Evaluation of Biodiesel Fuel:

Literature Review

by

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16. Abstract

This document reviews recent literature regarding the usage of biodiesel and biodiesel blend fuel in on-road applications. The report describes some of the principal characteristics of biodiesel and usage experience in and near the State of Montana. Several studies are summarized regarding biodiesel's effects on engine performance and warranties. Storage, handling and transportation requirements are also discussed. The emissions-related impacts of biodiesel on several pollutants are quantified, along with potential effects of these impacts on the state and vehicle users within the state. The legislative environment regarding biodiesel and existing motor fuel taxes – at a Federal level and in other states – is reviewed. Considerations regarding fuel cost and domestic productive capacity are discussed. The report concludes that most technical questions regarding biodiesel appear to be satisfactorily answered; the primary obstacles limiting broader biodiesel implementation relate to cost and user acceptance.

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GLOSSARY OF ABBREVIATIONS

AFV	Alternative Fuel Vehicles
ASTM	American Society of Testing & Materials
BOCLE	Ball on Cylinder Lubricity Evaluator
CAA	Clean Air Act
CFPP	Cold Flow Plug Point
CMSA	Consolidated Metropolitan Statistical Area
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DEQ	Montana Department of Environmental Quality
DI	Direct Injection
DOE	U.S. Department of Energy
EMA	Engine Manufacturers Association
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act
FAME	Fatty Acid Methyl Ester
FAPRI	Food and Agricultural Policy Research Institute
FTP	Federal Test Procedure
GCVTC	Grand Canyon Visibility Transport Commission
GHG	Greenhouse Gas
HC	Hydrocarbons
HFRR	High-Frequency Reciprocating Rig
LDV	Light-Duty Vehicles
MCA	Montana Code Annotated
MDT	Montana Department of Transportation
MECA	Manufacturers of Emission Controls Association
MoDOT	Missouri Department of Transportation
MSA	Metropolitan Statistical Area
NAAQS	National Ambient Air Quality Standards
NCOC	National Carbon Offset Coalition
NO_x	Nitrogen Oxides
OEM	Original Equipment Manufacturers
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
ppm	Parts per million
SIP	State Implementation Plan
SO_2	Sulfur Dioxide
USDA-ERS	U.S. Department of Agriculture Economic Research Service
VMT	Vehicle Miles of Travel
VOC	Volatile Organic Compounds
WRAP	Western Regional Air Partnership

ABSTRACT

This document reviews recent literature regarding the usage of biodiesel and biodiesel blend fuel in on-road applications. The report describes some of the principal characteristics of biodiesel and usage experience in and near the State of Montana. Several studies are summarized regarding biodiesel's effects on engine performance and warranties. Storage, handling and transportation requirements are also discussed. The emissions-related impacts of biodiesel on several pollutants are quantified, along with potential effects of these impacts on the state and vehicle users within the state. The legislative environment regarding biodiesel and existing motor fuel taxes – at a Federal level and in other states – is reviewed. Considerations regarding fuel cost and domestic productive capacity are discussed. The report concludes that most technical questions regarding biodiesel appear to be satisfactorily answered; the primary obstacles limiting broader biodiesel implementation relate to cost and user acceptance.

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1. INTRODUCTION

On February 12, 2003, the Transportation Committee of the Montana House of Representatives heard testimony on House Bill 502, which proposed that all diesel fuel sold for use in internal combustion engines contain at least 2 percent biodiesel fuel by volume. The bill was discussed but tabled by the committee because of "unanswered questions surrounding this relatively new technology." Specific concerns included:

- "the effects of biodiesel blends on engine performance – specifically fuel economy, torque, and power – as compared to diesel;
- cold weather product storage and potential for gelling;
- sulfur, carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxide (NO_x), and other emissions; and
- potential for engine damage." (1)

The Montana Department of Transportation (MDT) was asked by the House Transportation Committee to initiate a research project focusing on the viability of using biodiesel as an alternative fuel in MDT's vehicle fleet. To undertake this study, MDT is seeking to implement this project in two phases: first, a review of relevant literature regarding the performance of biodiesel in motor vehicles; and second, a test application using a B20 blend (20 percent oilseed-based biodiesel, 80 percent conventional diesel) in three MDT vehicles housed in Missoula and three housed in Havre.

This document concludes phase 1 of the research effort. It examines the body of literature that currently exists regarding laboratory and field experience with the use of biodiesel fuels, with an emphasis on oilseed-based biodiesel. The information gathered in this review should provide MDT and the State Legislature with better information to help them make decisions regarding the future usage of biodiesel fuels in the state.

Chapter 2 provides an overview as to what biodiesel is, what types of biodiesel exist, and its principal properties. Chapter 3 reviews engine performance characteristics for biodiesel, including fuel economy, torque and power, and engine fatigue and damage. Chapter 4 reviews storage, transport and handling characteristics of biodiesel, with a specific emphasis on cold weather properties. Chapter 5 reviews biodiesel emissions and associated air quality impacts. Chapter 6 provides a brief overview of taxation and revenue issues associated with biodiesel. Chapter 7 looks at other issues that were raised in the literature review that may be of interest to the state. Finally, Chapter 8 summarizes the main findings of this report, and provides guidance for the phase 2 field test.

2. BACKGROUND ON BIODIESEL

Before proceeding to answer the research questions, it is important to establish some background about what biodiesel is, what it is made of, what its principal properties are, and the extent of its current usage in the state. This chapter will provide that foundation.

2.1. Definition

In 1895, Rudolf Diesel developed a new engine with the intention that it could use a variety of fuels, including vegetable oil. When he showcased it to the public at the 1900 Paris World's Fair, he had the engine run on peanut oil. As the diesel engine became more widely adopted in subsequent years, however, petroleum-based diesel fuel proved to be less expensive and became the fuel of choice (2).

Biodiesel's definition has been a work in progress. Since the early 1900s, biodiesel has been defined as an alternative form of diesel fuel made from vegetable oils or animal fats and alcohol (3). The definition of biodiesel was neither legally definable nor defensible in the United States for about a century. This changed when biodiesel was registered with the U.S. Environmental Protection Agency (EPA) as a fuel and a fuel additive under section 211(b) of the Clean Air Act (4). With help from the American Society of Testing & Materials (ASTM), subsequent legislation such as the Energy Policy Act (EPAct) helped further define biodiesel. In December 2001, the ASTM issued defined physical/chemical constraints for biodiesel and subsequently for mixtures of biodiesel with diesel fuel (5).

An important distinction needs to be made between biodiesel and biodiesel blends. Biodiesel is commonly mixed with diesel No. 2 to form a biodiesel blend. As stated above, a mixture of biodiesel and diesel is not biodiesel, but is referred to as a biodiesel blend. Pure biodiesel, also known as neat biodiesel, is commonly noted as B100, indicating that the fuel has 100 percent biodiesel (noted by the 100) and 0 percent diesel. The most common biodiesel blend is B20, which contains 20 percent biodiesel and 80 percent diesel.

2.2. Manufacture

Biodiesel is derived from biological sources, such as vegetable oils or fats, and alcohol (3, 6). Commonly used feedstocks are shown in Table 2-1.

Table 2-1: Feedstocks Used for Biodiesel Manufacture

Vegetable Oils	Animal Fats	Other Sources
✍ Soybeans ✍ Rapeseed ✍ Canola Oil (a modified version of rapeseed) ✍ Safflower Oil ✍ Sunflower Seeds ✍ Yellow Mustard Seed	✍ Lard ✍ Tallow ✍ Poultry Fat	✍ Recycled Restaurant Cooking Oil (a.k.a. Yellow Grease)

Most commercial biodiesel is made by a chemical process called transesterification. This involves mixing the feedstock oil with an alcohol – typically methanol or ethanol – in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide. The reaction produces methyl esters (if methanol is used) or ethyl esters (if ethanol is used) – which comprises the biodiesel fuel – and glycerin (7). Methanol is typically used for economic reasons, as the physical and chemical properties between methyl esters and ethyl esters are, according to a University of Idaho study, "comparable" (8)[1].

Europe has been using biodiesel more extensively than the United States. Europe commonly uses rapeseed methyl ester. The predominant biodiesel used in the U.S. is soy methyl ester.

2.3. U.S. Standards

Biodiesel has been registered with EPA as a fuel and a fuel additive under section 211(b) of the Clean Air Act (4). Recently the definition of biodiesel was further sculpted through the ASTM standard for biodiesel, which may be added to conventional diesel fuels up to a B20 blend (5). This standard, issued in December 2001, is listed in Table 2-2.

The existence of a national biodiesel standard limits the quantity of poor quality biodiesel available on the market, providing buyers with more consistent fuel performance, and encouraging producers to provide an appropriate product. This also provides a more favorable environment for adoption of pro-biodiesel legislation at the Federal and State levels. The standards can be met with a variety of feedstocks and manufacturing processes; therefore, the biodiesel market is currently based not on the feedstock used, but on the standards that are met. If buyers are interested in using a specific feedstock, they may have to adjust the fuel specifications slightly to meet their needs (9). Ignoring parts of the standard could impact engine warranties.

2.4. Fuel Properties

Biodiesel is made up of fourteen different types of fatty acids, which are transformed into fatty acid methyl esters (FAME) by transesterification. Different fractions of each type of FAME present in various feedstocks influence some properties of fuels. Table 2-3 shows some of the properties defined in the ASTM standards for diesel and biodiesel[2]. These properties are described in the remainder of this section, and will be referred to later in this report.

[1] According to the study, cloud and pour points were slightly lower for ethyl esters than methyl esters. However, ethyl esters showed slightly higher viscosity and slightly less power and torque (8).

[2] ASTM PS121 was a provisional specification, superceded by ASTM D6751. The properties are understood to be the same.

Table 2-2: ASTM Specifications (D6751) for B100

Property	ASTM Method	Limits	Units
Flash Point	D93	130 min.	°C
Water & Sediment	D2709	0.050 max.	% Volume
Kinematic Viscosity (40 °C)	D445	1.9-6.0	mm^2/sec
Sulfated Ash	D874	0.020 max.	% mass
Sulfur	D5453	0.05 max.	% mass
Copper Strip Corrosion	D130	No.3 max.	
Cetane	D613	47 min.	
Cloud Point	D2500	Report	°C
Carbon Residue (100% Sample)	D4530*	0.050 max.	% mass
Acid Number	D664	0.80 max.	Mg KOH/gm
Free Glycerin	D6584	0.020 max.	% mass
Total Glycerin	D6584	0.240 max.	% mass
Phosphorous Content	D4951	0.001 max.	% mass
Distillation Temperature, Atmospheric Equivalent Temperature (90% Recovered)	D1160	360 max.	°C
*The carbon residue shall be run on the 100% sample.			

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

(Source: 10)

Table 2-3: Comparison of Fuel Properties between Diesel and Biodiesel

Fuel Property	Diesel	Biodiesel
Fuel Standard	ASTM D975	ASTM PS 121
Fuel composition	C10-C21 HC	C12-C22 FAME
Lower Heating Value, Btu/gal	131,295	117,093
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, ppm by wt	161	.05% max
Carbon, wt %	87	77
Hydrogen, wt %	13	12
Oxygen, by dif. wt %	0	11
Sulfur, wt %	.05 max	0.0 - 0.0024
Boiling Point (°C)	188-343	182-338
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
BOCLE Scuff, grams	3,600	>7,000
HFRR, microns	685	314

(Source: 11)

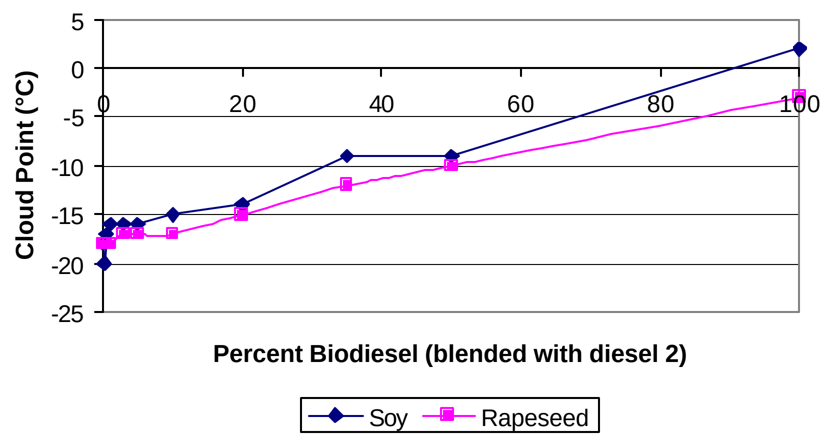
The *lower heating value* refers to the energy content, or energy per unit mass, of the fuel excluding the heat produced by evaporation of water vapor in the fuel (12). As can be seen, B100 has lower energy content than diesel by eleven percent. This results from the higher oxygen content of the fuel that produces more complete combustion of the fuel and soot (11). B100 has higher *kinetic viscosity* than diesel, which improves injector efficiency. Biodiesel has a higher *specific gravity* and *density* (pounds per cubic foot) than conventional diesel No. 2. Since fuel flow is controlled by volume, the expected peak power reduction for engines using B100 is only 5 to 7 percent less than conventional diesel No. 2 because more pounds per gallon would flow and vaporize more efficiently given a set throttle (volume) (13). It should be noted that biodiesel produces more than three times the energy as the same amount of fossil fuel (14). Biodiesel's higher *specific gravity* and *density* relative to diesel No. 2 means that on-road biodiesel blends are normally made by splash blending the biodiesel fuel on top of the conventional diesel fuel (11).

By weight, biodiesel contains less carbon, sulfur and water and more oxygen than diesel. The reduced carbon content decreases tailpipe emissions of carbon monoxide (CO), carbon dioxide (CO_2) and soot (elemental carbon). The lower sulfur content of biodiesel is important for two primary reasons. First, as a low sulfur fuel, biodiesel produces little or no emissions of sulfur dioxide (SO_2). SO_2 contributes to respiratory illness, aggravates existing heart and lung diseases, contributes to the formation of acid rain, can impair visibility, and can be transported over long distances (15). Second, EPA regulations will reduce the level of sulfur in highway diesel fuel by 97 percent by mid-2006 (16). Biodiesel is already compliant with the 2006 standard (17). Biodiesel's higher oxygen content allows it to burn more completely than conventional diesel, thereby reducing hydrocarbon and carbon monoxide emissions (18).

Biodiesel and diesel have a common *boiling point*, but biodiesel has a higher *flash point* – the temperature at which a fuel will catch fire – because biodiesel has a high number of FAMEs which are generally not volatile. Thus, biodiesel is safer to handle at higher temperatures than diesel.

Biodiesel is similar to diesel no. 2 in that both fuels need to be used cautiously in cold climates, as wax crystals can form in either fuel at lower temperatures. These wax crystals can plug fuel filters, causing engine stumbling or stalling. A variety of temperatures are used to reflect wax crystal formation, two of which – cloud point and pour point – are listed in Table 2-3. *Cloud point* is the temperature at which a haze or cloud of wax crystals first appears in the fuel when it is cooled under test conditions. *Pour point* is the lowest temperature at which diesel fuel will flow when cooled under test conditions (19). Both of these temperatures are related to the lowest temperature at which a diesel engine will be able to operate. As can be seen in Table 2-3, the pour point and cloud point are both higher for biodiesel fuel than for gasoline-based diesel, indicating that biodiesel will tend to gel at higher temperatures than diesel, causing engine problems.

Biodiesel's effects on cloud point for soy methyl ester and rapeseed methyl ester biodiesel can be seen in Figure 2-1. Slight effects on cold weather performance emerge when biodiesel comprises 20 percent or less of the fuel. It should be noted that there is some difference in cloud point based on feedstock used, with vegetable source biodiesel having the lowest cloud points, animal sources having the highest cloud point, and yellow grease falling in between the two (20).

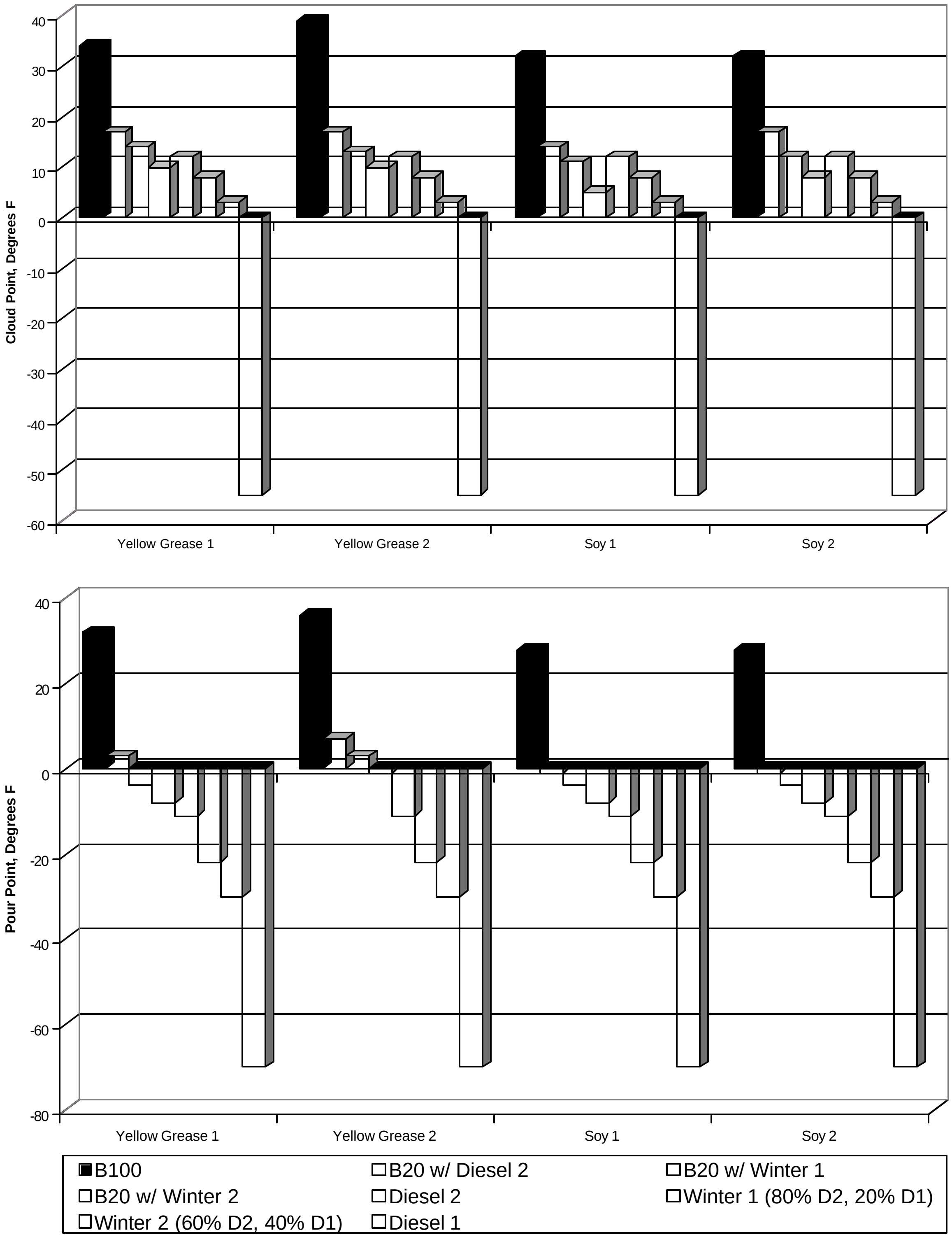


(Source: 22)

Figure 2-1: Cloud Point as Function of Increasing Biodiesel Percentage

With respect to vehicle use, a more meaningful measurement that can be listed by the user in fuel specifications is the *cold flow plug point* (CFPP), or the temperature when fuel flow stops through an unheated 4-micron fuel filter mesh. The CFPP for diesel No. 2 is -31 °C compared to -10 to -14 °C for rapeseed methyl ester B100 (21).

The National Biodiesel Board says that B20 blends can be used in cold weather environments in a similar manner as diesel No. 2, such as by using pour point depressants (especially malan-styrene esters [21]), blending with diesel No. 1, using engine block heaters, and storing vehicles in or near buildings (23). Adjusting the blend of kerosene in the diesel fuel can modify the cloud and pour point temperatures of B20 as well. Figure 2-2 shows the cloud and pour point when B20 is produced from diesel fuels. Four different biodiesel feedstocks are shown – two varieties from yellow grease and two from soy. B20 with D2 is a blend of 20 percent biodiesel with 80 percent diesel No. 2. The other two B20 blends shown are blends of 20 percent biodiesel with 80 percent winterized diesel fuel. In one case the winterized diesel consists of 80 percent diesel No. 2 and 20 percent diesel No. 1 and in the other case the winterized diesel consists of 60 percent diesel No. 2 and 40 percent diesel No. 1. The cloud and pour points of the diesel No. 2, diesel No. 1, and the two winterized diesel fuels are also shown for comparison. This chart ultimately demonstrates that the cloud and pour points of B20 can be improved (lowered) by adjusting the amount of diesel No. 1 in the diesel fraction of the mix. Diesel No. 1 (kerosene) and pour point depressants, which work on the diesel part of a biodiesel blend and can reduce the gelling and clouding properties of blended fuels, have been used with good results in B20. No additives have been shown to be effective on B100 (11).



(Source: 11)

Figure 2-2: Cold Weather Properties of Biodiesel Fuels and Blends

The *cetane number* is a measurement of how well a diesel fuel combusts. Cetane numbers measure the ignition of diesel, much like octane numbers measure the ignition of gasoline. These numbers represent the measure of a fuel's willingness to ignite. Biodiesel has a higher cetane number than that of diesel, largely because of its higher oxygen content (24). It is important to note that biodiesel's cetane number can vary widely, based on differences in fatty acid composition of the feedstock oil and the saturation level of the fatty acids (25).

Lubricity, an important characteristic of fuel, is an indication of the amount of wear or scarring that occurs between two metal parts as they come in contact with each other (26). Different from viscosity (reviewed in Section 3.4), which measures a liquid's resistance to shear forces, lubricity measures the extent to which a liquid diminishes friction. Two primary tests are used to measure lubricity: the Ball On Cylinder Lubricity Evaluator (BOCLE) and the high-frequency reciprocating rig (HFRR) test. A BOCLE test involves pressing a ball bearing against a rotating ring immersed in the diesel fuel. Weight is applied on the bearing until the diesel fuel fails, leaving a scuff mark on the rotating cylinder (27). The HFRR test consists of a ball that is placed on a flat surface and then rapidly vibrated back and forth with a stroke distance of one millimeter while 200 grams of weight is applied. The vibratory motion closely models engine vibration. After a given time, the flat spot that has been worn into the ball is measured (27, 28).

According to both BOCLE and HFRR tests, biodiesel shows greater lubricity than diesel, which is an important benefit. As EPA regulations have required changes in diesel fuel – through removal of sulfur and aromatics – lubricity has often been removed from diesel fuel in the process (26). B2 is being marketed as a lubricity additive or injector cleaner for diesel in some parts of the country, at a price of $2-4 per quart (9). Even such a small amount of biodiesel can significantly enhance lubricity. According to a National Biodiesel Board review of tests conducted by Stanadyne Automotive Corporation, "most of the lubricity benefits of the biodiesel

Table 2-4: Summary of Biodiesel Properties for Various Feedstocks

	Fuel						
Property	Diesel No. 2	Soybean Methyl Ester	Rapeseed Methyl Ester	Soybean Ethyl Ester	Rapeseed Ethyl Ester	Tallow Methyl Ester	Frying Oil Ethyl Ester
Cetane Number	40 - 52	50.9	52.9	48.2	64.9	58.8	61.0
Flash Point, °C	60 - 72	131	170	160	185	117	124
Distillation							
IBP, °C	185	299	326			209	
T10, °C	210	328	340			324	
T50, °C	260	336	344	336		328	
T90, °C	315	340	348	344		342	
EP, °C	345	346	366			339	
Specific Gravity	0.85	0.885	0.883	0.881	0.876	0.876	0.872
Lower Heating Value, MJ/kg	43.4	37.0	37.3				37.2
Higher Heating Value, MJ/kg	44.9	40.4	40.7	40.0	40.5	40.2	40.5
Cloud Point, °C	-25 to -15	-0.5	-4.0	-1.0	-2.0	13.9	9.0
Pour Point, °C	-25 to 5	-3.8	-10.8	-4.0	-15.0	9.0	8.0
Cold Filter Plugging Point, °C	-20 to -10	-4.4	3.6			11.0	
Viscosity at 40 °C, CS	2.60	4.08	4.83	4.41	6.17	4.80	5.78
Iodine Number	8.60	133.20	97.40	123.00	99.70		

(Source: 29 cited in 30)

were achieved by adding only 2% biodiesel to either number 1 or number 2 diesel." (26).

Biodiesel properties can vary according to the feedstock used. As shown in Table 2-4, however, there is a greater difference between conventional diesel and biodiesel than between various types of biodiesel.

2.5. Regional Experience

Anecdotal evidence indicates that biodiesel usage is growing in Montana. This section discusses the Yellowstone National Park "Truck in the Park" project, as well as other regional users of biodiesel fuel.

2.5.1. Yellowstone National Park

The most significant test demonstration of biodiesel in the region has been Yellowstone National Park's "Truck in the Park" project. Started as a cooperative effort between the park and Montana Department of Natural Resources and Conservation (now Department of Environmental Quality [DEQ]) to look for ways to reduce the smell and smoke of diesel in the park, this pilot project used rapeseed ethyl ester biodiesel (B100) in a new 1995 ¾-ton 4X4 pickup truck donated by Dodge Truck to DEQ for use in the Park. No modifications were made to the engine or fuel delivery systems. The project was pursued in a two-phase approach. Phase 1 involved answering technical questions about biodiesel, including safety and operation differences, performance capabilities at high elevations and over a broad range of temperatures, changes in performance over 100,000 miles (including chassis dynamometer tests), information on costs and benefits, and information on benefits and drawbacks of using biodiesel in environmentally sensitive areas. Phase 2 (the second 100,000 miles) investigates additional questions on biodiesel, assessing tradeoffs, and identifying specific applications for biodiesel (31).

A 1995 Dodge pickup truck with a 5.9-liter Cummins B engine was operated on rapeseed-based B100 for three years, with about 100,000 driving miles logged as of 1997. No modifications were made to the engine; however, because of concerns with refueling for emissions tests in California, a 300-gallon heated tank was added to the truck (32).

As of May 1999, no fuel-related problems had been reported. Initially, the engine lubrication oil was changed and tested every 6,000 miles. The first lube oil sample showed high silica content, which the manufacturer attributed to the final engine preparation. The first cold weather lube oil sample reported a change in viscosity, indicating possible fuel dilution. However, the manufacturer recommended increasing the frequency of oil changes for this engine type in the winter (regardless of fuel used) to every 4,000 miles because of increased idling. After following this recommendation, fuel dilution was never again detected. Chassis dynamometer tests showed 6 percent less power with biodiesel than diesel, although drivers reported feeling no difference[3].

[3] Chris Sharp, Southwest Research Institute, at the Commercialization of Biodiesel: Environmental and Health Benefits Conference at Yellowstone National Park in May 1996, said operators will only see a difference between diesel and biodiesel at peak power requirements that are seldom used in most field applications.

Chassis and engine dynamometer Federal Test Procedure (FTP) emissions testing at Los Angeles and San Antonio showed a reduction in air toxic and criteria pollutants (e.g. hydrocarbons, carbon monoxide and nitrogen oxides) and the catalytic converter was reported to operate more efficiently with biodiesel. Emissions performance did not degrade over time, and no new compounds were detected (31).

The park stored the biodiesel fuel at Mammoth Hot Springs in a 10,000-gallon, single-walled unheated, gravity-fed, above-ground tank. There were initial concerns over cold weather performance, but it was soon realized that the biodiesel fuel would flow from the unheated, gravity-flow tank at temperatures as low as –20 °F if the nozzle was first cleared of solidified biodiesel (31). The tank was situated to face south, so fueling was often done at mid-day to take advantage of solar heating in reducing gelling problems. With that measure in place, no gelling problems were reported (33). No cold flow or other additives were used in the biodiesel to improve its thermal properties. The park took no unusual cold weather precautions with the biodiesel truck. In the first three winters of operation, the truck failed to start during cold weather once, when the temperature was –37 °F and the block heater had not been plugged in (31).

Semiannual chassis dynamometer tests were conducted with no noticeable differences in performance, power or fuel economy relative to diesel. An engine teardown by a Cummins engineers in 1999 revealed a spot of rust on the lube oil-side tip of the oil filter housing. However, there were no carbon deposits and the cylinders were exceptionally clean – like new (32, 34). According to one project partner, the engine was rated by the manufacturer after the 100,000 mile test as “good or better than if diesel had been used.” (35). The fuel economy for the truck was 16.3 miles per gallon, about 1 mpg less than conventional diesel[4] (31).

While there were some areas of concern in the evaluation, the park considered the demonstration to be a success, to the point that their entire diesel vehicle fleet – approximately 300 vehicles – now uses B20 (33). The park’s usage of biodiesel makes it one of the most significant users of biodiesel in the country. According to Howard Haines from the Montana Department of Environmental Quality, the greater Yellowstone area used about 10 percent of biodiesel (B100) sold nationally (35). The park has installed a 15,000-gallon underground tank at Gardiner, where a local distributor splash blends the B100 fuel into trucks carrying conventional diesel (or winterized diesel) for delivery of B20 into Park tanks. The size of the tank allows the park to achieve significant price advantages on biodiesel. At the outset of the Truck in the Park project, biodiesel fuel for the park cost about $3 per gallon; now the park can get the fuel for only 2 cents per gallon more than diesel (33). The park plans to seek additional ways to use biodiesel fuel. They now use it for off-road applications, including generators and boilers, and are seeking to offer biodiesel fuel for sale to park visitors in 2004. The park hopes to increase the richness of biodiesel blends so as to eventually become petroleum-free (33).

[4] At the conclusion of the project, fuel economy was 17.1 miles per gallon, after the heads were adjusted per manufacturer’s regular specs after 100,000 miles.

2.5.2. Glacier National Park

Glacier National Park converted their vehicle fleet to B20 in October 2002. Their primary motivations were to reduce vehicular emissions and reliance on fossil fuels. They are using the fuel year-round on approximately 50 vehicles within the park, including dump trucks and transports. The primary challenge they have reported is the price of the fuel, which has fluctuated. They have received funding assistance from the U.S. Department of Energy to make the fuels more affordable. According to the park's facility manager, biodiesel is "here to stay" (36).

2.5.3. Grand Teton National Park

Grand Teton National Park converted their entire fleet of diesel maintenance vehicles to biodiesel blends in June 2001. According to the park's fleet manager, the decision to use biodiesel was in response to a National Park Service mandate for parks to explore using alternative fuels. Biodiesel was perceived to be the best alternative fuel option in terms of fuel acquisition. The park uses B20 for eight months of the year, and B10 for four months with the base diesel being 50 percent diesel No. 1 and 40 percent diesel No. 2. They used this approach on blending in order to achieve a cold pour point of -25 to -28 °F. The park did this proactively – not in response to fuel gelling – to ensure that emergency response vehicles would have no difficulties.

The fleet manager reports that the park has not had any significant problems with using biodiesel blends. There has been some difficulty starting vehicles that are stored outside – most park vehicles are stored inside – but vehicles have been able to start with biodiesel blend. They had initial problems with the quality of fuel supplied, but have been more proactive in testing fuel quality and have had no problems since. The park is reporting better fuel economy with biodiesel blends. After conversion, there was an initial need to change fuel filters more frequently, but there are reported to be no additional maintenance costs at this point. Moreover, because it is a cleaner fuel, the fleet manager anticipates that long-term engine life will be better. The park has concluded that there is additional cost with biodiesel – 4 to 5 cents per gallon in the summer and 11 to 12 cents per gallon in the winter[5] – but that it is cheaper than alternatives. The park has also received favorable press for using biodiesel.

Grand Teton is investigating long-term incorporation of other alternative fuel options in addition to biodiesel and ethanol, including propane and compressed natural gas. Nevertheless, the fleet manager sees biodiesel playing a major role in fuel for park vehicles even with other alternative fuels entering the mix (37).

[5] The additional cost is relative to the cost of conventional diesel (diesel No. 2 in summer, and winterized diesel in winter.)

2.5.4. Other Regional Users

Biodiesel is now being used at Malmstrom Air Force Base in Great Falls, where the base's entire diesel fleet has been converted to B20 (38). Fleet usage is also reported in Bozeman and at the Bureau of Land Management in Lewistown (9).

At the time of publication, there is one Montana public fueling station that provides year-round biodiesel blend fuel. The station, in West Yellowstone, charges the same price for biodiesel as others charge for diesel. However, they change the blend rates varying between B10 and B20 based on fuel cost and ambient temperature (9).

3. ENGINE PERFORMANCE CHARACTERISTICS

One of the biggest concerns for any prospective biodiesel user is whether an engine using biodiesel will perform differently than an engine using normal gasoline-based diesel. This section of the report will assess previous studies' findings on engine performance effects of biodiesel in the following categories: torque and power, engine fatigue and damage, fuel economy, and viscosity. This chapter will also discuss issues related to engine warranties and studies of off-road use of biodiesel.

Before exploring the results of various studies, a couple of considerations are in order. First, the introduction of a standard for biodiesel fuel has improved the quality of biodiesel and made its properties more consistent. Second, there have been changes in diesel fuel (reduced aromatic, benzene and sulfur content) lubricating oil specifications in the last few years. As newer research has incorporated these improved standards and specifications, some of the engine problems found in testing biodiesel fuel have been addressed.

3.1. Torque and Power

Performance of any fuel can be judged by the power and torque output that it can generate. Biodiesel has a higher cetane number than conventional diesel, but has a lower energy content per volume. Because of the lower energy content, using biodiesel without any change in the fuel injection system would result in a slight loss of engine power. Numerous studies have been undertaken to test these theoretical results. It should be noted that power and torque is difficult, if not impossible, to accurately measure in-use; therefore, power testing has occurred in controlled laboratory environments with specific duty cycles that are designed to stress engines. For example, the 200-hour Engine Manufacturers Association (EMA) test includes significant time where the tested engine is operating at full throttle (39).

However, the results of various studies have not been uniform. Studies indicate that the amount of power loss may be influenced by various factors, such as the engine make, overall maintenance of the vehicle, type of diesel used as base fuel, and condition of the air filter. B20 users may or may not experience this loss of power, whereas people using B100 may feel a loss of power. Ziejewski et al. (40), Niehaus et al. (41), Schumacher et al. (42), Reece and Peterson (43), and Marshall (44) observed power reductions ranging from one to seven percent. Schumacher observed a three percent increase in power using a 1991 Cummins 5.9L direct injection (DI) turbocharged engine. Increased power was also observed by Feldman and Peterson (45) during a 200 hour EMA test using a 3 cylinder, DI, naturally aspirated diesel engine with the injection timing advanced 2 degrees. Schumacher (46) detected very small differences in power until the fuel contained at least 50 percent biodiesel by volume. He also observed a steady drop in exhaust gas temperature for both the rated and peak torque condition, indicating a shift in the peak pressure point toward top dead center, resulting from an increasingly shorter ignition delay. The lower exhaust gas temperature was a result of increased heat transfer into the coolant.

Results with B20: Schumacher (47) tested B20 with diesel No. 2 with a 20:80 ratio on Navistar engines and found a power change ranging from a 13 percent increase to a 3 percent decrease. It should be noted that most of these engine tests showed a slight decrease in power with B20 as compared to conventional diesel. The Iowa Department of Transportation (48) used B20 in nine snow removal trucks, four tractors, a motor-grader and a wheel-loader during a one-year demonstration in 1995[6]. A seven percent loss of power was observed when the snow removal trucks where filled with a combination of diesel No. 1 and biodiesel, whereas no loss of power was observed when the trucks were filled with diesel No. 2.

Results with B100: Schumacher (49) filled a Cummins engine from a 1992 Dodge truck with B100 and found that there was a change in power ranging from a 6 percent increase to a 7.8 percent decrease; the change of power depended on the engine design and fuel delivery. User trials have found a general loss of power ranging from 5 to 10 percent.

Studies at the University of Idaho for Yellowstone National Park concluded that power output is reduced by about 6 percent when measured at the wheels (31). Although studies have found that there is a reduction in power output ranging from 1 to 8 percent for B100, there is no overall marked difference in biodiesel blends between B20 and B50. User trials have shown that drivers generally do not perceive any loss of power. The loss of power may result from various reasons dependent on the make and model of engine and general vehicle maintenance. User trials have not shown any instances of vehicles failing midway or engines breaking down as a result of a biodiesel or biodiesel-blend fuel. There have been some instances of engines overheating, but there are no overall trends in that regard.

3.2. Engine Durability and Materials Compatibility

While engine durability testing of biodiesel blends is ongoing, most studies have shown no appreciable difference between biodiesel and conventional diesel fuel. A 1984 study conducted by Clark et al (50) found that engine wear rates for engines in 200, 500 and 1,000 hour tests were well within specified ranges. In one study conducted at the University of Missouri (49), a 1992 Dodge pick-up truck with a Cummins engine was tested after approximately 100,000 miles of operation. After the miles were logged on the truck, the engine was disassembled and sent to a team of Cummins Engine Company experts. The report from Cummins engineers revealed a normal wearing rate of the engine. During the same study, Bosch diesel fuel injectors were analyzed by the manufacturer after 50,000 miles of operation with 100 percent biodiesel. They reported no problems with the injectors and approved the use of B100 in their fuel systems.

The lubricity benefits of biodiesel, especially compared to low-sulfur petroleum diesel, help to reduce engine wear. Research at the University of Saskatchewan since the early 1990s has indicated that the use of biodiesel contributes to a tenfold reduction in engine wear (51). A research project at the University of Idaho focused on biodiesel made from used vegetable oil (hydrogenated soy ethyl ester or HySEE). Test vehicles included several trucks, newer tractors, and a Kenworth semi-tractor with a Caterpillar engine driven with 50 percent HySEE for 200,000 on-the-road miles. These studies showed that various blends of biodiesel produced

[6] Iowa DOT reported some problems with B20. An instance of fuel gelling occurred on a truck that had an in-line heater and not an in-tank heater. Gasket deterioration was observed in a couple of locations. A high amount of particulate emissions was observed during start-up. Nevertheless, Iowa DOT concluded that there did not seem to be any major operational problem with B20. They discontinued the project for cost reasons (48).

engine wear similar to, or less than, petroleum diesel and produced the same or better engine durability (52, 53).

Some earlier studies showed fuel dilution as a result of using biodiesel (54, 55, 56), while other studies, including more recent studies (Schumacher et al [57] and Schumacher and Madzura [58]) indicated that fuel dilution of engine oil was not a problem. Most earlier studies showing fuel dilution used a diesel fuel significantly different than current No. 2 specifications, and diesel engine technologies that are significantly different than the drier, tighter designs used on the road since 1996. The EMA has taken a conservative stand on this issue, recommending that when using biodiesel, the normal oil change interval should be cut by half to minimize problems associated with engine lubricating oil (59).

There are some precautions that should be considered when utilizing biodiesel (60). Since biodiesel is a natural solvent and will soften and degrade certain types of elastomers and natural rubber compounds, precautions are necessary to ensure that engines manufactured before 1994 do not have seals made of these types of elastomers. Due to the switch to low-sulfur diesel fuels in 1993, virtually all diesel original equipment manufacturers (OEMs) have pursued fluorocarbon (Viton) type seals, which do not experience problems with biodiesel. In general, problems with gaskets, hoses and seals are less pronounced as the percentage of biodiesel in the fuel decreases (61).

3.3. Fuel Efficiency

A study organized by Schumacher & Madzura (58) found that there was no significant difference in fuel economy between a normal diesel fuel and B20 fuel. Their observation was based on a study that monitored the fuel economies of five B20-fueled buses and five buses fueled with conventional diesel in St. Louis. In another research project conducted at the University of Missouri (57), a 1991 and a 1992 Dodge pick-up truck were fueled with diesel until 3,000 miles and 1,500 miles of operations respectively, and then filled with soy diesel. Results indicate that fuel efficiency fluctuated depending on how the trucks were used. The overall efficiency of the 1991 truck was 16.7 mpg and the 1992 truck was 16.6 mpg. The highway fuel efficiency of the trucks was 22.8 mpg for diesel fuel, but it was 22.3 mpg when operated on 100 percent soy diesel. It was concluded that fuel economy was the same for both types of fuel under same circumstances. In a similar kind of study (62), 100 percent soy diesel was used in a heavy-duty DDC 6V-92TA-coach engine provided by Fosseen Manufacturing and Development. Fuel consumption for both biodiesel and diesel on a mass basis was very similar for all blends tested. User trials in Yellowstone National Park (as described in section 2.5.1) have also not found any differences in fuel economy (32).

3.4. Viscosity

Viscosity measures the resistance of a liquid to shear forces. Viscosity is another important property of biodiesel since it affects the operation of fuel injection equipment, particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel. Biodiesel has higher viscosity than conventional diesel fuel. High viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors. The viscosity of biodiesel and biodiesel blends also increases more rapidly than diesel as temperature is decreased. Certain impurities also tend to significantly increase the viscosity of biodiesel.

According to Romano (63), in an experiment involving fueling a diesel engine with methyl ester, when metals such as tin, lead and cobalt come in contact with fatty acids at high temperatures, they react readily with these acids, thereby reducing the viscosity of fuel. He cautioned that after 200 to 250 hours of operation, the diesel engine crankcase oil fueled with 100 percent vegetable oil methyl ester lost its lubrication properties. Hassett and Hasan (64) also expressed concerns about diluting lubricating oil.

3.5. Warranties

A critical issue regarding adoption of biodiesel blends is whether their use in on-road diesel engines would void warranties with engine manufacturers. Moreover, the warranty policies of engine manufacturers may shed light on the industry's assessment of the suitability of biodiesel for long-term use. Engine manufacturers do not cover damage caused by fuels – diesel, biodiesel, or otherwise. Fuel producers and/or distributors cover damage traceable to the products they sell.

The general view of the EMA – the self-described "voice of the engine manufacturing industry on domestic and international public policy, regulatory, and technical issues that impact manufacturers of engines" (65) – is that biodiesel blends at less than five percent are generally acceptable, but higher blends need to be evaluated (13). Caterpillar (66), Cummins (67) and John Deere (68) all specifically allow B5 or lower biodiesel blends in their engines. Caterpillar allows pure biodiesel in some of its engines, including the 3046, 3064, 3066, 3114, 3116, 3126, 3176, 3196, 3208, 3306, C-10, C-12, 3406, C-15, C-16, 3456, 3408, 3412, 3500 series, 3600 series, CM20, CM25 and CM32 engines (66). Detroit Diesel allows blends up to B20, although doesn't advise use of fuels above B5 (69). International had initially suggested a maximum blend of B5, but now permits a maximum of B20, to allow users to take alternative fuel credits (70) (see section 6.2.2). One of the problems faced by EMA (71) in certifying the use of biodiesel in engine warranties is that biodiesel suppliers must warrant their fuel quality that has to be used in the engines; therefore, OEMs require that the biodiesel fuel used in a biodiesel blend meet the ASTM standard. Many engine manufacturers, including Caterpillar (66), Cummins (67) and International (70), indicate that the use of biodiesel fuel does not affect the engine material and workmanship warranties. Another problem for EMA is that the diesel fuel injection equipment manufacturers, Injection Equipment Manufacturers Association, only provides coverage for their products up to 5 percent of any additive until a certain amount of field data is evaluated (72).

No engine manufacturers provide warranties to cover damage that may be attributed to the use of any fuel, including biodiesel blends. Engine manufacturers take responsibility for defects attributable to materials and workmanship; fuel producers and distributors are responsible for the fuel, whether it is biodiesel or conventional diesel. Engine manufacturers seem to agree that low biodiesel blends (less than B5) will not cause problems. Cummins states, "Given the current industry understanding of bio fuels and blending with quality diesel fuel, it would be expected that blending up to a 5% volume concentration should not cause serious problems." (67) Nevertheless, engine manufacturers do recommend some additional precautions, such as the following, when biodiesel is used (66, 67, 68).

?? Monitor the engine oil condition to determine the optimum oil change interval.

?? Increase the frequency of fuel filter replacement in the early stages of conversion of an older engine to biodiesel use.

?? Monitor the condition of seals and hoses (this reflects OEM concern over the long-term compatibility of Viton with biodiesel).

?? At low ambient temperatures, consider the use of heated storage for fuel, and heated fuel lines, filters and tanks.

?? Consider the usage of oxidation stability and anti-microbial additives.

?? Monitor water content of fuel regularly, as it facilitates microbial growth and can create acids in bonding with the biodiesel.

?? Keep storage and vehicle tanks as full as possible to prevent moisture from collecting inside.

Some engine manufacturers may permit richer biodiesel blends, but they may require additional specifications, such as iodine number, cold flow plug point number or a pour point specification on the biodiesel or biodiesel blend (9, 73). The Federal government and Department of Defense require additional specifications for diesel and biodiesel, including a cold flow plug point and the use of "virgin" vegetable oils (74).

3.6. Off-road Vehicles

The primary focus of this analysis has been to look at on-road vehicles. This section provides a brief examination of off-road vehicles, since they represent important users of diesel fuel in Montana.

A study documented in a 1994 report monitored and recorded quantitative data related to fuel consumption, power, and exhaust emissions while fueling Case-International 5120, 5130 and 5250 and Ford 4600 and 7740 tractors with blends ranging from 0 to 100 percent biodiesel (75). Material compatibility problems were noted when fueling with an experimental biodiesel fueling station. The B100 dissolved the rubber fill hose after one month of use so that fuel leaked from the hose when refueling. John Deere tractor models 6300, 7200 and 7800 ran hotter when fueled with biodiesel. The tractors were tested for power while changing between blends of 0, 10, 20, 30, 40, 50 and 100 percent biodiesel blended with diesel No. 2. Testing occurred on the same day, under similar temperature and humidity conditions, and within minutes of the previous test. When each engine was fueled with conventional diesel, the viscous fan that is designed to engage when cooling needs are the greatest, seldom engaged. The viscous fan almost always engaged when fueled with a biodiesel blend. The power that each engine was able to produce declined as the concentration of biodiesel increased. However, the decline in power seldom exceeded 1 to 3 percent except when the engine was converted to B100.

Changes in lubricating oil and fuel specifications in recent years may make results of previous studies incomparable. The University of Idaho completed testing of off-road vehicles with rapeseed methyl ester. The Mitsubishi Satoh Tractor operated the first 650 hours on a fuel blend of 50 percent rapeseed methyl ester and 50 percent diesel No. 2 (56). Rubber fuel lines were replaced with Viton fuel lines, but no other changes were necessary to convert the tractor to methyl ester fuel. Routine maintenance included collecting engine oil analysis samples and changing the oil and filters for oil, fuel, and air every 100 hours. No problems attributable to the fuel were noted. Specifically, no fuel filter plugging or power loss was noted when fueling with methyl esters. In another study, a John Deere 3150 tractor operated for 50 hours with diesel No. 2 and then with a B50 rapeseed methyl ester blend thereafter, and showed no detectable power loss. Rubber fuel lines were replaced with Viton fuel lines. Routine maintenance included engine oil analysis of the lubricating oil and replacement of fuel, air and oil filters every 100 hours. Smoke emissions (opacity) appear reduced when performing heavy tillage loads.

Recent experience with B20 in off-road applications has been favorable. In the spring of 2001, the Missouri Department of Transportation (MoDOT) began using B20 in approximately 600 diesel vehicles and pieces of diesel equipment, including motor graders, dump trucks, off-road vehicles, high lifts, pull-behind message boards, and other miscellaneous diesel powered equipment. A MoDOT mechanic supervisor noted that biodiesel has “excellent lubricating qualities” and “much better” emissions, and that the switch from diesel to B20 was “a transparent change.” (76) The U.S. Department of Agriculture (USDA) issued a memorandum in August 2001 requiring USDA agencies, such as the Forest Service, that maintain diesel fuel tanks for their fleet vehicles, off-road vehicles, marine vessels and other motorized diesel equipment to buy and use biodiesel in B20 or higher blends “where practicable and reasonable in cost.” (77) Regional Forest Service users of B20 include the Bridger-Teton, Salmon-Challis, and Caribou-Targhee National Forests, where they have used B20 in about 100 off-road vehicles over the past year or so (53).

A variety of tractor engines have warranties for biodiesel or biodiesel blends, as shown in Table 3-1.

Table 3-1: Summary of Warranties for Tractors, Since 1996

Manufacturer	Type of Vehicle	Warranty Status
Case IH	tractors	all models since 1971
Claas	combines, tractors	warranties exist
Faryman Diesel	engines	warranties exist
Fiatagri	tractors	for new models
Ford AG	tractors	for new models
Holder	tractors	warranties exist
Iseki	tractors	series 3000 and 5000
John Deere	tractors, combines	warranties since 1987
KHD	tractors	warranties exist
Kubota	tractors	series OC, Super Mini, O5, O3,
Lamborghini	tractors	serie 1000
Mercedes-Benz	tractors	since 1989
Steyr	tractors	since 1988
Steyr	boats	series M 16 TCAM and M 14 TCAM
Valmet	tractors	since 1991

(Source: 78)

4. TRANSPORTATION, HANDLING, STORAGE

For any new fuel to be widely accepted and used, its characteristics relative to ease of use should be comparable to existing fuels. The following chapter of the report addresses the transportation, handling and storage of biodiesel fuels.

4.1. Transportation

Since biodiesel gels at low temperatures, it is difficult to transport biodiesel like any other diesel fuels at low temperatures. Some of the methods recommended for transportation of biodiesel (11) are:

?? Kept hot in tank cars for immediate delivery,

?? in insulated rail tank cars equipped with steam coils (the tank cars are melted with steam at the final destination as needed),

?? in 20 percent blends with available winter diesel, or

?? in a 50 percent blend with diesel No. 1 (kerosene). A 50:50 blend of soy biodiesel and kerosene has a pour point of 0° F in most cases.

4.2. Handling

"Clean" B100 – made from methyl and ethyl esters of soy and other vegetable oils – is not corrosive to skin. However, blends of biodiesel can cause irritation and a burning sensation to sensitive body parts, so it is advisable to wear rubber gloves while dealing with biodiesel. Spontaneous combustion may be a problem because the fuel can oxidize in the air; consequently, rags that contain biodiesel and other combustible material should be put in closed metal cans or dried individually (7, 23). Biodiesel is also considered essentially nontoxic (11).

4.3. Solvency

Since biodiesel is a mild solvent, it may help to remove engine deposits that settle in the storage tanks of vehicles as well as systems. As a result, fuel filters in vehicles may become plugged, giving a false impression that biodiesel plugs filters, while it actually helps clear out sediments deposited in storage tanks. If biodiesel or a biodiesel blend is used in an engine where diesel No. 2 was previously used, fuel filters will initially get clogged as the biodiesel cleans out deposits left by diesel No. 2. These problems are most pronounced in B100 in older (pre-1992) engines; some problems have been observed with B20, and no problems have been reported with B2 (61). It is recommended that one should read the guidelines provided for that kind of biodiesel before using higher biodiesel blends in their vehicles.

As was mentioned in the last chapter, biodiesel can also act as a solvent for certain elastomers and natural rubber compounds, thereby affecting engine components like gaskets and seals as well as older fuel dispensing equipment. As is true with recent engine designs, fueling station systems have started using materials that are compatible with biodiesel. One fuel dispenser manufacturer states that there should be no problems with low-blend biodiesel blends (e.g. B5[7]) (79). It should be noted that the Department of Defense has concluded that biodiesel is fully compatible with military specification diesel No. 2 (80).

Biodiesel can act as a solvent on painted surfaces, so spills on painted surfaces should be wiped immediately (23).

4.4. Biodegradability and Stability

Biodiesel degrades about four times faster than conventional diesel (11): European tests of rapeseed-based biodiesel show that it is 99.6 percent biodegradable within 21 days (81). Moreover, blending biodiesel with diesel fuel accelerates its biodegradability. For example, B20 with a diesel No. 2 base degrades about twice as fast as diesel No. 2 alone (11).

A possible downside to biodiesel's high biodegradability is the potential for the fuel to have a shorter stability for storage. As biodiesel contains more polyunsaturates in its fuel composition than conventional diesel, it will have reduced stability (unless stability additives are used). Stability encompasses thermal stability under both hot and cold temperatures, resistance to oxidation, polymerization, water absorption, and microbial activity (30). Instability in biodiesel is caused by the presence of unsaturated fatty acid chains.

Oxidative stability test methods, currently under development, will allow customers to determine if the fuel will remain stable in storage over extended periods and to test fuels to determine if they have degraded during storage. ASTM D6751 does not contain any test methods for stability at this time.

4.5. Storage

Diesel fuels gel at lower temperatures; likewise biodiesel gels at lower temperatures. The main factor that defines the temperature at which any fuel gels is the presence of saturated components in that fuel. As the fuel gels, its flow properties are affected, inhibiting its ability to flow out of storage tanks and choking fuel filters and hoses. If any degraded fuel in a storage tank gets consumed by an engine, there is a potential for deposits and sludge in the fuel system. Biodiesel degrades four times faster than diesel and at the same rate as dextrose (a sugar). Hence, it becomes necessary to store fuel at proper temperatures and in stable environments.

B100 can be stored at temperatures 15 degrees higher than the pour point of the fuel (30-50 °F). Temperatures of 45-50 °F are acceptable for most B100. Normally, diesel and biodiesel blends should be stored at 15 °F higher than the pour point of the blended fuel.

[7] For blends up to B20, the same manufacturer recommends potential replacement of fueling hoses, use of different paints, and some filtering (79).

Biodiesel's required storage temperature generally depends upon the storage environment. Like petroleum diesel, biodiesel should be stored in a clean, dry, dark environment. Extremes of temperature should be avoided when possible, since biodiesel has a higher cloud point and pour point than petroleum diesel. Acceptable materials for biodiesel storage include black mild steel[8], stainless steel, fluorinated polyethylene, and fluorinated polypropylene. Concrete and concrete lined tanks should be avoided since biodiesel tends to degrade concrete over time (82).

B100 can be stored underground in most climate conditions, but above ground fuel systems should be protected with insulation, agitation, heating system, or other measures. The requirements for above-ground storage of B20 are the same as for petroleum diesel. In the case of B100, it may be treated the same as the storage of vegetable oil. The biodiesel user should check with the local fire marshal and appropriate agencies to determine whether any special local regulations pertain to such storage. There are no special concerns at a state level: the Montana Department of Environmental Quality does not regulate the storage of biodiesel as it is not a hazardous substance.

The requirements for underground storage of B20 or other biodiesel blends are regulated in accordance with EPA standards, and are the same as for petroleum diesel. Storage of B100 is not regulated by EPA, but must be reported to the local fire marshal as with storage of vegetable oils and chemicals. Information concerning these regulations can be found in the Code of Federal Regulations 40 CFR 280.[9]

Regarding cold weather storage, user experience at Yellowstone National Park, which has an above ground storage facility[10], showed fuel stratification at –20 °F. But the fuel flowed at even colder temperatures (9). B20 blends have been used in Wyoming and Minnesota where the temperature has fallen below –40° F (11).

The U.S. Department of Energy (DOE) fact sheet on biodiesel reports that "in most cases" biodiesel can be stored as long as conventional diesel – up to six months (23). DOE did not recommend storage of biodiesel longer than six months without the use of fuel additives (83). Howard Haines from the Montana Department of Environmental Quality (DEQ) added that storage of biodiesel blend fuel could be a problem if the base diesel is dirty or has a high glycerol content. He noted that in Yellowstone's demonstration the same fuel was used for 28 months with the energy output and a viscosity within three percent of original levels (9).

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[8] According to staff at the Montana Department of Environmental Quality, there is some evidence reported in work done at the University of Idaho that heated mild steel tanks may have problems for storing biodiesel, whereas ambient temperature mild steel tanks have no problem.

[9] Yellowstone National Park currently uses a 15,000-gallon underground storage tank for B100. The Montana Department of Environmental Quality reviewed the installation of the tank and determined that neither DEQ nor EPA regulate such activity. However, complete permitting and an inspection were conducted at installation, so that the tank could be converted for storage petroleum products in the future, if necessary.

[10] No permit was needed for the above ground tank, as it contained B100.

5. EMISSIONS AND AIR QUALITY IMPACTS

This section of the report examines the differences between biodiesel and conventional diesel, with respect to emissions of hazardous airborne toxins. After a discussion of the types of emissions considered in this chapter, various studies are reviewed to summarize the effects of biodiesel on emissions, with air quality implications reviewed at the close of the chapter.

5.1. Emission Types

The scope of the emissions impact analysis of this report covers five types of emissions: NO_x (nitrogen oxides), PM (particulate matter), HC (hydrocarbons), CO (carbon monoxide), and CO_2 (carbon dioxide). While CO_2 is not a hazardous air toxin, it is considered a greenhouse gas emission causing global warming and, in some cases, may be capable of generating emissions credits.

5.1.1. NO_x

Nitrogen oxides (NO_x) is the generic term for a group of highly reactive gases containing nitrogen and oxygen in varying amounts, including nitric oxide (NO), nitrous oxide (N_2O), nitrates (NO_3^-), and nitrogen dioxide (NO_2). NO_x and volatile organic compounds, in the presence of hot, stagnant air and sunlight, convert to ozone.

NO_x are classified as hazardous airborne toxins because of their deleterious health and environmental effects. The U.S. Environmental Protection Agency (EPA) has noted that NO_x is a major cause of ground-level ozone (a.k.a. smog), acid rain, respiratory disease (emphysema and bronchitis), water quality determination, and global warming (84).

5.1.2. PM

Particulate matter (PM) is a generic term used for a type of airborne pollution which consists of varying mixtures, complexity and sizes of particles. PM is problematic because it compounds respiratory problems, such as asthma and cardiopulmonary disease (85). The American Lung Association reports that high concentrations and/or specific types of particles have been found to present a serious danger to human health (86).

There are two types of regulated PM: $PM_{2.5}$ and PM_{10}. $PM_{2.5}$ is a particulate matter of 2.5 micrometers or less in diameter and PM_{10} is a particulate matter of 10 micrometers or less in diameter. Both $PM_{2.5}$ and PM_{10} are byproducts of internal combustion engines (85). There are two major differences between $PM_{2.5}$ and PM_{10}. First, the size contributes to greater health risks because larger particles can be inhaled and accumulated in the respiratory system (87). Secondly, in contrast to $PM_{2.5}$, PM_{10} easily reacts with chemicals such as SO_2, NO_x, and volatile organic compounds (VOCs). All of these chemical reactions can result in smog (85).

5.1.3. HC

The Agency for Toxic Substances and Disease Registry reports that hydrocarbons (HC) "enter the air mostly as releases from volcanoes, forest fires, burning coal, and automobile exhaust" (88). A 1999 EPA study estimates that on-road vehicle sources were responsible for 29 percent of the total emission of HC (89).

Mobile sources release two types of regulated HC measured as speciated hydrocarbons (C_1-C_{22}) and a subset of known or suspected carcinogenic compounds titled polycyclic aromatic hydrocarbons (PAH). A presentation given to the National Biodiesel Board entitled "Biodiesel Tier I Health Effects" presented a correlation between the emission rate of C_1 to C_{12} and the potential reduction of ozone and also stated that HC are a carcinogen (90). The Department of Health and Human Services reiterated this health concern, specifying that some PAHs are known to cause cancer (91).

5.1.4. CO

Carbon monoxide (CO) is produced from incomplete combustion whenever any carbon fuel, such as gas, oil, kerosene, wood, or charcoal is burned (92). Unlike many gases, CO has no odor, color, or taste, and it does not cause skin irritation. According to the Centers for Disease Control and Prevention¸ red blood cells can attach themselves to CO at a quicker rate than oxygen. If there is a large quantity of CO in the air, the red blood cell may replace oxygen with CO, leading to possible tissue damage, carbon monoxide poisoning or death (93). As CO levels increase and remain above 70 parts per million (ppm), symptoms may become more noticeable (headache, fatigue, nausea). As CO levels increase above 150 to 200 ppm, disorientation, unconsciousness, and death are possible (94).

5.1.5. CO_2

Carbon dioxide is a naturally occurring gas that is linked to global warming. It is also released into the atmosphere by human activity, such as when solid waste, fossil fuels (oil, natural gas, and coal), and wood and wood products are burned (95). Carbon dioxide by itself is not considered to be a toxin. However, any impacts on global climate could cause health problems (89).

5.2. Review of Emissions Studies

The EPA conducted a review of studies comparing the emissions of heavy-duty highway engines[11] using diesel No. 2 with similar vehicles using biodiesel (B100) or biodiesel blend fuels.

[11] The report focused on studies examining heavy-duty highway engines because of the lack of studies on heavy-duty highway engines reporting data taken using Federal test procedure (FTP) testing. Statistical correlations were developed for highway engines, and these were compared to those estimated through heavy-duty engine studies. The report concluded the following: "For PM and HC, the vehicle data appears to produce emission benefits that are smaller than those predicted by the [statistical] correlations. For NO_x the vehicle data appears on average to produce emission reductions whereas the [statistical] correlations predict emission increases. For CO, the vehicle data

They conducted a regression analysis estimating the relative emissions change as a function of the percent of biodiesel used in the fuel blend. They conducted analyses for biodiesel based on the percent blend of biodiesel using different types of feedstock (soy, rapeseed and animal). This study documented the percentage for each type of biodiesel used (soy, rapeseed or animal-based) and its respective change, relative to diesel No. 2, of four types of emissions – NO_x, PM, HC and CO. As this review encompassed nearly 40 studies, it is believed that it provides a comprehensive picture of the differences in emissions between biodiesel and diesel (96).

Table 5-1 summarizes the change in levels of toxic emissions between diesel No. 2 and a soy-based B20 blend – a commonly used biodiesel blend. The following source impacts, for emission reductions due to soy-based biodiesel compared to diesel No. 2, are ranked from greatest to lowest: HC, CO, PM. These comparative benefits are chiefly related to biodiesel's high oxygen and low sulfur content (24). Conversely, soy-based biodiesel NO_x emissions increased slightly as compared to diesel No. 2.

Table 5-1: Source Impacts on Using Soy-Based B20 Compared to Average Diesel

Source Effect	Percent Change in Emissions
NO_X	2.0%
PM	-10.1%
HC	-21.1%
CO	-11.0%

(Source: 96)

The report also examined whether there were statistically significant differences in emissions levels between biodiesel and diesel. They expressed the results of this analysis in terms of p-values. A p-value greater than 0.05 illustrates that there is no statistically discernable difference at a 95 percent confidence interval. The p-values in Table 5-2 show that emissions levels are significantly different between biodiesel and diesel No. 2 for all four pollutants. They also show that there is a significant difference between biodiesel types for NO_x, PM and CO emissions. There was no significant difference in HC emissions between biodiesel types (animal fat, rapeseed and soy). These results are described in more detail for each pollutant in the sections below.

Table 5-2: P-Values for Biodiesel Source Effects

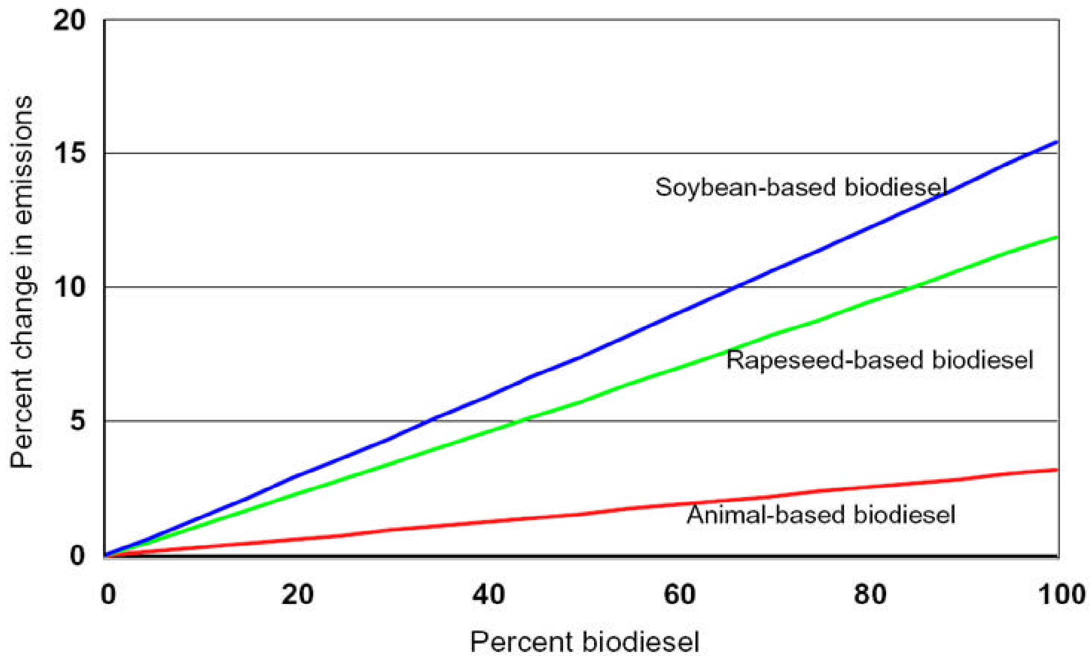
	NOx		PM		HC		CO	
Do Source Effects…	Test	P-value	Test	P-value	Test	P-value	Test	P-value
Change with % biodiesel?	**Yes**	**0.0001**	**Yes**	**0.0001**	**Yes**	**0.0001**	**Yes**	**0.0003**
Animal x % biodiesel	**Yes**	**0.0001**	**Yes**	**0.0001**	**No**	**0.5525**	**Yes**	**0.0001**
Rape x % biodiesel	**Yes**	**0.0311**	*No*	*0.6316*	*No*	*0.9162*	**Yes**	**0.0164**
Soy x % biodiesel	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*

(Source: 96)

appears to produce larger emission benefits than the [statistical] correlation predictions. Based on this comparison, we do not believe that the vehicle data can be used to represent the emission effects of biodiesel on heavy-duty diesel engines." (96) Vehicles carrying a greater load will produce more vehicle emissions; however, there are no indications that the emissions impacts of biodiesel change as vehicle load increases.

5.2.1. NO_x

As seen in Table 5-1, soy-based B20 emits 2.0 percent more NO_x than diesel No. 2. According to the EPA study, the biodiesel types are significantly different from one another. As seen in Figure 5-1, each type of biodiesel showed higher emissions of NO_x than diesel No. 2. Soy-based biodiesel showed the most significant increase in NO_x emissions, animal-based biodiesel the smallest, and rapeseed showed an increase between the two (96).



(Source: 96)

Figure 5-1: Biodiesel Source Effects of NO_x

The increase in NO_x is partially rooted in biodiesel's higher cetane number. Dr. Kerr Walker from the Scottish Agricultural College reports that higher NO_x emissions result primarily from the shorter ignition delay time of biodiesel[12] (97). The piston of the engine moves due to advancement of a hot flame front that results from the ignition of the air-fuel mixture. The typical air-to-fuel mixture for a diesel engine is 7 parts of air to 10 parts of fuel. As air contains 80 percent nitrogen, most of the air-fuel mixture is nitrogen. NO_x is created when an oxygen/nitrogen mixture is subjected to high temperatures and pressures. At the start of combustion, the combustion chamber on a diesel engine is filled with air. The oxygen and nitrogen mixture is under high pressure and is fairly hot. If there is a delay in the ignition timing,

[12] According to staff from the Montana Department of Environmental Quality, recent studies suggest that NO_x emissions are related to engine technology and injection pressure: slow and medium-speed (medium-pressure) diesel engines show no or little increase in NO_x, while engines with high injector pressure (~300 psi) show slight rises in NOx (53).

a large amount of accumulated fuel suddenly ignites, creating a very hot flame front, and probably creating a large amount of NO_x (98).

This problem can be remedied by changing the engine timing. Steve Howell of the Society of Automotive Engineers reported that research indicates retarding engine timing to lengthen ignition time can mitigate increases in NO_x emissions from biodiesel (99). This statement is echoed by Dr. Walker: "Adjustment of injection timing and engine operating temperature will result in these levels [of nitrogen oxides with biodiesel] being reduced below mineral diesel levels." (97)

Although the mean engine timing has the potential of matching the cetane number, there still lies the problem of biodiesel's cetane rating varying more than diesel. According to the EPA study, biodiesel has a "widely varying natural cetane" relative to diesel[13] (96). Therefore, regardless of engine timing modification, biodiesel is statistically expected to emit more NO_x than diesel due to its greater cetane level variance. It's important to note that cetane numbers in association with engine timing are a significant factor in NO_x emissions, but not the only factor. The National Biodiesel Board notes that, because of biodiesel's lack of sulfur, a variety of NO_x control technologies may be applied that would not be applicable with conventional diesel (100). Examples of these technologies include NO_x adsorbers and lean NO_x catalysts, which have demonstrated the potential to control greater than 50 percent of diesel engine NO_x emissions (101)[14].

There are other strategies that may be used to reduce NO_x in biodiesel blends[15]. Lowering the aromatic content in the base fuel, or using diesel No. 1 (kerosene) as a base fuel, can both be effective. Cetane enhancers di-tert-butyl peroxide (DTBP) and ethyl-hexyl nitrate (EHN) may also be helpful (102). Another option is to blend biodiesel using different feedstocks. It has been reported that iodine numbers in animal-based biodiesel are lower than those for soy- or rapeseed-based biodiesel, so it has been suggested by Thornton that blending high iodine number fuels and low iodine number fuels could help mitigate the increase in NO_x (103). Exhaust gas recirculation has also been shown to reduce NO_x of B20 by 10 percent, in comparison with the results obtained through altering injection pressure and optimizing engine timing (104).

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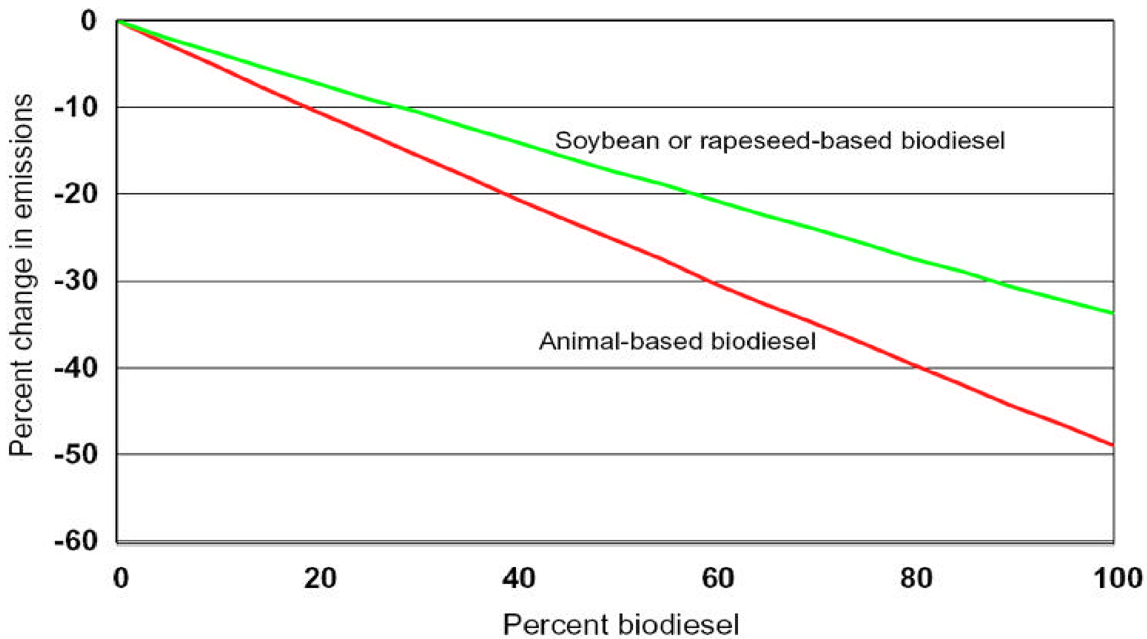
[13] Both conventional diesel and biodiesel can be blended to achieve a certain cetane. Cetane number is not typically included as a specification for biodiesel, although it has been added as a specification by some users (for example, the military).

[14] The Manufacturers of Emission Controls Association (MECA) adds the lower sulfur fuel can lead to adoption of control technologies to impact HC and PM emissions as well, such as commercially available PM and HC filters that use a NO_x catalyst to help destroy diesel particulate emissions. MECA adds that lower sulfur fuel "further enhances the performance of other PM and HC control technologies, such as oxidation catalysts and catalyzed diesel particulate filters, which can operate on current diesel fuels." (101)

[15] According to staff from the Montana Department of Environmental Quality, chassis dynamometer testing conducted at lower temperatures (~35° F) showed that less NO_x was produced at lower operating temperatures. Therefore, the actual NO_x impact of biodiesel in Montana may be less than indicated by the EPA analysis (53).

5.2.2. PM

According to the EPA study, B20 soy-based biodiesel produces 10.1 percent fewer PM emissions than diesel No. 2 (96). Further, the percentage of PM being emitted decreases as the percentage of biodiesel increases, as seen in Figure 5-2. It should be noted that there was no significant difference between soybean and rapeseed-based biodiesel PM emission, but both exhibited a greater PM emission than that of animal-based biodiesel.



(Source: 96)

Figure 5-2: Biodiesel Source Effects of PM

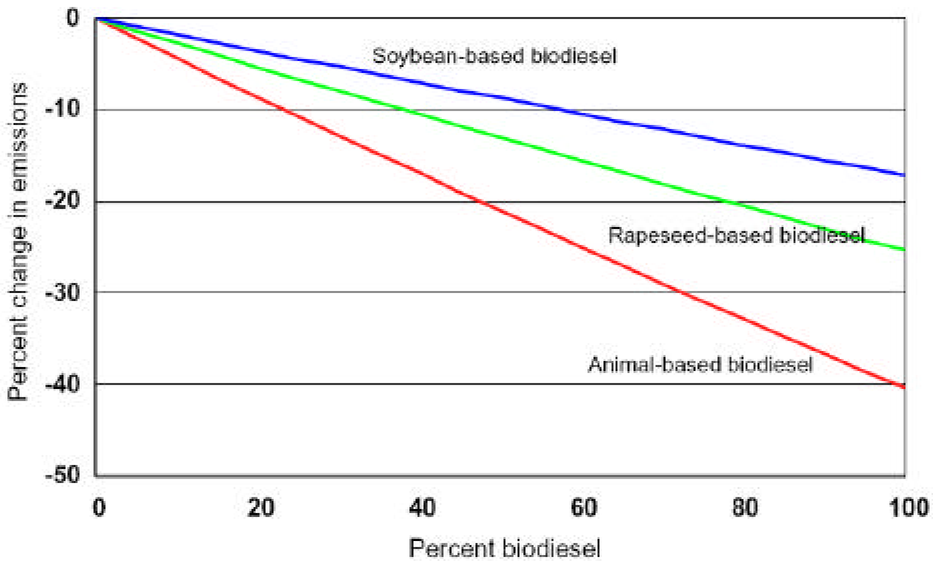
There is a tradeoff in diesel engine technology between producing fewer PM emissions (as seen in Figure 5-2), while creating more NO_x emissions (as seen in Figure 5-1), since these emissions can react with other agents to form smog. The tradeoff of PM and NO_x emissions may or may not be a problem. First, Alfuso found that rapeseed methyl ester oil reduced smoke levels in direct injected diesel engines (105). Figure 5-1, Figure 5-2, and Figure 5-3 show that soy, rapeseed and animal-based biodiesel blends have similar emissions attributes to that of the rapeseed methyl ester used in Alfuso's experiment; it is likely that that there will also be a reduction in smoke. More specifically, it is possible that the tradeoff of PM and NO_x for soy, rapeseed and animal-based biodiesel blends are tilted in favor of less smog. Secondly, NO_x is a precursor to ground-level ozone formation. This process needs heat: in Montana, the temperatures are cool enough and there is a summer wind to prevent significant NO_x formation (9). Therefore, given Montana's seasonal characteristics, it's unlikely for the potential of haze forming in Montana if smog is a factor.

5.2.3. HC

Biodiesel has noteworthy benefits in reducing HC emissions relative to diesel No. 2. As seen in Table 5-1, soy-based B20 emits 21.1 percent fewer HC than diesel No. 2. The EPA report shows that there is no significant difference in the percent reduction of HC emissions between different feedstock types (rapeseed, soy and animal-based) (96).

5.2.4. CO

As shown in Table 5-1, B20 (soy-based) biodiesel produces 11.0 percent less CO than No. 2 diesel fuel. This trend is similar to biodiesel base types (soy, rapeseed and animal), as seen in Figure 5-3. The EPA report indicates that CO emission reductions vary according to the feedstock used[16]. As seen in Figure 5-3, the following biodiesel bases are in order of decreasing percent reduction of CO per percent biodiesel: animal, rapeseed then soybean-based biodiesel (96).



(Source: 96)

Figure 5-3: Biodiesel Source Effects of CO

5.2.5. CO_2

Regarding carbon dioxide, the EPA report was not able to identify a clear difference between biodiesel and diesel. It noted that carbon dioxide benefits are attributed to biodiesel because of its nature as a renewable resource; however, the report did not quantify those benefits (96).

[16] An analysis by the University of Idaho shows that CO and other emissions vary by iodine number, which represents the amount of unsaturated carbon bonds. High oleic vegetable oils have the lowest CO emissions, lower PM emissions, relatively little impact on NO_x emissions, and are the most stable (53).

A Department of Energy fact sheet on biodiesel did seek to quantify these benefits. It noted that plants that are used to make biodiesel draw CO_2 from the atmosphere and recycle it back as the plants decompose. Because of the renewable nature of biodiesel, DOE estimated that methyl ester biodiesel produces 78 percent less CO_2 than diesel (14, 83).

5.3. State and Regional Emissions Impacts

Widespread adoption of biodiesel fuel within Montana may potentially have air quality impacts on a state or regional level. This section will examine the context for understanding the broader emissions impacts associated with biodiesel usage.

5.3.1. Background

In order to understand the potential air quality impacts of biodiesel, it is necessary to clarify some of the key regulatory agencies and legislation that govern air quality in Montana.

EPA

The U.S. Environmental Protection Agency (EPA) was established in 1970 in response to a growing public demand for cleaner water, air, and land. The EPA develops and enforces regulations that implement environmental laws passed by Congress, offering financial assistance, performing environmental research, sponsoring voluntary partnerships and programs, and furthering environmental education. According to its Internet site, the agency researches and establishes “national standards for a variety of environmental programs, and delegates to states and tribes the responsibility for issuing permits and for monitoring and enforcing compliance. Where national standards are not met, EPA can issue sanctions and take other steps to assist the states and tribes in reaching the desired levels of environmental quality.” (106)

Clean Air Act

The 1970 Clean Air Act (CAA) was the first piece of Congressional legislation to address air pollution on a national scale. It provides the primary framework for protection of air quality from all pollution sources, including stationary and mobile sources (16).

CAA was significantly amended in 1977 and 1990. The 1977 amendments included establishing a national goal for visibility as “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas[17] where impairment results from manmade air pollution.” The 1990 amendments provided additional emphasis on regional visibility, requiring EPA to work with several western states to address visibility in Class I areas in the Colorado Plateau. This led to the formation of the Grand Canyon Visibility Transport Commission (GCVTC) in 1991 (107). GCVTC issued its recommendations for dealing with visibility pollution in June 1996 (108).

[17] Class I Federal areas are defined by CAA as national parks over 6,000 acres, wilderness areas over 5,000 acres, national memorial parks over 5,000 acres, and international parks that were in existence as of August 1977.

CAA requires each state to develop a state implementation plan (SIP) that explains how it will do its job in meeting the requirements of CAA. The SIP is a collection of regulations that a state will use to fulfill CAA and other environmental regulations. The SIP includes estimates of emissions from all sources, including stationary sources (e.g. heavy industry, power plants) and mobile sources (e.g. vehicles).

NAAQS

The Clean Air Act, which was last amended in 1990, requires EPA to set National Ambient Air Quality Standards (NAAQS) for certain pollutants. The Clean Air Act established two types of national air quality standards: primary standards, which are aimed at protecting public health, and secondary standards, which protect the public welfare. EPA set NAAQS for the six principal pollutants shown in Table 5-3. It should be noted that the NAAQS only includes one nitrogen oxide compound – nitrogen dioxide (NO_2). Nitrogen dioxide is a highly reactive gas formed in the ambient air through the oxidation of nitric oxide (NO).

Table 5-3: National Ambient Air Quality Standards

		Standard Type	
Pollutant	**Standard Value**	Primary	Secondary
Carbon Monoxide (CO)			
8-hour Average	9 ppm	X	
1-hour Average	35 ppm	X	
Nitrogen Dioxide (NO_2)			
Annual Arithmetic Mean	0.053 ppm	X	X
Ozone (O_3)			
1-hour Average	0.12 ppm	X	X
8-hour Average	0.08 ppm	X	X
Lead (Pb)			
Quarterly Average	1.5 µg/m^3	X	X
Particulate (PM 10) *Particles with diameters of 10 micrometers or less*			
Annual Arithmetic Mean	50 µg/m^3	X	X
24-hour Average	150 µg/m^3	X	X
Particulate (PM 2.5) *Particles with diameters of 2.5 micrometers or less*			
Annual Arithmetic Mean	15 µg/m^3	X	X
24-hour Average	65 µg/m^3	X	X
Sulfur Dioxide (SO_2)			
Annual Arithmetic Mean	0.030 ppm	X	
24-hour Average	0.14 ppm	X	
3-hour Average	0.50 ppm		X

(Source: 109)

DEQ

While EPA has overall authority for enforcing environmental regulations, it delegates substantial authority to agencies in each state. In Montana, the Board of Environmental Review adopts regulations administered and enforced by the Department of Environmental Quality (DEQ). The state has responsibility for submitting a SIP to EPA for its approval and for enforcing the regulations and control plans in the SIP.

DEQ is responsible for a statewide ambient air monitoring network. NAAQS attainment is determined on an intrastate geographic basis depending on the nature of the pollutant and the extent of the concentration exceeding the NAAQS. For example, certain ozone precursors and $PM_{2.5}$ tend to be regional in scope while ground-level ozone[18], PM_{10} and CO, tends to be more localized. DEQ is responsible for monitoring air quality levels and defining the boundaries of attainment or non-attainment areas (110).

Regional Haze Rule

In 1999, EPA adopted a regional haze rule to address visibility impairment on a regional basis (111). All fifty states are covered under the regional haze rule. The rule relates to fine particles that are transported across state boundaries and includes specific provisions – 40 CFR 51.309 (also known as "section 309") – for the nine states covered by GCVTC, which does not include Montana but does include two neighboring states (Idaho and Wyoming). Montana is subject to 40 CFR 51.308 (section 308) which is more flexible in allowing states to implement what they believe to be the most effective measures for reducing their contributions to regional haze. Montana is only required to examine mobile sources if they are believed to be significant contributors to regional haze. Mobile sources are not a significant contributor to regional haze in Montana. According to Trista Glazier from DEQ, analysis by the Western Regional Air Partnership has indicated that regional haze reduction benefits from mobile sources are not as significant as originally believed. This reflects the usage of cleaner fuels over time and the continuing turnover of more efficient vehicles into the fleet (112). After the natural background levels are established, Montana will focus its compliance efforts on emissions from various sources (including smoke management, prescribed burning and industrial sources) that cause or contribute to visibility impairment (112).

Section 308 states need to develop a state implementation plan by 2007 that will deal with SO_2, NO_x and PM emissions. Section 309 states are allowed to focus on SO_2 in their 2008 SIP, and will address NO_x emissions afterward (113).

WRAP

The Western Regional Air Partnership (WRAP) is a consortium of 12 western states including Montana and 12 Native American tribes (including the Northern Cheyenne Tribe and the Confederated Tribes of Salish and Kootenai in Montana) who have partnered to deal with issues related to the Regional Haze Rule. WRAP is a collaborative effort of these governments and various federal agencies to implement the GCVTC's recommendations and to develop the technical and policy tools needed by western states and tribes to comply with the regional haze rule (114).

[18] According to staff from Montana DEQ, Montana does not have any ozone non-attainment areas, and DEQ does not currently monitor for ozone (53).

The primary role of WRAP is to provide modeling and technical expertise for member states in conducting air quality analyses to assist them in developing SIPs and emissions control strategies. Its current focus is primarily on section 309 states because these states have a more stringent timeline for demonstrating reasonable progress on visibility. WRAP will complete modeling and analytical work for section 308 states like Montana as well. WRAP has no statutory or regulatory authority, but is an important collaborative forum for dealing with regional air quality issues (112).

According to the Wyoming Department of Environmental Quality's emissions inventory coordinator, all states within WRAP – regardless of whether they follow section 308 or 309 – are presented with similar regional strategies as a result of WRAP's analysis. Each state can choose strategies based on what is most appropriate for their needs (113).

5.3.2. Potential Positive Impacts

As was indicated in section 5.2, EPA studies indicate that biodiesel produces fewer emissions of several pollutants, including CO, PM and SO_2, that are regulated by the NAAQS. Some potential impacts are discussed below.

Reallocation of Emissions in SIP Budget

A decrease in mobile source emissions of these pollutants could provide room in the state's emission budget to pursue less stringent emissions control strategies on stationary sources. To take advantage of this, the state would need to quantify the emissions reductions resulting from biodiesel. Therefore, WRAP would need to develop estimates of revised mobile source emissions with a significant biodiesel component; a significant reduction could affect air quality compliance strategies. Such reallocation must be approved by both DEQ and EPA.

Emissions Credit Trading

Another way to take advantage of reductions in mobile source emissions might be through the use of emissions credit trading. To this date, emissions trading has not been established for mobile source pollutants such as HC, CO and PM in Montana nor nationally. There is currently no emissions credit trading program for section 308 states (9, 112).

Emissions trading has been used for SO_2, a major contributor to acid rain, in the Northeast. This concept imposed caps on SO_2 emission levels on the dirtiest power plants in the Northeast. Plant owners that would find it costly to cut SO_2 emissions can buy allowances from utilities that find it less costly. The program resulted in emissions reductions that were quicker than required at a cost level below forecast (115). The Chicago Climate Exchange, which had its first auction in September 2003, is one organization that has formed to help develop similar markets for greenhouse gases, including CO_2.

Several Montana companies recently formed a group called the National Carbon Offset Coalition (NCOC). NCOC intends to help landowners, corporations and government agencies participate in a market-based conservation program that can help to offset the environmental impacts of greenhouse gases, like CO_2. Example projects include conversion of pastureland to forested land.

The carbon sequestration benefits of a given project – how much CO_2 is removed from the atmosphere – would be measured by long-term increases in the amount of carbon in soil. NCOC has produced initial guidance in assisting landowners who are interested in developing projects. One key element in the documentation is the discussion of "additionality," which essentially refers to the net carbon sequestration benefits of a given project. It takes into account what would have happened with a given piece of land under normal conditions and what the landowner decided to do to take advantage of credits for carbon sequestration (116).

If land were put into active production of crops that could be used for biodiesel feedstocks, farmers could conceivably claim some carbon sequestration benefit. Theoretically, this could provide additional revenue to farmers, thus helping to offset some of the higher costs associated with producing biodiesel fuel (see section 7.1). The guidance indicates, however, that the critical question for assessing a carbon sequestration benefit is what the use of the land would otherwise have been. If a farmer converts one crop to another (for example, winter wheat to canola), it may not have any carbon sequestration benefit at all.

Another possible benefit of biodiesel related to emissions trading is whether a large-scale producer of pollutants could financially benefit by producing fewer emissions. For example, a trucking company with a large fleet of vehicles that converts to biodiesel could show a reduction in emissions based on using biodiesel. They might be able to then sell these credits to another emissions producer (such as a factory). This could reduce emissions compliance costs for the factory, and could help the trucking company to offset the additional cost of fuel. The Chicago Climate Exchange does permit emissions from smaller sources (including vehicles) to be considered, although the focus is on electric power plants, and fossil fuel combustion and process emissions associated with the manufacturing sector. Mobile source emissions would need to be quantified using the Greenhouse Gas (GHG) Protocol, developed by the World Resource Institute/World Business Council for Sustainable Development, or other protocols developed by the Chicago Climate Exchange in order to be included (117). The GHG protocol standard includes mobile source emissions as part of a company's overall emissions production (118); however, no calculation tools are currently available to estimate emissions impacts of changing vehicle fuels or other aspects of a company's transportation infrastructure (119). Without approved calculation tools, it is unlikely that a firm could take credit for emissions reduction gained by switching to a biodiesel blend.

Because of increased concern over greenhouse gases and the success of market-based approaches, emissions trading for carbon dioxide could occur in the future. This could provide a potential economic benefit with broader implementation of biodiesel fuel. Given the lack of a legislative mandate and the infancy of the emissions trading market, however, it is probably not prudent to count this as a significant advantage to using biodiesel at this time.

Net Clean Air Benefits

The state may choose to simply reduce mobile emissions in the state, which may help with conformity for areas in non-attainment (such as Billings, Great Falls, and Missoula). For parts of the state that are in attainment, the use of biodiesel allows for even cleaner air than required by Federal standards.

In considering this, it is important to put the net emissions reduction in context. For example, Missoula has a mobile source budget for PM-10. Of that budget, less than 2 percent comes from tailpipe emissions; the remainder is from re-entrained road dust (110). (Dust can be dealt with through reductions in vehicle miles of travel [VMT] and/or paving of roads; in other words, it is independent of fuels used.)

5.3.3. Potential Negative Impacts

Section 5.2 indicated that, apart from altering engine timing and using fuel emulsions, biodiesel may lead to higher emissions of NO_x per diesel vehicle. Potential negative impacts are described as follows.

Conformity

Although NO_2 is a pollutant regulated under CAA, increases in NO_2 are not likely to cause Montana to fall into non-attainment for NO_2. One favorable element for Montana is that ground-level ozone formation requires heat and Montana's air tends to cool at night better than other parts of the country (such as the Los Angeles basin) (110). Moreover, ozone formation in the west tends to be limited by hydrocarbon availability, not NO_x; therefore, increased NO_x emissions will not increase ozone formation without a significant increase in HC emissions (110).

Regional Effects

One concern with increased NO_x is how it would influence regional frameworks, such as WRAP. First, Montana – like all states outside of California – must use fuels and vehicle engines that comply with national standards. Biodiesel and biodiesel blends have been approved by EPA as acceptable fuels for on-road engines and approved diesel engines may use biodiesel as well as diesel. All WRAP analyses reflect these standards.

Second, section 309 states are not required to address NO_x mobile source emissions in their SIP until 2008. According to an environmental agency staff person in one section 309 state, biodiesel's contribution to NO_x could be an item of discussion at that time. However, given biodiesel's minimal effect on NO_x emissions – an estimated 2 percent increase for a B20 blend would be far smaller with a B2 blend – he indicated that such an effect would be insignificant from a regional perspective (113).

Third, evidence indicates that increases in NO_x emissions may be addressed through improvements in engine timing, which would render this question moot.

Random Roadside Testing

Some Western states, including Arizona and Nevada, conduct random roadside emissions testing of commercial vehicles. To date, this testing has focused on opacity only – the percentage of light blocked by exhaust – with a sliding scale used based on the age of the engine (120, 121). Some communities in Montana also have opacity laws (53). Since opacity is a measure of smoke (or visible PM emissions), it would not include NO_x emissions (122); consequently, this should be of no concern to vehicles using biodiesel. Moreover, studies have indicated that biodiesel decreases opacity: a 40 percent reduction using a B30 blend (123) and a 15 to 58 percent decrease using a B20 blend according to the University of Missouri (124).

California has done experimental testing with in-use NO_x measurement. The primary concern of their testing appears to be related to identifying engines in need of repair. Initial testing has indicated that engine repairs have resulted in minimal NO_x reduction, and that there is no clear cut-off between low NO_x- and high NO_x-producing vehicles. Further testing is still underway (125).

Given the state of current roadside testing programs and the minimal adverse NO_x impacts of biodiesel, it appears to be unlikely that heavy-duty vehicles would face fines in other states for using a B2 to B20 biodiesel blend.

6. LEGISLATION

Increased utilization of biodiesel could have a wide range of impacts on the national economy. For the agricultural sector, biodiesel would provide a new market for their products. As biodiesel fuel may cost more than conventional diesel, there could also be adverse economic impacts if costs are passed on in a variety of consumer goods. Those economic impacts are beyond the scope of this report. More pertinent to the thrust of this paper are the ramifications of increased biodiesel usage with respect to taxation, legislation and motor fuel tax revenues. These concerns are addressed at the Federal and State levels in this chapter.

6.1. Europe

Due to legislation between the years of 1992 and 1994, the European Parliament helped increase the production capacity of biodiesel to over 1.1 million tons per year. The increase in crop production and the resulting increase in biodiesel production are partially attributable to incentives created by two legislative factors. First, the Reform of the Common Agricultural Policy in 1992 helped biodiesel obtain a higher potential for market entrance. The reform added substantial subsidies for non-food crop production. The amount of land used to grow oilseeds for industrial purposes is estimated to have increased by 50 percent (about 0.9 million hectares) from 1995 to 1996. Secondly, a tax break for non-imported (non-petroleum) fuels was instituted in February 1994; this was another major step for biodiesel's entrance into the marketplace. Prior to this legislation, 50 percent of the pump price of diesel in Europe was due to taxes. The legislation created a 90 percent tax exemption for biodiesel, which provided monetary incentives for customers to use biodiesel over its counterpart, petroleum diesel (126).

6.2. Federal

6.2.1. Motor Fuel Tax

The Federal government currently taxes diesel fuel at 24.4 cents per gallon. This taxation rate applies to diesel, biodiesel and biodiesel blend fuels equally. Some alternative fuels – liquefied propane gas, for example – have different tax structures, but these have not been applied to biodiesel yet. Interest in Federal tax incentives to promote biodiesel has led to discussion regarding reducing the motor fuel tax on diesel by one percent for every percent biodiesel blend used, up to B20 (9). However, no tax reductions have been applied to date.

As a side note, if it is accepted that biodiesel offers less energy per unit volume than diesel, the current tax structure would mean that increased use of biodiesel would have a positive effect on Federal fuel tax revenues from diesel, since more gallons would be required to go the same distance. If relatively weak biodiesel blends (e.g. B2) are used, however, the positive effect would likely be trivial.

6.2.2. EPAct

Congress passed the Energy Policy Act (EPAct) in 1992. The primary objective of EPAct was to reduce U.S. reliance on foreign oil by the promotion of alternative fuels. EPAct accomplishes this by giving tax breaks for supplying alternative fuels, such as biodiesel. This allows a higher priced biodiesel to more easily compete with diesel on the open market. The EPAct milestone in 2000 was for "alternative fuels to represent 75 percent of all affected vehicle purchases for government fleets and 90 percent of all affected vehicle purchases by companies that manufacture alternative fuels." (30) The long-range goal of EPAct is a 30 percent reduction in imported petroleum by the year 2010 (30). Sections 501 and 507 of EPAct were designed to promote the use of non-petroleum fuels, such as ethanol, methanol, natural gas, propane, hydrogen, electricity and biodiesel (127). Subsequently, in October 1997, the definition of alternative fuels was expanded from biodiesel (B100) to any gradient between B100 and B20 (128). This is important from a policy perspective because it provides additional incentive for fleets to invest in biodiesel. Although these are the current definitions, future additions to the alternative fuel list can be made though the Alternative Fuel Petition Program Section 301(2) of EPAct (128).

EPAct encompasses the following three alternative fuel vehicle (AFV) credit programs: (1) State and Alternative Fuel Provider Program, (2) Federal Fleet Program, and (3) Private and Local Government Fleet Program. Due to community population requirements, however, all but a few Montana fleets are exempt from EPAct compliance and enforcement.

?? The *State and Alternative Fuel Provider Program* requires certain fleets to acquire a given percentage (75 percent for state fleets and 90 percent for alternative fuel providers) of alternative fuel vehicles (AFVs) (30). Compliance is required by state government and alternative fuel provider fleets that operate, lease, or control 50 or more light-duty vehicles (LDVs) within the United States (20 of which need to be in a Metropolitan Statistical Area [MSA] and/or Consolidated Metropolitan Statistical Area [CMSA], neither of which are located in Montana). "Fleets that are subject to AFV acquisition requirements may comply by acquiring new or used AFVs, purchasing credits from other covered fleets, or using credits they have earned." (129) For every 450 gallons of B100 (2,250 gallons B20) purchased and consumed, a full vehicle credit is awarded (130). "They may also purchase certain biodiesel fuel blends or acquire conventionally fueled vehicles and have them converted within four months of purchase." (129) The Alternative Fuel Vehicle Credit Program allows covered fleets to buy and sell AFV credits and tax credits through the EPA website.

?? The *EPAct Federal Fleet Program* is a legislative requirement for AFVs by Federal agencies. Starting in fiscal year 2000, this program required that alternative fuel vehicles "represent 75 percent of all affected vehicle purchases for government fleets." (30) Further, 2005 Federal fleets are required to reduce their petroleum consumption by 20 percent. EPAct set forth the statutory requirements for the acquisition of AFVs by Federal agencies (131). All EPAct Federal Fleets must be in the MSA and/or the CMSA areas, neither of which are located in Montana.

?? The *Private & Local Government Fleet Program* is a program where the "EPAct gives DOE the authority to develop a vehicle acquisition program for private and local government fleets. However, before it can implement a private and local government fleet rule, DOE must first determine that a rule is necessary to achieve EPAct's petroleum replacement fuel goals and that it is technically and economically practical. DOE is continuing to evaluate whether to implement a rule." (132) The following criteria must be met:

- The company or local government owns, operates, leases or otherwise controls 50 or more LDVs within the United States;
- At least 20 of those LDVs are used primarily within a MSA/CMSA;
- Those same 20 LDVs are centrally fueled or capable of being centrally fueled. LDVs are considered centrally fueled if they are capable of being refueled at least 75 percent of the time at a location that is owned, operated, or controlled by any fleet, or under contract with that fleet for refueling purposes; and
- Vehicles in the Private and Local Government Fleet Program cannot also be in the State program or the Federal program described earlier.

For individuals or small businesses other than trucking, the purchase of large quantities of biodiesel doesn't seem to be a cost-effective solution. It is likely that this incentive, the tax break, will be passed on to the customer based on the comparatively high price of biodiesel to biodiesel's competitor, diesel, and the assumption that the biodiesel distributor wants to stay in business.

It should be noted that one of EPAct's intents is to diversify the fuels used in transportation in the U.S. Therefore, an additional stipulation is that fleets may only substitute their biodiesel fuel consumption for up to one half of their total annual alternative fueled vehicle fuel purchase requirements (130).

6.3. State Legislation

Several states have been considering biodiesel legislation in recent years, primarily out of a motivation to provide additional markets for local agriculture producers. A study by the Food and Agricultural Policy Research Institute (FAPRI) estimated that a demand for 70 million gallons of soy biodiesel could add from \$0.10 to \$0.18 per bushel to the price of soybeans (133). The USDA Economic Research Service (USDA-ERS) estimated that if demand is 100 million gallons per year, then the price of soybean oil would increase by 14 percent (133). The following are some examples of this legislation.

6.3.1. Minnesota

Minnesota passed major biodiesel legislation in 2002, which requires 2 percent by volume biodiesel in diesel fuel sold in the state. One interesting component of this legislation is that it has contingencies that affect when the B2 requirement is in effect. A first contingency is that the mandate will be in force only after the state's agriculture commissioner certifies that the state has the capacity to produce 8 million gallons of biodiesel per year. The second contingency is that the mandate will not take effect until eighteen months after there is a two cent reduction in Federal taxes on biodiesel blend fuels, or June 30, 2005, whichever comes first (134).

The Minnesota Soybean Growers Association used the economic analyses conducted by USDA-ERS and FAPRI to speculate that the Minnesota legislation would add 1.7 to 4.2 cents per bushel to the price of soybeans in the U.S. and 6 to 8 cents per bushel for Minnesota farmers, based on their favorable location. This would result in an estimated $4 million and $11 million in gross farm income, respectively, in Minnesota and would decrease federal outlays under the soybean marketing loan program in similar amounts (133).

6.3.2. Illinois

Illinois Bill SB 46, which gave tax exemptions to biodiesel and ethanol fuel sold in the state, was signed into law in 2003. The law exempted biodiesel blends exceeding B10 from state sales taxes and reduced taxes by 20 percent on biodiesel blends between B1 and B10 (135). The state estimated that the exemptions would boost production of soybeans to 30 million bushels per year, adding $22.5 million to the Illinois economy. This was predicated on an assumption that the price of soybean bushels would increase by $0.05 (136). Illinois forecasts that they will increase the annual U.S. production of soybeans, about 3.0 billion bushels, by 30 million bushels (137).

It should be noted that the Illinois Bill SB 46 has secondary effects that may not have been adequately considered. First, SB 46 is likely to increase the marginal benefit of producing soybeans. This may result in more people producing soybeans and less production of other agricultural goods, such as corn. This shift in the marketplace, from corn to soybeans, has been going on since 2001 (138) and SB 46 is expected to continue this shift. In other words, Illinois may not end up increasing their economy by $22.5 million, but rather, marginally increasing their economy by artificially creating incentives for shifts in agriculture markets. Secondly, it should be noted that the alternative cost of SB 46 is less sales tax revenue going into state coffers to fund other government programs.

6.3.3. Missouri

In 2002, Missouri passed a law creating a biodiesel producer incentive fund with a $0.30 per gallon incentive on 15 million gallons per year for the first five years after the law takes effect. The funding for this incentive was to be provided by Proposition B, which would have increased fuel taxes in the state to generate nearly $500 million per year, primarily for transportation projects (139). More than 72 percent of Missouri voters rejected the measure (140), preventing implementation of the fund.

6.3.4. North Dakota

Legislation in 2003 provided tax credits for retrofitting facilities to produce biodiesel. Other legislation, which would have mandated 2 percent biodiesel in all diesel sold in the state by 2007, was defeated (141).

6.3.5. South Dakota

Legislation mandating 2 percent biodiesel content in diesel fuel was considered in the state during 2002, but failed (142). Legislation that would have reduced fuel taxes on biodiesel blends by two cents per gallon was also defeated (141).

6.3.6. Hawaii

Legislation effective as of January 1, 2002 reduced motor fuel taxes on alternative fuels as a proportion of diesel fuel taxes; biodiesel was charged at 50 percent of the diesel rate, with an additional 1 cent per gallon added (143).

6.4. Montana

Montana Code Annotated (MCA) 15-70-301 essentially defines biodiesel as a B20 blend (144). Currently, according to MCA 15-70-370, the fuel tax is reduced by 15 percent for all biodiesel or ethanol fuel sold in the state (145, 146), an incentive which is in effect four years after an ethanol plant begins operation in Montana (147). It should be noted that the B2 blend, which was being proposed in the legislation considered by the Montana House, would not be included in this tax reduction. Montana currently taxes diesel fuel at 27.75 cents per gallon (148). In addition to the temporary tax reduction on biodiesel and ethanol fuels, motor fuel tax revenues are currently reduced by production incentives to encourage the use of Montana agricultural products to produce alcohol that could be mixed into motor fuels (149).

7. OTHER FACTORS

Research for this literature review identified a couple of additional factors that could affect policy decisions regarding biodiesel implementation in the state: cost and production considerations.

7.1. Cost

Perhaps the most significant reason that biodiesel has not gained wider acceptance in the U.S. is the cost of biodiesel relative to conventional diesel. Favorable taxation in Europe has allowed biodiesel to achieve approximate cost parity with conventional diesel. It is important to emphasize, however, that fuel taxes make fuel in European substantially more expensive than fuel in the United States.

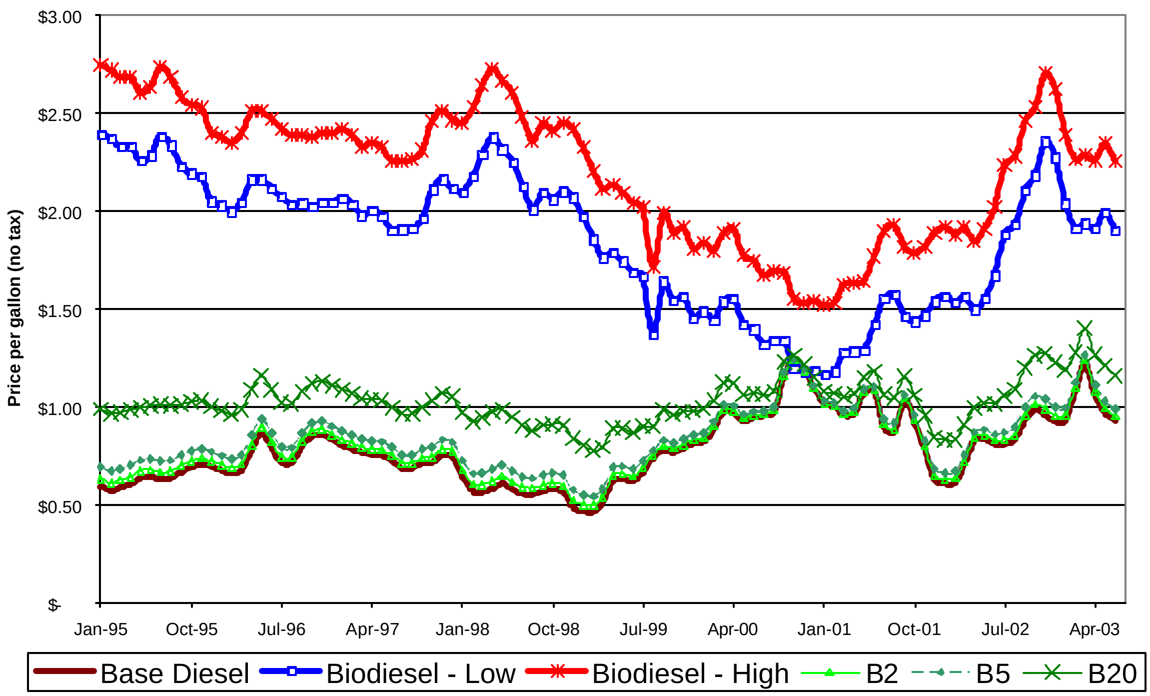
When looking at the cost of biodiesel production, most of the cost is from the feedstock used. Carnigal estimated that 91.52 percent of the production cost of biodiesel is the cost of feedstock, with operating cost and capital cost representing 3.12 percent and 5.34 percent of the production cost, respectively (cited in 150). Figure 7-1 (see page 43) compares estimated prices of canola-based biodiesel versus diesel from January 1995 to June 2003. The cost estimate for canola-based biodiesel assumes that 7.7 pounds of canola oil are required to make 1 gallon of biodiesel, with processing costs ranging from $0.15 to $0.50 per pound. As can be seen, the cost of biodiesel is generally much higher than diesel. Biodiesel blends, however, may be relatively competitive. Over the time period shown in the graph, B2 would cost 2.5 cents more per gallon than conventional diesel, while B5 and B20 would have premiums of 6.2 cents and 24.9 cents per gallon, respectively, as compared to conventional diesel.

The cost of biodiesel may be reduced by using alternative feedstocks. For example, current prices of canola and soybean oil are approximately 20 to 22 cents per pound. Prices per pound are lower for inedible tallow (14 cents), mustard oil (10 cents), yellow grease (9 cents), and brown or trap grease[19] (5 cents or cheaper) (151, 152). In terms of oilseeds, it should be noted that different oilseeds have different oil content. Soybeans, for example, have about 20 percent oil content, while other oilseeds have as much as 50 percent. Rapeseed, the primary feedstock used for biodiesel in Europe, is about 40 percent (81).

Lower quality feedstocks may help as well. While fuel quality does not appear to be affected, there are concerns that pour point could be increased. Moreover, a higher free fatty acid content may make processing more expensive (30).

Few studies have examined life cycle costs associated with biodiesel as compared with conventional diesel. A 1994 study from the University of Georgia compared the costs of operating an urban bus for conventional diesel versus biodiesel and other alternative fuels. The report determined that while biodiesel was the lowest cost alternative fuel option for an urban

[19] Brown grease has significantly more free fatty acids than yellow grease, and therefore would not be suitable for use as a standalone feedstock in biodiesel (152).



(Sources: Canola Prices from 154, 155; Biodiesel Price Methodology from 156; Diesel Prices from 157, adjusted for 52.15 cents per gallon combined Federal and State tax)

Figure 7-1: Price Comparison of Diesel Fuel vs. Canola Biodiesel Blends

bus, it was still more expensive than diesel. The authors concluded that the economics of biodiesel (and other alternative fuels) require "compelling environmental or socioeconomic benefits … to warrant incentives for promoting alternative fuels." (153)

From a biodiesel production standpoint, a 1998 University of Missouri-Columbia study indicated that between soybeans, sunflower, canola and animal fats, canola would be the lowest cost feedstock for production. However, because of the value of its co-products (e.g. meal), soybeans would result in a lower cost of production for biodiesel than canola (158). This may be one reason why soybean oil continues to dominate the U.S. market as feedstock for biodiesel.

Another consideration beyond the cost of production is the cost of transportation. The price point for shipping is dependent on sales volume, so larger volumes of biodiesel freight are less expensive to ship. Rates for shipping are currently estimated at $0.34/gallon for shipment by truck and $0.12-0.17/gallon for shipment by tank cars (9). Shipping costs would decrease as a biodiesel industry develops in Montana to meet local demand.

7.2. Production Capacity

In 2001, the National Biodiesel Board estimated the dedicated production capacity for biodiesel at 60 to 80 million gallons per year (159). Actual production, according to biodiesel producer applications to the U.S. Department of Agriculture's Commodity Credit Corporation bioenergy program, was about 35 million gallons in 2001, with most of that coming from soybeans (160). Fuel-grade mono-alkyl esters can also be produced by the oleochemical industry, where there is an estimated excess capacity sufficient to produce 200 million gallons of biodiesel per year. The Board reported that production capacity could increase fairly quickly (159). About half of this capacity is designed for soybean oil, half for recycled restaurant cooking oil; both commodities are currently in surplus, so prices are not resource-constrained (161). In a study that examined the availability of various feedstocks for biodiesel, it was concluded that "current and future raw material availability far exceeds current and future predicted demand based on the expected price uncompetitiveness of biodiesel versus diesel." (162)

For comparison, the Federal Highway Administration reports that approximately 200 million gallons of diesel fuel were sold in Montana for motor vehicles in 2001, out of a national market of 30.2 billion gallons of fuel (163).

8. SUMMARY AND CONCLUSIONS

The purpose of this report has been to review current literature regarding the use of biodiesel in on-road vehicle applications. This chapter will summarize the main findings of the literature review, and outline recommendations for the phase 2 field test.

8.1. Summary of Findings

This section looks at some of the key findings of this literature review.

?? In general, engine performance has not appeared to suffer significantly because of the introduction of biodiesel. There may, however, be some peak power loss and some increase in fuel viscosity.

?? Recent studies have shown no significant wear concerns with biodiesel, especially when biodiesel is blended with good quality petroleum diesel. Material compatibility with seals and gaskets may be a concern on B100 or in older engines.

?? One engine concern arises when an engine alternates between different fuel types. Conventional diesel leaves deposits in engines that biodiesel, as a solvent, will clean out. This can mean additional costs for replacing fuel filters initially, but these additional costs are not sustained over time. Moreover, this is less of an issue if a low biodiesel blend (B20 or less) is used or if biodiesel is used as an additive (B2).

?? Cold weather product storage for low (less than B20) biodiesel blends should not be a problem. Biodiesel blends are already used on a widespread basis in several cold weather locations, including Yellowstone National Park, Glacier National Park, Grand Teton National Park and Malmstrom Air Force Base. Moreover, biodiesel has been approved by the EPA as a fuel additive (B2 or less). At least one public fueling station in Montana blends biodiesel into its conventional diesel.

?? Numerous emissions studies have been conducted, and ably summarized by EPA. Most tests have been completed with B20 biodiesel blends. Biodiesel blends show emissions benefits for SO_2, CO, CO_2, HC and PM. Biodiesel blends show increased NO_x emissions, which may be partly or fully mitigated by changing engine timing.

?? There appear to be no significant motor fuel tax revenue implications from increasing the use of biodiesel in Montana.

?? A significant barrier to broader implementation of biodiesel is its price. This is a difficult issue to resolve at this time since much of the cost of biodiesel is attributable to the feedstock and transportation, and not to production. Given a higher price, it would be important to consider how biodiesel might be superior to diesel. Biodiesel's primary benefits are increased lubricity, domestic production, and reduced emissions.

Only some instances have shown that biodiesel has significant performance advantages compared to conventional diesel.

8.2. Recommendations for Phase 2 Testing

Based on the findings of this literature review, many of the technical questions regarding biodiesel have been answered. Given increased utilization of biodiesel in cold-weather environments, and favorable reports regarding engine performance and maintenance, there seems to be a broad consensus that biodiesel is a safe and reliable fuel that can be used in limited quantities in biodiesel blends with minimal or no additional accommodation.

The broader questions affecting future biodiesel policy in Montana would appear to be related to blend rate, user acceptance and cost. Therefore, the proposed field test of B20 blend in MDT maintenance vehicles in Havre and Missoula should provide an important screening for user acceptance of the fuel. There is significant cold weather experience with biodiesel and biodiesel has been used in winter roadway maintenance activities as well. Combining these factors in a field test in Montana would lend more credence to the ability of biodiesel fuels to succeed on a long-term basis in the state.

Most research projects that have examined biodiesel performance have involved expensive testing procedures, such as chassis and engine dynamometers to test emissions and performance and engine teardowns by manufacturers' engineers. For example, the Yellowstone "Truck-in-the-Park" demonstration cost close to $500,000 with much of these costs from partners and grants (including the State of Wyoming) involving emissions and performance tests and fuel analyses (35). The results of these tests are conclusive enough that it would be inadvisable for MDT to re-do these tests in their own field test. The field test should focus on fuel economy, which can be easily measured, along with anecdotal evidence regarding fuel transportation, handling and storage, and engine maintenance. Operator and maintenance staff surveys will be important to gauge overall user acceptance.

Perhaps a more critical question regarding the future of biodiesel in the state is the additional cost associated with using biodiesel blend fuels. Apart from changes in motor fuel tax policy on biodiesel at either a Federal or a State level or significant production levels, biodiesel blends will be more expensive than diesel. Some fuel vendors may choose to absorb the increased costs, as in West Yellowstone, but this would not be necessary if B2 is required for all diesel sold in the state. More detailed analysis regarding the economic impacts of biodiesel – positive impacts for farmers in general and Montana farmers in particular and negative impacts in terms of increased fuel prices that are directly or indirectly absorbed by consumers – would be essential when considering long-term policy regarding biodiesel.

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