuel properties, required for engine certification. It is unclear what implications the use of biodiesel fuel has on emissions warranty, in-use liability, anti-tampering provisions, and the like. As previously noted, more information is needed on the impacts of long-term use of biodiesel on engine operations.

2.2.4 Engine Performance

The EMA made some technical observations about the differences in engine performance that owners should expect expected due to the differences in fuel properties (EMA, 2009). For example, the energy content of neat biodiesel fuel (B100) is lower than that of petroleum-based diesel fuel on a per gallon or volume basis, which results in a power loss in engine operation. The EMA gives a net effect of using B100 as a loss of approximately five to seven percent (5-7%) in maximum power output. The actual power loss will vary depending on the percentage of biodiesel blended in the fuel and the operating cycle, but is generally not identifiable for B20 and lower blends. EMA points out that adjusting the engine to compensate for power loss may violate EPA's anti-tampering rules, and is not recommended. EMA states that more information is needed to assess the viability of using biodiesel over the mileage and operating periods typical of heavy-duty engines.

2.2.5 Biodiesel Solvency & Filter Plugging

The building blocks of biodiesel, methyl esters, are commonly used in solvent products and cleaners. When using biodiesel, there is some tendency for it to dissolve accumulated sediments in diesel storage tanks and engine fuel tanks. These dissolved sediments can travel through the system and lead to clogged fuel filters. In some cases, injector deposits or injector failure can occur, but this is a rare occurrence. Most users of B20 typically do not clean their fuel tanks prior to use since B20 is sufficiently diluted to mute the solvent effect. It has been suggested that extra fuel filters be maintained on hand during initial use, since cases of filter plugging have been reported and are more likely in the first few tanks. The effects of B100 would be greater so it is suggested that fuel tanks be cleaned and extra precautions be taken with the fuel system for B100 use (NREL, 2009).

2.2.6 Materials Compatibility

Biodiesel can cause degradation, softening, or seeping through some hoses, gaskets, seals, elastomers, glues, and plastics with prolonged exposure. Concern about elastomer degradation is more critical for applications where B100 is used, as opposed to B20. Nitrile rubber compounds, polypropylene, polyvinyl, and Tygon are particularly vulnerable to B100. Materials such as Teflon, Viton, fluorinated plastics, and Nylon, on the other hand, are compatible with biodiesel. A more comprehensive listing of the compatibility of biodiesel with various elastomer materials

and metals is provided in the latest NREL Biodiesel Handling Guide (NREL, 2009). In an earlier Biodiesel Handling Guide, (US DOE, 2006) it notes that older vehicles manufactured before approximately 1993 are more likely to contain materials that could be affected by B100 over longer periods of time. Engines newer than 1993 and modern repair kits may contain biodiesel compatible materials, but not always. For use at more standard B20 and lower blend levels, NREL (2009) indicates that fleet experience over the last 10 year has shown that material compatibility issues are minimal, even for elastomers made of materials such as nitrile rubber that are not compatible with higher biodiesel blends.

2.3 Biodiesel Use and Handling

2.3.1 Biodiesel Low-Temperature Operability

One key concern with pure biodiesel is that it has less favorable cold weather flow characteristics compared with convention diesel fuel. In general, long-chain saturated fatty acid esters contribute to biodiesel's poor temperature operability. Biodiesel fuels produced from feedstocks with highly saturated fatty acid structures (such as palm oil and tallow) have poorer cold weather operability than fuels generated from feedstocks with highly unsaturated fatty acid structures (such as rapeseed and safflower oil) (Hoekman, 2009).

Some key properties in this regard are the cloud point and the pour point. The cloud point is the temperature at which wax formation can begin to plug the fuel filter. The pour point is a measure of the temperature at which the fuel is no longer pumpable. Other than cloud point and pour point, some other laboratory tests commonly used to define low temperature operability of biodiesel are cold filter plugging point, low temperature filterability, wax appearance point, and cold soak filterability.

The Cold Soak Filterability test is the newest requirement and it was included in the ASTM D6751 test method "Annex A_1" in 2008. This test was added to measure the presence of trace levels of species such as metals, sterol glucosides, glycerides, soaps, and water that can form precipitates above the cloud point in biodiesel blends. This test was developed in response to field experiences, such as issues with clogged fuel filters in Minnesota in the winter of 2005-2006. Along with cloud point, this test provides a measure of low-temperature operability. For the test, B100 is chilled to 40°F for 16 hours, then warmed to room temperature and filtered under a vacuum. For a typical B100 used throughout the year, a filtration time of 360 seconds or less is required, while for a B100 to be used in temperatures below 10°F, a filtration time of less than 200 seconds is required. This annex method has been turned into a separate ASTM test method D7501, which requires tighter control of the chilling apparatus, the warming temperature and time, and the filter type (Alleman et al., 2009b). Comparisons are currently be made between the annex method and D7501 in order to ballot on the replacement of the annex method by D7501.

The cloud points of diesel #2 and Diesel #1 can range from -10 to +10°F and -40 to -60°F, respectively. Diesel #1 is often blended into diesel #2 in colder climates to produce more favorable cold flow specifications. The effects of biodiesel addition on the cloud and pour points for a petroleum diesel fuel are shown in Figure 2-1. Cold flow additives are available to mitigate these issues by inhibiting crystal formation, but they have varying degrees of success depending

on the feedstock. Since the level of saturated compounds in U.S. oils and fats is too high for current cold flow additives to be effective, B100 flow property cannot be improved effectively with current commercial cold flow additives. Cold flow properties could be a limitation to the use of B100 in the winter time. Typically, blends with lower levels of biodiesel, with some diesel No. 1, or with the addition of cold flow additives are used to facilitate cold weather applications. NREL suggests that users specify to the blend supplier that the fuel remains crystal free at temperatures down to -14°F during the winter season (NREL, 2009). B20 has been used in cold temperature climates such as northern Minnesota and Wyoming, where temperatures regularly fall to below -30°F.

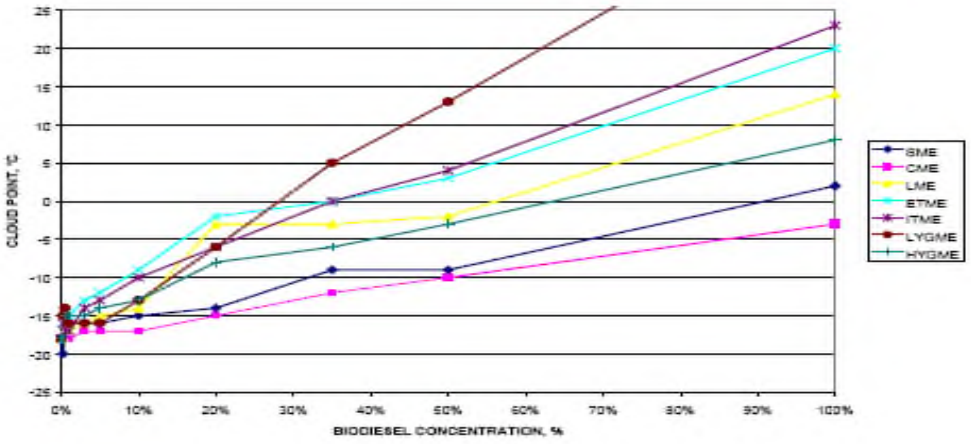

Figure 10. Biodiesel/diesel blend cloud point test results[11]

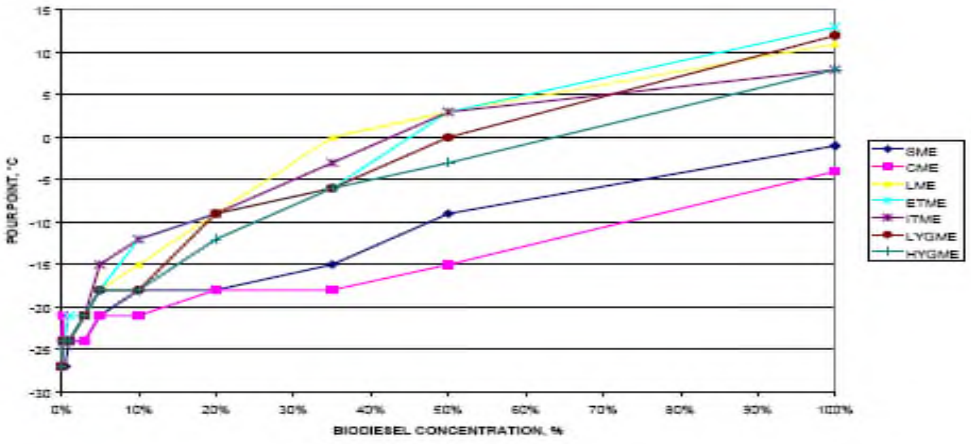

Figure 2-1. Effects of Biodiesel Addition on Cloud and Pour Points of Blends with #2 Diesel

2.3.2 Biodiesel Stability

Fuel stability during storage and use is a major industry issue for diesel and biodiesel fuels. Distillate fuels deteriorate due to complex oxidation and degradation reactions that occur when fuel is stored for long intervals or thermally stressed as in the fuel delivery system to a diesel engine. Oxidative stability refers to the potential of a fuel to undergo reactions with oxygen. Thermal stability refers to the potential of a fuel to undergo reactions at the upper temperatures

that might be encountered in the fueling process in an engine. In general, this mechanism of thermal degradation refers to pyrolysis or coupling reactions that do not involve oxygen and generate deposits. Both oxidative and thermal degradation lead to deposits that eventually become the sludge found in fuel tanks, fuel lines and fuel filters. In the field, these products can cause filter plugging, fuel line restriction, nozzle fouling, and deterioration of fuel pumps and injector performance. Fuel composition and environmental factors directly influence the rate at which these processes proceed.

Processes leading to sediment formation for petroleum diesel and biodiesel differ substantially as compounds suspected of destabilizing the petroleum diesel fuel are not even found in biodiesel fuel. Instability of petroleum distillates is keyed to numerous heterocyclic compounds like indoles, pyroles, thiols and carbozoles. Biodiesel behaves more like a vegetable oil and none of these compounds are in vegetable oils. The resistance to oxidation for vegetable oils depends on the degree of saturation, natural or added antioxidants and pro-oxidants, and prior abuse. For vegetable oils, oxidation is slow until this resistance is overcome at which point the oxidation accelerates and becomes very rapid.

An oxidation stability test (the Rancimat, ASTM - EN 14112 method) was added to the D6751 biodiesel specification in 2007. In evaluating potential oxidation stability tests for biodiesel, several studies were conducted by NREL and the Coordinating Research Council (CRC). Accelerated oxidation stability tests involve stressing the biodiesel using a combination of elevated temperature, time, and enhanced oxygen exposure. Properties such as peroxide value, insolubles, evolution of volatile short chain acids, or heat of reaction are then measured to evaluate the effects of the oxidation. Some methods that were examined as possible methods for biodiesel include ASTM D2274 (oxidation stability of distillate fuel oil), ASTM D4625 (long term distillate fuel storage stability), ASTM D6468 (accelerated stability), AOCS Method 12b-92 (oil stability index or Rancimat test used in Europe), and others. Westbrook (2005) reviewed these and other methods and proposed that the Rancimat and a modified version of the D2274 would be the most appropriate for biodiesel. Another review of oxidation stability methods and biodiesel oxidation was also performed by Waynick (2005) as part of the CRC AVFL-2b program.

McCormick et al. (2006a,b) reviewed the oxidation stability of biodiesel and biodiesel blends as part of their quality survey. They performed accelerated stability tests on 19 B100 samples and prepared a subset of 8 biodiesel blends for additional testing. The samples were tested for oxidation stability, thermal stability, gravimetric deposit formation, and measurements of iso-octane. Overall, they found that the stability of the biodiesel blends is dominated by the stability of the B100. A 3 hour Rancimat test for B100 appeared to be adequate to ensure stability of both B5 and B20 blends. They also found a correlation; samples with high total insolubles also had high iso-octane insolubles. Tests for this program included storage and handling, fuel tank testing, and aging in high temperature engine fuel system.

A recent study of biodiesel and biodiesel blend oxidation stability by McCormick et al. (2009) showed that B100 samples that do not contain synthetic antioxidants, will immediately begin to oxidize during storage. The study suggested that B100 should not be stored more than several months unless it is treated with synthetic antioxidant. McCormick's study also confirmed that the

stability of B5 and B20 blends is mainly affected by the B100 stability, and is essentially independent of diesel fuel aromatic content, sulfur level, or stability. The antioxidant testing conducted in this study showed that commercial phenolic antioxidants were very effective at preventing acid and insoluble formation during the storage of B100 and biodiesel blends.

Given that in the normal fuel system there are accelerants that destabilize biodiesel fuel, the issue is how to control the pathways that cause sediments and harm to the engine. One approach is to use natural antioxidants that work with biodiesel such as TBHQ (t-butyl hydroquinone), Tenox 21, and tocopherol (Vitamin E), usually sold by food additive companies. Tenox is a mix of TBHQ as powdered antioxidants and is often difficult to mix into biodiesel. Canakci (1999) studied a number of blends of petroleum and biodiesel and used additives to stabilize the fuel. He found that TBHQ was effective for biodiesel and biodiesel blends. Williams Labs (1997) investigated oxidation and thermal stability for several biodiesel blends using ASTM 4625. They found some additives to be effective, but others were not. TBHQ and Ethyl Hitec 4733 seemed to be the best additives. Waynick (2005) noted that TBHQ, pyrogallol (PY), and propyl gallate (PG) were the most effective antioxidants for fatty oils and esters.

While research continues in this area, DOE/NREL provided guidelines for conditions that will provide the highest levels of fuel stability for biodiesel (NREL, 2009):

- The higher the level of unsaturation, the more likely the fuel will oxidize. As a rule, saturated fatty acids (such as 16:0 or 18:0) are stable. 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. Points of unsaturation on the biodiesel molecule can react with oxygen, forming peroxides that breakdown into acids, sediments, and gums.
- Heat and sunlight will accelerate the 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 accelerate the degradation process and form even higher levels of sediment than would be formed otherwise. B100 should not be stored for long periods in systems that contain metals. Metal chelating additives, which serve to de-activate these metals, may reduce or eliminate the negative impact of the presence of these metals. See also (National Biodiesel Board, 2002).
- Some types of feedstock 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 away 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.

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

2.3.3 Other Issues with Biodiesel Storage

Biodiesel can cause filter plugging at the engine and at the fuel dispenser. In general, several things contribute to biodiesel's filter plugging problem: 1) Biodiesel will dissolve the sediments in the storage tanks and fuel lines previously used for petroleum diesel, and dissolved sediments will cause filter clogging. 2) Biodiesel can gel in cold climates because of biodiesel's poor low temperature operability. 3) Microbial growth in the biodiesel storage tank can generate sludge which will plug the filter. Biodiesel is very sensitive to microbial growth. Adding biocides to the biodiesel storage tank is a common method to control microbial growth.

Water contamination is another issue with biodiesel storage. Since water dissolved in the biodiesel promotes microbial growth in biodiesel storage tank, water is undesired in the biodiesel. Excessive water contained in biodiesel fuels can also cause engine surface corrosion and wear. Water is much more soluble in pure biodiesel than petroleum diesel, so B100 should be stored in clean and dry tanks (NREL, 2009). The use of a 10 micron filters at biodiesel fuel dispensers is an effective practice to prevent water from entering the fuel injector and engine system.

Other steps to prevent or reduce water and microbial contamination in the fuel and storage tanks include (Schiavone, 2007):

- Make sure the caps on all fuel tanks are in place and in working condition, especially gaskets.
- Keep tanks full of fuel to minimize condensation buildup inside the tank caused by large temperature swings.
- Insulate above ground storage tanks (double wall) and provide shade if possible to moderate temperature swings and the formation of condensation.
- Check for the presence of water and other signs of contamination when measuring tank levels.
- Periodically drain a small amount of fuel from the bottom of storage tanks to remove any water accumulation.
- Avoid prolonged exposure of fuel to light, which can induce bacterial growth (above ground fiberglass tanks should be painted and/or placed in shaded areas).

2.3.4 Biodiesel Fuel Quality

NREL is the lead manager of the US biodiesel program and they have conducted several studies of the quality and stability of biodiesel and biodiesel blends in the US, dating back to 2004. Of the 27 B100 samples collected in 2004, 85% were found to meet all of the ASTM D6751 specifications (McCormick et al., 2005). Samples failing one requirement were often found to have an outlier or failing results for a second requirement. As a part of this study, oxidation

stability tests were conducted using the Rancimat test which is used for the European biodiesel standard. The results showed that the typical biodiesel sample exhibited an induction of less than one hour on the test. The main factors affecting biodiesel stability are natural antioxidation content, polyunsaturated fatty ester content, and the level of mono and di-glycerides. This issue was resolved with the addition of the Rancimat specification to ASTM D6751 in 2008.

A follow-up study fuel quality survey in 2006 showed more significant fuel quality problems (Alleman et al., 2007). Of the B100 samples collected, the failure rate was found to be 59%. The primary failures were for total glycerin (33%) and flash point (30%). In the study, it was noted that even considering that the results apply only to the samples collected and was not based on a production volume, these researchers characterized these results as "alarming".

A follow-up study in 2007 found significant differences in the quality levels between different producers (Alleman and McCormick, 2008). BQ-9000 and large producers were rarely found to fail to meet the specifications. Seventeen samples in the survey were collected from BQ-9000 producers, which included 14 large producers and three medium ones. The samples from the large producers were overwhelmingly on specification, with the exception of one, showing a significant fuel quality improvement. The one sample failed to meet the D2709 water and sediment specification, indicating that contamination of the sample was likely. Small and medium producers, however, still had significant failure rates. Small and medium biodiesel producers failed to meet the oxidation stability specification most often, with 30% of their samples failing. Failure rates for all other properties were less than 10%. The small and medium producers represented in this survey account for approximately 11% of the market by volume.

Some issues and concerns have been identified with the proper blending of biodiesel to a nominal B20 or other level. Two options are available to produce blends of biodiesel with petroleum diesel, either in-line blending or splash-blending. In-line blending requires more expensive equipment so almost all biodiesel blends are currently manufactured using splash blending. In the process of splash blending, biodiesel and petroleum diesel are sequentially added to the tank on a transport truck. Completion of the mixing process to achieve uniformity in the blended fuel either occurs during the sequential addition of the fuels components to the tank or during the drive to the customer location (also known as stop-sign blending as the mixture will slosh from front to back of the tank as the delivery truck stops and starts). As compared with in-line blending, there are fewer controls for the splash blending process, but ethanol has been added to gasoline for many years by this process without problems. The key issues are how the manufacturer mixes the denser biodiesel and the distance of driving to the customer's tank. Foster et al. (2006) suggested that to alleviate poor mixing in the splash blending process, as discussed above, in-line blending should be utilized where the petroleum diesel and biodiesel streams would be mixed by pumping them at the appropriate ratio of flow rates into a common pipe under turbulent conditions. This method is universally used in other refinery fuel blending operations to ensure accurate, homogeneous blends, such as blending fuel components at the refinery, additives at the refinery or terminal, and today ethanol into gasoline at the terminal, but it is much more equipment and capital intensive. It is anticipated that these issues will be resolved as the biodiesel industry in conjunction with the petroleum industry matures.

NREL conducted a B20 quality survey in 2004 (McCormick et al., 2005). Fifty samples were collected from the fleets using B20. Eighteen samples (36%) fell out of range of 18% to 22%,

ranging from 7% to 98%. Seven out of the eighteen samples out of range are above B20, indicating poor mixing during the splash blending. NREL conducted another quality survey on B20 in 2008 in an effort to gain market information of B20 (Alleman et al., 2009a). Thirty-two samples were collected nationwide from fleets using B20 and public pumps labeled with B20 before ASTM D7467 was released. The samples were then tested according to the parameters in ASTM D7467, as well as some additional parameters. The survey found that 60% of the samples were nominally B20. Two samples were higher than B20, indicating less splash blending issues. Most of the out range samples were below B20 and actually were B2, B5 or B11 indicating a mislabeling of the pumps. The survey results showed that 74% of samples met D7467 induction period stability requirements for B20, while one sample was off specification for D7467 acid value. NREL is also planning on conducting a B20 survey in December 2009, focusing on colder areas, but including some warmer climates such as Southern California. Initial results from this survey are expected to be available in spring of 2010.

Minnesota was the first state to require diesel fuels sold in the state to be blended with 2% biodiesel. Minnesota initially experienced quality problems with some biodiesel in the state not meeting D6751 specifications (Howell, 2006b). A number of issues were observed during cold weather episodes, with fuel filter plugging and wax build-up on filters. As a result, the vehicles ran poorly or stalled in cold conditions. The quality issues were traced to the biodiesel not meeting the specification for unreacted or partially reacted oils and fats (total glycerin). The program was temporarily halted from December 23, 2005 to February 10, 2006 and some enforcement measures were put into place, including BQ-9000 like practices (see below), requiring a certificate of analysis for each batch of biodiesel sold, and fines/suspensions for producers making off-spec fuel. Since these measures were implemented and the biodiesel program was reinstated, no further quality issues have been found.

The National Biodiesel Accreditation program is a cooperative and voluntary program for the accreditation of producers and marketers of biodiesel fuel called BQ-9000. The program is a combination of the ASTM standard for biodiesel, ASTM D6751, and a quality systems program that includes storage, sampling, testing, blending, shipping, distribution, and fuel management practices. BQ-9000 helps companies improve their fuel testing and greatly reduce any chance of producing or distributing poor quality fuel. To receive accreditation, companies must pass a rigorous review and inspection of their quality control processes by an independent auditor. This ensures that quality control is fully implemented. Three categories of companies or laboratories can be BQ-9000 certified, including BQ-9000 producers, BQ9000 marketers and BQ-9000 laboratories. BQ-9000 is open to any biodiesel manufacturer, marketer or distributor of biodiesel and biodiesel blends in the United States and Canada. A list of accredited producers and certified marketers can be found at www.bq-9000.org.

The BQ-9000 standards also specify requirements for testing of fuel batches prior to delivery. All production lot samples are to be tested to ensure they are free from particulate matter, water, and unreacted material per ASTM D4176. Additionally, each production lot should be tested for the full specifications. This includes all of the tests and limits defined under ASTM D6751 and visual appearance via ASTM D4176. The full specification testing is to be conducted until there is sufficient confidence in the production process, which is a minimum of 7 consecutive lots meeting specification. Once this criteria has been met, the number of tests required on each

production lot is reduced to those specified under the critical specification list, which is provided in Table 2-5. Additionally, full specification testing is required on one production lot every 6 months, while sodium, potassium, calcium and magnesium tests are required on a production lot every month. The number of cetane number tests is slightly less than for the other tests, with only 3 cetane tests needed to provide confidence of meeting specifications, and only 1 cetane number test per year for periodic testing. If a significant process change occurs, confidence in the production process must be reestablished by producing a minimum of three consecutive lots that meet the full specification requirements.

Other researchers have also provided suggestions for similar subsets of tests that could be utilized to ensure production quality. Researchers at the Desert Research Institute suggested a list of tests similar to, but not identical to the BQ-9000 requirements (Hoekman et al., 2009). The tests recommended for each batch are provided in Table 2-5. Additionally, they recommended that cetane number, methanol, metals (Na, K, Ca, Mg), total sulfur, phosphorous, carbon residue, T90, ester content, and iodine number be conducted periodically.

Table 2-5. QC Tests to be conducted on each production lot of biodiesel.

BQ-9000 Tests	DRI recommendations
Flash point/Methanol content	Flash Point
Water and sediment	Water and sediment
Cloud Point	Cloud Point
Acid Number	Acid Number
Free Glycerin	Free Glycerin
Total Glycerin	Total Glycerin
Sulfur	
Oxidation Stability	Oxidation Stability
Visual Appearance	
Cold Soak Filterability	Cold Soak Filterability
	viscosity
	Sulfated Ash
	Copper strip corrosion

The European Biodiesel Board (EBB) and its member companies have also developed a quality program for testing fuel quality. The EBB is a non-profit organization that was established in January 1997. Its member companies account for about 80% of the EU biodiesel production. The EBBB established a biodiesel Quality report in 2006 that requires bi-annual sampling of all operational production sites for EBB member companies. This includes one sample from the beginning of winter and one from the beginning of summer. The samples are required directly from the companies, but are sent to an independent laboratory for a testing of all EN14214 parameter (EBB, 2006). The first round of tests for the winter of 2006-2007 showed production was largely within specifications for the 32 plants monitored, with the exception of 4 border-line samples on only one parameter and 1 sample out of specification for one or more parameters (EBB, 2007a). The second round of testing for the summer of 2007, with 38 plants monitored, showed similar levels of compliance, with most production being well within specification except 4 border-line samples on only one parameter and 1 sample out of specification for one or

more parameters (EBB, 2007b). Similar results were also achieved for the winter 2007/2008 study (EBB, 2008). While this program represents an important step in quality monitoring, it is important to note that the study does have some limitations since the production plants are providing samples directly that could create a bias.

There have also been some efforts into methods that can be used as a quick check of biodiesel quality. Von Wedel (2006) developed a field test indicator kit for B100. The test is designed as a quick check in the field for detecting traces of catalyst, mono/di/triglycerides, soaps, acids, and oxidized (aged) fuel. For the test, B100 is added to a ph indicator test vial, mixed by flipping and then allowed to settle into two phase with the fuel phase floating on top. The extraction of catalyst or acid from the fuel to the aqueous pH indicator elicits a visible color change. Soluble contaminants in the biodiesel can be extracted into the aqueous phase (fatty acid soaps) as visible turbidity, concentrated at the water-fuel interface (glycerides & fats, oxidized esters), and hydrated in the fuel as visible turbidity (mono, di, and triglycerides, fatty acids). It should be noted that for California, it is expected that more complete specifications would be required than could be measured to a simple test such as this.

3 Biodiesel Fleet Durability Survey

A survey was conducted on various biodiesel fleets throughout the country. For this project, the survey included national park sites, airports, county and municipal fleets, school districts, private companies, state Department of Transportation agencies, various city transit agencies, as well as a few other users of biodiesel such as the US Postal Service. The objective of this survey was to evaluate the impacts of biodiesel fuel on engine, fuel system, exhaust system, and aftertreatment devices. The survey also covered biodiesel fuel storage and handling, weather problems, cost, blend level, engine performance, types of engines/vehicles used, amount of gallons used, and any maintenance or other operational issues. Forty agencies that had biodiesel fuel experience responded to the survey and are included in the survey results.

3.1 Survey Methodology

A survey form was prepared by listing all pertinent questions associated with biodiesel use (Appendix A). The survey form was focused on the objective of obtaining information on biodiesel fuel impacts on engine/vehicle performance, maintenance, and fleet durability. A contact list was developed from the National Biodiesel Board website and state DOT websites. The biodiesel user survey contact information is provided in the Appendix B. The contact people were mostly fleet services or operation managers who are very familiar with their organization's fleet repair and maintenance records. The survey was conducted by sending the contacts the survey forms through emails and following up with phone calls. Upon receiving the filled-out survey forms, thank you letters were sent back to the contacts and additional follow-up calls were made to clarify responses.

3.2 Fleet Survey Results and Discussion

3.2.1 Biodiesel Usage

The fleet usage ranged in size from approximately 80 to 220,000 gallons per week. Some of the larger fleets, Yellowstone National Park, the US Postal Service, North Carolina State DOT were also relatively long term users, with use dating back to 1995. The fleets that have been using biodiesel fuel utilize all types of diesel engines including school buses, transit buses, ambulance, road maintenance trucks, shipping trucks, construction vehicles, boats, and off-road machinery (generators, tractors, lawn mowers, air compressors, etc.).

Out of the forty agencies who responded to the survey, thirty-three answered the blend level question. The biodiesel fuel blend level varies a lot among the biodiesel fleet users, ranging from B5 to B100. The number of biodiesel users for each biodiesel blend level is shown in Table 3-1. Some fleets operate several different biodiesel fuel blends. For example, the biodiesel blend fuel usage by the city of Portland in Oregon is 1,000 gallons/week of B5, 10,000 gallons/week of B20 and 1,000 gallons/week of B100. The most common biodiesel blend fuel operated by the biodiesel fleet users is B20. Some biodiesel users in the states with cold winter run B20 during the warm seasons and switch to B5 for the winter season. The petroleum component blend with the neat biodiesel by the biodiesel users is mostly No.2 diesel. Twenty-five biodiesel fleet users use No.2 diesel throughout the year. The state of Washington DOT uses No.1 diesel year round.

Some biodiesel users choose different types of petroleum diesel according to the season, such as, No.1 diesel in winter and No. 2 diesel or a blend of No.1 diesel and No.2 diesel for the rest of the warm seasons. Picture Rocks National Seashore in Michigan and Minnesota Hennepin County reported using a blend of 50% No.1 diesel and 50% No.2 diesel in all seasons. The survey showed that the most common type of feedstock for biodiesel fuel is soy methyl ester, although rape methyl ester, yellow grease, tallow and canola is also used by some biodiesel users including Biscayne, Yellowstone, Channel Island, the Salt Lake City Airport, the City of Hoover in Alabama, the city of Portland, California Blue Sky Shipping, the Nevada Clark School District, etc. Some agencies indicated that the type of feedstock used for biodiesel fuel blend was not known.

Table 3-1. Number of Biodiesel Users versus Blend Level

Blend Level	B5	B10	B20	B50	B100
Number of Users	13	4	27	7	4

The fuel prices were higher for the biodiesel in most of the reported cases, although there was quite a bit of variation in the amount of the increase of biodiesel blend level. The fuel price data was based on data collected in early 2009, with many regional differences between the fleets. The fuel price differential ranged between essentially $0.00 and $4.00 per gallon depending on a number factors including the blend level, with the price differential for B20 typically less than $0.50. According to Arlington County's experience, the price of biodiesel blend fuels adds 1 cent per gallon for each percent of B100 in the final blend product.

3.2.2 Fuel Filter Plugging Issues

Filter plugging was one issue addressed in the questionnaire, and it is also discussed in section 2.2.5. Among the forty agencies who responded to the survey, eighteen agencies reported no fuel filter plugging problems. The other twenty-two agencies or companies recorded fuel filter plugging issues. These agencies used a range of biodiesel blend levels from B2 to B100, although filter plugging appeared to be mostly at levels of B20 or higher. Most agencies with filter plugging problems experienced filter plugging at both the engine and the fuel pump, with Biscayne, Channel Island National Park, the United States Postal Service, and the Las Vegas Water District reporting filter plugging only at the engine. Filter plugging only at the fuel pumps was reported by the Medford Township School District, New Jersey and the Georgia Power Company. Eighteen out of the twenty-one agencies that experienced fuel filter plugging issues reported filter plugging problems were encountered only at the initial period when biodiesel fuel was introduced to the tanks previously storing diesel fuel. These filter plugging problems were solved after fuel storage tanks were cleaned and filters were changed. Biodiesel fuel has solvent properties that will dissolve the deposits in the storage fuel tanks that were used for diesel fuel storage fuel. Biodiesel fuel will also dissolve the sediments in the fuel dispensing line and vehicle engine fuel delivery systems. The sediments dissolved in the biodiesel fuel will clog the filters at the fuel dispensing pumps and engines. Once the fuel storage tanks are thoroughly cleaned and filters are changed, filter plugging issues generally abated. The Postal Service, the Salt Lake International Airport, the Illinois State DOT, and the Washington State DOT were the only four agencies that reported persistent filter plugging problems. Salt Lake international

Airport stopped using biodiesel fuel in 2008, after five years of use, due to filter plugging. During that period, they used a range of biodiesel levels from B20-B80, but they did not provide any information on whether filter plugging was more prevalent at higher biodiesel levels. The Illinois State DOT and the Washington State DOT found filter plugging when using B20 biodiesel, as discussed below. The postal service did not provide the blend level. These persistent filter plugging problems may have been caused by different factors, including biodiesel's solvent properties, winter gelling, or microbial growth.

Arlington County, Virginia's fleet management team prepared the first B20 shipment by cleaning storage tanks and switching to 10 micron less fuel filters on the dispensers. There was no unexpected rise of fuel filter plugging after using B20. The fleet management indicated they thought that fuel filter replacement interval may be extended due to B20.

A follow-up survey was sent out to the biodiesel users to ask about the impact of biodiesel blend level on filter plugging issues. Filter plugging issues were generally not observed when the vehicles were operated with low blend levels of biodiesel, such as B5 or B10. Among the fourteen agencies who responded to the follow-up survey, seven biodiesel users experienced filter plugging at the engine or pumps. A summary of the plugging issue and the associated biodiesel blend level for these seven users is provided in Table 3-2. Filter plugging issues for these users were generally found for biodiesel levels of B20 or higher. Five biodiesel users operated two or more different blend levels of biodiesel. However, filter plugging was observed when the fleets were running B20 and above. The Oregon State DOT did experience filter plugging from B2 to B40, however.

Most agencies who had filter plugging problems did not report the material causing the filter plugging. Algae or microbial growth was identified as the filter plugging material by the Las Vegas Water District, the Clark County School District, and the Washington state DOT. As mentioned in the previous literature review section, biodiesel's susceptibility to microbial growth may lead to filter plugging problems. Microbial growth can be controlled by adding biocides to the fuel storage tanks. The city of Portland and the Nevada Clark County School District stated that the clogging residues at the filters were the glycerin. The presence of excessive glycerin in the poor quality biodiesel, which will settle down in the fuel storage tanks, can cause filter clogging. Thus, acquiring biodiesel meeting ASTM standards are very important for implementing biodiesel. The Oregon DOT and the National Capitol noticed the plugging residue was wax or gel-like, but did not identify the material.

A question about the types of filters that encounter filter plugging was included in the biodiesel fleet survey questions. The agencies who responded this question mostly reported the fuel filter clogging problems occurred in multiple types of filters. However, Pictured Rocks National Seashore identified the fuel filter plugging only happened with one type of paper filter. The model of the paper filter was not given in the returned survey form.

Table 3-2. Biodiesel Blend Level on Filter Plugging

Biodiesel Users	Filter Plugging at Pump or Engine?	Blend Level Used	Blend Level Caused Filter Plugging	Filter Problems Persist?
Hennepin County, MN	Pump	B5, B20	B20	No Answer
Illinois DOT	Pump and Engine	B5-B20	B20	Yes
Washington State DOT	Pump and Engine	B10, B20	B20	Yes
Clark County School District, NV	Engine	B5, B20, B100	B20	Abated after cleaning biogrowth
Oregon DOT	Pump and Engine	B2-B40	B2-B40	Abated after Cleaning Tank
Medford Township Board of Education, NJ	Pump and Engine	B10, B20	B20	Abated
Arlington County, VA	Pump and Engine	B20	B20	Abated after initial period, and adding winter treatment

3.2.3 Engine and Fuel System Durability

The agencies that had biodiesel fleet experience were asked about the impact of biodiesel fuel on engine wear and fuel system durability, including questions about any changes in used engine oil analyses, lubricant degradation and engine oil maintenance interval. These issues are also discussed in Section 5. All of the twenty-three agencies who responded to the engine wear question stated that they did not notice any abnormal engine wear problems. Used biodiesel fleet engine oil analyses results by Alco Mill Products, the Michigan St. Johns Public School District, and the South Ohio Regional Transit Authority indicated less engine wear due to biodiesel use. The city of Portland noticed engine oil from biodiesel fleet was diluted compared to petroleum diesel. All other fleets reported no changes in engine oil viscosity, acidity, and other oil characteristics. In addition, there were no noticeable engine lubricant degradation problems, although eleven biodiesel users indicated engine lubricant degradation problems were not monitored. The state of North Carolina DOT reported engine lubricant degradation occurred when ULSD was used to blend with neat biodiesel to make B20. In fact, the biodiesel feedstock added some lubricity to back to the ULSD. Ninety percent of the fleets indicated their fleet engine oil change interval schedule was not changed after biodiesel fuel was adopted. The city of Portland documented that engine oil was changed more frequently with biodiesel, while South Ohio Regional Transit Authority reported engine oil was changed less frequently.

The effect of biodiesel fuel on the long-term durability of fuel pumps or injectors is an important subject for all biodiesel fleet users since fuel injectors are a costly part. Thirty-nine out of forty

fleet users responded to the fuel system durability question, with eleven stating that the fuel system durability was not monitored. More than half of the agencies reported that no difference in the fleet fuel pump or injector durability was noticed when comparing biodiesel to petroleum diesel. Those biodiesel users without fuel pump or injector problems utilized blend levels ranging from B5 to B100. Six agencies recorded fuel injector or pump problems attributed to biodiesel use, including Biscayne National Park, Glacier National Park, the city of Portland, the Post Service, the Washington State DOT, and the District of Columbia. The St Louis International Airport observed longer life for fuel pumps and injectors when biodiesel blend fuel was used in the fleets. Among the six agencies that experienced early fuel injector and pump failure, two agencies did not report the biodiesel blend level being run. One agency ran several blends (B5, B20, B50 and B100), but did not specify which blend level of biodiesel caused fuel pump and injector problems. Biscayne observed that fuel injectors were eroded when B100 was used. The other two users included one using B20 and one using B10-B20. According to Glacier National Park, fuel injectors and pumps in a Chevy Duramax failed as early as 80,000 miles using B20.

3.2.4 Engine Performance and Fuel Efficiency

Engine power and fuel economy have always been an important topic for biodiesel fleet users, given the slightly lower energy content of the biodiesel fuel, as discussed in Sections 2.2.1 and 2.2.4. The experiences of our survey agencies suggest biodiesel will not have a noticeable impact on engine power. Thirty-one of the forty biodiesel users reported no engine power difference was noticed when biodiesel fuel was operated. Biscayne, Grand Teton, Glacier and the city of Portland observed the biodiesel fleets had less power compared with fleets powered with petroleum diesel. However, biodiesel fleets at Pictured Rocks, Las Vegas Clean Cities, the Michigan St. Johns Public School District, and the Southwest Ohio Regional Transit Authority suggested more power was observed when operating on biodiesel.

Biodiesel fleet users were asked if they have documented any change in vehicle fuel economy since beginning the use of biodiesel fuel. Survey results from the biodiesel fleet experience suggested that vehicle fuel mileage did not change significantly with biodiesel use. Twenty-seven agencies reported no change in fuel economy while using biodiesel fuel. Las Vegas Clean Cities found an increase of fuel mileage of 0.6 mile/gallon for biodiesel use. An increase of 0.2 mile/gallon fuel efficiency on Kenworth ECMs was recorded by Grand Teton, Wyoming, when the trucks were powered with biodiesel fuel. Neither of these agencies specified the blend level used. St. Johns Public Schools, the Southwest Ohio Regional Authority, and the King County Metropolitan found that fleet fuel mileage was reduced as much as 1.5 mile/gallon attributed to the use of B2. It should be noted the statistical significance of these increases or reductions was not characterized. Nine agencies did not track fuel mileage when the biodiesel fuel was implemented. The National Biodiesel Board reports that:

> "Biodiesel has a higher cetane number than U.S. diesel fuel. In more than 50 million miles of in-field demonstrations, B20 showed similar fuel consumption, horsepower, torque, and haulage rates as conventional diesel fuel. Biodiesel also has superior lubricity and it has the highest BTU content of any alternative fuel (falling in the range between #1 and #2 diesel fuel)."

3.2.5 Vehicle Exhaust, Aftertreatment System, and Other Maintenance Issues

Sixteen out of forty biodiesel fleet users responded to the question about the impact of biodiesel fuel on vehicle exhaust and aftertreatment systems. The Nevada Clark County School District and the Washington State DOT are the only two of the sixteen respondents that had installed diesel partticle filters (DPF) and/or oxygen catalysts on all their biodiesel vehicles. B5, B20 and B100 are used by the Clark County School District and no problems with the aftertreatment systems have been observed to date. Washington State DOT runs B10 during winter and B20 for the rest of the seasons and no problems have been observed with their aftertreatment systems. Five biodiesel users reported that some of their vehicles running on B5 to B100 have DPF or oxygen catalyst aftertreatment devices. The other nine users reported that their biodiesel fleets were not equipped with aftertreatment devices. All sixteen responders reported that no noticeable difference was observed in the fleet exhaust and aftertreatment systems when biodiesel fleets were compared with petroleum diesel fleets.

In this survey, the biodiesel fleet user agencies were also asked about other vehicle maintenance issues associated with the use of biodiesel. The majority of fleets reported no other maintenance problems caused by biodiesel use in the fleets. Biscayne, the Post Service, the New York City Park system, and Blue Sky Shipping reported some exceptions. Various maintenance problems occurred in these fleets. New York City Park stated that their Toro ride mowers needed special fuel filters to run biodiesel. Biscayne documented tank floats being stuck on the engine because the tank deposits were dissolved by B100. The Post Service observed abnormal sludge in the valve train. Blue Shipping had one incidence of replacing return fuel lines on Cummins engines. The Arlington County management team reported that the repairs performed on fuel systems were slightly reduced after B20 was adopted in the diesel fleets, due to biodiesel's added lubricity and detergent properties. St John's Public Schools in Michigan and the New Jersey Medford Township School District reported vehicle service costs were reduced for the biodiesel fleets, although the statistical significance of this change was not provided.

3.2.6 Materials Compatibility

Biodiesel fleet users were also asked about elastomer seal and other material compatibility problems in the engine fuel system. These issues are also discussed in sections 2.2.6 and 5.2. Twenty-one out of the twenty-three biodiesel users responded to this question reported no elastomer incompatibility problems with biodiesel use. Most biodiesel fleet users among these twenty-one agencies were using B5-B50. In addition, the city of Portland and California Blue Sky Shipping recorded no adverse effect of biodiesel on engine elastomer when their trucks were powered with B100. Biscane reported more frequent engine elastomer seal failures, although this fleet was using B100 instead of a biodiesel blend. Alcoa Mill Products found that the engine elastomer seal problems attributable to biodiesel use only occurred with Perkin engines. The rest of the agencies did not respond to the material compatibility question in the survey. Biodiesel fleet experience from this survey indicated that issues of vehicle engine fuel system materials compatibility with biodiesel were minimal when fleets were operated with biodiesel blend levels of 20% or lower.

3.2.7 Cold Weather Problems

The fleets were asked about any cold weather issues they experience with using biodiesel. Cold weather issues with biodiesel are also discussed in section 2.3.1. Thirty-eight out of forty fleet users responded this question, with nine survey respondents reporting fuel gelling in the fuel supply lines and filter plugging at the engines when biodiesel was used under cold conditions. The fleets who had problems with running biodiesel blend fuel in winter were mostly in the states with severe winters, including Hennepin County in Minnesota, the Salt Lake City Airport in Utah, Glacier National Park in Montana, Arlington County in Virginia, the King County Metro in Washington State, the Oregon State DOT, Kenton County in Kentucky, and the Washington State DOT. Because of filter plugging in cold weather, the Salt Lake City Airport and King County Metro have stopped using biodiesel blend fuel since the end of 2008. Glacier National Park runs biodiesel blend fuel only from April to October. Among the nine fleet users that experience cold weather problems with biodiesel use, all of them are B20 users, with five of them also running several different blends from B5 to B80.

Thirty biodiesel users experienced no cold weather problems attributable to biodiesel fuel, although most of these users are located in the states without severe winter. Eight biodiesel diesel users with cold weather problems stated they managed to use biodiesel blend fuel year round by adding flow additives, blending in a certain percentage of No. 1 petroleum diesel, or switching to a lower percentage of biodiesel in winter. For example, Arlington County has experienced no cold weather related operating problems after the county's biodiesel supplier added a cold flow additive to the B20 from October 1st through March 15th. The Oregon State DOT has been using 50% No.1 diesel and 50% No.2 diesel as the petroleum component in the winter season to avoid fuel gelling in the fuel lines. The State of Washington DOT and Minnesota Hennepin County also use a lower percentage of biodiesel in the winter season. New York City operates B20 and B50 in its city fleets from March to December and switches to B5 in January and February to avoid fuel gelling problems.

The survey results about biodiesel cold weather related problems suggested that biodiesel blends can be operated year round in most of the states by developing a cold weather management plan, such as, adding cold flow additives, using lower biodiesel blend levels, and/or blending in a certain percentage of No.1 diesel with the biodiesel fuel in winter to improve its cold flow properties.

3.2.8 Fuel Storage and Handling

The biodiesel fleet users were asked if they have experienced any biodiesel fuel storage problems. Potential problems with storage and handling of biodiesel are also discussed in sections 2.3.2 and 2.3.3. The majority of fleets stated that they did not make any changes in their fuel storage routines to accommodate biodiesel fuel and experienced no biodiesel fuel storage problems. The Las Vegas Water District, the Salt Lake City Airport, Blue Sky Shipping, the Nevada Clark County School District, and the state of Oregon DOT observed incidental microbial growth in the biodiesel fuel storage tank. The Clark County School District, Blue Sky Shipping, and the Oregon DOT stated that algae growth problems disappeared after the fuel storage tanks were cleaned and biocides were added. Grand Teton National Park, Blue Sky Shipping, the Clark County School District, the New Jersey Medford Township School District, Arlington County Virginia, the Washington State King County Metro, Georgia Power Company, the Oregon State

DOT, the Arizona DOT and the North Carolina DOT have increased biodiesel fuel tank and storage tank maintenance procedures. They include an increase in fuel dispenser filter changing, more rigid tank cleaning, monitoring fuel storage tanks and fuels, and adding winter additives and biocide. Picture Rocks National Seashore kept their supply of B100 in portable drums so that the fuel can be warmed up before splash blending during the winter season.

Biodiesel fuel has a shorter storage life than petroleum diesel. The National Biodiesel Board recommends that B100 should be stored no more than six months. A common practice among the biodiesel users from this survey is that they usually do not store biodiesel more than 120 days. Some biodiesel users indicated that they were very careful not to fuel vehicles or machines that are likely to sit unused for periods of more than 30 days.

3.2.9 Biodiesel fuel Quality

A very important issue associated with biodiesel implementation is biodiesel fuel quality. The Medford Township School District reported one incidence of developing solid particles in their fuel storage tank due to poor fuel quality. The city of Portland and the Nevada Clark County School District reported that filters were clogged due to excessive glycerin in the biodiesel. The state of North Carolina DOT fleet management team emphasized that it is very important to obtain biodiesel from the biodiesel producers compliant with BQ-9000 to minimize filer plugging and storage problems. BQ-9000 is a cooperative and voluntary program initiated by NBB for the accreditation of producers and marketers of biodiesel fuel to ensure good quality of fuel, as discussed in Section 2.3.4. Some other biodiesel users stated it is important to obtain B100 biodiesel conformed meeting ASTM D6751. A list of biodiesel refueling stations in California is provided in the Appendix C.

Table 3-3. Survey Results from Biodiesel Fleet Operators

	Assateague Island, MD	Biscayne, FL	National Capitol, DC	Pictured Rocks, MI
When did you start?	2002	2004	1998	2000
Still Using?				
Feedstock?	Don't know	Rape Methyl Ester, Yellow Grease	Soy Methyl Ester	Soy Methyl Ester
Biodiesel Blend Level?		B100		
Petroleum component?	#2 year round	None	#2 diesel	Blend of 50% #1 + 50% #2
How is it blended?	At terminal + "splash mixed"		At terminal + "splash mixed"	Blended in storage tanks
Changes to storage routine?	No	Keep less in stock.	N/A	No
Cold storage?	No changes needed.	No changes needed.	No changes needed	Yes
Storage Problems?				
Types of engines	All diesel in fleet	Other diesel equipment	All diesel engines in fleet	All diesel engines in fleet
Use Year Around?				
Gal/week	Est. 250	450	200	80
Price difference?	$1.59/gal for B20	$1.00/gal		$0.15
Filter problems? Blend level?	None	Filters plugging at the engine	Unusual residue: gel	Unusual residue: sludge
Filter problems persist?		Abated	Not Yet	One time occurrence
What kind of filters?		Multiple types of filters	Don't know	One type: paper
Weather problems?	None	None	None	None
Power difference?	No	Less	No	More
Change in fuel mileage?	Not measured	Not measured	No change noted	Not measured
Fuel system problems?	Not monitored	Seals+injectors fail more frequently	gel from HUM bugs	Not monitored
Engine oil analysis?	No changes noted.	No changes noted	No changes noted	No changes noted
Lubricant degradation?				
Oil change interval?	No change.	Only when main engine seals fail	No	No
Elastomer seal problem?		Yes		
Abnormal engine wear?				
Other Maintenance issues?	No	Day tank floats stick on engine	Yes	No
Type of exhaust and aftertreatment? Problems?				

	Grand Teton, WY	Yellowstone, WY	Redwood NP, CA	Glacier NP, MT
When did you start?	2000	1995	2005	2003
Still Using?			Yes	Yes, only for summer
Feedstock?	Soy Methyl Ester	Other	Don't know	Don't know
Biodiesel Blend Level?			B20-B80	B20
Petroleum component?	#1 (Nov-Feb), Blend 50% #1 + 50% #2	None	#2 Year round	#1 Oct.-April
How is it blended?	At terminal + "splash mixed"	At terminal + "splash mixed"	Don't know	Blended in tank
Changes to storage routine?	Monitor fuel storage tanks + fuels	No	No	No
Cold storage?	No changes needed	No changes needed	No changes needed	No changes needed
Storage Problems?			NA	
Types of engines	All diesel engines in the fleet	All diesel engines in fleet	Off-road machinery	Road Maintenance truck
Use Year Around?			NA	No, too cold in winter
Gal/week	1300	4000	200	500
Price difference?	$0.18	None	$o.30	$ 0.50
Filter problems? Blend level?	No Problems	No problems	No	Filter plugging in winter
Filter problems persist?				Abated after stop in winter
What kind of filters?				Napa filter for chevy duramax
Weather problems?		None	None	Filter plugging, fuel gelling in supply line
Power difference?	Less	No	No	Less
Change in fuel mileage?	Increase of 0.2 MPG on Kenworth ECMs	Zero change in MPG	No change noted	No change noted
Fuel system problems?	Routinely monitored, but no differences	Routinely monitored, but no difference	Not monitored	Fuel pump and injector changed at 80,000 miles
Engine oil analysis?	No changes noted	No changes noted	No changes noted	No changes noted
Lubricant degradation?			NA	Not monitored
Oil change interval?	No	No	No	No
Elastomer seal problems?			NA	No
Abnormal engine wear?			NA	No
Other Maintenance issues?	No	No	No	No
Type of exhaust and aftertreatment? Problems?				

	Channel Island NP, CA	Salt Lake City International Airport , UT	Sky Harbor International Airport (Phoenix), AZ	St. Louis Airport, MO
When did you start?	2000	2003	2007	Test in1997, all units in 2001
Still Using?	Yes, major reduction	No, end in 2008	Yes	Yes
Feedstock?	Soy methyl ester, yellow grease	Rape methyl ester	Don't know	Soy Methyl Ester
Biodiesel Blend Level?	B5-B99.9	B20-B80	B20	B5-B50
Petroleum component?	#2 Year round	#2 Year round	#2 Year round	#2 Year round
How is it blended?	At fueling vehicle fuel tank	At terminal + "splash mixed"	At terminal + "splash mixed"	At terminal
Changes to storage?	No	No	No	No
Cold storage?	No changes needed	No changes needed	No changes needed	No changes needed
Storage Problems?	NA	Yes, algae	No	No
Types of engines	Off-road machinery (boat)	All diesel engines in fleet	Road maintenance truck, off-road machinery, standby generators	Off-road maintenance truck, machinery, airport equipment
Use Year Around?	Yes	Yes	Yes	Yes
Gal/week	5-10	NA	1150	1000-2000
Price difference?	$0.34	$0.10	$0.02 less	unknown
Filter problems? Blend level?	Filters plugging at the engine	Filters plugging at the engine and pump	No	No problems
Filter problems persist?	Abated	Stopped using biodiesel		
What kind of filters?	NA	Multiple types of filters		
Weather problems?	None	Yes, filters plugging under cold conditions	None	None
Power difference?	No	No	No	No
Change in fuel mileage?	Not measured	No change noted	No change noted	No change noted
Fuel system durability problems?	Routinely monitored, but no difference	Routinely monitored, but no difference	Routinely monitored, but no difference	Longer life for pumps and injectors
Engine oil analysis?	No changes noted	No changes noted	No changes noted	No oil analysis
Lubricant degradation?	NA	NA	No	No
Oil change interval?	No	No	No	No
Elastomer seal problem?	NA	NA	No	No
Abnormal engine wear?	NA	NA	No	No
Other Maintenance issues?	No	No	No	No
Type of exhaust and aftertreatment? Problems?				No

	Hoover, AL	Hennepin County, MN	Arlington County, VA	Las Vegas Clean Cities
When did you start?	2006	2003	2002	2001
Still Using?	Yes,	Yes	Yes	
Feedstock?	Soy methyl ester , yellow grease	Soy methyl ester	Soy methyl ester	Soy Methyl Ester
Biodiesel Blend Level?	B20, B100	B5-B20	B5 (Oct-April), B20 (April-Oct.)	
Petroleum component?	#2 Year round	Blend 50% #1 + 50% #2	#2 Year round	#2 Year round
How is it blended?	At terminal + "splash mixed"	At terminal + "splash mixed"	At terminal + "splash mixed"	At terminal + "splash mixed"
Changes to storage?	No	No	Yes	
Cold storage?	No changes needed	No changes needed	More frequent anti-gelling additives	No changes needed
Storage Problems?	NA	No	NO	
Types of engines	All diesel engines in fleet	Road maintenance truck, off-road machinery, ambulance	School buses, fire trucks, heavy and medium duty trucks	All diesel engines in fleet
Use Year Around?	Yes	Yes	Yes	Yes
Gal/week	500	B5 7700, B20 7700	12,500	6000
Price difference?	No	$0.05-0.10 more	+/- 10% , volatile	$0.08
Filter problems? Blend level?	No problems	Filters plugging at the pump with B20	Filters plugging at the engine and pump	No problems
Filter problems persist?			Abated	
What kind of filters?			Don't know	
Cold weather problems?	None	Yes	Filter plugging	None
Power difference?	No	No	No	More
Change in fuel mileage?	No change noted	No change noted	No change noted	Increase of .6 MPG
Fuel system durability problems?	NA	Routinely monitored, but no difference	Routinely monitored, but no difference	Routinely monitored, but no difference
Engine oil analysis?	No changes noted	No changes noted	No changes noted	No changes noted
Lubricant degradation?	NA	No	Not monitorted	
Oil change interval?	No	No	No	No
Elastomer seal problem?	NA	NA	Not monitored	
Abnormal engine wear?	NA	No	No	
Other Maintenance issues?	No	No	No	No
Type of exhaust and aftertreatment? Problems?	No aftertreatment devices, no problems	Some with DPF, no problems	No	

	Las Vegas Water District, NV	Carnegie Mellon University, PA	Alcoa Mill Products, IA	Georgia Power Company, GA
When did you start?	2001	2007	2001	1999
Still Using?	Yes	Yes	Yes	Yes
Feedstock?	Soy methyl ester	Don't know	Soy methyl ester	Soy Methyl Ester
Biodiesel Blend Level?	B20	B20	B20	B20
Petroleum component?	#2 Year round	#2 Year round	#2 Year round	#2 Year round
How is it blended?	At terminal + "splash mixed"	Don't know	At terminal + tanker truck delivered	At terminal + "splash mixed"
Changes to storage routine?	No, once the system is cleaned, it stays clean	Yes	No	No
Cold storage?	No	No changes needed	No changes needed	Yes, winter additive in northern part of state
Storage Problems?	Yes, bio growth in 2001	NA	No	No
Types of engines	Road maintenance truck, off-road machinery, all diesel engines fleet	All diesel engines in fleet	All diesel engines in fleet, generator	Road maintenance truck, off-road machinery
Use Year Around?	Yes	NA	Yes	Yes
Gal/week	7,600	Unknown	5,000	15,000
Price difference?	Ever changing, more and less	Unknown	Vary	$0.05-0.25
Filter problems? Reasons? Blend level?	Filters plugging at the engine, bio growth	No problems	No, problems	Filters plugging at pump , gunk already in tank
Filter problems persists?	Abated			Abated
What kind of filters?	Multiple types of filters			Multiple types of filters
Cold weather problems?	Filters plugging at engine	None	None	None
Power difference?	No	No	No	No
Change in fuel mileage?	Not measured	Not measured	No change noted	No change noted
Fuel system durability problems?	Routinely monitored, but no difference	Not monitored	Routinely monitored, but no difference	Routinely monitored, but no difference
Engine oil analysis?	No	No changes noted	Less wear of engine	No changes noted
Lubricant degradation?	No	NA	No	No
Oil change interval?	No	No	No	No
Elastomer seal problem?	No	NA	Yes, only with Perkins engines	No
Abnormal engine wear?	No	NA	No	No
Other Maintenance issues?	No	No	No	No
Type of exhaust and aftertreatment? Problems?	No		No aftertreatment devices, no problems	

	Blue Sky Shipping, CA	Clark County School District, NV	Deer Valley School District, AZ	St. Johns Public Schools, MI
When did you start?	2003	2001	1998	2001
Still Using?	Yes	Yes	Yes	Yes
Feedstock?	Soy methyl ester and yellow grease	Soy methyl ester and yellow grease	Soy Methyl Ester	Soy Methyl Ester, some yellow grease
Biodiesel Blend Level?	B50-B100	B5, B20, B100	B5	B20
Petroleum component?	#2 Year round	#2 Year round	#2 Year round	#2, 10%#1+90% #2 in winter
How is it blended?	At fueling vehicle fuel tank	At terminal + "splash mixed"	At terminal + "splash mixed"	At terminal + tanker truck delivered
Changes to storage routine?	Yes, use biocide to prevent algae growth	Yes, yearly tank treatment and cleaning	No	No
Storage Problems?	Yes, algae growth	Bio growth at beginning, after cleaning, no problems	No	No
Types of engines	Pickups and flatbed trucks	All diesel engines in fleet	School buses	Road maintenance trucks, off-road machinery, school buses
Use Year Around?	Yes	Yes	Yes	Yes
Gal/week	B50-75 100; B100 125	B5 100,000; B100 5,000	B5 8,000	500
Price difference?	$1.00	$0.004	$0.05-0.25	$0-0.20 more
Filter problems? Reasons? Blend level?	Filters plugging at pump and engines, algae	Filters plugging at engines, glycerin, algae, B20	Filters plugging at pump and engines at beginning	No
Filter problems persist?	Abated	Abated	Once it is clean, no problem	
What kind of filters?	Multiple types of filters	Multiple types of filters	Don't know	
Cold weather problems?	No	None	None	None
Power difference?	No	No	No	More
Change in fuel mileage?	No change noted	No change noted	No change noted	1.5mile/g
Fuel system durability problems?	Routinely monitored, but no difference	Routinely monitored, but no difference	Not monitored	Routinely monitored, but no difference
Engine oil analysis?	No changes noted	No changes noted	No changes noted	Less engine wear
Lubricant degradation?	Not monitored	No	No	No
Oil change interval?	No	No	No	Longer
Elastomer seal problem?	No	No	No	No
Abnormal engine wear?	No	No	No	No
Other Maintenance issues?	Replaced return fuel lines on Cummins engines	No	No	Maintenance cost reduced
Type of exhaust and aftertreatment? Problems?		DPF and OXC, no problems	No aftertreatment devices, no problems	Some with aftertreat ment devices, no problems with B20

	Hardin County School District, KY	Kenton County School District, KY	Medford Township Board of Education, NJ	North Carolina DOT
When did you start?	2003	2004	1997	1995
Still Using?	No, Stopped in 2003	Stopped in 2005, price reason	Yes	Yes
Feedstock?	Don't know	Soy methyl ester, yellow grease and tallow	Soy methyl ester	Soy methyl ester , yellow grease
Biodiesel Blend Level?	B20	B20	B10, B20	B20
Petroleum component?	#2 Year round	#1 Dec., Jan. and Feb.	#2 Year round	NA
How is it blended?	Don't know	At terminal + tanker truck delivered	At terminal + pipe line delivered	At terminal + "splash mixed"
Changes to storage routine?	No	No	Yes, yearly tank treatment and cleaning	Yes, increased tank maintenance procedure
Cold storage?	No changes needed	No changes needed	No changes needed	Yes, winter additives
Storage Problems?	No	No	Solid material developed in cold winter due to fuel quality	Fuel dispenser filter clogged due to glycerin
Types of engines	School buses	School buses	All diesel engines in fleet	All diesel engines in fleet
Use Year Around?	Yes	No, gel problem in winter	Yes	Yes
Gal/week	NA	400	3,000	220,000
Price difference?	$0.30	NA	$0.20 more	$0.09-0.40 higher, average $0.28
Filter problems? Reasons? Blend level?	Abated after monthly oil and filter change	No	Filters plugging at pump and engine with B20	Filters plugging at pump and the engine initially, B20
Filter problems persist?			Abated	No, after first two tanks
What kind of filters?	Multiple types of filters		Multiple types of filters	Multiple types of filters
Cold weather problems?	None	Gelling of fuel in supply lines	None	No
Power difference?	No	No	No	No
Change in fuel mileage?	No change noted	No change noted	No change noted	No change noted
Fuel system durability problems?	Not monitored	Not monitored	Routinely monitored, but no difference	Routinely monitored, but no difference
Engine oil analysis?	No changes noted	No changes noted	No changes noted	No changes noted
Lubricant degradation?	Not monitored	Not monitored	NA	Yes, from ULSD
Oil change interval?	No	No	No	No
Elastomer seal problem?	No	No	NA	No
Abnormal engine wear?	No	No	NA	No
Other Maintenance issues?	No	No	$0.02/mile service cost reduction	No
Type of exhaust and aftertreatment? Problems?			No aftertreatment devices, no problems	Some with aftertreatment, no problems

	Cedar-Rapids Transit, IA	Valley Metro, AZ	King County Metro	Southwest Ohio Regional Transit Authority (w)
When did you start?	2008	2007	2005	2001
Still Using?	Yes	Yes	No, stopped in 2008	Yes
Feedstock?	Soy methyl ester	Don't know	Soy methyl ester and canola	Soy Methyl Ester
Biodiesel Blend Level?	B10	B20	B20	B20
Petroleum component?	#1 oct. - March	#1 Dec., Jan. and Feb.	#2 Year round	#2, 10%#1+80% #2
How is it blended?	At terminal + tanker truck delivered	At terminal + tanker truck delivered	At terminal + "splash mixed"	At terminal + tanker truck delivered
Changes to storage routine?	No	No	Yes , more rigid tank cleaning and fuel filtering and metering	No
Cold storage?	No changes needed	No changes needed	No changes needed	No changes needed
Storage Problems?	No	No	Could not use in cold weather	No
Types of engines	All diesel engines in fleet	Transit buses	Trucks and buses	Road maintenance trucks, off-road machinery, school buses
Use Year Around?	Yes	Yes	NA	Yes
Gal/week	NA	380	NA	500
Price difference?	$0.40	$0.07	NA	$0-0.20
Filter problems? Reasons? Blend level?	No	No	Filters plugging at pump and the engine,	No
Filter problems persist?			Abated after changing filters more	
What kind of filters?			Multiple types of filters	
Cold weather problems?	NA	None	Filters plugging and gelling of fuel in supply lines	None
Power difference?	No	No	No	More
Change in fuel mileage?	No change noted	No change noted	3% loss	1.5mile/g
Fuel system durability problems?	Not monitored	Not monitored	Routinely monitored, but no difference	Routinely monitored, but no difference
Engine oil analysis?	No changes noted	No changes noted	No changes noted	Less engine wear
Lubricant degradation?	Not monitored	Not monitored	NA	No
Oil change interval?	No	No	No	Longer
Elastomer seal problem?	No	No	NA	No
Abnormal engine wear?	No	No	NA	No
Other Maintenance issues?	No	No	No	No
Type of exhaust and aftertreatment? Problems?				

	Oregon DOT	Maryland DOT	Arizona DOT	Illinois DOT
When did you start?	2004	2007	2000	2002
Still Using?	Yes	Yes	Yes	Yes
Feedstock?	Don't know	Don't know	Soy Methyl Ester	Soy Methyl Ester
Biodiesel Blend Level?	B5, B20, B40	B5	B5, B20	B5, B10, and small amount of B20
Petroleum component?	#2, 50%#1+50% #2	#2 Year round	#2 Year round	#2, 30%#1+70% #2 (Dec-Feb)
How is it blended?	At terminal + tanker truck delivered, splashed mixed	At terminal + tanker truck delivered	At terminal + tanker truck delivered	At terminal + "splash mixed"
Changes to storage routine?	Yes, increased maintenance procedure	No	Yes , increase fuel dispenser filter change during start-up	No
Changes for cold storage?	Yes, increased winterization	No changes needed	stop from Nov-Mar in snow area	No changes needed
Storage Problems?	Yes, cold flow and contamination	No	No	No
Types of engines	All diesel engines in fleet	Road maintenance trucks, off-road machinery, all diesel engines in fleet	Road maintenance trucks, off-road machinery, high way fleet	Road maintenance trucks, off-road machinery
Use Year Around?	Yes	Yes	Yes	Yes
Gal/week	B2 350; B5 6,000; B20 2,600	380	B5 > 2500; B20 > 1500	NA
Price difference?	B99 is $1.00 more than ULSD	$0.07	$0.36	NA
Filter problems? Reasons? Blend level?	Filters plugging at pump and the engine, wax residue B2-B40	No	No	Filters plugging at pump and the engine with B20
Filter problems persist?	Abated after cleaning the tank			Yes
What kind of filters?	Multiple types of filters			Don't know
Cold weather problems?	Gelling of fuel in supply lines	None	No	None
Power difference?	No	No	No	No
Change in fuel mileage?	Not measured	No change noted	No change noted	No change noted
Fuel system durability problems?	Routinely monitored, but no difference	Not monitored	Routinely monitored, but no difference	Routinely monitored, but no difference
Engine oil analysis?	No changes noted	No changes noted	No changes noted	No changes noted
Lubricant degradation?	Not monitored	Not monitored	No	Not monitored
Oil change interval?	No	No	No	NA
Elastomer seal problem?	No	No	NA	No
Abnormal engine wear?	No	No	NA	No
Other Maintenance issues?	No	No	No	No
Type of exhaust and aftertreatment? Problems?	Some with DPF, no problems		No aftertreatment devices, no problems	No aftertreatment devices, no problems

	Washington State DOT	United States Postal Service	Portland, OR	New York City Park, NY
When did you start?	2005	Yes	2004	2005
Still Using?	Yes	1995	Yes	Yes
Feedstock?	Soy methyl ester , yellow grease	Don't know	Rape methyl ester, tallow, canola	Soy methyl ester
Biodiesel Blend Level?	B10-B20		B5, B20, B50, B99	B5, B20, B50, mostly B20
Petroleum component?	#1year round		#2 Year round	#2 Year round
How is it blended?	At terminal + "splash mixed"	Don't know	At terminal + tanker truck delivered	At terminal + tanker truck delivered
Changes to storage routine?	No	Yes, more frequent maintenance and cleaning	No	No
Changes for cold storage?	Yes, use lower % of blend	No changes needed	Additional filtering at fuel dispensers	No changes needed
Storage Problems?	Yes, fuel degradation	No changes needed	No	No
Types of engines	Road maintenance trucks, off-road machinery, all diesel	Delivery vehicles	Road maintenance truck	All diesel engines in fleet
Use Year Around?	Yes		Yes	Yes
Gal/week	3,500	4000	B5 1,000; B20 10,000; B100 1,000	B5 8,000; B20, 1360; B50 384
Price difference?	$2-$4 for B20-B80	10% more	B5, $0.15; B20, $0.60; B99, $3.16	Vary
Filter problems? Reasons? Blend level?	Filters plugging at pump and the engine caused by algae, B20	Filters plugging at the engine	Filters plugging at the engine and pump, excessive glycerin	No
Filter problems persist?	Persisted	persists	Abated	
What kind of filters?	Multiple types of filters	Mack Tractor Fuel System	Multiple types of filters	
Cold weather problems?	Filters plugging and gelling of fuel in supply lines	None	B99 changed to B50 (Nov.- April.)	No start, but infrequent ; B20 to B5 (Jan, Feb)
Power difference?	No	No	Less	No
Change in fuel mileage?	Lower	No change noted	Not measured	No change noted
Fuel system durability problems?	Yes, fuel injector problems	Fuel injector wear	Fuel pump and injector problems	Not Monitored
Engine oil analysis?	No changes noted	No changes noted	Engine oil dilution	No changes noted
Lubricant degradation?	Not monitored		No	No
Oil change interval?	No	No	More frequently	No
Elastomer seal problem?	No		No	No
Abnormal engine wear?	Fuel injector problems		No	No
Other Maintenance issues?	No	Yes	No	Toro mower riders need special filter
Typ of exhaust and aftertreatment? Problems?	DPF, OXC, no problems			Some with DPF or OXC, no problems

4 Other Biodiesel In-Use Experiences

4.1 Government Implementation Programs

Some of the most important experiences with the use of biodiesel are related to programs initiated by state, national, or regional governmental agencies. These programs generally include mandates for wider spread use of biodiesel in the general diesel market, although the blend levels are fairly low.

Biodiesel has been used to the greatest extent in Europe, where European Union (EU) directive 2003-20-EC (EU, 2003) established progress targets for the implementation of biofuels into transportation fuels. The directive targeted the use of 2% biofuels, calculated on the basis of energy content, in the fuels by 2005, ramping up to 5.75% by 2010. The EU is also aspiring for a 20% share of renewables in the EU´s energy mix and a minimum target of 10% for biofuels in transportation by 2020, although this is not a legal requirement (EU, 2007a,b). The 2% mandate has already been achieved, but Hoekman et al. (2009) estimated that the 5.75% mandate would not be met until 2012, as opposed to 2010, due to feedstock shortages and high prices. Germany, France, and Italy are the largest consumers and producers of biodiesel in Europe (Bozbas, 2008).

Biodiesel blends being utilized in Europe must meet the European diesel fuel standard EN 590:2009, which includes biodiesel fuel blends up to B7. The biodiesel itself must comply with EN14214. These standards are similar to those for the US, but have some differences, including a stability standard that is not included in the D975 specification. The biodiesel blends used in Europe are predominantly lower blends (B5 and lower), although B100 was used extensively in Germany until 2006 due to a loophole in the tax law that specified fuel taxes only for mineral fuels, which biodiesel is not (Bozbas, 2008). Overall, it appears that there have not been significant issues with the implementation of biodiesel on vehicle performance and durability in Europe.

Biodiesel has also been promoted in a number of states in the United States. This includes Minnesota (2005) and Washington that have active mandates, Illinois that has a special tax incentive (NBB, 2003), and Massachusetts, Louisiana, New Mexico, Oregon, and Pennsylvania that have passed mandates that are expected to be in place by July 2010 (NBB, 2009). Biodiesel use in Minnesota began in 2005 with a B2 requirement. As discussed above, the implementation of biodiesel in the first winter encountered a number of issues due to off-spec biodiesel that required the temporary suspension of the mandate in conjunction with an implementation of fuel quality monitoring requirements. Subsequent to the initial problems, there do not appear to be any significant negative impacts on vehicles related to biodiesel use. Minnesota has now adopted legislation designed to increase the percentage of biodiesel to B20 by 2015 (NBB, 2008). In Illinois, biodiesel in the form of B11 has become common, since special tax advantages have been provided to blends above B10 (NBB, 2003). Although no large problems have been reported with this program, it is worth noting that in the most recent B20 blend study conducted by NREL, several B11 samples were found to be mislabeled as B20 (Alleman and McCormick, 2008). This survey was conducted prior to the implementation of pump labeling requirements from the Federal Trade Commission that took effect in December of 2008.

4.2 Biodiesel Fleet Demonstration Studies

The use of biodiesel has increased considerably in recent years and there is a growing body of data on the use of biodiesel in fleet or vehicle applications. Still, the information available on fleet operations in the peer review literature or obtained through a systematic study is more limited. This section focuses predominantly on fleet studies where the use of biodiesel in a fleet was systematically controlled, monitored, and subsequently reported.

In Europe, as part of the "Stability of Biodiesel" (BIOSTAB) study (2003), a four vehicle fleet was run for 19 months on a B5 made from used frying oil. Over 40,000 miles of operation was accumulated with the B5 fuel. The engine lubricant, fuel delivery system, and fuel storage system did not show any significant deterioration. Some problems were reported with the oxidation stability of the bottom layers of the storage vessel significantly exceeding the EN 590 limits, however.

NREL evaluated a fleet of 9 buses from the Regional Transportation District of Denver over a period of 2 years (Proc et al., 2005, Proc, 2006). The buses were 2000 Orion Vs equipped with Cummins ISM engines. Five of the buses were operated on B20 while the other 4 were operated on regular petroleum diesel and each bus accumulated approximately 100,000 miles over the same bus route. The in-use data showed no difference in the average fuel economy, although laboratory testing showed a 2% reduction in fuel economy for the B20 vehicles. Engine and fuel system related maintenance costs were nearly identical between the two groups with the exception of repairs needed during the final month on one of the B20 buses. There were some problems with fuel filter plugging, which was likely caused by out of specification biodiesel, although the exact cause was not determined. The actual biodiesel levels in the delivered loads showed an erratically varying biodiesel content. The fuel samples collected from the vehicles, on the other hand, were near or at B20 indicating a more complete blending occurred during delivery and in offloading of the fuel. Oil analyses indicated no additional wear metals and significantly lower soot levels from the use of B20.

NREL worked with the St. Louis Metro on an in-use evaluation of biodiesel in their transit buses (Proc, 2006). The objective of this demonstration project was to compare B20 and ULSD buses in terms of fuel economy, vehicle maintenance, engine performance, component wear, and lube oil performance. The study included 15 2002 Gillig Phantom buses with Cummins ISM engines, with 8 operating on B20 and 7 operating on ULSD. The buses were initially monitored for a period of one year from October 2006 to September 2007. Throughout the operation period, documentation was collected for vehicle performance and operation (mileage accumulation, fuel use, maintenance costs) and subsequently analyzed. The study showed the B20 group exhibited similar reliability to the ULSD group (measured by road calls), but B20 group had higher incidence of fuel filter and fuel injector replacements. Lube oil analysis indicates soot and wear metals were notably lower with B20 group. Viscosity and corrosive metals were generally less degraded from ULSD use, but the results from the B20 group were still "in grade".

Biodiesel has been used extensively by the US Postal Service (USPS), with usage near the 1,000,000 gallon level per year during 2003 and 2004. In 2004, 929 USPS cargo vans, truck tractors, spotter tractors, and step were using B20. The USPS removed engines and fuel systems from 8 vehicles that were operated on biodiesel, including four 1993 cargo vans and four 1996

Mack tractors (Fraer et al., 2005). The engines represented 4 years and more than 600,000 miles of use on B20. The engines and fuel system components were disassembled, inspected, and evaluated. The results indicated little differences between the operational and maintenance costs for the B20 and petroleum fueled groups and no differences in wear or other issues were noted during engine teardown. The Mack tractors did have a higher frequency of fuel filter and injector nozzle replacement, as well as some sludge build-up on the rocker arms. Similar observations were not found for the Ford vehicles, which could be related to the smaller volume of fuel circulated in these smaller engines. Additional work was done with the USPS with a new cargo van to evaluate and compare fuel economy and maintenance over a one year period (Proc, 2006)

The military is the largest user of biodiesel in the United States. One B20 demonstration was conducted at Scott Air Force Base in Illinois (Kearny and Benton, 2002). No filter plugging or other operational problems were reported during this demonstration. Fuel quality was monitored throughout the study, and several loads of B20 exceeded the military limit on solids content, with many containing visible solids.

Arlington County, Virginia, implemented B20 in 138 school buses and other vehicles in 2001 (Atheron). By 2004, Arlington County was consuming 602,000 gallons of B20 a year. During the years of B20 use, maintenance personnel reported no increase in problems attributed to B20 use. Arlington County reported no operational other changes for storing and dispensing B20. Before the initial B20 was shipped to the site, the diesel storage tanks were thoroughly cleaned and fuel filters on the dispensers were switched to a size less than 10 microns. Arlington County reported there was no unexpected rise of filter plugging and fuel system problems were slightly reduced. Arlington experienced no cold weather-related operating problems after additives were added to the B20. A user survey from Arlington County, Virginia is included under section 3.

In Las Vegas, the Clark County School District has extensively used B20 with its buses (Clean Cities News, 2004b). The school district began with a small pilot project in 2001. Beginning with the 2002-2003 school year, the school district began running almost all of its 1,140 buses on biodiesel. The biodiesel is supplied by Biodiesel Industries, which utilizes locally obtained restaurant grease from the hotel-casino industry. A user survey from the Las Vegas Clean Cities is included under section 3.

A feasibility study for the use of biodiesel in the Caltrans fleet was conducted by the University of California, at Riverside (UCR) (Miller, 2008). Twenty-one diesel vehicles were fueled on B20 and operated over their typical driving conditions during the one-year demonstration period. The vehicles operated in the demonstration program included construction equipment, utility trucks and dump trucks with model years from 1986 to 2003. A total of 10,807 gallons of B20 were consumed during the initial six months of the program. No special precautions were taken with respect to cleaning of fuel storage tanks, vehicle fuel tanks, or accelerated changes of fuel filters. The demonstration pilot program results showed no adverse maintenance issues were identified. The fuel was utilized in a variety of ambient conditions from desert heat to colder mountain weather operation. Equipment operators and drivers all indicated that performance was comparable to that of typical diesel fuel.

UCR conducted an experimental pilot program using a 5% biodiesel blend with the Riverside County Waste Management District (RCWMD) (Durbin, 2006). The demonstration lasted for a period of 9 months and included between one to six vehicles. The demonstration was conducted in two separate periods of 2 months and 7 months, respectively. A total of 1000 gallons of B5 was used over the course of the demonstration program. The demonstration vehicles experienced no adverse effects as a result of the fuel use. This includes vehicle maintenance, fuel mileage and driver satisfaction. The B5 blend was utilized with two vehicles that were equipped with diesel particulate filters (DPFs). No adverse effects, such as increased backpressure or the need to clean the DPF, were observed for the DPFs used with the B5.

DNC Parks and Resorts at Yosemite, Inc. (DNC) conducted a small demonstration program in conjunction with UCR and CARB (Durbin, 2005). The demonstration was conducted over two week long periods, including one in the summer and one in the winter. The in-service DNC fleet used approximately 1,000 gallons of B20 fuel during these two test periods. During these periods, the buses experienced no significant operational or maintenance problems with biodiesel or biodiesel storage. Emissions measurements were also performed using a portable emissions measurement system (PEMS) and at CARB's Heavy-Duty Vehicle I/M Development Laboratory in Stockton, CA.

In 2002, the Kentucky Division of Energy provided grant funding to offset the incremental cost of biodiesel for several school districts (Clean Cities News, 2004a). Six school systems signed up to utilize the fuel with blend levels of B2 or B20. A total of 300 buses in this project used B20 and 50 used B2. The fuel was supplied by in state suppliers, Griffin Industries for the yellow grease and the Kentucky Soybean Board for the soy-based biodiesel. The cost differential for the B20 is approximately $0.15 to $0.20 more for B20 than regular diesel.

Several small size biodiesel fleet studies were conducted back in the 1990s. NREL surveyed and compiled biodiesel demonstration projects that were conducted between 1992 and 1997 (Tyson, 1998). This included demonstrations in a steamboat on the Ohio River, a bus at the 1996 Atlanta Olympic Games, and a work boat in Virginia. The Ohio Department of Transportation had a demonstration project of B20 in five dump trucks/snow plows (Malcosky and Wald, 1997). The focus of the study was on maintaining fuel quality and a total of 60,000 miles of B20 operation was accumulated. A two year trial was conducted in Minnesota on-road maintenance vehicles using B20 (Bickel and Strebig, 2000). The vehicles utilized 25,000 gallons of B20 and operated for approximately 135,000 miles. The B20 use showed no adverse effects on fuel economy, no deposits or wear in the fuel system, and the oil analysis showed no unusual engine wear or fuel dilution.

The University of Idaho in conjunction with various partners, such as the Pacific Northwest and Alaska Regional Bioenergy Program, conducted several demonstrations (Chase, 2000). This include running a Dodge pick-up truck for over 90,000 miles on 100% Canola ethyl ester (Taberski, 1998) and running a Kenworth class 8 truck equipped with a Caterpillar 3406 engine for 200,000 miles with B50. Oil analyses, compression, injector tests, and engine and fuel pump teardown inspections did not show any excessive wear or deterioration resulting from biodiesel use.

4.3 Biodiesel User Surveys in the literature

Humburg et al. (2004) conducted a survey of biodiesel fleet use in different state Department of Transportation (DOT) agencies in an effort to gather performance, storage and economic information with biodiesel fuel use. They found at that time 31 states were either actively considering, using or had tested biodiesel blends in or for their fleets. Nineteen states reported program experience with the use or testing of biodiesel in their fleet operations. A number of the states reported increases in filter plugging with the biodiesel use, although all of the states indicated the problems were resolved when the filters were replaced. Problems with using biodiesel in cold weather were not found to be widespread, although Iowa and Ohio did report filter plugging during cold weather periods. Eight states reported no changes in fuel pump or injector durability when biodiesel blended fuel was operated, while nine states did not monitor this characteristic.

In 2007, University of Missouri conducted a biodiesel implementation program survey in the states DOT with the goal to provide best practices for implementing a biodiesel program in Missouri DOT (Grasman, 2007). Thirty-six of forty-nine states responded to the survey. Nineteen states have a state-funded biodiesel program. The study showed most states that have state programs are able to use biodiesel year round, although some states lower the biodiesel fuel blend level to B2 or B5 in the winter season. The states that operate biodiesel year round are illustrated in Figure 4-1. The survey results indicated that almost all states had fuel filter clogging problems in the initial days of biodiesel usage due to the solvent effect of biodiesel. However, with continued use of biodiesel, fuel filter plugging problems abated since biodiesel did not generate new deposits. The survey results also showed there were no significant material compatibility issues with B20 and lower blends. In terms of storage tank maintenance, the states that responded followed different practices to keep tanks free of moisture and microbial growth. Some states used biocide to prevent microbial growth. Some agencies stated water traps must be used with the fuel filters at the storage tank to prevent water from entering into a vehicle's fuel system. The study recommended that procuring biodiesel of best quality is the most critical step in implementing biodiesel. At the time of this survey, seven states had requirements that biodiesel suppliers be BQ 9000 certified and three states had partial BQ 9000 certification compliance with many other suppliers going for the certification. Figure 4-2 shows the states that require BQ-9000 accreditation.

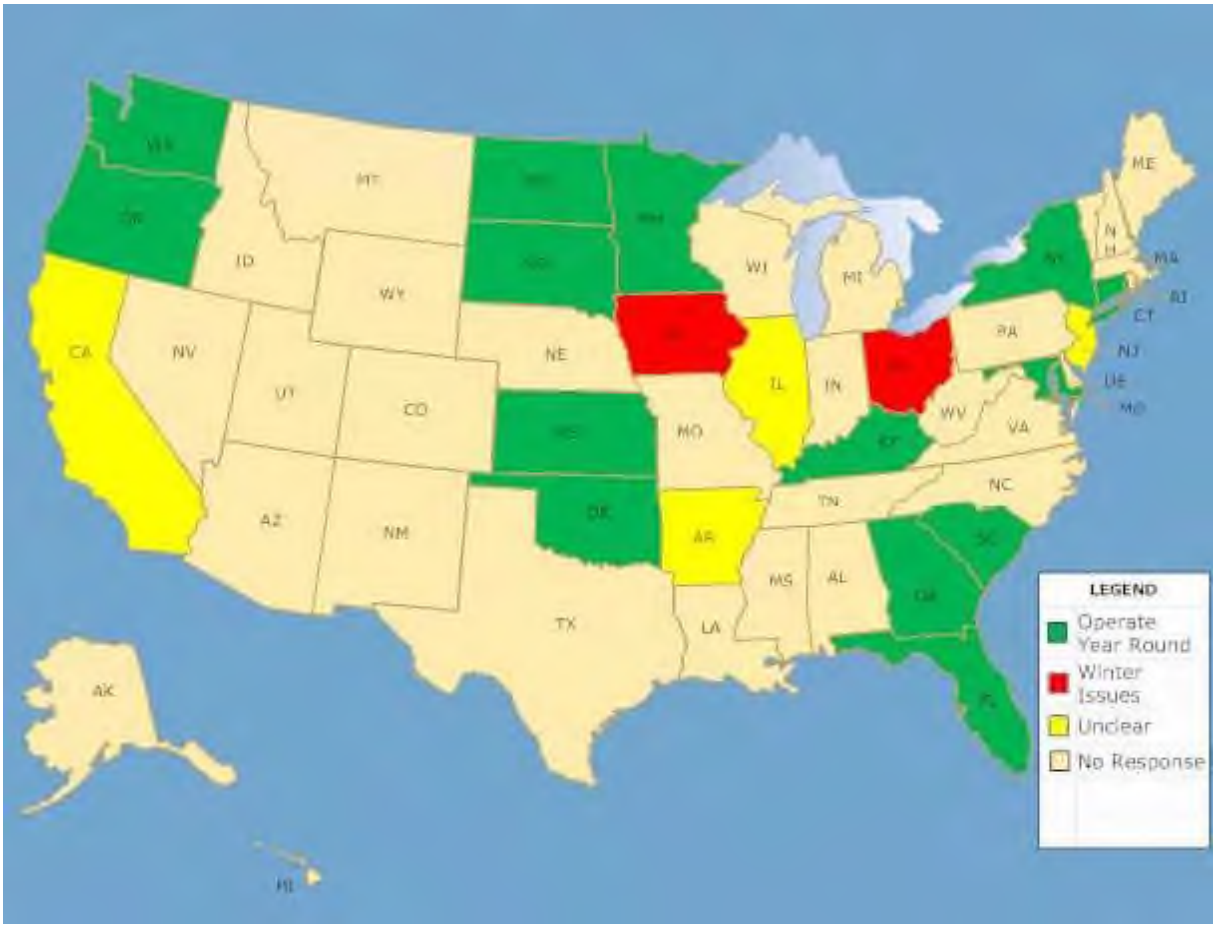

Figure 4-1. States Operate Biodiesel Blend Fuels Year Round

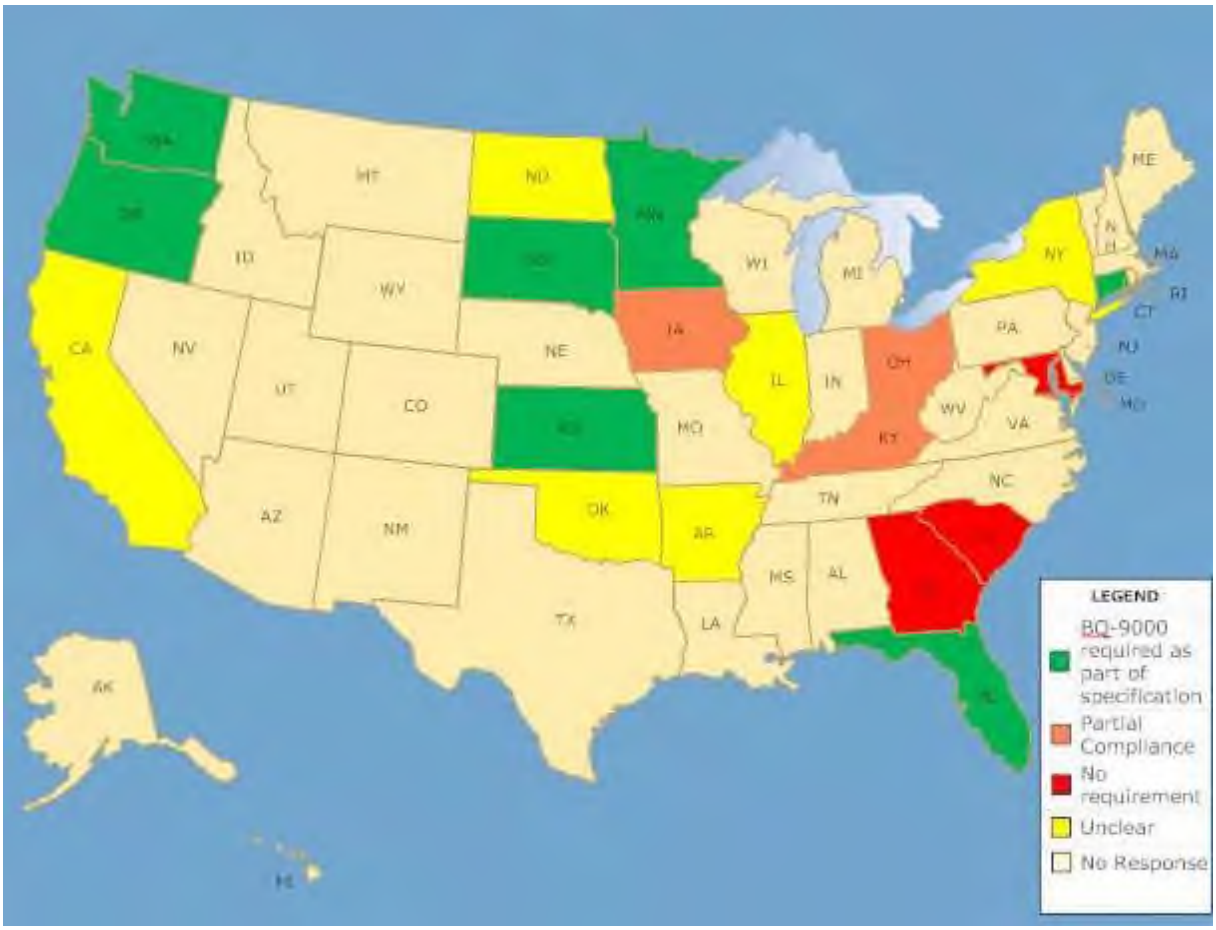

Figure 4-2. States Require BQ9000

5 Other Research Study of Biodiesel Fleet Durability

5.1 Earlier Studies

Several engine durability tests have been conducted over the years on biodiesel, although data in this area is still limited. The National Biodiesel Board conducted two 1,000-hour durability studies in the mid-1990s. One was conducted with a 6V-92TA DDC engine on a B20 soy-biodiesel blend (Fosseen, 1995). Several problems were noted in this study including deterioration of fuel injectors, serious ring damage, and problems with fuel atomization. The authors speculated that the B20 may not have been the cause of these issues, although this was based on similarities of the B20 and regular diesel in viscosity, heat output, and specific gravity. The other study used a B20 soy-based biodiesel with a Cummins N14 engine (Tao, 1995). This test was terminated after only 650 hours due to fuel pump deposits, filter plugging, and early pump failure. Composition tests showed the deposits included fatty acid esters.

Peterson et al. (1999) conducted a 1000 hour engine durability test using blends of B25, B50, and B100 of a hydrogenated soy-ethyl ester on a 3 cylinder diesel engine. They did observe some filter plugging during the winter months for the biodiesel blends. They concluded that cold weather operation required heating for the fuel tanks and fuel filters. The engine operated on the biodiesel blend showed equal or reduced wear metals and was much cleaner internally when operated on 100% biodiesel. Perkins et al. (1991) did a 1,000 hour engine test with three identical engines powered by 100% rapeseed methyl ester (RME) biodiesel, B50, and straight diesel. RME use was similar to that of D2 for engine performance, wear metals in the lubricating oil, and injector deposits. Zhang et al. (1998) conducted additional tests on these engines and fuels over a 200-hour test. They found a slight decrease in power for the neat RME, but no significant differences in engine wear. Fuel dilution was also noted, but only during the first 50 hours of the test. Ali and Hanna (1996) conducted a 200 hour engine test on a Cummins N14-410 using a blend of 13% beef tallow, 7% ethanol, and 80% diesel. The engine suffered some injection failures during the test, but these were traced back to cracks in the injector tips due to improper installation.

In a 1997 study (Williams Labs, 1997b), a series of fuel pump tests were conducted on two B20 blends. One of the blends was made with an on-spec B100, while the other sample exceeded the limits on the acid specification. The tests with the on-spec B20 showed no problems. The test with the off-spec B20 had problems with pressure drops across the filters and deposits. The authors indicated that these issues could be attributed to the high acid value, although Waynick (2006) in a subsequent review indicated that differences in the total glycerin may have contributed to the observations.

Some injector tests were performed with a Cummins L-10 injector using three B20 blends, a B100, and three diesel fuels (Stavinoha, 2000). The test results showed that while the average flow loss was never a problem for any of the fuels, the visual deposit rating of the injectors showed that each B20 fuel was significantly worse than either the B100 or the corresponding petroleum diesel.

5.2 More Recent Studies

The impacts of biodiesel on seals, gaskets, hoses, and metal surfaces that the fuels contact are one of the several concerns for biodiesel users. Frame and McCormick (2005) conducted a set of tests of evaluate the compatibility of elastomers with biodiesel and ethanol diesel blends. For this test, six different elastomers were soaked in a certification diesel fuel, a 15% ethanol blend, and a B20 blend for 500 hours at 40°C. The elastomers were subsequently examined for thickness, diameter, and break load before and after being soaked in the fuels. The elastomers soaked in the B20 blend did not show any significant differences from those soaked in the diesel fuel and it was concluded that all the tested elastomers were compatible with B20. Some effects were observed for the ethanol blends, and it was concluded that these elastomers may not be fully compatible with ethanol blends for all applications.

The Associated Octel Company Limited of the United Kingdom (Terry et al., 2005, 2006) conducted several tests on biodiesel blends to evaluate system durability as part of the CRC-2a program. This included elastomer immersion tests, injector wear tests and fuel pump wear tests with B5 and B20 blends using rapeseed methyl ester and soy methyl ester, including some highly oxidized blends. The elastomer immersion tests showed that fluorocarbon elastomers of medium to high fluorine content were the most compatible with the biodiesel blends. Some of the other candidate materials showed generally good resistance to changes in physical properties, but exceeded the typical acceptable levels of degradation in one or more tests. The injector wear tests over the 500-hour test period and fuel pump lubricity tests both showed satisfactory performance for the typical B5 and B20 blends. The injector and fuel pump wear tests for the highly oxidized B20 blend had to be cut short due to filter blockage, however. Tests on a common rail test rig also showed that the test fuels provided adequate lubricity over the range of fuels and test pumps evaluated.

Thomas et al. (2007) from Dupont conducted a study to evaluate fluorocarbon elastomer compatibility with B20 and B100 fuels contaminated with water and/or free fatty acids. The research study results showed that several fluorocarbon elastomers were damaged by both contaminated B20 and B100. The study indicated that it is necessary to improve the formula of elastomers in order to meet material compatibility requirements under the worst fuel conditions.

More recently, Caprotti et al. (2007) conducted a series of tests to study the impacts rapeseed methyl ester (RME) biodiesel and biodiesel blends on the performance of fuel injectors of future light-duty, indirect injection engines. The test results indicated that RME could generate higher levels of deposits on swirl chamber and future Euro V type rail injection systems.

5.3 Engine Oil Dilution

Engine oil dilution is an important issue for both petroleum diesel and biodiesel applications. While both fuels can dilute the engine oil to some extent, the petroleum diesel more readily volatizes off for the oil and eventually is released through the ventilation system. Biodiesel, on the other hand, has a higher and narrower boiling range and also tends to form larger droplets exiting the fuel injectors (Kotrba, 2009). Thus, biodiesel tends more to remain in a liquid form on the cylinder wall, and to bypass the rings into the crankcase. Once in the crankcase, the

biodiesel can degrade to form organic acids that can react with metals and start to polymerize, leading to deposits.

NREL has conducted some research to better understand the possible impacts of oil dilution on emissions control systems (Thornton et al. 2009). Engines with DPF-type aftertreatment systems utilize fuel injection either late in the combustion cycle or downstream of the engine, providing additional potential pathways for oil dilution. The NREL research focused on a light-duty engine platform with two different emission control systems: a NO_x adsorber catalyst (NAC) with a DPF, and a selective-catalytic reduction catalyst (SCR) with a DPF. The NAC/DPF system utilized late in-cylinder fuel injection for regeneration. For the NAC/DPF system, biodiesel oil dilution levels ranged from 5-10% for oil samples ranging from 50 to 150 hours in age. For the SCR/DPF system, biodiesel oil dilution ranged from <4-8% for oil samples ranging from 50 to 75 hours in age. The impacts of this biodiesel oil dilution on engine performance and the emissions control system showed no differences from those for a baseline diesel.

Chevron Oronite has developed an oil additive to help mitigate the impacts associated with biodiesel oil dilution in the engine crankcase (Morcos, 2009). The engine oil additive is designed to counteract the effect of the organic acids and to prevent oxidation of the FAME and formation of deposits.

6 Conclusions and Recommendations

The California Air Resources Board is conducting a comprehensive study to better characterize potential issues with the use of biodiesel with respect to durability or emissions as part of its efforts to implement a low carbon fuel standard. This study focuses on the potential impacts of biodiesel on vehicle/engine durability and implementation and represents one element of this comprehensive study. This study included a comprehensive literature review and a survey of biodiesel fleet users to study the impacts of biodiesel, biodiesel blend level, and feedstocks on engine durability, fuel systems, material compatibility, exhaust and aftertreatment systems, cold weather problems, storage and handling, and cost. Forty agencies responded to the survey including national park sites, airports, county and municipal fleets, school districts, private companies, state Department of Transportation agencies, various city transit agencies, as well as a few other users of biodiesel, such as the US Postal Service.

A summary of the conclusions of this study for the primary topic areas is provided as follows:

Biodiesel Production and Use

- The use of biodiesel has increased considerably in the United States from a production level of 2 million gallons per year in 2000 to 700 million gallons per year in 2008.
- Biodiesel is also extensively used throughout Europe, where governmental initiatives have promoted the use of up to B5 in the marketplace. This program has been largely successful in terms of impacts to the vehicle fleet, and indicates that biodiesel can be implemented successfully into the larger marketplace. It is suggested that the fuel specifications and monitoring and enforcement programs in Europe be used as a guide for the implementation of biofuels in California. Several states have either implemented or are in the process of implementing programs to increase the use of biodiesel and other biofuels. These programs should be monitored as they are being implemented, especially as higher levels of biodiesel become required. It is important to note that issues with fuel quality were identified during the initial implementation of the biodiesel program in Minnesota, reinforcing the important of monitoring and enforcement programs.
- In our survey, some national parks and cities have been using biodiesel blends dating back to 1995. The amount of biodiesel fuel used by the surveyed fleet users varied significantly, ranging from 80 to 220,000 gallons/week.
- The most common biodiesel blend fuel used by the surveyed fleets is B20. The biodiesel fuel blend level varies significantly among the biodiesel fleet users, ranging from B5 to B100. Soy methyl ester is the major feedstock for biodiesel fuel. Some users also use Biodiesel fuels made from other feedstocks, such as rape methyl ester, yellow grease and tallow.

Fuel Quality and Warranty Issues

- ASTM fuel quality standards are in place for the addition of up to 5% biodiesel in traditional petroleum diesel (ASTM D975), for biodiesel blends between 6 and 20% (ASTM D7467), and for the pure biodiesel (B100) use to produce these blends (ASTM D6751). These specifications are comparable to those used in Europe for blends of B7

(EN 590) and for the B100 (EN 14214), although the European specifications include a stability requirement in EN 590 for the low level blends.

- All engine manufacturers provide certain warranties on the engines powered by biodiesel. While B5 is accepted by all engine manufactures, the use of biodiesel at blend levels higher than B5 depends on the specific engine manufacturer and engine being used. The potential impact of regulations requiring blend levels higher than 5% should be examined by CARB as part of their regulation implementation. A consortium of diesel fuel injection equipment manufacturers ("FIE Manufacturers") has also expressed concern that ASTM D975 does not include a stability requirement and that the stability induction period of 6 hours for ASTM D7467 for B6 to B20 blends is considerably less than the induction period of 20 hours required in EN 590 for blends up to B7.
- Fuel quality surveys have shown issues with fuel quality in the recent past. Fuel quality appears to be improving in the more recent surveys, although there still appears to be issues with biodiesel produced by smaller production volume facilities. The biodiesel industry has developed a BQ-9000 program that is a quality control and monitoring program for biodiesel producers and distributors. This program includes requirements for the testing and monitoring of fuel quality for all participants who receive accreditation. It is suggested that the appropriate California agency should evaluate developing fuel quality monitoring and enforcement programs for biodiesel that are comparable to those used for other motor vehicle fuels. This could include provisions such as more aggressive enforcement during the initial implementation to ensure no off-spec fuel enters the marketplace and specifications for a subset of fuel parameters that will be tested on each batch of biodiesel produced, similar to the BQ-9000 requirements.
- Biodiesel fleet surveys strongly suggested that all biodiesel users obtain B100 and B20 or lower blends complying to ASTM D6751 and ASTM D7461 standards, respectively. Procuring biodiesel fuel from BQ 9000 certified producers and distributors was considered a critical step by those surveyed to ensuring successful implementation of a biodiesel program at a fleet level.

Fuel Storage, Handling, and Operational Issues

- Biodiesel fuel has solvent properties and will dissolve the deposits accumulated in the vehicles run petroleum diesel before and fuel storage tanks used to store petroleum diesel previously. The dissolved sediments can cause filter plugging at the initial stage of biodiesel use. Once the filters have been changed and fuel storage tanks are thoroughly cleaned, filter plugging problems should be resolved. It is suggested that extra fuel filters be maintained on hand during initial use, as filter plugging is more likely in the first few tanks. Filter plugging was more prevalent at biodiesel levels of B20 and above, although other factors, such as the quality of the biodiesel, microbial growth, the cleanliness of the fuel tank, and other components, also appear to be important factors.
- In practice, most users of B20 typically do not clean their fuel tanks prior to use since the solvent effect for B20 is not as strong as that for B100. The effects of B100 would be greater so it is recommended that the fuel tanks be cleaned and extra precautions be taken with straight B100 use. Most biodiesel users in the survey did not make any changes in fuel storage routine to accommodate biodiesel fuel. Nine of the surveyed biodiesel users increased biodiesel fuel tank and storage tank maintenance procedures, including more

rigid storage tanks, increasing fuel dispensing filter changes, and adding winter flow additives and biocides.

- Of the 40 agencies surveyed, 22 recorded fuel filter plugging issues, while 18 reported no fuel filter plugging issues. Filter plugging appeared to be mostly at levels of B20 or higher, and 18 of the agencies reporting fuel filter plugging indicated that the problems were encountered only during the initial period when biodiesel fuel was introduced to tanks previously storing diesel fuel. Persistent filter plugging was reported by four agencies.
- The oxidation stability of biodiesel is generally worse than that for petroleum diesel fuel. Studies have shown that B100 that does not contain a synthetic antioxidant will begin to oxidize immediately during storage and that B100 should not be stored more than several months unless it is additized. Studies have shown that phenolic–based antioxidants are effective in preventing acid and insoluble formation during storage. The National Biodiesel Board recommends a six month storage life for B100 meeting ASTM specifications.
- Other potential issues associated with biodiesel storage include microbial growth, water contamination, and gelling in cold climates (discussed below). These problems can be mitigated with the cleaning of fuel tanks, the use of biocides, and the use of filters on the fuel dispensers (e.g., 10 micron) that can prevent water from entering a vehicle's fueling system.
- Microbial growth in the biodiesel fuel storage tanks was found by several biodiesel users that were surveyed. Biocides can be used to prevent microbial growth in the biodiesel fuel storage tank.
- Given the likelihood that large numbers of fuel distributors and storage facilities will not make changes to accommodate the biodiesel fuel, it is suggested that precautions be taken or advisements be provided on potential issues, at least during the initial stages of widespread implementation.

Material Compatibility and Engine Durability Issues

- Biodiesel can cause degradation, softening, or seeping through some hoses, gaskets, seals, elastomers, glues, and plastics with prolonged exposure. Concern about elastomer degradation is more critical for applications where B100 is used, as opposed to B20. Nitrile rubber compounds, polypropylene, polyvinyl, and Tygon are particularly vulnerable to B100. Materials such as Teflon, Viton, fluorinated plastics, and Nylon, on the other hand, are compatible with biodiesel. Older vehicles manufactured before approximately 1993 are more likely to contain materials that could be affected by B100 over longer periods.
- For use at more standard B20 and lower blend levels, NREL (2009) indicates that fleet experience over the last 10 years has shown that material compatibility issues are minimal, even for elastomers made of materials such as nitrile rubber that are not compatible with higher biodiesel blends.
- Studies where elastomers are soaked in biodiesel have shown fluorocarbon elastomers with good compatibility for biodiesel. A range of other candidate materials have also

shown good compatibility with biodiesel, although some studies have shown an exceedance of acceptable levels of degradation for some properties or higher levels of degradation when the elastomers are tested with off-spec biodiesel.

- For the survey, nearly all fleets reported no elastomer seal problems associated with biodiesel use, with twenty-four biodiesel fleet users answering the question. While one user noticed early elastomer failure when an engine was operated by B100, two other users recorded no elastomer failure problems with B100 use. Some users did not respond to the materials compatibility question.
- Biodiesel provides improved lubricity compared to petroleum diesel but also higher viscosity that can impact injection quality and fuel atomization. Laboratory or bench-scale tests have shown that biodiesel meeting specifications is generally acceptable from a durability standpoint, although there were a number of failures on tests where oxidized or otherwise off-spec biodiesel was used.
- The surveys showed no adverse effects of biodiesel on the vehicles or engine wear. Some biodiesel fleet users observed less engine wear after implementing biodiesel, which could be due to biodiesel's enhanced lubricity.
- More than 50% biodiesel fleet survey respondents reported that fuel pumps or injector systems were routinely monitored and no difference in the fleet fuel pump or injector durability was found with blend levels ranging from B5 to B100 when comparing biodiesel to petroleum diesel. Six biodiesel fleet users recorded more frequent fuel injector or fuel pump failures, but with no clear blend level effect. The St. Louis Airport observed longer fuel pump and injector life after biodiesel was adopted.
- Biodiesel fleet repair and maintenance survey results indicated that biodiesel has minimal impact on fleet exhaust and aftertreatment systems. Two biodiesel fleet users documented a slightly vehicle maintenance cost reduction attributed to biodiesel, but this was not a finding from a systematic study.
- Since biodiesel has a higher and narrower boiling range, it tends to form larger droplets exiting the fuel injectors. This can lead to greater amounts of biodiesel remaining on the cylinder wall where it can bypass the rings into the crankcase and cause oil dilution. In some limited studies, NREL found increased oil dilution for light-duty vehicles with aftertreatment after 50-150 hours of operation, but this did not have an impact on engine or emissions performance. Most of the surveyed fleets indicated they did not change their engine oil change interval after adopting biodiesel fuel.

Biodiesel Impacts of Vehicle Performance

- Biodiesel contains approximately 11% oxygen by weight, which accounts for its lower heating value and lower volumetric energy content. The energy content difference between petroleum diesel and biodiesel depends on a variety of factors including the feedstock and refining processing and blend level. NREL (2009) gives the energy of biodiesel (B100) as roughly 8% less than diesel No. 2. The EMA suggests that B100 may lower engine power approximately 5-7% lower compared to petroleum diesel fuel. Biodiesel blends of B20 and lower typically do not result in observable power loss or reduction in fuel economy.

- Biodiesel did not have a negative impact on engine power for the fleet users surveyed. Thirty-one biodiesel users reported no engine power difference was noticed when biodiesel fuel was used. Four fleet users recorded less power on biodiesel compared with conventional diesel. On the contrary, four biodiesel users observed increases in engine power.
- Twenty-seven biodiesel fleet users reported no change in fuel economy while using biodiesel fuel. A smaller subset of four biodiesel users found that fleet fuel mileage was reduced as much as 1.5 mile/gallon when using biodiesel. Other users did not track the fuel mileage.
- It should be noted that these comparisons are more qualitative, as they are not necessarily based on systematic studies and the results were not analyzed statistically, and, in the case of power, are not based on actual measurements.

Cold Weather Issues

- Biodiesel has a higher cloud point and pour point compared to petroleum diesel, which can lead to operational issues in cold climates, such as filter plugging due to wax buildup or reduced fuel flow.
- Biodiesel blend fuel can be operated year round in most of the states by developing a cold weather management plan, such as using lower percentages of biodiesel, adding cold flow additives, and blending in certain percentages of No.1 diesel with the biodiesel fuel in winter to improve the fuel cold flow property. NREL (2009) suggests that users specify to the blend supplier that the fuel remains crystal free at temperatures down to -14°F for regions that experience more severe winter seasons.
- Nine surveyed biodiesel fleet users observed fuel gelling and filter plugging in cold winter conditions and Glacier National Park indicated they only operate biodiesel in the summer.

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Appendix A – Brief Survey of Biodiesel Use

As a part of a research effort involving the use of biodiesel blends in California, we are surveying biodiesel users about their experience with biodiesel. We understand that your time is valuable and have tried to structure this survey to allow you to proceed quickly. Once complete, we request that it be saved and E-mailed to mjiang@cert.ucr.edu.

Thank you for your time,
Michelle Jiang
University of California, Riverside
CE-CERT

Please answer by marking the appropriate box preceding the appropriate response. In questions requesting additional input you may type in the underline area as necessary. Don't worry about formatting your response.

1) Has your department used or tested the use of biodiesel fuel?

☐ Yes **Proceed to question 4.**

☐ No

2) Has your department ***studied or considered*** using biodiesel or a biodiesel blend?

☐ Yes

☐ No **In this case you need proceed no further, but please forward this survey with your marked responses to** mjiang@cert.ucr.edu **Thank you for your time**.

3) If you considered a biodiesel blend but elected not to use it at this time, what factors affected your organization's decision? Check all that apply.

☐ a) Cost of fuel

☐ b) Questions regarding storage

☐ c) Questions regarding performance or endurance

☐ d) Questions regarding cold weather properties of the fuel

☐ e) Other factors ?

4) What year did you start to use biodiesel blends?

Are you still using biodiesel?

☐ a) Yes

☐ b) No. When did you end? ___

What were the reasons to stop using biodiesel? ____

5) What is the feedstock for the biodiesel blend used?

- ☐ a) Soy Methyl Ester?
- ☐ b) Rape Methyl Ester?
- ☐ c) Yellow Grease?
- ☐ d) Walnut?
- ☐ e) Tallow?
- ☐ f) Other? What is it? ___
- ☐ g) Don't know

6) What is your biodiesel blend level ___

7) What is your petroleum component?

- ☐ a) #2 diesel year around
- ☐ b) #1 diesel during the months of ___
- ☐ c) Blend of ___#1 and ___#2 during the months of

8) How is your fuel blended?

- ☐ a) Blended at a terminal and delivered by pipeline?
- ☐ b) Blended at a terminal and delivered by tanker truck?
- ☐ c) Blended at a terminal and "splash mixed" in a tanker delivery vehicle?
- ☐ d) Blended in your storage tank(s)?
- ☐ e) Blended at the point of fueling in the vehicle fuel tank?
- ☐ f) Don't know

9) Have you made changes in your fuel storage routines to accommodate biodiesel blends?

- ☐ a) Yes. If so, what type of changes? ___
- ☐ a) No.

10) Have you made changes in your storage system to accommodate biodiesel blends in cold weather storage differently?

- ☐ a) Yes. ..... What type of accommodations? ___
- ☐ b) No changes needed.

11) Have you experienced any biodiesel fuel storage problems?

☐ a) Yes. ..... What type of problem? ___

☐ b) No.

12) What type of diesel engines are utilizing the biodiesel blend fuel?

☐ a) Road maintenance trucks

☐ b) Off-road machinery (tractors, payloaders, skidsteers, etc)

☐ c) Other diesel equipment. What type of equipment? ___

☐ d) All diesel engines in the fleet. What type of fleet? ___

What type of engines? ___

13) Do you use biodiesel blend fuel year around?

☐ a) Yes. .....

☐ b) No. What are the reasons? ___

14) How many gallons of biodiesel are being used per week?

B2 ___ B5___ B20___ B100___

15) What is the price difference per gallon using biodiesel rather regular diesel? ___

16) Since beginning the use of biodiesel, have you experienced any documented or anecdotal problems with filtering fuel that you consider in excess of your experience with petroleum fuel?

☐ a) No problems? **Skip to question 19**

☐ b) Filters plugging at the pump?

☐ c) Filters plugging at the engine?

☐ d) Any unusual residue or material noted in the filter or fuel system?

If so... can you describe the type of material that appeared to plug the filter?

___

e) Were you able to identify the material causing filter problems? ___

17) If you encountered fuel filter problems, have you found these problems to persist (repeat), or have they abated? ___

18) If you encountered fuel filter problems, did the problems occur across different fuel filter types, or in a particular filter type and system?

☐ a) Multiple types of filters

☐ b) One type. What were the types of filters? ___

☐ c) Don't know.

19) Have you encountered any weather problems?

☐ a) No cold weather problems,

☐ b) Plugging of engine fuel filters under very cold conditions

☐ c) Gelling of fuel in vehicle supply lines

☐ d) Other problems that you associate with cold weather?

What were the problems? ___

20) Have you or your operators noted any differences in vehicle power when using biodiesel?

☐ Yes ☐ More or ☐ Less

☐ No

21) Have you noticed or documented any change in vehicle fuel efficiency (mileage) since beginning the use of biodiesel or biodiesel blends?

☐ a) Not measured

☐ b) No change noted

☐ c) Documented difference of ___ mpg when compared to historical use of petroleum

22) Have you noticed or documented any differences in fuel pump or injector durability in vehicles using biodiesel or biodiesel blends?

☐ a) Not monitored.

☐ b) Fuel systems routinely monitored, but no differences detected.

☐ c) Fuel pump problems have been encountered. Please describe in a few words the types of problems: ___

☐ d) Fuel injector problems have been encountered. What type of problems? ___

23) Have you noticed any differences in used engine oil analyses from engines operating on a biodiesel blend?

☐ a) No changes noted.

☐ b) Change in viscosity

☐ c) Change in oil acidity

☐ d) Engine oil dilution

☐ e) Change in other oil characteristics. What are they?___

☐ f) Change in indicated engine wear? ☐ More or ☐ Less

24) Have you noticed any engine lubricant degradation problems?

☐ a) Not monitored.

☐ b) Yes. What type of problems?___

☐ c) No.

25) Have you found reason to alter your oil change interval in vehicles utilizing a biodiesel blend?

☐ a) No.

☐ b) How has your oil maintenance schedule changed? ___

26) Have you noticed any elastomer seal problems in the engine fuel system?

☐ a) Yes. What type of problems?___

☐ b) No.

27) Have you noticed any abnormal engine wear problems?

☐ a) Yes. What type of problems?___

☐ b) No.

28) Have you encountered any other vehicle maintenance issues that you believe to be associated with the use of biodiesel blend in your fleet?

☐ Yes Please briefly describe the problem or issue. ___

☐ No

29) Have you encountered any vehicle exhaust system issues that you believe to be associated with the use of biodiesel blend in your fleet?

☐ Not monitored.

☐ Yes Please briefly describe the problem or issue. ___

☐ No

29) Have you encountered any vehicle aftertreatment device problems that you believe to be associated with the use of biodiesel blend in your fleet?

☐ Not monitored.

☐ Yes Please briefly describe the problem or issue. ___

☐ No

30) How many fleets are using biodiesel blend in your organization?

B2 ___ B5___ B20___ B100___

31) What is your organization name? ___

Thank you for taking the time to answer these questions. Please forward this marked survey as an attachment to mjiang@cert.ucr.edu.

Appendix B-Biodiesel Fleet Survey Contact Information

Biodiesel Fleet User	State	Contact Name	E-Mail	Phone
Channel Islands National Park		Kent Bullard, Fleet manager	Kent_Bullard@nps.gov	805-658-5745
Redwood National and State Parks	California	Rick Mayle	richard_mayle@nps.gov	707 464 6101
Glacier National Park		Frank Thompson	frank_thompson@nps.gov	406-888-7967
Salt Lake City International Airport	Utah	Ron Dallinga, Fleet Manager	ronald.dallinga.slcgov.com	801-531-4535
Sky Harbor International Airport, Phoenix	AZ	Claire Simeone Stern, Public Information Officer City of Phoenix Aviation Department	Claire.Stern@phoenix.gov	602-683-3804
St. Louis Lamber International Airport		Mike Bernich, Fleet Manager	mabernich@flystl.com	314-5515322
The Fort Leonard Wood (FLW) U.S. Army base in Waynesville, Missouri	MO	Gordon Whorton, FLW Motor Transport Officer	Gordon.J.whorton@us.army.mil	573 596 0130 ext 64535
Carneige Mellon University		Barbara Kviz,Environmental Coordinator Facilities Management Services	bk11@andrew.cmu.edu	412 268 7858
Las Vegas Water District	NV	James Morwood, Fleet Services Manager	James.Morwood@lvwwd.com	702-259-8103, 702-249-2495 (cell)
Deer Valley School District, Phoenix	AZ	Mike Morrissey	Mike Morrissey <Mike.Morrissey@dvusd.org>	602 467 5060
St. Johns Public School District	MI	Wayne Hettler, Director of Transportation	Hettler_w@stjohns.edzone.net	989-227-5333
Clark County School District	Nevada	Frank Giordano, director of vehicle maintenance,	fcgiordano@interact.ccds.net	702-799-6890 ext 5004
		Scott Castleberry, fleet Maintenance manager	pscastleberry@interact.cc.net	702-799-6890 ext 5305
Medford Township Board of Education	New Jersy	Joe Biluclk, Director of Operations and Technology	Joseph Biluck <jbiluck@medford.k12.nj.us>	609-953-5841 ext. 1507
Hardin County School District, KY	Kentucky	John, Director of Transportation	Tracey.stranahan@hardin.kyschools.us	270-769-8800
Kenton County Schools, KY	Kentucky	Gerald Turner, Director of Transportation	Gerald.Turner@kenton.kyschools.us	859-356-5164
Arlington County, VA	VA	John Morrill, Energy Manager, Arlington Couty Department of Environmental Services	John Morrill <Jmorrill@arlingtonva.us>	703-228-4426
Portland City	OR	John Hunt, City Fleet Manager	jhunt@ci.portland.or.us	503-823-4302
Hennepin County, MN	MN	Mike Judkins, Fleet Manager	michael.judkins@co.hennepin.mn.us	612-596-0272
Hoover Municipal Government	Alabama	David Lindon, Fleet Management Director	"Lindon, Dave" <lindond@ci.hoover.al.us>	
New York City Department of Park and Recreation	NY	Keith Kerman, Mahanth Joishy	Kerman, Keith <Keith.Kerman@parks.nyc.gov>	212-360-8223
Arizona Department of Transportation	AZ	Dennis Halachoff, Fleet Management Manager	Dennis Halachoff <DHalachoff@azdot.gov>	602-712-7284
Missouri Department of Transportation	MO	Jeannie Wilson, Fleet Manager	jeannie.wilson@modot.mo.gov	573-526-1199
New York City DOT	NY	Mark Simon	msimon@dot.nyc.gov	212-487-6818
Kansas DOT	KS	Peter Carttar	cattar@ksdot.org	785-296-7184
Oregon DOT	OR	Forrest Gitt,Supply Operations Support Services Supervisor	GITT Forrest O <Forrest.O.GITT@odot.state.or.us>	503-986-2736
New Jersy DOT	NJ	Satish Balh	satish.bahl@dot.state.nj.us	609-530-2204
North Carolina DOT	NC	Drew Harbinson, Equipment Director	"Harbinson, Drew" <dharbinson@ncdot.gov>	919-733-8000
Washington DOT	WA	Greg Hansen, Transportation Equipment Manager	hanseng@wsdot.wa.gov	360-705-7862, 360-480-2124(cell)
Maryland DOT	Maryland	Larry Thomas, Fleet Manager, Department of Operation	lthomas3@mdot.state.md.us	410-865-1139
Illinoise DOT		Tim Peters, Equipment Engineer	tim.peters@illinois.gov	217-782-8419
Cedar-Rapids Transit,Iowa	IA	Dennis Hogan, Fleet Manager, Fleet Services Division	D.Hogan@Cedar-Rapids.org	319-538-1065
Valley Metro Transit (Phoenix)	AZ	David Hyink, Program Supervisor	Dhyink@Valleymetro.org	480-287-5983
King County Metro Transit (Seattle)	WA	Jim Boon, Vehicle Maintenance Manager	Jim.Boon@kingcounty.gov	206-684-1498, 206-947-0297 (cell)
Southwest Ohio Metro Transit	OH	Donald Devore	Ddvore@go-metro.com	523-632-7612
Blue Sky Shipping	CA	Charles Whitwam, Company Owner	info@blueskyshipping.com	415-485-6767
Georgia Power	GA	Anthony G Saxon, Fleet Materials Supervisor	Saxon, Tony G. (Fleet Services) <AGSAXON@southernco.com>	404-608-5629, 678-371-9650 (cell)
Alcoa			Susan W. Leuthauser, susan.leuthauser@alcoa.com	563-459-2459, 563-271-1760 (cell)

Appendix C –Biodiesel Refueling Stations in California

Name	Location	Contact	Phone	Blend	Notes
Baker Commodities, Inc.	4020 Bandini Boulevard Los Angeles, CA 90023	Fred Wellons	323-268-2801		biodiesel plants
Bay Area Diablo Petroleum	3575 Pacheco Blvd Martinez, CA 94553	Jack Bene	925-372-5406	B100	Any Blend. Open 7-4 M-F.
BioFuel Oasis	2465 - 4th St. Berkeley, CA 94710	Gretchen Zimmerman	510-665-5509	B99	Sun, Tue, Thur. 4-8pm, Fri & Sat 10-5pm, cash/credit
Eel River Fuels, Inc	220 East Highway 20 Upper Lake, CA 95485	Woody	707-275-2045	B99	7 Days a week; cash/credit
Eel River Fuels, Inc	3371 North State Street Ukiah, CA 95482	Ken Foster / Al Banta	707-462-5554	B99	24/7, All Major Credir Cards
Golden Gate Petroleum	421 J Street Arcata, CA 95521	Patrick Okeefe	707-826-9268	B20	Credit/Cash & Open Mon-Sun 6am -9pm
ITL, Inc.	8330 Atlantic Ave Cudahy, CA 90201	Mike Rohrer	323-562-3230	B20	Premium B20 at the pump – cash/credit
Imperial Western Products	PO Box 1765 Indio, CA 92202	Bob Clark	760-398-0815		
McCormix Corporation	22 N. Calle Ceasar Chavez, Santa Barbara, CA 93117	Ken Olsen	805-963-9366	B20, B100	6am - 5pm
McCormix Corporation	55 Depot Rd. Goleta, CA 92117	Ken Olsen	805-963-9366	B20	24 hours a day
Mountain Feed and Farm Supply	9550 Highway 9 Ben Lomond, CA 95005	Jorah Roussopoulos	831-336-8876		Mon.-Sat. 9-6 Sun. 10-2
Pacific Biofuel	1601 Jarvis Rd Santa Cruz, CA 95065	Ray Newkirk	831-459-6774	B100	Retail purchasers must call ahead
Renner Petroleum/World Energy	76 Bear Canyon Rd. Garberville, CA 95542		707-443-1645	B20	public/no restrictions
RTC Fuels, LLC	4067 El Cajon Blvd. San Diego, CA 92105	Mike McCallen	619-521-2469	B20	
San Francisco Petroleum	4290 Santa Rosa Ave Santa Rosa, CA 95407	Rod Martin	707-586-2765	B100	
Solar Living Institute	13771 South Hwy 101 Hopland, CA 95449		707-744-2017	B100	M-F 8:30 - 5:30 / Sat/Sun 10-5
T.W. Brown Oil	1457 Fleet Ave. Ventura, CA 93003	Ted Brown, Sr.	805-339-2355	B20, B99	
The Biofuel Station	44440 Highway 101 Laytonville, CA 95454	Kimber or Eric	707-984-6818	B100	M-F 9-5
Toro Petroleum Corp	2109 Fremont St Monterey, CA 93940	James Hill	831-424-1691	B100	
Ventura Harbor Marine Fuel, Inc.	1449 Spinnaker Dr. Ventura, CA 93001		805-644-4046	B100	public
Western States Oil	1790 S. 10th San Jose, CA 95112				open 9-5 M-F; cash or credit card
Weststart	48 South Chester Ave Pasadena, CA 91106	Susan Romeo	626-744-5686		
World Energy Alternatives LLC	408 Broad Ste 11B Nevada City, CA 95959	Graham Noyes	530-478-9196		
Yokayo Biofuels	150 Perry Street Ukiah, CA 95482	Kumar Plocher	877-806-0900	B100	M-F 9-5; Cash, Check, MC/Visa