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Maine Department of Transportation

Transportation Research Division

Technical Report

Experimental Trial Using Biodiesel Fuel in Heavy Fleet Vehicles

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From July 2003 to April 2003, Maine DOT used a blend containing 20% of biodiesel fuel (B20) in five pieces of mobile equipment and in two furnaces at the Freeport Maintenance Facility, in lieu of conventional diesel fuel. This study found that biodiesel costs 40 to 50 cents more per gallon than conventional diesel.

Introduction

The preponderance of scientific evidence shows that the earth's surface temperature has risen by about 1 degree Fahrenheit in the past century and that most of the warming over the last 50 years is attributable to human activities. These activities have altered the chemical composition of the atmosphere through the build up of green house gases. Carbon dioxide (CO_2) and black carbon are two chemical compounds responsible for contributing significantly to global warming.

Atmospheric concentrations of CO_2 have increased nearly 30% since the beginning of the industrial revolution. These increases have enhanced the heat-trapping capability of the earth's atmosphere, resulting in global warming. The combustion of fossil fuels in responsible for 98% of United State's CO_2 emissions.[1] It is estimated that diesel vehicles in the State of Maine emit 558,436 metric tons of CO_2 every year.

Black carbon also contributes to global warming. When diesel fuel is combusted, fine carbonaceous particles are emitted. The carbonaceous particles, collectively referred to as soot, contain two forms of carbon: organic and elemental. The organic carbon fraction can be separated from the elemental carbon fraction by heating or by solvent extraction. What remains is the elemental fraction that is known as black carbon. Black carbon absorbs sunlight from the atmosphere, causing the particles to warm, and in turn heating the surrounding air. As a result, black carbon contributes to global warming.[2] In 2002, approximately 1,745.6 metric tons of black carbon was generated by mobile diesel engines in Maine.[3]

Because the combustion of diesel fuel contributes to the creation of CO_2 and black carbon in the State of Maine, MaineDOT has begun to look at various methods to reduce the amount of CO_2 and black carbon generated by its diesel vehicle fleets. In recent years, biodiesel has been identified as an alternative fuel that can be used instead of conventional diesel fuel (petrodiesel). The Maine Department of

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[1] Environmental Protection Agency. *Global Warming –Climate*. http://Yosemite.epa.gov/oar/globalwarming.nsf/content/Clmate.html. Website accessed April 7, 2004.

[2] Wolff, Gregory T. *Fact Sheet on Black Carbon and Global Warming.* General Motors Public Policy Center. November 2002.

[3] Environment Northeast. Memo to the Green House Gas Transportation Working Group. Subject of Diesel black carbon background and strawman. March 29, 2004.

Transportation has recently used biodiesel on a one-year test basis for vehicles in Freeport, Maine. The intent of this report is to summarize the benefits and the detriments of using biodiesel. Emission reductions associated with the use of biodiesel in the Freeport case study are presented and analyzed. A summary of reported difficulties associated with the use of biodiesel by vehicle operators is also provided. Although other emissions are discussed, this analysis focuses on the reduction of CO_2 emissions and black carbon because they are directly linked to global warming.

Biodiesel Overview

The diesel engine was designed with the intention of running it on a variety of fuels, including vegetable oil. When Dr. Rudolf Diesel demonstrated his engine at the World Exhibition in Paris 1900, he used peanut oil as fuel.[4] Since that time, however, the diesel engine has been modified to run on petroleum-derived fuel (i.e. petrodiesel) because historically it was the least expensive fuel. The diesel engine is still capable of running on "biodiesel" fuel that can be produced from a variety of renewable sources, including soybean oil, canola oil, sunflower oil, cottonseed oil, and animal fats. These potential fuel sources can be obtained from agricultural feedstocks or by recycling used oil such as cooking grease.

Biodiesel is usable in its pure form, known as "neat biodiesel" or B100, which contains no petrodiesel. In addition, it is also available in various blends with diesel, the most common of which is known as B20. B20 is comprised of 20 percent biodiesel and 80 percent petrodiesel. Biodiesel is one of the only alternative fuels usable in any conventional diesel engine with little or no modifications to the engine or fuel system. More than 40 federal and state fleets are already using biodiesel blends in their existing diesel engines.

Reported Biodiesel Benefits

General Biodiesel Benefits

Biodiesel operates in conventional combustion-ignition engines ranging from light to heavy-duty, just like petroleum diesel. No engine modifications are required, and biodiesel maintains the payload capacity and range of diesel. Because engine modifications are not required, there's no need to change vehicles, increase spare parts inventories, establish additional refueling stations or employ specially skilled mechanics.

B100 biodiesel is biodegradable, nontoxic and essentially free of sulfur and aromatics. Because biodiesel is biodegradable and nontoxic it poses less of an environmental hazard if there were a biodiesel spill than if there were a petrodiesel spill.

Biodiesel is also a renewable resource, based on soybean and other oil crops that are grown annually in the continental United States. Because biodiesel can be produced domestically, it reduces this country's dependence on foreign oil.

Biodiesel Emission Reductions

When looking at the emissions associated with biodeisel, the entire lifecycle is taken into account, including total emissions associated with the growth, production and use of a fuel product rather than focusing solely on the emissions that are generated at the tailpipe of mobile vehicles. Lifecycle emissions

[4] Environmental Protection Agency. *Clean Fuels Alternative: Biodiesel.* March 2002.

associated with biodesel take into account existing emissions in the atmosphere, the amount of emissions absorbed by soy or other crops grown to produce biodiesel, the amount of pollution generated to cultivate and harvest the crop with diesel farm equipment, the amount of emissions generated during the production of biodiesel, and the quantity of emissions emitted during combustion activities (i.e. tail pipe emissions).

When taking lifecycle emissions into account, using biodiesel in a conventional diesel engine substantially reduces emissions of carbon dioxide, carbon monoxide, particulates, hydrocarbons and sulfates. These reductions increase as the amount of biodiesel blended into diesel fuel increases. As shown in **Table 1**, the highest emission reductions are seen with B100.

If lifecycle emissions are not taken into account, and only the tailpipe emissions are measured and compared to those tailpipe emissions from conventional diesel, the use of B100 biodiesel results in a 4.6% increase in CO_2 emissions. The use of B20 results in a 0.94% increase in CO_2 emissions at the tailpipe. This indicates that the majority of CO_2 savings occur during production activities. Specifically, most CO_2 reductions occur in the Midwest where crops are grown and where biodiesel is manufactured. Although using B20 doesn't reduce CO_2 emissions at the tailpipe, it should be noted that CO_2 tailpipe emissions being created by the combustion of biodiesel are CO_2 emissions that have already existed in the atmosphere that were sequestered by the growth of the crop. This contrasts with mining of and use of fossil fuels that re-releases CO_2 emissions that have been removed from the earth's atmosphere and stored in coal or oil for thousands of years. For the purpose of this report, lifecycle emissions are used as a basis to compare biodiesel with petrodiesel because there are no B20 tail pipe emission estimates for all pollutants and because the only emission data available for B20 biodiesel is based on lifecycle emissions. Lifecycle emission reductions for the use of biodiesel, relative to the use of conventional diesel, are shown in **Table 1**.

As previously discussed, black carbon is a component of diesel particulate matter. Black carbon has recently been linked with global warming. In addition, diesel particulate matter has recently been identified as a health hazard by the Environmental Protection Agency. Diesel particulates can cause lung damage and respiratory problems and have been linked to the development of cancer. Diesel particulate matter can also exacerbate existing illnesses, asthma or allergies. As shown in **Table 1**, the use of B100 reduces particulate matter by 70% and B20 reduces particulate matter by 15%.

Carbon dioxide is associated with global warming and is largely responsible for the increase in the earth's ambient temperature during the last several decades. Carbon dioxide emissions are also reduced significantly with the use of biodiesel. With the use of B100, CO_2 lifecycle emissions are reduced by 78% and the use of B20 reduces CO_2 lifecycle emissions by 15%.

TABLE 1

LIFE CYCLE EMISSION REDUCTIONS FOR USE OF BIODIESEL

	CO_2	**CO**	**PM**	**HC**	**SO_x**
B100	-78%	-50%	-70%	-40%	-100%
B20	-15%	-10%	-15%	-10%	-20%
Source: EPA Clean Alternative Fuels: Biodiesel. Fact Sheet March 2002					

Reported Biodiesel Detriments

There are several noted problems with the use of biodiesel. Most of the problems cited with the use of biodiesel (both B100 and blends) are related to the cost of the fuel and the replacement of rubber hoses. The composition of hoses used in vehicles is designed to resist petroleum based products, with the use of biodiesel these hoses experience some premature deterioration. Some operators have cited complaints that the fuel gels or freezes in cold temperatures. In addition, there is fear of the unforeseen complications arising from materials compatibility, consistent fuel quality, gumming, and low temperature effects. Each of these issues is discussed in detail below.

The cost of biodiesel as a replacement fuel is a detriment. Estimated fuel costs for the B20 fuel blend (20% biodiesel and 80% petrodiesel) are 40 to 45 cents more per gallon than regular diesel. For the most part, the price difference is due to the price of the base vegetable oil or tallow (animal fat). In addition, there may be small reductions in fuel economy because biodiesel has lower energy density than standard diesel fuels.

Biodiesel acts as a solvent to some fuel system components and concrete lined tanks. This effect can release deposits accumulated on tank walls and pipes from previous diesel fuel storage.[5] As a result, vehicles should have the fuel filter changed after the first tank of biodiesel is consumed. B100 can also soften and degrade certain types of elastomers and natural rubber compounds (i.e. hoses) over time. When using biodiesel, vehicle hoses should be checked after the first 6 months of operation on biodiesel. This is less of a concern with biodiesel blends such as B20. Newer vehicles have biodiesel compatible hoses and rubber.

B100 biodiesel is known to have cold start problems relative to petrodiesel, however, this has not been a problem for B20 fuels. Conventional diesel starts to gel at temperatures around -20 degrees Fahrenheit. B20 biodiesel freezes at temperatures 3 degrees to 5 degrees Fahrenheit higher than petrodiesel, however, it has been used in upper Wisconsin and Iowa during 25 degree weather with no reported problems.[6] B100 will begin to freeze at 25 degrees Fahrenheit.

The use of biodiesel in most engines also results in a slight increase in nitrogen oxides (NO_x) emissions. When using a B20 blend, depending upon the make, model and year of the equipment used, the increase in NO_x emissions can range from 2.0% to 3.9 %[7] more than the levels produced from the use of petrodiesel. The average NO_x increase for B20 is estimated to be 2.4%. If a B100 blend is used the increase in NO_x emissions can range from 9.9% to 19.6%. [8] The average NO_x increase for B100 is estimated to be a 13.2% increase.

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[5] Environmental Protection Agency. *Clean Alternative Fuels: Biodiesel*. March 2002.
[6] Environmental Protection Agency. *Clean Alternative Fuels: Biodiesel*. March 2002.
[7] ENVIRON International Corporation. *Impact of Biodiesel Fuels on Air Quality and Human Health*. Summary Report. May 2003. Pg 7.
[8] ENVIRON International Corporation. *Impact of Biodiesel Fuels on Air Quality and Human Health*. Summary Report. May 2003. Pg 7.

> *No problems were experienced with biodiesel except a reported slight decrease in power with an off- road tractor. No emissions tests were done during this trial, however, the literature search for this project indicates that some studies show that biodiesel results in an increase level of emissions at the tailpipe for some atmospheric compounds, thereby increasing local emissions load. Nevertheless, biodiesel is a renewable fuel source, and unlike conventional diesel, is not derived from fossil fuel sources.*

In July of 2003, Maine DOT started the biodiesel pilot study in Freeport, Maine at the maintenance facility. This facility is responsible for general maintenance activities such as plowing, ditch digging, hauling debris and keep roads clear. During the study period of July 2003 to May 2004, fuel consumption, vehicle miles traveled, and equipment usage data were collected and used to analyzed the effectiveness of using this alternative fuel. During the course of almost a year, five pieces of mobile diesel equipment used the B20 biodiesel. Following is a list of diesel equipment in Freeport that used the B20 fuel:

- 1995 Ford 3-axle plow truck
- 2002 Sterling 2-axle patrol truck
- 2002 Sterling 2-axle patrol truck
- 1995 GMC 2-axle patrol truck
- New Holland 2 WD loader-backhoe

All equipment was used year-round. Equipment uses included snow removal, hauling material, sand and debris, and hauling and applying anti-ice chemicals. The backhoe is used for loading dump trucks and for ditch digging. The patrol trucks and plow truck traveled a total of 39,174 miles during the year. Mileage for the backhoe is not recorded but it is used an average of 244 hours per year.

In addition to the mobile equipment listed above, the B20 biodiesel was also used to fuel two furnaces. Historically, the furnaces have used between 5,000 and 6,000 gallons of diesel fuel per year. Data for the pilot study indicates that approximately 5,296 gallons of fuel were used in the furnances during the July 2003 to May 2004 time period. Each furnace has a distinct use. The first furnace is used to heat the maintenance building and maintain ambient air temperatures. The second furnace is used for heating hot water that is used within the buildings and to hose off equipment for cleaning. Both furnaces are approximately 20 years old.

Biodiesel Benefits in Freeport

<u>Mobile Equipment</u>

The use of biodiesel has created multiple benefits. First and foremost, several air pollutant emissions were reduced. Using the total vehicle miles traveled (VMT) by all vehicles in Freeport using B20, emissions factors from the EPA emissions model Mobile 6.2, and the estimated percent reductions in emissions associated with the use of biodiesel (see **Table 1**), the emissions associated with the use of the diesel equipment were estimated. Using recorded data, it was noted that the diesel vehicles would drive a combined total of 39,174 miles during the course of the study. As shown in **Table 2**, if these vehicles used conventional petrodiesel, approximately 124,042.36 lbs/year of CO_2 would be generated. In contrast, the use of B20 generated approximately 105,436.01 lbs/year of CO_2. This resulted in a net reduction of 18,606.35 lbs/year of CO_2.

VOCs generated with the use of B20 were also estimated. As shown in **Table 2**, the use of biodiesel also resulted in a slight decrease in the generation of VOCs. Estimated VOC emissions decreased by 5.18 lbs/year. Consistent with previous studies, NO_x emissions increased slightly with an estimated total of 23.34 lbs being generated during a year.

CO emissions were also reduced when using B20. As shown in **Table 2**, CO emissions decreased by 25.08 lbs/year.

TABLE 2

ESTIMATED CHANGE IN LIFECYCLE EMISSIONS WITH USE OF BIODIESEL (LBS/YEAR)

Pollutant	Conventional Diesel	Biodiesel	Net Difference
CO_2	124,042.36	105,436.01	**-18,606.35**
CO	250.80	225.72	**-25.08**
PM	33.27	28.28	**-4.99**
BC*	20.96	17.81	**-3.14**
NO_x	972.53	995.87	**23.34**
VOC	51.82	46.64	**-5.18**

* BC is Black Carbon
Source: Maine DOT, Using Mobile 6.2

As shown in **Table 2**, the use of biodiesel also reduced the amount of diesel particulate matter that was generated within the exhaust. The use of B20 reduced exhaust particulate matter by 4.99 lbs/year. Based on the Mobile 6.2 model outputs, black carbon comprises approximately 63 percent of diesel particulate matter. As shown in **Table 2**, black carbon emissions were reduced by 3.14 lbs/year.

In addition to emission benefits observed during the pilot study, it was noted that the use of biodiesel was convenient and easy. The machinery did not require additional maintenance and was not taken out of service for any retrofitting or repairs related to the use of biodiesel. The B20 biodiesel was simply used as a replacement for conventional petrodiesel.

It is important to note that the above emission estimates were based on annual VMT for all diesel vehicles in Freeport using the B20. These emission estimates did not take into account emission reductions that would occur while these vehicles, which were fueled with B20, generated while idling. To date, there is no length (i.e. minutes per day) or frequency (i.e. days per week) of idling information that is available for all equipment that used B20. Due to the lack of data and the fact that emission savings associated with idling were not taken into account, the actual emissions saved through the use of B20 are likely higher than those presented in **Table 2**.

Furnaces

At the present time there are no emission data available to quantify pollutant reductions from using biodiesel in the furnaces. However, it can be assumed that the use of B20 resulted in lifecycle emission reductions similar to those presented in **Table 1**.

Biodiesel Detriments in Freeport

The diesel equipment in the pilot study is used intermittently, because it is dependent upon work requirements (i.e. ditch digging or hauling material) and weather conditions (i.e. plowing snow). In addition to the above, often times equipment is left idling for long periods of time. This results in the consumption of fuel but does not result in any miles being recorded and can give the appearance of low fuel efficiency. Backhoe use is measured solely as "hours used" and the miles traveled are not recorded. As a result of the variability of use and extended idling times, determining the actual fuel efficiency for biodiesel use in the equipment is problematic. Although the maintenance crew did not notice a marked increase or decrease in fuel efficiency when using the B20 blend, based on the results from other B20 studies, it can be assumed that there was a slight decrease in fuel efficiency that resulted in fewer miles being traveled for every gallon of fuel consumed.

The backhoe operator noted a slight decrease in the power of the machine. However the backhoe was still used to load materials into the dump trucks and for digging ditches. Even with the slight loss of power, the backhoe was still used for an estimated 244 hours during 2003. Therefore, it is concluded that the loss of power was not significant because it did not hinder the work effectiveness of the machine.

There were no other complaints listed by equipment operators. It should be noted that although there have been reports from other studies of biodiesel freezing or gelling in cold temperatures, during the winter of 2003, Maine experienced weather conditions that approached 20 degrees below zero. The equipment in Freeport is kept in a heated garage during the winter. Storing the equipment in the garage prevented the fuel from gelling. However, when the equipment was used outside during these low temperatures, vehicle drivers did not experience any problems with the B20 biodiesel freezing or gelling.

The cost of the B20 blend was roughly $0.40-$0.45 cents more per gallon than conventional diesel. Historically, the Freeport maintenance facility and equipment has used approximately 15,400 to 27,200 gallons of fuel. Of the total fuel used, the furnaces consumed 5,200 to 6,800 gallons of fuel. The amount of fuel consumed by both the furnaces and vehicles is dependent upon the weather conditions and work demands. There is wide variability in the amount of fuel consumed year to year. Consequently, the cost of using biodiesel can be significantly higher than the cost of using conventional diesel.

Finally, the use of biodiesel generated an additional 23.34 lbs/year of NO_x emissions. NO_x is an ozone precursor and when combined with sunlight readily forms ozone. Although this is a relatively small amount of NO_x, southern Maine is designated by the Environmental Protection Agency (EPA) as non-attainment for ozone. The generation of additional NO_x emissions continues to hinder the ability of the Department of Environmental Protection to bring the region into attainment for Federal ozone standards.

Furnaces

The crew at the maintenance facility did not cite any problems with using B20 fuel in the furnaces. No complaints were noted.

Green House Gas Benefits

> *Due to the limited scope of the project, this study cannot make conclusions about global implications of biodiesel use. Other studies have demonstrated, however that on a life cycle basis, (which considers the reduction in some atmospheric compounds like CO2 at the site of the crops[soybeans] being grown for the fuel), biodiesel provides an overall global reduction in most air pollutants and atmospheric compounds*

Although the use of biodiesel reduces the generation of various types of emissions (i.e. CO, CO_2, VOC, and PM), when lifecycle emissions are taken into account, this report focuses on quantifying and evaluating biodiesel's effectiveness as it relates to global warming. More specifically, this analysis focuses on two pollutants CO_2 and PM. The use of B20 biodiesel saved approximately 18,606.35 lbs/year of CO_2 and 3.14 lbs/year of black carbon.

TABLE 3

AMOUNT OF CO_2 SAVED PER GALLON OF B20 USED IN MOBILE EQUIPMENT AT THE FREEPORT FACILITY

Gallons Consumed[1]	Total CO_2 saved[2]	Approximate amount of CO_2 saved/gallon consumed [3]
5,711	16,452.86	2.88 lbs

Notes:
1. On fuel used in mobile equipment between 07/03 and 05/04
2. Total CO_2 saved presented in Table 2 and assumes total VMT of 34,640
3. Reduction in CO_2 emissions per gallon of biodiesel used.

Table 3 shows the amount of CO_2 that was reduced for every gallon of B20 fuel consumed at the Freeport facility. As indicated in **Table 3**, the use of biodiesel saved an average of 2.88 lbs of CO_2 per gallon of fuel used. To restate this, in contrast to biodiesel, the use of conventional diesel generates 2.88 lbs more of CO_2 per gallon consumed.

The additional cost of using B20 as a replacement for conventional diesel varies and is dependent upon the following factors: 1) the amount of fuel used; and 2) the additional cost of biodiesel. As stated above, the amount of fuel consumed by each vehicle varies by season, activity and year. When fuel costs more, fewer CO_2 reductions are seen per dollar spent. As previously noted, the amount of diesel fuel consumed by the equipment in Freeport varies from 15,400 gallons/year to 27,200 gallons/year. The cost of biodiesel varies from an additional $0.40/gallon to $0.45/gallon when compared to petrodiesel. The estimated additional fuel costs associated with the use of B20 are listed in **Table 4** and can range from an additional $6,160 to $12,240 per year.

TABLE 4 ADDITIONAL YEARLY COST OF USING B20 AT THE FREEPORT FACILTIY		
Gallons Consumed[1]	**Cost at an Additional \$0.40/Gal.[2]**	**Cost at an Additional \$0.45/Gal.[3]**
15,400	\$6,160	\$6,930
27,200	\$10,880	\$12,240
Notes: 1.Based on historic annual fuel consumption in Freeport 2. Additional cost if B20 costs \$0.40 more per gallon than conventional diesel 3.Additional cost if B20 costs \$0.45 more per gallon than conventional diesel		

As stated above, recent studies show that black carbon contributes to global warming and various measures are being considered to reduce the generation of particulate matter associated with the combustion of diesel fuels. A cost benefit analysis was not completed for black carbon because the amount of black carbon reduced (3.14 lbs/year) is small compared to CO_2 (18,606.35 lbs/year). Therefore, quantifying the benefit (i.e. lbs of black carbon reduced) derived from the consumption of 1 gallon of B20 would be very small. This is not to imply that the reduction of black carbon through the use of B20 is insignificant, it simply means that quantification of the benefits would not provide addition insight.

To date, the most effective measure for reducing black carbon includes the installation of a diesel particulate filter in existing engines. These filters reduce the generation of particulate matter by 90% and cost \$5,000-\$12,000 per vehicle for installation.[9] Installing the filters on transit buses would cost \$5,000 while installing the filters on construction engines (i.e. front end loader) would cost as much as \$12,000.[10] The filters are expected to last the life of the vehicle.

Conclusions

There were noted benefits and detriments associated with using B20 at the Freeport Facility. The use of the fuel proved to be easy and convenient. When lifecycle emissions were taken into account, the use of B20 resulted in a reduction in air pollutant emissions. With the exception of a slight loss of power in the backhoe, all equipment using B20 performed the same as it would with the use of petrodiesel.

The primary drawbacks associated with using biodiesel include the increased cost per gallon which is approximately \$0.40 to \$0.45 more, the slight reduction in fuel efficiency and the slight increase in NO_x emissions. The increase in NO_x emissions would continue to contribute to the existing nonattainment status for ozone in several portions of the State and could hinder DEPs ability to bring the region into compliance for Federal ozone standards. The use of biodiesel in the State of Maine also would not reduce CO_2 emission levels within the state because most soybeans and other crops grown for the production of

[9] Environment Northeast. Memo to the Maine GHG Transportation Working Group. Subject Diesel Black Carbon Mitigation Measures. March 30, 2004. pg 2.
[10] Environment Northeast. Memo to the Maine GHG Transportation Working Group. Subject Diesel Black Carbon Mitigation Measures. March 30, 2004. pg 2.

biodiesel are located in the Midwest. As a result, the majority of CO_2 emission savings will occur in the Midwest and the State of Maine would not see a decrease in regional CO_2 emissions.

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