BIODIESEL FROM YELLOW MUSTARD OIL

FINAL REPORT
NOVEMBER 2001

Budget Number KLK310
#N01-25

Prepared for

OFFICE OF UNIVERSITY RESEARCH AND EDUCATION
U.S. DEPARTMENT OF TRANSPORTATION

Prepared by

NATIONAL INSTITUTE FOR ADVANCED TRANSPORTATION TECHNOLOGY
UNIVERSITY OF IDAHO

Charles L. Peterson, PhD
Joseph Thompson
Sam Jones
David Hollenback

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The goal of this project was to evaluate locally developed yellow mustard cultivars to determine their suitability as low cost feedstock for biodiesel. Rapeseed, canola, and yellow mustard are particularly well-adapted alternative crops for the Palouse of northern Idaho and eastern Washington. In addition, genetic modifications of these oils to produce a feedstock that has particularly advantageous properties for biodiesel is entirely possible. One of these varieties, Ida Gold, was selected based on the recommendations of the plant breeder. Other yellow mustard oils were also used in some of the tests. Oil extraction and biodiesel production efficiencies have been somewhat less for the yellow mustards than for rapeseed and canola. Extraction averaged only 58 percent compared to 78 to 80 percent for rapeseed and canola. Biodiesel production had a yield of 7 percent less than when rapeseed and/or canola were used.

Fuel characterization parameters according to the American Society of Agricultural Engineers EP 552 and the interim American Standards for Testing Materials (ASTM) standard for biodiesel are being evaluated. The data collected thus far indicates that the yellow mustard oil is fairly consistent with rapeseed and canola as far as its use as a fuel is concerned.

A 1999 Cummins-powered Dodge diesel pickup truck was used for on-road testing. The truck was operated for 23,980 miles on yellow mustard biodiesel (mustard ethyl ester or MEE). It averaged 15.23 mpg, which was quite good considering a considerable portion of the use was pulling a trailer to deliver alcohol and biodiesel. The truck was tested on a chassis dynamometer comparing operation on MEE and diesel fuel. No operational problems have been noted with the test vehicle. Oil analysis results from samples of the engine oil are normal. Test results showed a 6.4 percent reduction in power and an increase of 1.6 percent in fuel use when operated on MEE compared to diesel. Injector cutout tests conducted on this vehicle were normal.

A 2001 Volkswagen 1.9 L diesel new beetle was obtained for demonstration with yellow mustard biodiesel. The vehicle fuel was changed to yellow mustard biodiesel at 492 miles and a total of 5,109 miles has been run since then. The vehicle is being used to demonstrate the feasibility of using biodiesel in smaller vehicles and for urban use. The “Idaho Mustard Bug” has been used in numerous demonstrations, schools, field days, open houses, and was on display at the Renewable Energy Fair in Sun Valley and the Ethanol Conference at West Yellowstone. It has been particularly effective in teaching K-12 students about the advantages of alternative fuels.

Stationary engine tests, including a 200-hour Engine Manufacturers Association (EMA) durability test, are in progress. As part of this project, the University of Idaho (UI) test facility was upgraded with a new computer system and new instrumentation. A new 24 hp, 3 cylinder, direct injection engine was obtained and is currently under test on a biodiesel fuel produced from Ida Gold yellow mustard. During the durability startup tests, MEE power averaged 6.0 percent lower; fuel consumption was 2.2 percent higher and Brake Specific Fuel Consumption (BSFC) (hp-hrs/gal) was 8 percent higher than when operated on diesel.

We had available a machine vision system for scoring the results of the injector coking. This facility was made operational and upgraded to reduce the variability between readings with a particular injector. It has been used for both MEE testing and tests with used vegetable oil.

In August and September of 2001, a series of chassis dynamometer emissions tests were run with a 1994 Dodge Cummins diesel powered pickup. UI’s recently upgraded 602 SuperFlow Dynamometer was used to correlate emissions readings from a portable five-gas analyzer with emissions readings obtained in 1997 at the Los Angeles Mass Transit Authority testing facility with the same truck. Results of these these tests show that only the nitrous oxide (NOx) data may be comparable. The sensitivity of the analyzer was insufficient for carbon monixide (CO) comparisons, and the erratic nature of the data for hydrocarbons (HC) made it difficult to compare. Additional tests are suggested comparing biodiesel feedstocks to determine if the NOx data would follow trends developed earlier

DESCRIPTION OF PROBLEM

Biodiesel has been studied 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. 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 at the University of Idaho (UI) is from ethanol. The ethanol comes from used potato wastes at a J. R. Simplot plant in Caldwell, Idaho. The ruel 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 a replacement for petroleum fuel in diesel-powered vehicles such as trucks, tractors, and other heavy equipment, including many marine applications. Most biodiesel is produced by esterifying the lipids to produce esters. 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 oil, canola, rapeseed oil, safflower oil or sunflower oil and an alcohol.

The biodiesel process is a chemical reaction involving 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 that separates the vegetable oil into two components: ester and glycerol. The ester is lighter than the glycerol and 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. UI plant scientists have developed yellow mustard varieties that have the potential to significantly reduce the cost of the oil used in biodiesel production. This project is for purposes of producing quantities of biodiesel from these locally grown varieties to test in both laboratory engines and in a 1999 Dodge 2500 diesel-powered on-road pickup truck. As part of the test protocol, fuel characterization tests will be conducted to verify that the biodiesel produced meets the interim ASTM standard for biodiesel.

APPROACH AND METHODOLOGY

Objectives

The objectives of this project were to:

1. Produce and test biodiesel from a locally developed strain of yellow mustard oil.
2. Demonstrate on-road use of yellow mustard oil as a feedstock for biodiesel.
3. Perform fuel characterization tests of the fuel developed in accordance with the interim ASTM standard analysis procedures.
4. Perform dynamometer and engine testing procedures to compare yellow mustard biodiesel with rapeseed oil and canola biodiesel fuels.
5. Conduct tests with a chassis dynamometer to determine if a correlation can be developed between test data from local mode tests using a five gas analyzer and test data from the LA MTA emissions tests conducted earlier.

Facilities

The Department of Biological and Agricultural Engineering 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 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 and two batch type reactors, one with 1000 liter capacity and the second of 2000 liter capacity. Fuel storage tank availability includes a variety of 1050-liter totes and several 2000-liter tanks. We are an approved Bureau of Alcohol, Tobacco and Firearms small fuel production plant and can obtain non-denatured alcohol and store in an approved on-site locked area.

The analytical laboratory is equipped for biodiesel research. Fuel characterization data that can be performed at the UI include heat of combustion, cloud point, pour point, viscosity, density, flash point, acid number, fatty acid, and 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 Phoenix Chemical Laboratory, Inc., Chicago, Illinois. These parameters provide the information required for American Society of Agricultural Engineers standard engineering practice (EP) 552 and a comparison with the interim ASTM standard for biodiesel.

A SuperFlow SF-601 chassis dynamometer is available for in-chassis engine performance analysis and diagnosis. The SF-601 is a double drum, water brake dynamometer capable of about 750 hp in single drum configuration. The Superflow SF-601 Steady State Water-Brake Chassis Dynamometer was upgraded to the SF-602 system during the summer of 2001. This upgrade allowed for the expansion of sensors, as well as a user-friendly computer interface. The dyno can be monitored from a room adjacent to the testing bay, where observers can view both the vehicle as well as the outputs while remaining safe from the hazards of the testing bay. 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. Vehicle speed was monitored using a magnetic pickup and toothed gear assembly attached to the roller axle. Vehicle torque was measured using a linked load cell attached to the water brake.

An EMS Model 5001 emissions analyzer was used for this testing. Readings were reported as follows:

- NO_X—parts per million
- HC—parts per million
- O_2—percentage of exhaust gases
- CO—percentage of exhaust gases
- CO_2—percentage of exhaust gases.

All measurements were made using integrated circuit sensors. Because there was no link between the dynamometer and the gas analyzer, measurements were taken by hand while the dynamometer had stabilized on the set engine speed.

A machine vision facility for scoring the results of injector coking tests in diesel engines operating on alternative fuels is available. The facility consists of the hardware and software required for measuring the coking on the injector of an engine. The engine is operated according to a standard performance test plan. The injector coking equipment was re-calibrated and upgraded for this present series of tests.

During the time period of this project, the electric dynamometer normally available was unable to be used because of remodeling taking place of the Gauss-Johnson Engineering Laboratory. We therefore used the engine durability facility of the Department of Biological and Agricultural Engineering research for stationary engine tests. This facility consists of three-engine test cells, each with a hydraulic load bank. The control program has been completely rewritten for this research. New fuel measurement modules were constructed and incorporated into the program. Engine technology has advanced considerably in the past few years; therefore the existing test engines were replaced with a new Yanmar, 1.2 liter, three-cylinder, direct injection, 24 horsepower engine for testing with Ida Gold yellow mustard.

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 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 to 10,000 mile.

4. Engine performance tests including vehicle chassis dynamometer tests and stationary engine torque test
5. EMA durability test
6. Chassis dynamometer steady state emissions tests with the five-gas analyzer

Procedure for 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 107,420 miles on rape ethyl ester at the time of this test.

The engine was not modified in any way for use with the vegetable oil fuels. The fuel delivery system was modified to make convenient a change of fuels between test runs. Fuel delivery and fuel return lines were broken, and three-way, manually operated valves were installed so that stub lines with quick couplers could be installed on one part of the three-way valves. Fuel delivery was accomplished using the Superflow Fuel System controlled by the dynamometer. The fuel system consists of a 12-gallon can hanging from a load cell that measures the weight of the can on one-tenth of a second increment. This is then calculated into volumetric fuel consumption using the specific gravity of the fuel. Between tests, the fuel can was purged of all residual fuel using a return line bypass system. The fuel filter was also changed on both the vehicle as well as the fuel supply system. Upon startup with the new fuel, the return line was diverted to flush any residual fuel from the system.

In order to improve the data with five-gas analyzer, it was auto zeroed between test runs. The detector was calibrated daily using a precise blend of calibration gases.

FINDINGS; CONCLUSIONS; RECOMMENDATIONS

Yellow Mustard Processing

The expression plant was used to produce 280 gallons of oil from 12,700 pounds of Ida Gold variety yellow mustard. In addition, 6000 gallons of yellow mustard oil was purchased for biodiesel production. Because Ida Gold is a new variety, the available seed, and thus the oil, is very limited. The Ida Gold was processed into biodiesel and is being used only for a 200-hour EMA test. The purchased yellow mustard oil has been used to fuel the 1999 Dodge/Cummins pickup truck, vehicles in Yellowstone National Park and the 2001 Idaho Mustard Bug.

In the fall 2000,Yellowstone Park expanded its use of biodiesel to include fueling three buses and seven garbage trucks on a 20/80 blend of biodiesel to diesel. The UI Department of Biological and Agricultural Engineering committed to supply extra biodiesel for the Park's "green fuels" program. For this effort, over 4,200 gallons of mustard oil was purchased from Montana Specialty Mills in Great Falls, Montana, and used to produce 3,800 gallons of biodiesel, giving about a 90 percent conversion rate. That fuel, along with some produced from our own pressing operation, amounted to about 4,450 gallons of biodiesel delivered to Yellowstone Park during the last half of 2000 and to date in 2001.

In a research project designed to test mustard meal as a soil fumigant, the plant-breeding program supplied ten tons of Pacific Gold mustard seed and two tons of Ida Gold seed. The Pacific Gold, a higher oil content seed (35 percent), yielded 680 gallons of oil for an extraction efficiency of 74 percent. Ida Gold at 27 percent oil yielded 100 gallons of oil giving an extraction efficiency of 70 percent. This oil is being used to produce biodiesel for Yellowstone, for engine testing and to fuel a 1999 Dodge truck and the Idaho Mustard Bug.

Oil extraction has been less efficient from the Ida Gold yellow mustard than is normally experienced with rapeseed because of the reduced oil content. The Ida Gold has only about 27 percent oil content compared to 40-45 percent for rapeseed. Extraction efficiency with the small screw presses for the Ida Gold yellow mustard was 58 percent compared to 78-80 percent for rapeseed and canola.

When processing biodiesel from yellow mustard, reductions were noted in the final yield of esters (93 percent) when compared with rapeseed oil, which is normally close to 100 percent.

On-Road Demonstration of Yellow Mustard Biodiesel

Figure 1 1999 Dodge and the Idaho Mustard Bug—a 2001 Volkswagen Beetle

The two test vehicles are a 1999 Dodge truck with a Cummins Direct Injection, 5.9 L electronically fuel injected engine (Fig. 1) and a 2001 VW Beetle (Fig. 1 and 2), with a 1.9 liter, Direct Injection, 4 cylinder engine. The 1999 Dodge has logged 26,219 miles and the 2001 VW Beetle has logged 5,109 miles. Neither has experienced any problems and both have more than adequate power and fuel economy. Shorter than normal fuel filter change intervals are noted on the Dodge. Fuel filters have been changed at about 8,000 mile intervals.

The Dodge is used to deliver fuel to Yellowstone National Park, to transport oil from Great Falls, Montana, and to transport alcohol from the J. R. Simplot plant in Caldwell to Moscow.

It was used to transport a display to the International ASAE meeting in Sacramento in July and a Biodiesel Workshop in Superior, Montana, sponsored by Solar Energy International.

Figure 2: Idaho Mustard Bug

The average oil change interval for the Dodge has been 3,800 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.

Table 1 Wear Metals and Oil Properties from a 99 Dodge Powered by 100 Percent Mustard Biodiesel

Miles	Iron	Lead	Copper	Aluminum	Silicon
3020	64	5	24	3	22
7535	55	4	12	2	22
11569	34	1	5	2	15
14743	37	2	3	2	10
18775	17	3	2	2	5
23105	19	2	1	2	5

Both the Dodge truck and the 2001 Volkswagen appeared in the Johnson, Washington, Fourth of July Parade, and field days in Moscow, Idaho, Pendleton, Oregon and Freeman, Washington. The two vehicles were also displayed at the UI Design Expo in May and at numerous tours conducted on campus for student groups, as well as for corporate groups interested in biodiesel production.

The Idaho Mustard Bug was in Yellowstone National Park in June for the EPAC Ethanol Conference and Pacific Regional Biomass Energy Program meetings. The VW has been driven by a number of VIPs to demonstrate the usefulness of biodiesel in an urban setting. It was used by the IDWR Energy Division in Boise for a month during fall 2001.

Fuel Characterization Data

Table 2 lists the characterization of methyl esters from Gully, P66 and Ida Gold yellow mustard biodiesel compared with rapeseed oil ethyl ester (REE). Not all parameters were available at the time of writing this report but they will be available soon.

Table 2 Fuel Parameters for Mustard Ethyl Ester

Lab Tests	REE	Gully	P66	Ida Gold
Acid #	0.113			
Viscosity, cSt	6.04	5.68	2.70	5.66
Triglycerides, wt. percent	0.311	0.385	-	
Diglycerides, wt. percent	0.261	0.155	-	
Monoglycerides, wt. percent	0.139	2.299	-	
Ester, wt. percent	99.18	97.126	-	
Free Glycerin, wt. percent	0	0.035	-	0.002
Total Glycerin, wt. percent	0.107	0.694	-	0.103
Potassium, ppm	BDL	BDL		BDL
Water & Sed, percent	<0.005	<0.005		<0.005
Sp. Gr. @ 15 C	0.876	0.875	0.848	0.875
Conradson Carbon, percent	0.02	0.02		
Ash, percent	0.004	0.002		
Sulfur, percent	<0.005	0.003	0.033	
Carbon, percent	82.15	77.57		
Hydrogen, percent	12.58	12.54		
Oxygen, percent	5.25	9.89		
Nitrogen, ppm	2	4		
Cetane Number	56.9	56.9	45.3	54.9
Iodine No.	94.07	122.3		98
Particulate, mg/L	4.4	1.32	1.4	
Copper Corrosion	1A	1A	1A	
Phosphorus, percent	0	<0.001		
Boiling Point, C	15	313	193	
Heat of Combustion, BTU/lb	17,637		19,441	17,489

Lab Tests,cont'd.	REE	Gully	P66	Ida Gold
Flash Point, C	170		74	183
Cloud Point, C	-2		-19	1
Pour Point, C	-15		-20	-15
Fatty Acid, percent				
Palmitic (16:0)	3.1	2.5		2.8
Steric (18:0)	1.2	1.1		1.2
Oleic (18:1)	13.5	30.5		26.1
Linoleic (18:2)	9.5	9.2		9.8
Linolenic (18:3)	4.5	10.8		10
Eicosanoic (20:1)	8	10.2		10.6
Erucic (22:1)	54.40	31.9		33.10
Nervonic (24:1)				2.20

Engine Testing

1999 Dodge Cummins Performance Tests

A 1999 Dodge Cummins powered pickup was obtained for testing yellow mustard oil biodiesel. The truck operates on 100 percent yellow mustard biodiesel (MEE). It was put into operation May 30, 1999. The fuel was changed from diesel to MEE at 2240 miles. It has since accumulated 23,980 miles on MEE as of November 16, 2001. No maintenance or operation problems have been observed. To date the truck has used about 1575 gallons of fuel and has averaged 15.23 miles per gallon.

The vehicle was performance tested on a chassis dynamometer owned by Western States Caterpillar in Spokane, Washington (see Table 3). Figure 3 shows the torque and power as a function of engine speed for MEE compared to diesel.

Table 3 Chassis Dynamometer Test of the 1999 Dodge/Cummins Pickup Fueled with Diesel and Yellow Mustard Biodiesel (MEE)

Speed	Diesel – Corrected HP	Diesel - Torque	MEE – Corrected HP	MEE – Torque
1600	130	1844	121	1722
1700	136	1833	129	1724
1800	141	1784	137	1727
1900	146	1751	137	1640
2000	154	1751	141	1616
2100	158	1714	147	1592
2200	164	1692	151	1562
Mustard average Hp and Average Torque as a percent of Diesel			93.6 percent	93.6 percent

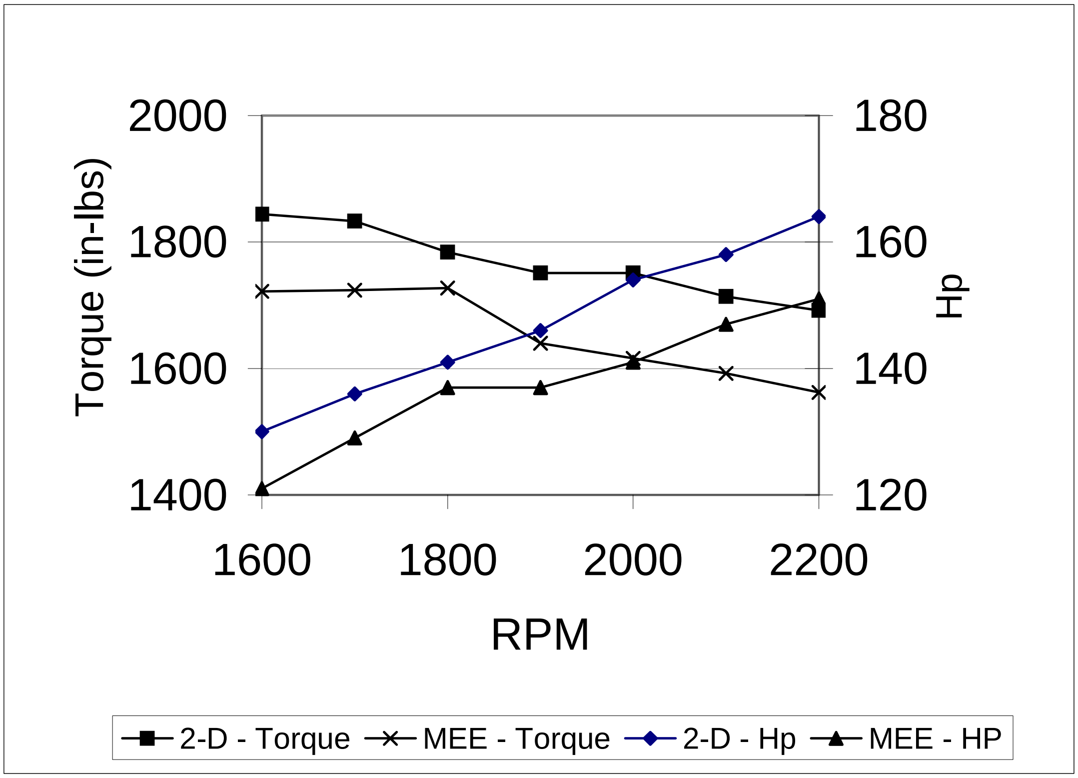

Figure 3 1999 Dodge/Cummins chassis dynamometer test

Cummins of Spokane conducted an injector cutout. The power contribution was 98 percent to 102 percent for the six cylinders. The cutout tests showed that all cylinders were functioning equally and normally.

During the chassis dynamometer tests, MEE fuel use was 1.6 percent higher than diesel fuel use during the same series of tests.

Ida Gold Durability Test with a Yanmar 1.2 L, Three-Cylinder, DI Engine

A 200-hour EMA test with MEE has been initiated and the test ran for 160 hours until the limited supply of Ida Gold fuel was exhausted. Since then, more Ida Gold seed has been processed and the fuel needed to complete the test is now available.

One of the problems associated with new yellow mustard varieties is that the seed is produced in small quantities. We have seed from the new crop and have extracted 400 liters of oil to complete the test. It should be finished during spring 2002. The durability dynamometer facility is in use for testing used fry oil. The completion of the Ida Gold yellow mustard tests cannot begin until the used fry oil tests are completed.

At the start and then after every 50 hours, the engine is evaluated for torque, horsepower, smoke and injector coking, and oil analysis samples are taken. During the EMA durability startup tests with the Yanmar engine, MEE power averaged 6.0 percent lower; fuel consumption was 2.2 percent higher and BSFC (hp-hrs/gal) was 8 percent higher than when operated on diesel. The torque, power curves, and BSFC for the test to date are shown in Fig. 4, 5, and 6.

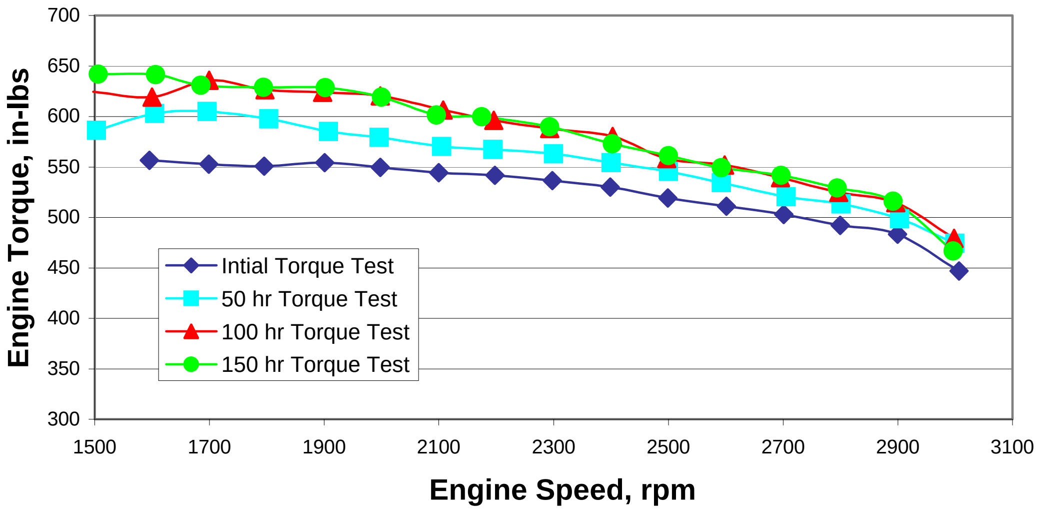

Figure 4 Torque test results

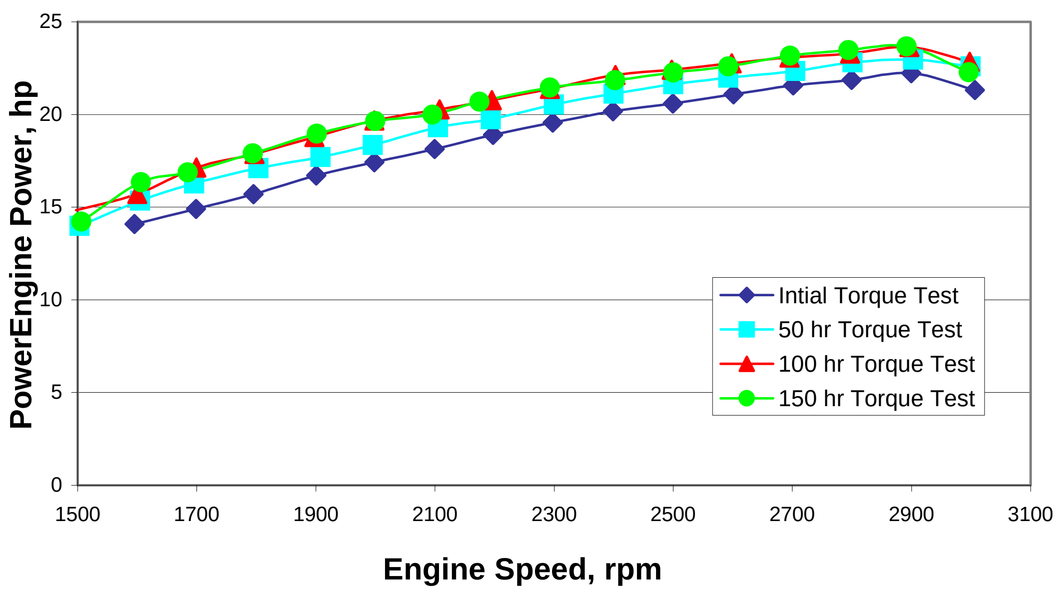

Figure 5 Power test results

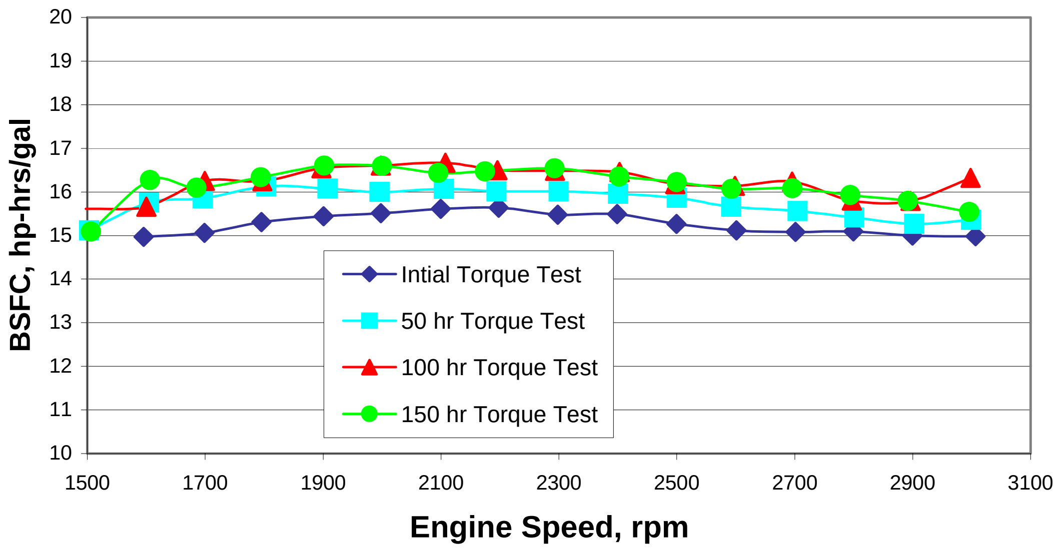

Figure 6 Brake Specific Fuel Consumption test results

At every 50 hours of operation, the oil samples are sent to a commercial oil analysis lab for evaluation. The results so far show not only no cause for concern but a very low level of all wear metals (Table 4).

Table 4 Oil Analysis Data for the Yanmar

	Yanmar 3TNE 78A-ESA Oil Analysis Data							
		Oil Type: Delo 400 15W/40						
		Fuel: Ida Gold Mustard Biodiesel						
		Test: 200 Hr. EMA Screening						
Hours on Oil	Iron	Lead	Copper	Aluminum	Silicon	Viscosity	F-Soot	SAE
Hours on Unit	(reported in ppm)					100 C (cSt)	(%)	(Weight)
50/85	11	2	5	2	18	12.42	0.1	30
100/135	20	2	6	3	17	11.24	0.1	30
50/185	8	1	2	2	11	12.28	0.3	30

One method of evaluating the potential of an alternative fuel in an engine is to conduct an injector-coking test. The department has a machine vision system for scoring the results of the injector coking. This facility was made operational and upgraded to reduce the variability between readings with a particular injector. It has been used for both MEE testing and tests with used vegetable oil.

Results of Chassis Dynamometer Emissions Tests

Because the heat of combustion of the fuels is different, they produce different power at the same engine speed. To compensate, the test was run two ways. First, the test was run with each fuel used to produce its maximum power. Next, a modification was made to the vehicle by placing a restriction below the accelerator pedal to remove approximately 10 horsepower at approximately 2400 rpm when running on diesel fuel. This created speed and torque curves that matched closely for each of the fuels. This allowed the removal of volumetric exhaust flow as a variable.

The UI chassis dynamometer tests were conducted first by simply changing fuels and testing the vehicle and next by matching the power level on diesel to that on biodiesel. Figures 7-10 show the results for HC, CO, CO2 and NOx for the LA MTA arterial and EPA test cycle and the UI full throttle and equal power tests. The data represented on the figures is the REE biodiesel divided by the average emission for diesel.

The hydrocarbon emissions (Fig. 7) were not comparable between the four tests. Biodiesel HC was considerable higher, and quite erratic when using the five gas analyzer.

The carbon dioxide tests (Fig. 8) show very similar results between REE and diesel as would be expected since CO_2 is the major product of combustion. However, UI data shows less CO_2 from biodiesel compared to diesel in the full power data and considerably more CO_2 from biodiesel compared to diesel in the matched power tests. This would be expected since less diesel fuel is being burned when the power is reduced.

The carbon monoxide tests (Fig. 9) show the diesel level below that of REE in each case. Because the analyzer shows results in percentage of emissions gases the results were quite low (approx .01 percent). The analyzer sensitivity is only to the hundredth of a percent, thus very little change was shown or reported. Since the CO produced would depend heavily on the power and fuel consumption of the engine, and since in a steady state chassis dynamometer test it is difficult to adjust both load and throttle it is difficult to make inferences regarding CO production when the sensitivity of the instrument is so low. For the emissions tests at UI, the average decrease in carbon monoxide was 11 percent at full throttle with an increase of 57 percent with reduced power. At LA MTA the drop in CO was 48 percent. The difference between the tests is likely due to the low sensitivity of the analyzer. Many of the readings were at the bottom of the scale. It is clear that the analyzer is not sufficiently sensitive to reliably report CO levels from a modern diesel engine.

Oxygen was not analyzed at LA-MTA and therefore will not be discussed in this review.

NOx results (Fig. 10) appeared to be the most reliable of the five gases analyzed. The overall change in NOx was an increase from biodiesel to diesel of between 2 and 5 percent. 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. Figure 11, which is a plot of NOx production for biodiesel and diesel with equivalent power, shows a crossover in these steady state tests. The NOx for biodiesel was below that of diesel at maximum torque and less than that of diesel at reduced torque. Additional tests with NOx comparisons would be justified. Perhaps, the feedstock tests (Peterson et al., 2000) that show reduced NOx with reduced double and triple bonds in the vegetable oil used to produce biodiesel could be replicated to determine if that same relationship could be found in steady state tests on the UI chassis dynamometer.

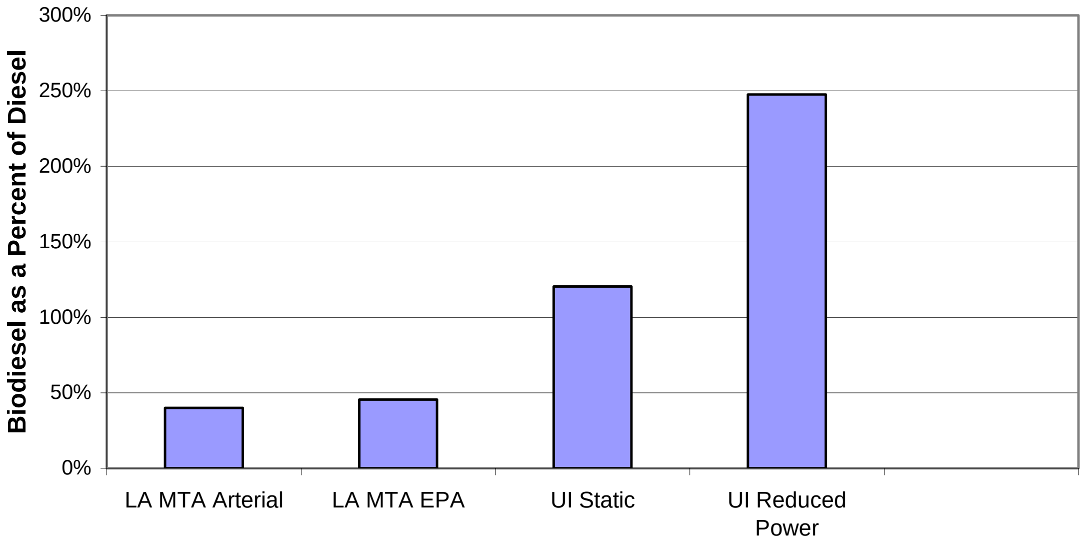

Figure 7 Comparison of UI chassis dynamometer emissions data with LA MTA transient emissions data—hydrocarabons (HC)

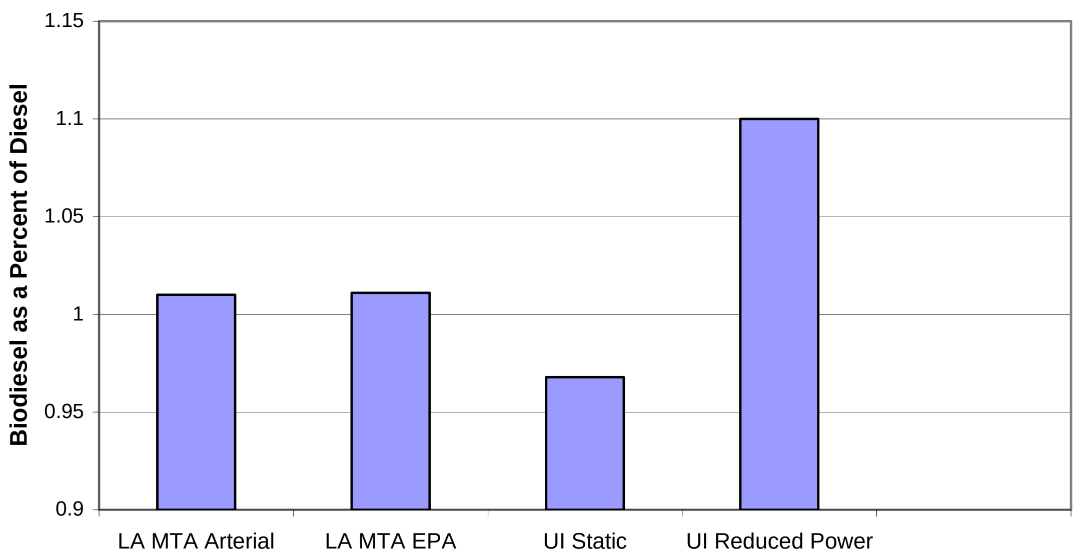

Figure 8 Comparison of UI chassis dynamometer emissions data with LA MTA transient emissions data—carbon dioxide (CO2)

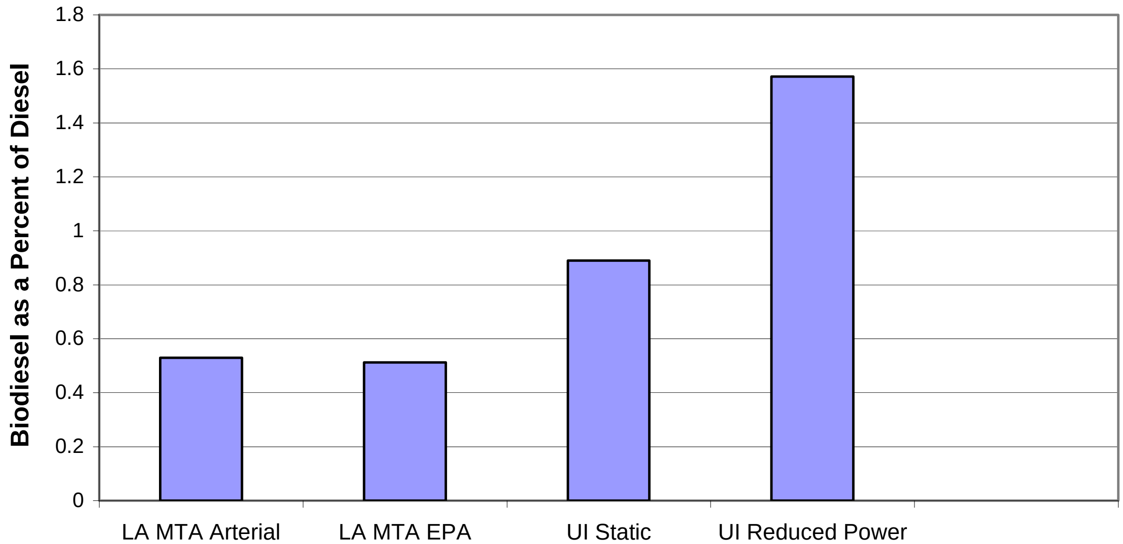

Figure 9 Comparison of UI chassis dynamometer emissions data with LA MTA transient emissions data—carbon monoxide (CO)

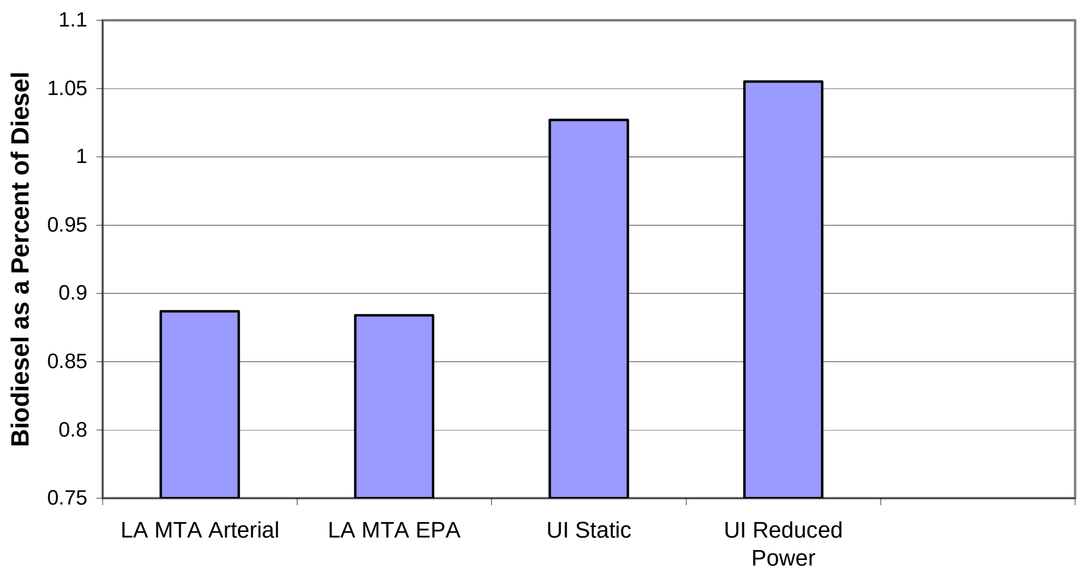

Figure 10 Comparison of UI chassis dynamometer emissions data with LA MTA transient emissions data—NOx

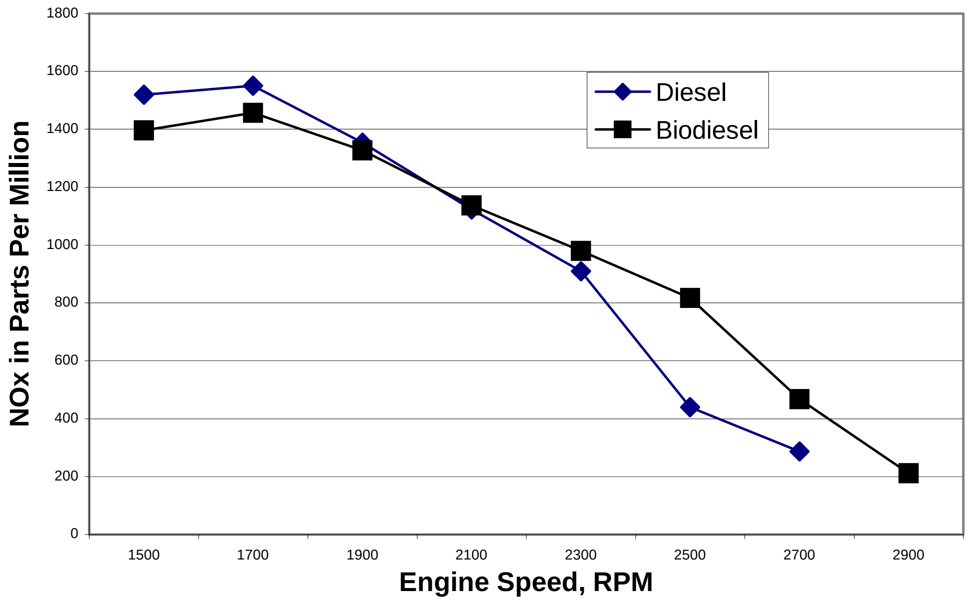

Figure 11 NOx emissions data for chassis dynamometer tests—engine power normalized

CONCLUSIONS

- Extraction of 280 gallons of oil from 12,700 pounds of Ida Gold variety yellow mustard has been completed. An additional 6000 gallons of yellow mustard oil was purchased for biodiesel production.
- Oil extraction has been less efficient from the Ida Gold yellow mustard than is normally experienced with rapeseed because of the reduced oil content. The Ida Gold has only about 27 percent oil content compared to 40-45 percent for rapeseed. Extraction efficiency, with the small screw presses, for the Ida Gold yellow mustard was 58 percent compared to 78-80 percent for rapeseed and canola.
- When processing biodiesel from yellow mustard reductions were noted in the final yield of esters (93 percent) compared with rapeseed oil normally at close to 100 percent.
- Fuel characterization data show that yellow mustard biodiesel is comparable to that produced from canola oil.
- On-road testing with a 1999 Cummins 5.9B diesel engine in a Dodge pickup truck fueled with yellow mustard biodiesel has accumulated 26,219 miles with no difficulties. Fuel consumption is increased and fuel filter change intervals are decreased.
- On-road testing with a 2001 Volkswagen 1.9 L diesel engine has accumulated 5,109 miles. Fuel consumption would be expected to increase but no data is available. Drivability of the vehicle is very good. Power and acceleration are excellent. The vehicle is a very “photogenic” ambassador of alternative fuels.
- A 200-hour engine durability test with Ida Gold yellow mustard biodiesel is in progress with no apparent difficulties to date.
- Hydrocarbon measurements tended to be somewhat erratic with no relationship to earlier transient tests.
- Carbon Monoxide levels appeared to be below the sensitivity level of the five gas analyzer.

- Carbon dioxide results tended to be more erratic that at the LA MTA test site. CO_2 release data should take into consideration the CO_2 used in plant growth when comparing biodiesel with diesel.
- Nitrogen Oxides emissions show a trend different from the LA-MTA but similar to other static tests performed by other agencies in engine pto dynamometer tests.. It is suggested that a study comparing saturation levels of vegetable oil biodiesels be replicated to further verify the comparison.
- The steady state dynamometer provided a very stable platform to produce load settings that could possibly be used for modal emissions tests. A method for controlling the throttle is required for part load tests.

REFERENCES

1. Chase, Craig L., Charles L. Peterson, Gary A. Lowe, Paul Mann, Jeffrey A. Smith, and Norman Y. Kado. 2000. "A 322,000-Kilometer (200,000 mile) Over the Road Test with HySEE Biodiesel in a Heavy Duty Truck," SAE Technical Paper No. 2000-01-02647. Warrendale, PA: Society of Automotive Engineers.
2. Chase, Craig L., Charles L. Peterson, Paul Mann, Jeffrey A. Smith, and Norman Y. Kado. 2000. Final Report on the Cat/Kenworth 200,000 Mile Over-the-Road Project with HySEE Biodiesel. ASAE Paper No. 006012. St. Joseph, MI: American Society of Agricultural Engineers.
3. Peterson, C. L., J. C. Thompson, J. S. Taberski, D. L. Reece, and G. Fleischman. 1999. "Long-Range On-Road Test with Twenty-Percent Rapeseed Biodiesel," *Transactions of American Society of Agricultural Engineers* 15(2): 91-101.
4. Peterson, C. L., J. C. Thompson, and J. S. Taberski. 1999. One-Thousand-Hour Engine Durability Test with HySEE and Using a 5X-EMA Test Cycle. *Transactions of American Society of Agricultural Engineers* 42(1): 23-30.
5. Taberski, Jeffrey S., Charles L. Peterson, Joseph Thompson and Howard Haines**.** 1999. "Using Biodiesel in Yellowstone National Park—Final Report of the Truck in the Park Project." *Transactions of American Society of Agricultural Engineers* 108(2): 153-175.
6. Peterson, C. L., J. L. Cook, J. C. Thompson, J. S. Taberski. 1999. "Continuous Flow Biodiesel Production." ASAE Paper No. 996110, St. Joseph, MI: American Society of Agricultural Engineers, 49085-9659, 1999
7. Peterson, C. L., J. S. Taberski, J. C. Thompson and C. L. Chase**.** 2000. "The Effect of Biodiesel Feedstock on Regulated Emissions in Chassis Dynamometer Tests of a Pickup Truck." *Transactions of American Society of Agricultural Engineers* 43(6): 1371-1381.