COMPARISON OF ESTERIFIED AND NON-ESTERIFIED OILS FROM RAPESEED, CANOLA AND YELLOW MUSTARD AS DIESEL FUEL ADDITIVES

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16. Abstract

The main goal of this project was to experiment with the oils and biodiesel made from locally developed rapeseed, canola and yellow mustard cultivars. The fuel was characterized according to ASTM standards and used as a lubricity additive for two- and four-cycle engines. Additionally, on-road testing as well dynamometer and NOx emissions testing continued under this project with the additional goal to study the utilization and recovery of by-products from the biodiesel process. The University of Idaho Biological and Agricultural Engineering department has also been conducting on-farm demonstrations with several farm vehicles operating on a 50/50 blend of biodiesel and diesel at the UI Plant Science Farm. Numerous research papers report that ultra low sulfur diesel (ULSD), which is mandated by the EPA to replace low sulfur diesel by 2006, does not meet lubricity standards and can be harmful to diesel engines A lubricity study was conducted with esterified and non-esterified vegetable oils used as an additive at low level blends with ULSD. The results of this study were somewhat mixed. A test for screening lubricating oils for two-cycle engines was conducted using fish oil, and results indicate that unadulterated fish oil is not an adequate lube oil for two-cycle engines.

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EXECUTIVE SUMMARY

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The Vandal Trolley was a popular vehicle for campus events this year and provided an excellent platform for testing locally grown and produced biodiesel in typical bus service. The University of Idaho Biological and Agricultural Engineering (BAE) department has dynamometer tested the trolley for baseline power and fuel consumption data and has been fueling it with B20 (a blend of 20 percent biodiesel and 80 percent diesel fuel) for two years now. Permanent lettering has been added to the sides and back of the trolley indicating its use of biodiesel and BAE involvement.

Additional ongoing on-road demonstrations include a 1999 Dodge Ram 2500 and a 2001 Volkswagen 1.9 L TDI beetle. Both vehicles continue to run on 100 percent yellow mustard biodiesel (MEE). The truck has accumulated 32,120 miles and has averaged 15.78 mpg. No operational problems have been noted. Oil analysis results from samples of the engine oil were normal. The VW has been prominently displayed at numerous demonstrations, conferences and fairs. It now has 14,370 miles operating on biodiesel without a problem. The fuel filter was replaced at 10,000 miles as part of normal routine maintenance.

The BAE department has also been conducting on-farm demonstrations with several farm vehicles operating on a 50/50 blend of biodiesel and diesel at the UI Plant Science Farm. These vehicles include a John Deere 3150 and Mitsubishi Bison tractors, a Winterstiger plot combine and a Swift plot swather. The John Deere tractor has been operating on some form of biodiesel or raw oil/diesel blend for over 15 years.

In a 2001 attempt to correlate emissions readings from a portable five-gas analyzer with emissions readings obtained at the Los Angeles Mass Transit Authority (Peterson et al, 2000), it was found that only the nitrous oxide data was comparable. Additional tests were conducted in August of 2002 comparing six biodiesel feedstocks to the NOx data from LAMTA and were determined to follow a similar trend but with slightly higher readings for HySEE and REE.

It has been reported in numerous research papers that ultra low sulfur diesel (ULSD), which is mandated by the EPA to replace low sulfur diesel by 2006, does not meet lubricity standards and can be harmful to diesel engines (Schumacher and Adams, 2002; Hertz, 2001). Expanding on past studies, the BAE department conducted a lubricity study with esterified and non-esterified vegetable oils used as an additive at low level blends with ULSD. Samples were evaluated for lubricity with ASTM D 6079 (HFRR). In this test samples are used to lubricate a ball on plate apparatus. The resulting wear scar is an indication of the fuel's lubricity. ASTM does not currently state a wear scar limit but according to European standards a wear scar of over 450 microns at 60 C is unacceptable. The results of this study were somewhat mixed. It was discovered that the diesel fuel, supplied by Chevron Phillips, used to blend the samples contained a synthetic lubricity additive. The ULSD alone met the lubricity standard and the addition of small amounts of raw vegetable oils and biodiesel did not make a significant improvement in the lubricity of the fuel.

A test for screening lubricating oils for two-cycle engines was developed and conducted by the BAE department in 1996 using rapeseed ethyl esters (Peterson et al. 1997). This test was conducted again in 2002 using fish oil obtained from Steigers Corporation, a company operating seafood-processing plants in Alaska. Two Stihl leaf blowers (Model BG-55) were used for this test. The engines were 23.9 cc, rated at 0.7 kW capable of delivering 600 m^3/hr of air. One engine was fueled with a blend of 50 parts standard gasoline to1 part fish oil. The lube oil for the second engine was a 50/50 blend of fish oil and standard Stihl two-cycle engine oil at the same 50:1 ratio with gasoline. Both engines failed prematurely with carbon build-up and stuck piston rings indicating that unadulterated fish oil is not an adequate lube oil for two-cycle engines.

DESCRIPTION OF PROBLEM

Air quality standards have led the EPA to continue to limit the amount of sulfur allowed in diesel fuel for "on-road" vehicles. Prior to 1993, the limit for sulfur was 5000 ppm; the current limit is 500 ppm (low sulfur diesel) and by the year 2006, the limit will be 15 ppm (ultra low sulfur diesel). Ultra low sulfur diesel (ULSD) is currently being used in some areas of California to reduce SOx emissions (La Pera, 2000). The reduction of sulfur has led to a reduction in the lubricating quality of the fuel. This has resulted in an increase in fuel injection wear problems, particularly in high pressure injection pumps, some of which rely solely of the fuel to lubricate close tolerance moving parts (Schumacher and Adams, 2002). It has been reported that vegetable oils and their esters (biodiesel) have excellent lubricating properties and can be used in low level blends with diesel fuel to improve its lubricity (Drown, et al, 2001).

Vegetable oils and their esters have been under study at the University of Idaho since 1979. The program is recognized as a pioneering research program with feedstocks from rapeseed oil and used French fry oil (Chase et al, 2000). It is also recognized for the use of ethanol as the alcohol for the esterification reaction. While most biodiesel is produced with methanol, most of the biodiesel produced here is from ethanol. The ethanol comes from used potato wastes at a J. R. Simplot plant in Caldwell, Idaho. The fuel produced has been used in a variety of off-road and on-road engine tests and research projects.

Biodiesel produced from vegetable oil or animal fat can be used as an enhancement or a complete replacement for petroleum fuel in diesel powered vehicles such as trucks, tractors, and other heavy equipment including many marine applications. Esterifying the lipids to produce esters produces most biodiesel. This process reduces the viscosity and removes the glycerol making the resulting fuel more compatible with the engine. Most biodiesel is made from vegetable oil such as soybean, canola, rapeseed, sunflower or mustard and an alcohol.

The biodiesel process involves alcohol, such as methanol or ethanol into which a catalyst such as sodium hydroxide or potassium hydroxide is added. This mixture is stirred into the vegetable oil causing a chemical reaction, which separates the vegetable oil into two components: ester and glycerol. The ester is lighter than the glycerol and so rises to the top after the reaction is complete. The ester, after carefully washing to remove all remaining catalyst, alcohol and glycerol, is the product used as a fuel in diesel engines. The second component is a heavier liquid called glycerol. Glycerol has many food and industrial uses such as cosmetics, toothpaste, pharmaceuticals, foodstuffs, plastics, explosives and cellulose processing. However, the material obtained from biodiesel production requires purification before it can be used for these purposes.

The UI-produced biodiesel has emphasized use of feedstocks of economic significance to the state. Rapeseed, canola and yellow mustard are good alternative crops in northern Idaho. University of Idaho plant scientists have developed yellow mustard varieties, which have the potential to significantly reduce the cost of the oil used in biodiesel production through the utilization of a high value meal (a byproduct of the crushing operation) as a soil fumigant.

This project is for purposes of producing quantities of vegetable oils and their esters from these locally grown varieties to be used as diesel fuel enhancers and extenders and as a replacement for diesel fuel to test in both laboratory engines and in several on-road vehicles. As part of the test protocol, fuel characterization tests were be conducted to verify that the biodiesel produced meets the interim ASTM standard for biodiesel.

APPROACH AND METHODOLOGY

Project Objectives

1. Continue to produce and test biodiesel from locally developed strains of rapeseed, canola and yellow mustard oil.
2. Document the continued on-road use of yellow mustard oil as a feedstock for biodiesel.
3. Perform fuel characterization tests of the fuel developed in accordance with ASTM standard analysis procedures.
4. Research methods for glycerol recovery and disposal including possibilities for direct sale.
5. Dynamometer test the Vandal Trolley for baseline power and fuel consumption data and continue supplying it with a 20 percent blend of mustard oil biodiesel to support the concept of alternative student transportation around campus with a cleaner burning alternative fuel.
6. Conduct follow-up NOx emissions tests with a chassis dynamometer, a five-gas analyzer and the 1994 Dodge Ram with six different feedstocks to replicate the LA MTA emissions tests conducted earlier.
7. Conduct lubricity tests with both esterified and non-esterified blends of brassica oils to determine what levels of these oils add adequate lubricity benefits to diesel fuel.
8. Conduct cylinder-coking tests using a test developed with two-cycle engines using fish oil, which has been used successfully in the raw form in Alaska.

Facilities

The University of Idaho Department of Biological and Agricultural Engineering (BAE) has facilities for producing, characterizing, and testing alternative fuels. Laboratory facilities include a biodiesel production pilot plant facility; an analytical laboratory; an EMA computer controlled durability engine test facility; a machine vision system for evaluating injector coking; a maintenance and engine diagnostics laboratory for vehicle and engine research, and a double roll chassis dynamometer facility.

The biodiesel production pilot plant consists of two CeCoCo seed presses of 45 kg/hr each with seed pre-heating capability and instrumented feed bins; several small biodiesel reactors; two batch type reactors, one with 1000 liter capacity and the second with 2000 liter capacity. Fuel storage tank availability includes a variety of 1050-liter totes and several 2000-liter tanks. The plant is an approved BATF small fuel production plant and can obtain non-denatured alcohol and store it in an approved on-site locked area.

The analytical laboratory is equipped for biodiesel research. Fuel characterization data which can be performed at the UI include: heat of combustion, cloud point, pour point, viscosity, density, flash point, acid number, fatty acid, free and total glycerol determination, water and sediment, and cold filter plugging point. Additional fuel characterization including cetane number, ash, particulate matter, copper corrosion, elemental analysis, iodine number, and boiling point are performed by Magellan Analytical Services, Kansas City, KS. These parameters provide the information required for the ASTM standard D 6751 for biodiesel.

A SuperFlow SF-602 chassis dynamometer is available for in-chassis engine performance analysis and diagnosis. The SF-602 is a double drum, water brake dynamometer capable of about 750 hp in single drum configuration. Measurements taken by the dynamometer include: vehicle torque, vehicle speed, engine speed, engine coolant temperature, air intake temperature, exhaust temperature, engine oil pressure, manifold pressure and volumetric fuel consumption.

An EMS Model 5001 Emissions five-gas analyzer able of reading HC, O_2, CO, CO_2, and NOx was used to perform the NOx emissions tests. Readings are generally reported as parts per million or percentage of exhaust gases.

Departmental-owned research vehicles purchased exclusively for biodiesel research include a 76 kW John Deere 3150 four wheel drive tractor, a 1994 Cummins 5.9B powered Dodge pickup truck; a 1999 Cummins 5.9B electronically injected Dodge four wheel drive pickup truck; and a 2001 Volkswagen 1.9 L diesel powered new beetle. The latter two vehicles are used exclusively for testing on 100 percent yellow mustard biodiesel fuel.

Data Collected

1. Oil extraction and biodiesel production data.
2. Fuel characterization parameters.
3. On-Road Tests
4. Chassis dynamometer tests with the Vandal Trolley.
5. HFRR Lubricity tests on blends of oils and esters with ultra low sulfur diesel.
6. Two-Cycle endurance test with fish oil.
7. Chassis dynamometer steady state NOx emissions tests with the five-gas analyzer.

Procedure for NOx Emissions Tests:

The vehicle tested was a 1994 Dodge pickup with a DI, turbocharged and intercooled, 5.9-L Cummins diesel engine. The vehicle had accumulated 1500 miles on diesel and 109,270 miles on rape ethyl ester at the time of this test.

Fresh biodiesel from six different vegetable oils were made up to duplicate the 1997 tests conducted in LA (Peterson et al, 2000). The engine was not modified in any way for use with the vegetable oil fuels. The fuel delivery system was modified for convenience of changing fuels between test runs. Fuel delivery and fuel return lines were broken and an electrically operated tank switching valve was installed so that stub lines with quick couplers could be installed on one side of the valve while the main fuel tank was attached to the other. The fuels were held in five-gallon cans with supply lines attached near the bottom and return lines near the top. The lines had quick couplers to mate with the stub lines on the truck. The fuel filter on the truck was changed after each test. Upon startup with the new fuel, the return line was diverted to flush any residual fuel from the system. The biodiesel fuels as well as the diesel control were run in triplicate.

Procedure for Lubricity Testing

The rapeseed, canola, and mustard samples were processed from seed at the UI. The seeds were locally grown and crushed in a CeCoCo 45 Kg/hr oil seed expeller, which is a part of the BAE farm-scale oil seed and biodiesel processing plant. The ethyl esters of those oils were made at the BAE analytical Lab. The remaining samples (soy oil and soy methyl ester) were obtained from Ag Processing Inc. in Omaha, Nebraska.

After settling for one week, the UI oils and the soy oil to be used for direct blending were filtered through a Buchner funnel fitted with a 76mm type A/E glass filter paper, Gelman Sciences #61663. The ethyl esters of the oils was prepared using a 6:1 molar ratio of anhydrous ethanol to oil with 1.1 percent KOH by weight of triglycerides. After washing the UI esters as well as the soy esters were also filtered using the above-mentioned filter paper.

The ULSD used in this study was obtained from Chevron Phillips, The Woodlands, TX (Lot 0IPULD01). The oils and esters were blended at 0.5, 1 and 2 percent by volume with ULSD to make up 470ml samples using the densities of each component as described in Table 1.

Table 1 Blending Ratios for Lubricity Study

470 ml samples	g/ml	Percentage by Volume			
	Sp. Gr.	0.0%	0.5%	1.0%	2.0%
D2	0.829	389.63	387.68	385.73	381.84
Rapeseed Oil	0.912		2.14	4.29	8.57
REE	0.874		2.05	4.11	8.22
Canola Oil	0.920		2.16	4.32	8.65
CEE	0.878		2.06	4.13	8.25
Mustard Oil	0.916		2.15	4.31	8.61
MEE	0.875		2.06	4.11	8.23
Soy Oil	0.920		2.16	4.32	8.65
SME	0.871		2.05	4.09	8.19

A total of 24 470ml blended samples were prepared along with one ULSD sample. Three identical 50ml samples were made up from each of the 25 base samples and randomly assigned to an ID number of 1 through 75. The samples were sent to Magellan Analytical Services in Kansas City, Kansas for evaluation by the High-Frequency Reciprocating Rig (HFRR), ASTM D 6079-99.

Oil Seed Processing and Biodiesel Production

BAE personnel have continued working with Ida Gold and Pacific Gold mustard seed varieties that were developed by the UI Plant Science Department. Work with canola and rapeseed continued as well and the meal produced from these seeds (canola meal was used as a check) shows ever-increasing promise as natural herbicides and pesticides.

Approximately1000 pounds of Dwarf Essex rapeseed, 2600 pounds of Sunrise canola, three tons of Ida Gold mustard and five tons of Pacific Gold mustard were processes in the BAE oilseed processing plant. The rapeseed and canola had an average oil content of 48 percent oil and yielded 180 gallons of oil and 2160 pounds of meal. The Ida Gold seed had an average oil content of 25 percent and produced 147 gallons of oil and 4,875 pounds of meal. The oil content of the Pacific Gold seed was 37 percent and yielded 356 gallons of oil and 7,300 pounds of meal. The meal from all of the oil seeds had an oil content of approximately 11 percent. Extraction efficiency, with the small screw presses, for Ida Gold and Pacific Gold was 58 and 70 percent respectively compared to 78-80 percent for rapeseed and canola.

The oils were processed into biodiesel or used directly as an additive in lubricity research and in two-cycle engine testing. The biodiesel was also used in ongoing on-road and on-farm demonstrations and in dynamometer and emissions tests.

On-Road Demonstration of Yellow Mustard Biodiesel

The test vehicles are a 2001 VW Beetle with a 1.9 liter, direct injection, four cylinder engine (Fig. 1), a 1999 Dodge truck with a Cummins Direct Injection, 5.9 L electronically fuel injected engine and a 1994 Trolley with a 5.9 L Cummins engine (Fig.2). The 1999 Dodge has logged 32,000 miles, the 2001 VW Beetle has logged 14,000 miles and the Trolley has been operating on B20 for two year. Other vehicles at the University farm operating on B50 include a John Deere 3150, a Winterstiger plot combine, a Swift plot swather and a 34 hp Mitsubishi Bison. There have been no fuel related problems associated with the operation of these vehicles except for a shorter than normal fuel filter change interval noted on the Dodge. Fuel filters have been changed at about 8,000 mile intervals.

Figure 1 VW Beetle Fueled from 1999 Dodge Slip Tank

The average oil change interval for the Dodge has been 3,890 miles. Oil samples were taken and analyzed for wear metals, soot and viscosity. All data to date, following the initial break-in period, has been well within the normal range.

Figure 2 Trolley Fueled from 1994 Dodge Slip Tank

The Vandal Trolley continues to be prominently displayed on campus shuttling students, alumni and others to special events around campus and to places in the Moscow-Pullman area. It is powered by a Cummins 5.9 liter diesel coupled to a three-speed automatic transmission. It serves as a good demonstration project to document the efficiency and long-term effects of this alternative fuel on stop-and-start drives.

The vehicle was tested on the chassis dynamometer for power, torque and fuel consumption prior to initial campus trial runs. Compared to diesel the engine developed 3.9 percent and 5.3 percent less power and torque respectively on MEE averaged over the range of 2300 to 2800 rpm’s. Figure 3 shows the fuel consumption in miles per gallon of the three fuels tested. Typically it is difficult to obtain accurate and consistent data on a vehicle with an automatic transmission and the trolley was no exception. The fuel consumption was about the same over the entire range for the three fuels tested. It measured very low (just over 2 mpg) at low speeds, which is typical for a very heavy bus with an automatic due to torque converter slip.

The high was just over 8 mpg at full speed. The trolley has been running on B20 (20 percent biodiesel, 80 percent diesel) for over two years with no operational problems.

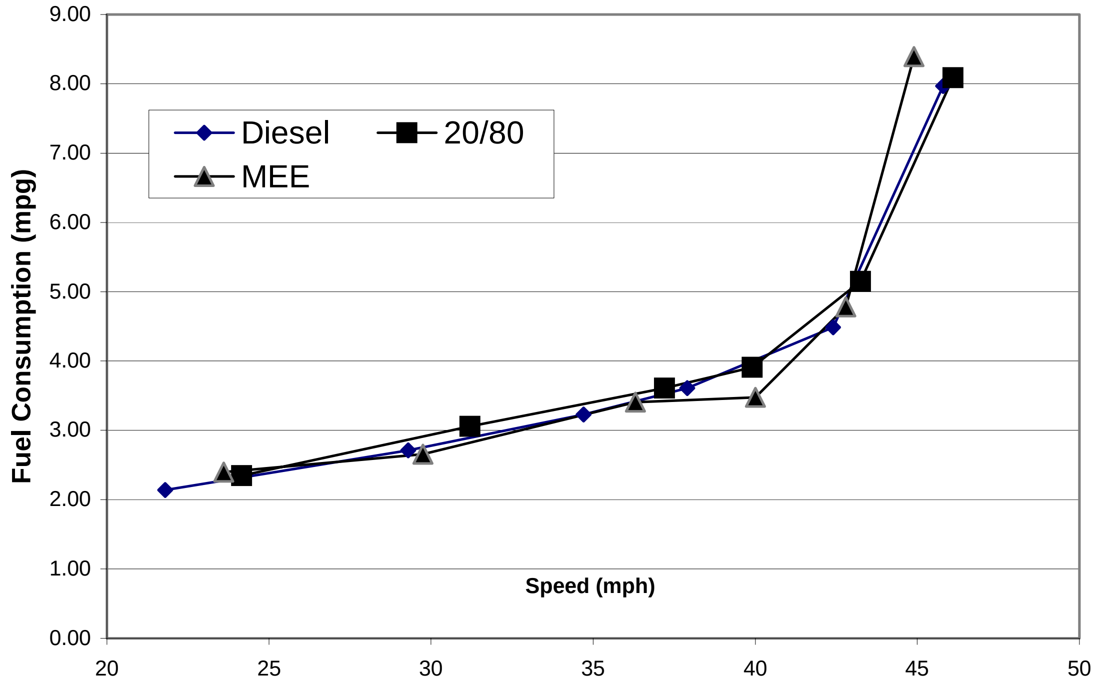

Figure 3 Fuel Consumption in MPG vs Speed in MPH for Trolley

Glycerol Recovery

Crude glycerol, a by-product of the biodiesel production process, contains about 35 percent ethanol, 30 percent free glycerol, 20 percent water and 15 percent other material such as free fatty acids, soaps, gums and phosphatides. One of the objectives of this study was to look at ways to use or dispose of our waste glycerol. The most obvious first step was to recover the ethanol for further use. As a result of the research by a BAE senior design team, a used 20-gallon batch solvent recovery unit was purchased. The excess ethanol recovered was about 90 to 95 percent. It could not be used in the biodiesel production process without first being dried; however it could be used directly as a fuel by the mechanical engineering department's aquanol team. To date, 350 gallons of ethanol have been recovered for use with the aquanol project.

Erin Cochran researched uses for and methods of disposal for the remaining crude glycerol during her NIATT internship this past year. Figure 4 shows the results of some of her work. Among her suggestions were to further purify it for the food and pharmaceuticals industry, to compost it, burn it directly and/or use it to make soap and solvents.

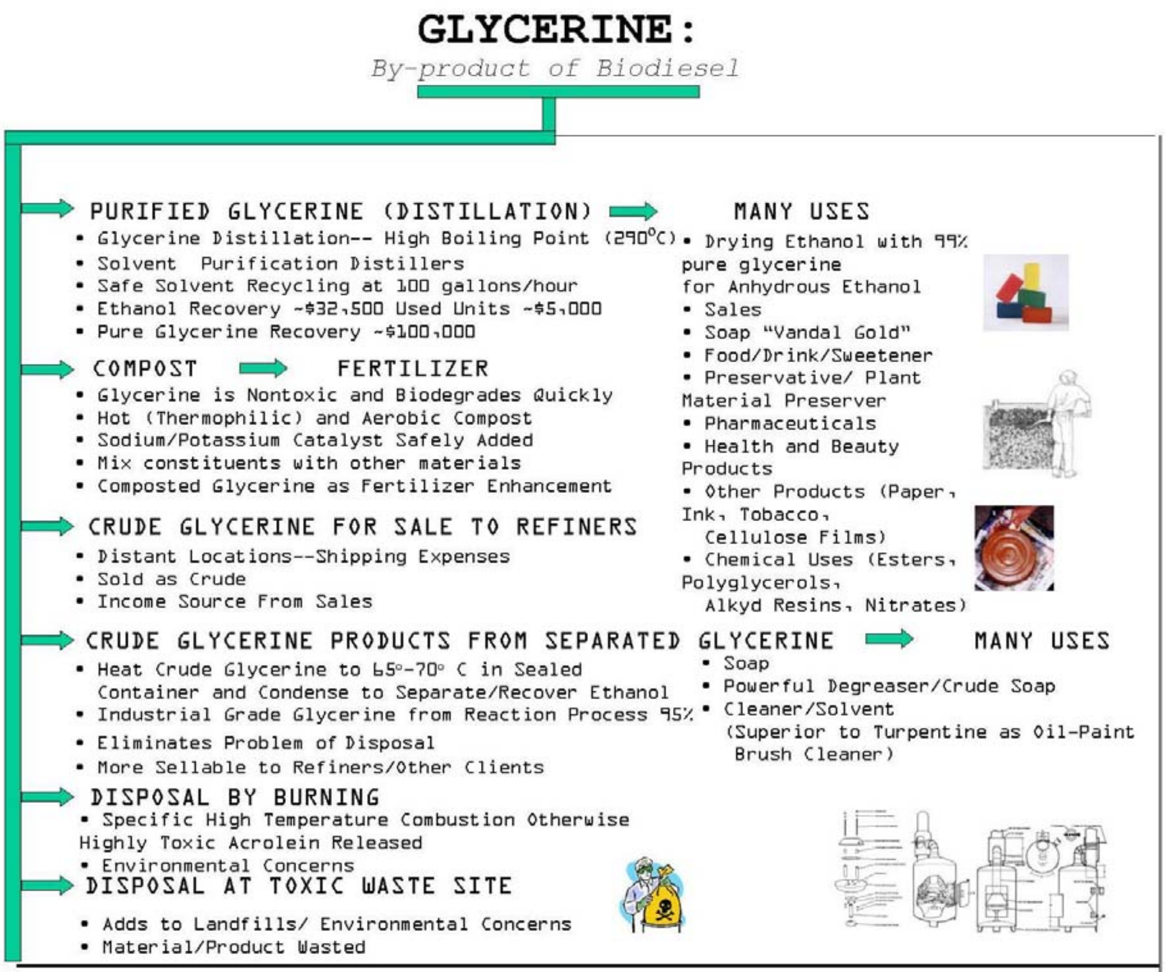

Figure 4. Uses for Crude Glycerol By-Product

Other options that deserve further exploration are to break it down using a sludge bed digester into methane and potassium fertilizers, to run it through a hydrogen generator and/or to conduct direct feeding trials in cooperation with the animal science department.

A method of direct disposal would be to dilute it with water and spray it onto wheat stubble at the rate of 100 gallons/acre at the plant science farm in cooperation with the plant, soils and etymological science department. According to farm manager Roy Patten, crude glycerol has a similar consistency to agricultural crop oils used as surfactants. It most likely would have a beneficial effect on the slightly acidic soils of the Palouse by helping to neutralize them while adding potassium, a natural fertilizer. It contains about two percent by weight of potassium and has a BOD of 900,000 mg/L. It is water soluble and biodegradable and should be completely broken down in a matter of 28 days.

Fuel Standards

Table 2 lists the characterization data of ethyl esters from Ida and Pacific Gold yellow mustard biodiesel compared with standard petroleum diesel.

Table 2. Fuel Parameters for Mustard Ethyl Ester and Diesel

Lab Tests	Ida Gold	Pacific Gold	Diesel
Acid #	0.210	0.113	
Viscosity, cSt	5.66	5.71	2.70
Free Glycerin, wt.%	0.002	0.01	-
Total Glycerin, wt.%	0.103	0.107	-
Potassium, ppm	BDL	BDL	
Water & Sed, %	<0.02	<0.02	
Sp. Gr. @ 15 C	0.875	0.876	0.848
Conradson Carbon, percent	0.02	0.02	
Ash, percent	0.002	0.004	
Sulfur, percent	<0.005	<0.005	0.033
Carbon, percent	76.73	76.34	
Hydrogen, percent	11.85	11.99	
Oxygen, percent	11.41	11.65	
Nitrogen, ppm	47	52	

Lab Tests	Ida Gold	Pacific Gold	Diesel
Cetane Number	54.9	56.9	45.3
Iodine No.	98.24	94.07	
Particulate, mg/L	3.18	4.41	1.4
Copper Corrosion	1A	1A	1A
Phosphorus, percent	<2	<2	
Boiling Point, C	315	306	193
Heat of Combustion, BTU/lb	17,489	17,637	19,441
Flash Point, C	183	170	74
Cloud Point, C	1	0	-19
Pour Point, C	-15	-15	-20
Fatty Acid percent			
Palmitic (16:0)	2.8	2.5	na
Steric (18:0)	1.1	1.1	
Oleic (18:1)	27.8	30.5	
Linoleic (18:2)	10.45	9.2	
Linolenic (18:3)	9.15	10.8	
Eicosanoic (20:1)	9.6	10.2	
Erucic (22:1)	32.75	31.9	
Nervonic (24:1)	2.20	1.90	

NOx Emissions Testing

In August and September of 2001, a series of chassis dynamometer emissions tests were run with a 1994 Dodge Cummins diesel powered pickup. A 602 SuperFlow Dynamometer was used to correlate emissions readings from a portable five-gas analyzer with emissions readings obtained at the Los Angeles Mass Transit Authority testing facility with the same truck in 1997 (Peterson et al., 2000). Results of these tests show that only the nitrous oxide data may be comparable. As a result of this work, additional tests were made comparing six biodiesel feedstocks to determine if the NOx data would follow trends developed earlier.

The six biodiesel fuels used in LA were derived from coconut, safflower, soy, used frying oil, rapeseed and mustard. Fresh fuels were produced and used at the BAE testing facility. Table 3 and Figure 5 show the NOx data for each fuel ,including diesel at engine rpms from 1600 to 2800 in 100-rpm increments. The difference in NOx between diesel and the various biodiesel fuels ranged from 4 percent over for REE at 1900 rpm to 36 percent under that of diesel for CocoEE at 2700 rpm. The results of the NOx tests from the UI steady state tests were similar to that normally reported from transient PTO tests where NOx generally increases in contrast to the transient chassis dynamometer tests where NOx has generally been found to decrease. The difference in NOx for biodiesel verses diesel was generally less at maximum torque and greater at reduced torque in favor of biodiesel.

Table 3. Normalized Values for NOx as a Percent of Diesel

RPM	MEE	SEE	REE	HySEE	CocoEE	SaffEE	Diesel
1600	100.42	96.62	99.69	95.48	81.58	100.88	100.00
1700	99.32	96.68	101.26	95.91	80.27	100.11	100.00
1800	98.32	94.98	103.52	97.71	79.25	102.74	100.00
1900	97.17	93.49	104.39	95.40	78.46	98.96	100.00
2000	97.36	92.87	102.94	95.27	79.03	98.53	100.00
2100	97.84	94.38	103.86	95.99	77.22	100.10	100.00
2200	98.07	93.15	101.39	94.78	73.75	98.86	100.00
2300	97.52	92.38	101.48	94.18	71.90	98.17	100.00
2400	96.85	91.25	101.42	92.92	71.39	96.33	100.00
2500	96.97	93.37	103.42	93.44	71.24	96.58	100.00
2600	89.72	88.35	99.84	90.15	70.13	96.05	100.00
2700	91.17	89.01	103.80	90.36	69.20	97.55	100.00
2800	71.84	70.56	77.65	69.53	63.17	80.51	100.00
Average	94.81	91.31	100.36	92.39	74.35	97.34	100.00

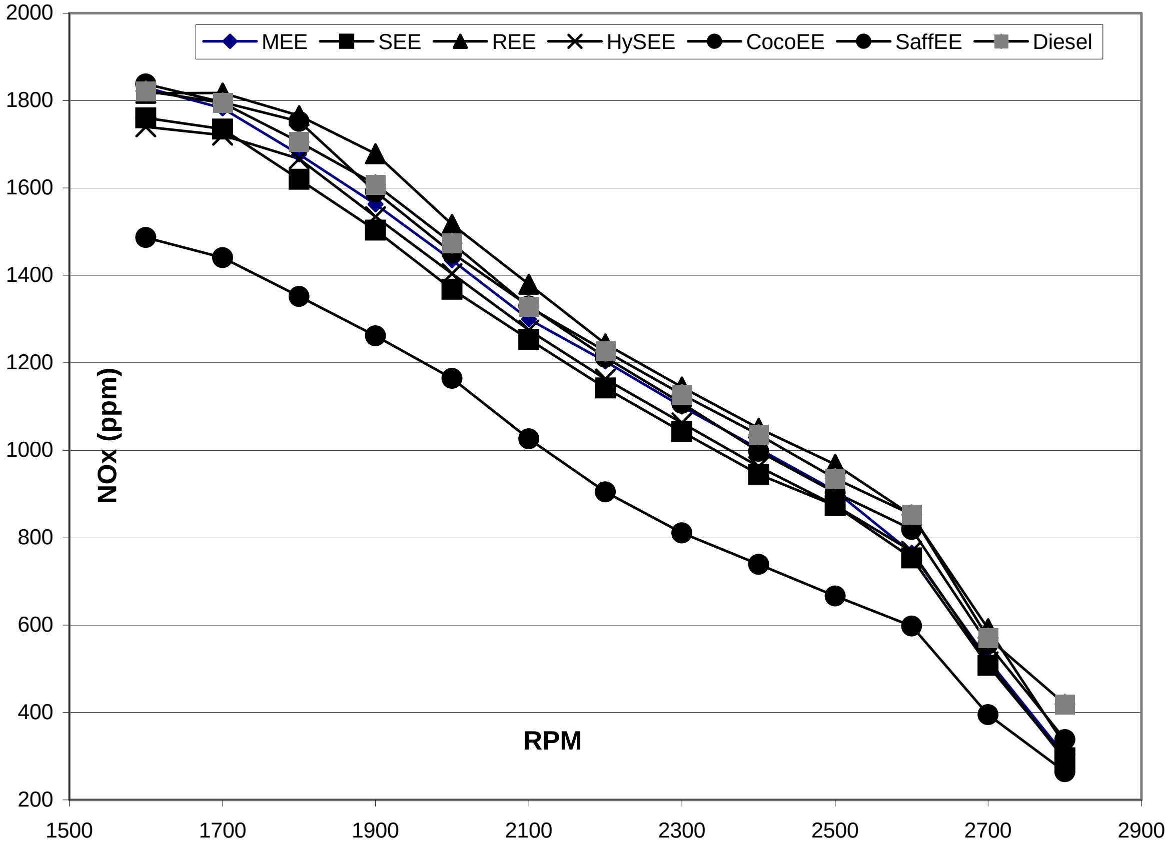

Figure 5 NOx vs RPM for Six Feedstocks and Diesel on 1994 Dodge

Figure 6 shows NOx as a percent of diesel for the two data sets from LA and the UI. On average the data from the UI does not quite follow the same trend as the LA data, which showed a linear increase of NOx with an increase in Iodine number of the fuel. The average NOx values for REE were too high and the NOx values for SEE were too low for the trend to be directly comparable. One explanation for the SEE to be low is that the fuel used in LA was SME purchased from Midwest Biofuels and was not available at the time of the UI testing. Another explanation could be that the five-gas analyzer was out of calibration when testing those two fuels. However, the results are close enough to bear further testing.

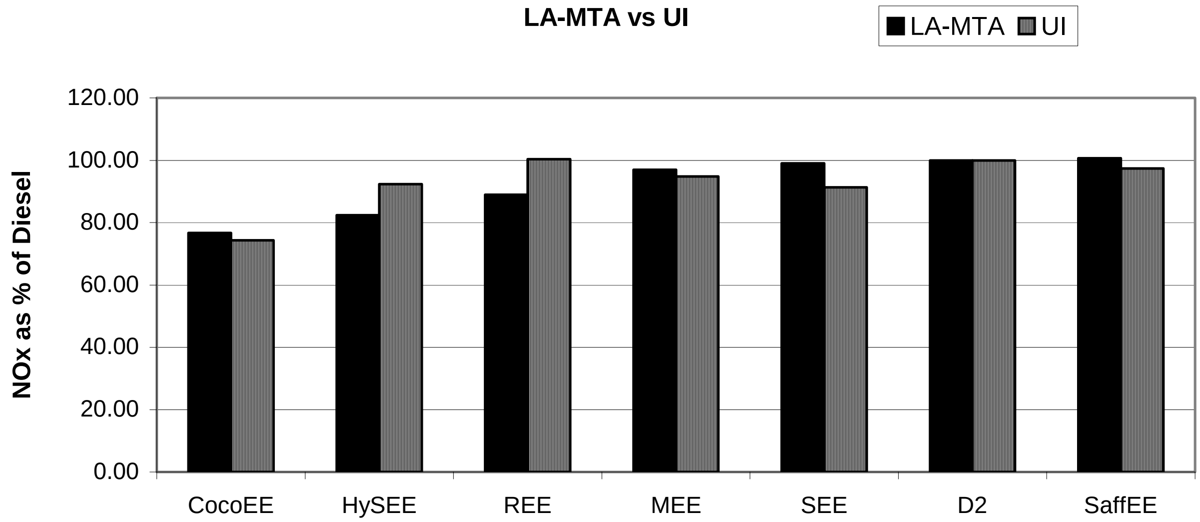

Figure 6. Comparison of NOx Data as a Percent of Diesel NOx

Lubricity Tests on Low Level Blends of Oils and Esters with Diesel.

Four vegetable oil and their esters were blended with ULSD and sent to Magellan Analytical Laboratory in Kansas City, Kansas, and evaluated for lubricity by ASTM test D 6079-99, High-Frequency Reciprocating Rig (HFRR). The oils sampled were rapeseed, canola, mustard and soy. The ULSD used in this study was obtained from Chevron Phillips, The Woodlands, TX (Lot 0IPULD01). The oils and esters were blended at 0.5, 1 and 2 percent by volume with ULSD. After the samples were blended, three replicates were drawn from each, and three diesel-only samples were taken for a total of 75 samples.

Nomenclature for the sample identification was as follows: C, R, YM, S signifies canola, rapeseed, yellow mustard and soy respectively; followed by an E represents esters and by an R represents raw oil. The numbers after the dash, 5, 10 and 20 indicate 0.5, 1 and 2 percent by weight of ester or oil in the sample. Finally D represents the ULSD alone.

In this, test samples were used to lubricate a ball on plate apparatus. The resulting wear scar is an indication of the fuel's lubricity. ASTM does not currently state a wear scar limit but according to lubricity standards established by European engine manufactures, a wear scar of over 450 microns at 60 C is unacceptable. Schumacher (2002) reported that a sample of ULSD obtained from Chevron Phillips did not meet the European standard. Drown (2001) stated that JP-8 and some low-sulfur diesel fuels do not provide adequate wear protection for fuel injection pumps.

It can be seen from the data (Fig. 7 and Fig. 8) that none of the samples failed the HFRR test; in fact the ULSD alone scored better that some of the blends. There is no satisfactory explanation for this phenomenon. It should be stated here that upon completion of the test, it was found to our surprise that the ULSD contained a synthetic lubricity additive. Upon questioning the fuel blender at Chevron Phillips, it was learned that indeed the company had received complaints about inadequate lubricity of the ULSD and had decided on a lubricity additive for all future shipments.

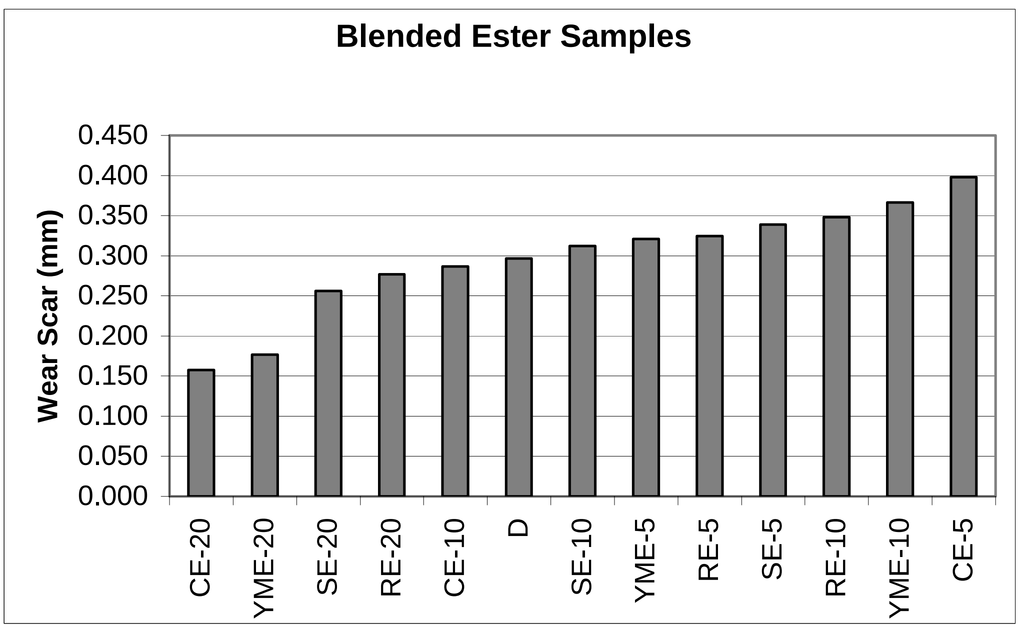

Figure 7 Average Wear Scar for Esters and Diesel

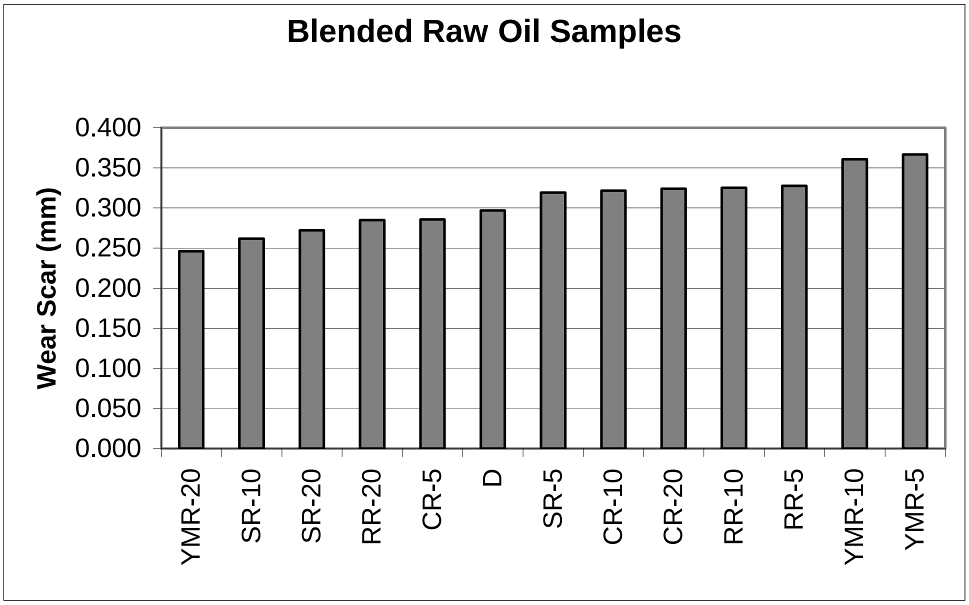

Figure 8 Average Wear Scar for Raw Oils and Diesel

Considering the data from these tests, it was clear that the margin of error was quite high and the test repeatability was poor. This might help to explain that the ULSD samples averaged lower than some of the blends. Statistically speaking, there was no significant difference between the ester and the raw oil blends when compared to each other or to the diesel alone. To date, the ASTM standard for diesel fuel, D 975, does not include a lubricity component. However, one will be incorporated by the year 2006 when ULSD becomes a mandated commodity. If the ULSD use for this study was representative of standard issue, there may not be a lubricity problem to worry about.

Two-Cycle Engine Testing with Fish Oil

In cooperation with Steigers Corporation, a company operating seafood-processing plants in Alaska, fish oil was obtained for evaluation in its raw form as a fuel or a fuel additive. As part of the evaluation process an endurance test with two cycle engines was conducted using fish oil as the lubricant added to the fuel. A similar screening test had been developed and conducted by the BAE department in 1996 using rapeseed ethyl esters as the lube oil (Peterson and Reece, 1997). The same protocol was used for this test. The two engines used were in Stihl leaf blowers (Model BG-55). The engines were 23.9 cc, rated at 0.7 kW capable of delivering 600 m^3/hr of air. One engine was fueled with a blend of 50 parts standard gasoline to1 part fish oil. The lube oil for the second engine was a 50/50 blend of fish oil and standard Stihl two-cycle engine oil at the same 50:1 ratio with gasoline. The blowers were set on a stand, each connected to a 19 L fuel supply tank and run at full throttle for nine hours/day or until they quit and required attention.

The engine with the 50/50 (two-cycle oil/fish oil) lube oil began having starting and running difficulties after the second day of operation. Attempts, such as cleaning the plug and exhaust port, were made to keep it running, but after 20 hours of operation the engine would not start. It was pulled off the stand and disassembled for inspection. The spark plug was black and glazed over with carbon build-up. The piston top was covered with carbon and the skirt was tarnished. The piston rings were stuck in the piston but the cylinder wall was clean and unscratched.

The other engine lubricated with 50:1 fish oil started exhibiting problems after 27 hours of operation. It was hard to start and would not run at full throttle. At that time, the spark plug and the exhaust port and muffler screen were cleaned. The engine then started and ran normally but required service every 2 to 6 hours of operation. The spark plug was replaced at 30 hours of operation and the exhaust port was cleaned out several times before the test was terminated at 60 hours due to carbon build-up resulting in a sharp increase in piston drag. Upon disassembly, it was found that the spark plug, top of the piston and the piston pin area were black with considerable carbon build-up. The rings were stuck in the piston. The piston pin and rod bearings were carboned up and starting to drag. The piston skirt and crankcase were tarnished and the cylinder wall was scratched.

It seemed counter intuitive that the 50/50 lube oil engine was the first to fail and in such a short period of time. It could be speculated that the two oils were incompatible and reacted negatively with each other and/or in combination with the gasoline during combustion. The engine itself or the carburetion could have been flawed in some way from the factory but this is unlikely and cannot be confirmed at this point.

The fish oil-lubed engine started exhibiting problems shortly after the first one failed and required excessive maintenance to keep running. It was quite obvious that both engines failed earlier than would be expected of an engine fueled with gas mixed with an adequate lubricating oil.

It had been planned to experiment with mustard and canola oils as two-cycle lubricating oils in the same fashion; however, with results of this test coupled with poor results of the previous two-cycle lube oil test with rapeseed ethyl esters (Peterson et al. 1997), it was decided that further testing would not continue at this time. Perhaps with some conditioning and an additive package, vegetable oils and animals fats could successfully be used as a two-cycle engine lubricant.

CONCLUSIONS

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- The extraction of 690 gallons of oil from 20,000 pounds of locally grown oil seeds has been completed. Along with the oil, 14,340 pounds of meal were produced for soil fumigation research.
- Extraction efficiency, with the small screw presses, for Ida Gold (25 percent oil) and Pacific Gold (36 percent oil) was 58 and 70 percent respectively compared to 78-80 percent for rapeseed and canola.
- On-road testing with a 1999 Cummins 5.9B diesel engine in a Dodge pickup truck fueled with yellow mustard biodiesel has accumulated about 32,000 miles with no difficulties. Fuel consumption is increased and fuel filter change intervals are decreased over what was experienced with petroleum diesel.
- On-road testing with a 2001 Volkswagen 1.9 L diesel engine has accumulated nearly 14,000 miles. Fuel consumption is about 43 miles per gallon of biodiesel. Drivability of the vehicle is very good. Power and acceleration are excellent. This vehicle continues to be displayed an all major alternative energy events around the state.
- After two years of operating on B20, the Vandal Trolley continues to provide a high profile alternative fuel for stop-and-start operation.
- Crude glycerol, a by-product of biodiesel production, has provided 350 gallons of recovered ethanol. Uses for and methods of disposal for the remaining glycerol include composting, direct combustion and/or using it to make soaps and solvents.
- Fuel characterization data show that yellow mustard biodiesel is comparable to that produced from canola oil.
- Nitrogen oxides emissions using biodiesel from six different oils show a trend similar to the LA-MTA data but with two fuels seemingly out of order with previous data.
- Lubricity testing with low-level blends of vegetable oils and esters with ultra low sulfur diesel proved inconclusive due to the adulterated ULSD sample obtained. Follow-up testing will be conducted upon the procurement of proper diesel fuel blending stock.

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