BIODIESEL USE IN MONTANA

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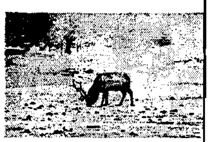
Presented to:
Montana Environmental
Quality Council
October 8, 2003

POINTS TO COVER:

- What is biodiesel
- Montana background
- Truck in the Park project results
- Follow-up
- Challenges and status



BIODIESEL IN MONTANA

Biodiesel is an animal or plant oil reacted with a catalyst and alcohol to make an ester used as fuel in conventional diesel engines (1998).

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October 8 and 9, 2003 Ex. No. 4

MONTANA AND DIESEL FUEL

Fuel supply disruptions in 1973 and 1979

Consumes twice the national per capita average for transportation

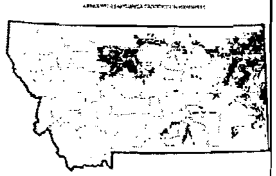
Petroleum based vulnerability

Mobile source air quality concerns

MONTANA AND BIODIESEL FUEL

In 1982-3, Investigation of crops for a "grown" biodiesel

High oleic (HO) safflower the most promising



MONTANA AND BIODIESEL FUEL

8,650,000 acres ~171,000,000 gallons/yr biodiesel 38% oil content seed (not ester)

Developed world-class oilseed lab, Sidney

1989, "Montola" sold in health-food market as high as ~$9/liter.

Investigate rapeseed/canola

AIR POLLUTION IN YELLOWSTONE

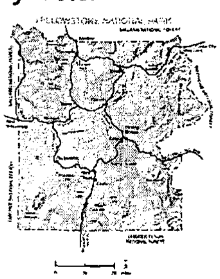
Tourism, Transportation

Climate, Topography

WHY BIODIESEL in YNP

- •Safe
- •Biodegradable, renewable, indigenous
- •Low odor, no smoke
- •Blind to the driver
- •Cleaner burning

1994 DNRC/DEQ with DOE and YNP started a pilot demonstration of 100 % canola ethyl ester



To Document:

-Cold Climate-high elevation operation

-Impacts

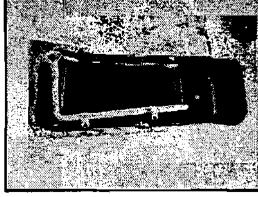
-Costs

-Wildlife Concerns

Biodiesel was found to be no more attractive to bears than regular diesel

Biodiesel BENEFITS

- LOW INITITAL COST
- SIMILAR POWER, VEHICLE RANGE



- HIGH BIODEGRADABILITY, EASIER SPILL CLEAN-UP FOR B-100
- REDUCED CO, ODOR, SOOT

BIODIESEL EMMISSIONS

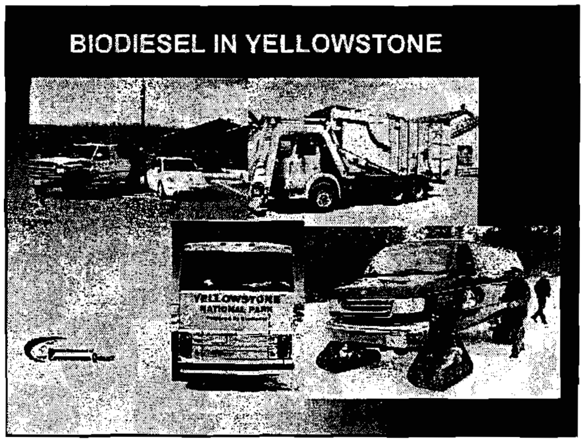
Fuel	CO, %	HC, %
Diesel, 2D	100	100
Biodiesel, B-100	-35 to-45	-62 to -74
Biodiesel, B-20	-16 to -28	-17 to -23

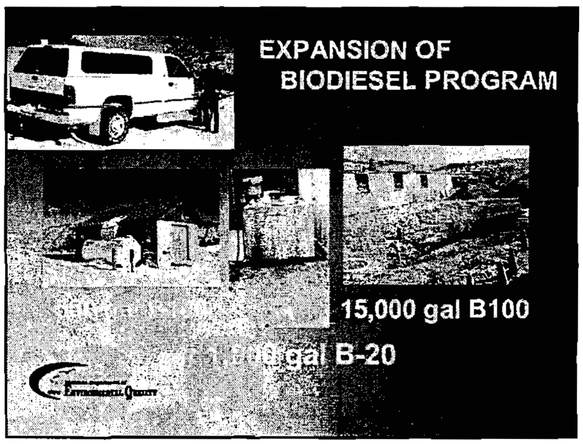
FTP chassis dynamometer at Los Angeles C-MTX and HD transient emissions at Southwest Research Institute

BIODIESEL EMISSIONS

Fuel	PM, %	NOx, %	Smoke
Diesel, 2D	100	100	100
Biodiesel, B-100	-50 to 11	-5 to 9	-54 to -78
Biodiesel, B-20	-10 to 5	-4 to -8	-47

FTP chassis dynamometer at Los Angeles C-MTX and HD transient emissions at Southwest Research Institute



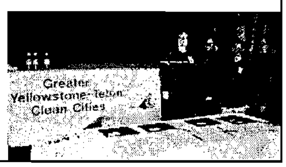


BIODIESEL IN YNP RIDESHARE

MARKET DEVELOPMENT

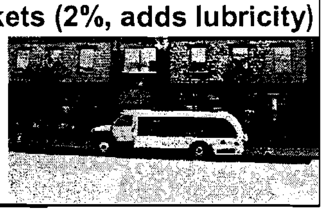
Challenges: cost and availability

-Federal regulations to use non-petroleum fuel
-Green Energy Parks Program
-Yellowstone-Teton Clean Cities Coalition
(~1.3 million to 2.2 million gal/yr use)
-Possible lower cost feedstocks (mustard, UFO, and ethanol from cellulose)

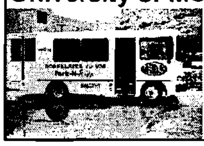


WHY BIODIESEL IN MONTANA

- Regulated markets
- Mission-driven markets
- Low-blend markets (2%, adds lubricity)



BIODIESEL FUEL USERS
Yellowstone and Glacier National Parks
Charlie Russell National Wildlife Refuge
Maelstrom Air Force Base
Mountain Line, Missoula
City of Bozeman and Gallatin County
EconoMart West Yellowstone--priced as diesel
Citi Service, Kalispell
University of Montana



BIODIESEL CONTACTS

- ALLEN OIL COMPANY, HELENA
- CITI SERVICE, KALISPEL
- STORY DISTRIBUTING, BOZEMAN
- MONTANA BIODIESEL, MISSOULA

FOR MORE INFORMATION

www.deq.state.mt.us/bioenergy

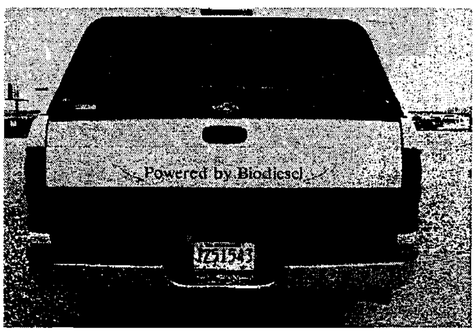
www.energizemontana.com

www.biodiesel.org

hhaines@state.mt.us, 406 444 6773

THANKS TO OUR PARTNERS

US DOE Regional Bioenergy Program MT Renewable Energy & Loan Program Montana State University, Wyoming Southwest Research Institute, NPS USFS, EPA, West Yellowstone University of Idaho, Dodge Truck Cummins, Montana Oilseeds-Great Falls, Xanterra JR Simplot Co, T&E Equipment, and MANY OTHERS



THE END

Pacific Regional Biomass Energy Program
Montana Project Summary Sheet

1. **Title:** ***Pilot Demonstration of Biodiesel in Tourism-Related Transportation: A Truck in the Park***

2. **Brief Description:** DEQ is spearheading a project to demonstrate biodiesel use in Yellowstone National Park (YNP). With visitation increasing yearly, there is a need for more efficient transportation, such as buses, and reduced pollution, odors, and smoke caused by tourism transportation. Rapeseed ethyl ester (REE) could be at least part of the remedy for pollution generated by motor vehicles in Yellowstone. REE is produced from rapeseed oil reacted with ethanol that is made from potato waste generated by the food processing industry. Yellowstone offers an opportunity to demonstrate this low emission, biodegradable fuel in an environmentally sensitive and extremely cold area. Such areas may prove to be a near-term niche market for this and similar bio-based fuels.

3. **Grantee:** Montana Department of Environmental Quality, Pollution Prevention Bureau, 1520 East Sixth Avenue, P. O. Box 200901, Helena, MT 59620-0901.
   Contact: Howard E. Haines, Bioenergy Engineering Specialist Phone 406-444-6773, FAX 406-444-6836, Email hhaines@state.mt.us web site http://www.deq.state.mt.us/bioenergy

4. **Project Manager: Jeffrey W. James, Program Manager,** jeffrey.james@hq.doe.gov
U. S. Department of Energy Seattle Regional Office, 800 Fifth Avenue, Suite 3950, Seattle, WA 98104 Phone 206-553-2079, FAX 206-553-2200 Identification No: **DE-FG51-94R020493**, DEQ CNo. 780006 formerly EDG- 95-7562, file TiPP.100

5. **Estimated total cost:** $344,294 DOE **Regional Program Funds: $111,102**
6. **Cost Sharing and Project Partners:** $233,619
   Montana Department of Environmental Quality (DEQ): project design and lead ($53,000)
   U. S. Department of Interior, National Park Service, Yellowstone National Park (NPS), truck equipment, lube oil, fuel storage facilities, canola ethyl ester (CEE) and operator (in-kind) + $35,419
   Wyoming Department of Commerce, Energy Office, emissions testing ($30,000)
   Dodge Truck of Chrysler Corporation [vehicle + technical oversight + in-kind]
   Cummins Engine Company (engine + technical support)
   Cummins Intermountain Distributor, Pocatello ID
   J.R. Simplot Company, Boise, ID (ethanol and catalyst for biodiesel)
   Koch Agricultural Services Company, Great Falls, MT [rapeseed oil + shipping)
   Tractor & Equipment Company (T & E), Billings, Montana [performance testing)
   University of Idaho (UI), Agricultural Engineering Department, (fuel, emissions, performance test analysis, reduced indirect)
   McGreggor Company [biodiesel and feedstock storage]
   University of California, Davis, Environmental Toxicology Department [PAH evaluation]

7. **Expanded Description:** The "Truck in the Park" Project was designed with two purposes: to define a market for biodiesel and to provide data on emissions and performance that could be used by land managers, regulators, and providers of commercial tourism transportation. This project was a first-step to reduce environmental impacts resulting from diesel fuel use in the tourism industry. The Montana Department of Environmental Quality (DEQ, successor to the Department of Natural Resources and Conservation) in cooperation with the National Park Service (**NPS**) and Dodge Truck Division of the Chrysler Corporation operated a 1995 ¾ ton 4x4 diesel truck fueled by 100 percent rapeseed ethyl ester produced by the University of Idaho (**UI**) and private cooperators. Basically, the project placed an unaltered diesel pickup truck into service in Yellowstone National Park, fueled this truck with 100 percent rapeseed ethyl ester, and monitored performance and emissions. Data were collected to determine the reliability, benefits, and costs of using biodiesel in Yellowstone National Park and the surrounding region. The project included fuel characterization, detailed performance and emissions tests before and

after (approximately) 149,408 km (92,838 miles) (using EPA protocols), and other quality control testing to document benefits and costs.

8. **Needs Addressed:** Each year about 3 million people visit Yellowstone National Park. The nearly 900,000 automobiles they use to travel to the Park burn thousands of gallons of fuel and produce tons of air pollution, endangering the clear air and water that people expect to see during their visit to the Park. The air in the Park meets EPA air standards, but not always the visitors' expectations.

With visitation increasing steadily over the last several decades, concern has arisen because of increasing congestion on park roads and the threat of increased pollution. One possible solution is to limit visitation, an option not likely to please the members of the public who may not be able to arrange their visit to the park when there are openings. Limiting visitation also is not favored by park concessionaires or economic interests in communities near Yellowstone.

A more desirable choice is to reduce congestion by encouraging use of high occupancy vehicles, such as buses, and by reducing the amount of pollution produced by each vehicle. One way of doing this is to use fuel that produces less pollution when burned in a conventional diesel engine and has exhaust that is less obnoxious to riders and visitors. Vegetable oil can be processed into a diesel fuel--a biodiesel--that produces less pollution than conventional diesel fuel. Exhaust emissions from these biodiesels smell less unpleasant than conventional diesel exhaust. Conventional diesel fuel also has other characteristics that are undesirable in areas valued for environmental cleanliness. These include toxicity and low biodegradability. Reformulated diesel fuel, intended to meet air emission requirements, is not enough of an improvement to meet the requirements of places like Yellowstone.

Rapeseed ethyl ester (REE) biofuel is a regional development by the University of Idaho (UI) from resources in Montana and Idaho. UI research has shown that REE has increased biodegradability and reduced emissions, odor, and smoke compared to petroleum diesel fuel. REE is at the stage of development where a higher value market, such as this tourist-related application, is the next logical step on the way to commercialization.

9. **Project Objectives:**

- Assist NPS and private industry develop options for reducing environmental degradation without adversely impacting visitation and associated industries;
- Support development of a process to convert food processing waste oil to an environmentally friendly transportation fuel, reducing both dependence upon imported petroleum and the impact on the environment;
- Encourage the development, production, and use of this biofuel within the region;
- Make the first step toward use of low odor, low smoke fuels for tourism leading to use in buses;
- Determine the impacts, benefits, and results from using biodiesel under variable conditions including high elevations and low temperatures; and
- Link the tourism industry with agriculture and energy.

Approach: To help commercialize REE, this project: 1. Introduces public and private operators to rapeseed ethyl ester biodiesel as an alternate fuel or blend with regular diesel in environmentally sensitive applications; 2. Develops data to support decisions regarding these fuels in areas with economies based on tourism, such as YNP.
To accomplish this, the National Park Service operates a 1995 Dodge 3/4 ton 4X4 pickup with 5.9 liter Cummins diesel engine, supplied by Dodge Truck. The truck runs under normal operating conditions as a maintenance inspection vehicle in YNP. No modifications are made to the truck's engine or fuel system. The truck uses 100 percent REE as fuel to develop data for warranty purposes. The demonstration includes normal service and maintenance, and periodic performance and emissions testing to determine if there is any degradation in emissions or performance caused by the fuel. Initial tests were conducted to determine the safety of the fuel and its use relative to the area's wildlife.
This project is in an area that brings humans and wildlife such as bears into close proximity. REE is a vegetable oil derivative that smells similar to oil used in cooking food. The exhaust from a diesel engine

'eled by REE smells like a French fry cooker, and may attract bears if the bears in the area connect the ent to a food reward. Attracting bears to vehicles operated by humans should be avoided. A bear attractant analysis was conducted, first to determine if bears are attracted by the scent of biodiesel more so than they are to regular petroleum products, and second to identify if a blend of petroleum diesel with biodiesel reduced the attraction. These data were needed for other users located in environmentally sensitive applications. The demonstration concluded with a detailed emissions test followed by disassembly and inspection of the engine and low pressure fuel systems by Cummins Intermountain Distributor and Bosch.

11. Major Milestones: Term, October 15, 1994 through December 30, 1998
Bear attractant analysis (completed March 1995, report November 1995)
Establish dedicated biodiesel fueling station at YNP (12/5/94)
Vehicle acquisition and preparation (Delivered 2/7/95, markings 3/10/95)
Biodiesel fuel delivery, operational demonstration (University of Idaho from 4/15/95 to 11/96, then to August 2001; Eco-Conscious Fuels, 9/2002-ongoing)
Engine oil analysis (every change)
Engine performance analysis (start, middle, and end of each year, 3/7 & 8/17/95)
Emissions tests (Dynamometer Transient Conditions Emission Tests 3/20-24/95 and 5/26-29/98)
Engine disassembly and inspection, Cummins Engine Company, July 1998.
Reporting, information transfer, presentations, January, 2000.
Expansion to Rideshare and VIP buses and garbage truck fleet: September 2000
Biodiesel incorporated into fuel supply contract with Story Distributing: July 1, 2002
Underground 15,000-gallon B-100 storage tank filled by Story Distributing and Eco-Conscious: September 2002
Use of B-100 or B-20 for all 134 diesel vehicles: September 2002
As of December 17, over 9,000 gallons of biodiesel were used in Yellowstone since September, representing about 43,750 gallons as B-20 and 250 as B-100.

12. Results: (Also see item 11. Major Milestones, above)
Abstract The "Truck in the Park" Project was designed with two purposes: to define a market for biodiesel and to provide data on emissions and performance that could be used by land managers, regulators, and providers of commercial tourism transportation. This project was a first-step to reduce environmental impacts resulting from diesel fuel use in the tourism industry. The project placed an unaltered diesel pickup truck into service in Yellowstone National Park, fueled this truck with 100 percent rapeseed ethyl ester, and monitored performance and emissions. Data were collected to determine the reliability, benefits, and costs of using biodiesel in Yellowstone National Park and the surrounding region. The project included fuel characterization, detailed performance and emissions tests before and after (approximately) 149,408 km (92,838 miles) (using EPA protocols), and other quality control testing to document benefits and costs. The technical data and results of this demonstration are documented in a number of papers listed below. This demonstration showed that:

1. The effects of biodiesel on criteria emissions with and without the catalytic converter were unaffected over the course of time, and that no new compounds are generated in blends of biodiesel with conventional diesel. Air toxics are significantly reduced by increasing the amount of biodiesel in a blend. Overall, hydrocarbons, carbon monoxide were reduced by the use of biodiesel. Oxides of nitrogen were either slightly reduced or unaffected by the use of 100 percent biodiesel, and particulate matter was slightly increased or unaffected;
2. The project developed data for use in modeling air quality so the impacts can be assessed before a large scale conversion is implemented;
3. Biodiesel or a blend may be the fuel of choice for restricted or poor air dispersion conditions. Tests also showed that the sweet odor of biodiesel exhaust does not attract bears, which was a concern to Park and land management officials.
4. Operation during six Yellowstone winters showed that normal cold-weather diesel modifications were sufficient to enable use of biodiesel in cold weather operations. These included engine coolant, an engine block heater, battery heaters, an external (electric, magnetic) fuel tank heater, and a heating loop to the slip tank. The truck failed to run on only one occasion with a daytime temperature of -38.3 degrees C (-37 degrees F), a time when most things were only running for cover). However, biodiesel in Europe does use a biodegradable cold flow plug point additive for cold climate operations. If a problem occurred, the remedy would be to add No. 1 diesel.

5. The benefits of biodiesel include reduced toxicity, emissions, smoke, unpleasant odor, and increased safety and biodegradability. Two challenges yet remain: availability and cost. For this project, the refueling infrastructure and availability was carried in the bed of the truck, somewhat reducing the truck's usefulness for work. The cost factor was overcome in part by the generous contributions from our many sponsors.

Commonly Asked Questions at Truck Demonstrations:

1. What was modified to enable the truck to use biodiesel? No modifications were made to the engine or low-pressure fuel system—it is stock. A quick disconnect was added to the fuel line for emissions test purposes. An in-bed fuel tank was added to extend the range to about 6,000 miles, also for the trip for emissions testing in Los Angeles, California.

2. What was the mileage?

During Phase 1, the ¾ ton 4X4 Dodge truck averaged 17.3 miles per gallon under load for the first 92,000 miles, or about 1 mile per gallon lower than with conventional diesel. The engine was torn down and inspected to determine that durability was equivalent or better than petroleum diesel fuel.

3. How did the truck perform, including power, compared to petroleum diesel?

A survey of operators reported that the truck performed as any diesel truck, except the odor was better. The truck had regular chassis dynamometer tests that did not show any loss in power over time. Biodiesel has a lower energy content (BTUs per pound) but higher density (more pounds per gallon) than conventional diesel fuel. The loss in peak power was measured to average +/-7 percent.

4. Does the fuel attract bears?

A study conducted by the National Park Service, Montana Department of Environmental Quality, University of Idaho, and Washington State University showed that biodiesel was no greater an attractant for bears than conventional diesel fuel.

5. What was the yield of fuel per acre?

For rapeseed, about 100 gallons per acre, net, and with canola, about 110 gallons per acre.

6. How much did/does biodiesel cost?

For the small batch process used in this project, and including all the ($70,000 of) emissions testing, the fuel would have cost $7.50 per gallon. Commercial scale production would reduce that amount to between $1.35 to $2.00 per gallon. A January 2002 comparison (bid) FOB the blend site (Bozeman, Montana) was $900 per 1,000 gallons for conventional diesel and $944 for B-20, before taxes and delivery. The September 2002 cost with delivery was about $1.30 per gallon (B-100).

7. Where can the public buy biodiesel? Biodiesel can be purchased by the public at Economart, 307 Firehole Ave (and Electric Ave), West Yellowstone, Montana. Distributors can obtain biodiesel from Dan Alexander, Story Distributing, Bozeman, Montana (406-587-0702, storydist@usa.net) or Mike Allen, Allen Oil, in Helena (406 442 7703 mikea@allenoilcompany.com). Today, the National Biodiesel Board lists 55 public biodiesel stations in the US (www.biodiesel.org, buying biodiesel, 800-841-5849). Biodiesel is widely used in Europe since the mid-1990s. B-20 is used in the diesel powered administrative fleet in Yellowstone National Park exclusively since September 2002. Plans are to expand B-20 availability to public service stations in the next several years.

Table 1. Summary of emissions reductions of biodiesel compared to 2D low-sulfur diesel from FTP chassis and engine dynamometer testing

Fuel	2D	B20	B100
Carbon monoxide	100%	-16 to –18%	-35 to –45%
Unburned hydrocarbons	100%	-17 to –23%	-32 to –74%
Particulate matter (PM-10)	100%	-10 to 5%	-50 to 11%
Oxides of nitrogen (NOx)	100%	-4 to –8%	-5 to 9%
Smoke	100%	-47%	-54 to –78%

Status: From February 7, 1995 to March 27, 2003, the National Park Service at Yellowstone National Park operated the first alternate fueled vehicle for 148,00 miles fueled by 100 percent rapeseed ethyl ester biodiesel. The first phase of the project successfully determined measures to operate in cold climates. During its tenure at Yellowstone, the truck was used for a number of demonstrations starting with one at the Montana Legislature in May 1995, and including appearances at Bioenergy 96 in Nashville, Tennessee, a number of wildfire schools, national Park Service maintenance meetings in Reno, NV, and Big Sky, MT, and Montana Ethanol Conferences. The initial grant was funded in May 1994 by the Department of Energy, the Montana Department of Natural Resources and Conservation, and others. The project was submitted in response to a request for proposal submitted by the Montana Department of Natural Resources and

Conservation Energy Division, which has become part of the Montana Department of Environmental Quality. As a result of this project and the recent Greening of Yellowstone Workshop, the Park Service is expanding the use of biodiesel in its fleet and throughout 20 million acres of the greater Yellowstone region. By October 2000, three MCI buses were converted to run on B20, a blend of 20 percent biodiesel with 80 percent conventional diesel. The buses had been donated to Yellowstone National Park from the Idaho National Engineering and Environmental Laboratory (INEEL) in Idaho Falls for the Rideshare Program and the VIP bus. By May 2001, all seven packer garbage trucks in Yellowstone use B20 fuel. On June 14, 2001 a meeting at Old Faithful started the coordination 27 fleets in the region to use B20 in their roughly 700 vehicles and 1.3 million gallons of diesel fuel. On June 18, 2001 the Town Council of Jackson, Wyoming, voted to use B20 in their bus fleet at least during the summer months. The fleet manager of many of the surrounding national forests (Bridger-Teton, Caribou-Targhee, Salmon-Challis) has converted their 150 vehicle diesel fleet to B20. Xanterrra Parks and Resorts, Inc, the largest concessionaire in Yellowstone, is using their Yellowstone activities to determine if they will use biodiesel nation-wide at their other park operations. Other private fleets are considering use of B-20 in the summer 2003.

Awards:
U. S. Environmental Protection Agency EPA Region VIII. Outstanding Achievement Award to DEQ for Teamwork and Environmental Stewardship in Yellowstone Nation Park as exemplified by the Snowmobile and Truck in the Park Teams, August 27, 1996.
National Park Foundation 2001 National Park Partnership Award Honorable Mention for Environmental Conservation, April 22, 2001, Washington, D. C.

Reports, Papers, Other:
Biel, M. J., H. E. Hoekstra, and K. A. Gunther. November 1995. **Bear Attractant Test of Alternate Fuel Rapeseed Ethyl Ester**. Bear Management Office, Yellowstone Center for Resources, National Park Service. Yellowstone National Park, Wyoming.

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Kado, N. Y., P. A. Kuzmicky, R. A. Okamtot, and T. L. Huang. June, 1998. **Bioassy and Chemical Analyses of the Emissions from Rapeseed Ethyl and Methyl Ester Biodiesel Fuels**. Final Report, EDG-95-7561. Department of Environmental Toxicology, University of California, Davis, California, and Montana Department of Environmental Quality. Helena, Montana.

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Peterson, C., C. Chase, H. Haines, D. Reece. November 1995. Emissions Testing with Blends of Esters of Rapeseed Oil Fuel With and Without a Catalytic Converter: Interim Report EDG-95-7562, TiPP.106.10. Montana Department of Environmental Quality. Helena, Montana.

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Sharp, C. A., H. E. Haines. November 1996. **Emissions and Lubricants Evaluation of Rapeseed Derived Biodiesel Fuels.** EDG-93-7549, SwRI 7507. Montana Department of Environmental Quality. Helena, Montana.

Taberski, Jeffrey S, C. L. Peterson, and H. E. Haines. October 1998. Emission Analysis from Chassis Dynamometer Tests of the "Truck-in-the-Park" Project. Bioenergy '98 Conference. Madison, Wisconsin.

Taberski, Jeffrey S. January 1999. Performance, Durability, and Emissions of 100 Percent Canola Ethyl Ester Biodiesel for an Environmentally Sensitive Application. College of Graduate Studies, University of Idaho, Moscow, Idaho.

Taberski, J. S., Peterson, C. L., Thompson, J., and Haines, H. E.. September 1999. Using Biodiesel in Yellowstone National Park – Final Report of the Truck in the Park Project.. SAE 1999-01-2798, New Diesel Engines, Components, and Cooling Systems, International Off-Highway and Powerplant Congress and Exposition, Indianapolis, Indiana. Society of Automotive Engineers, Warrendale Pennsylvania.

13. Future Activities: Text and photos for a brochure depicting the most important findings has been drafted, and will be used to add to the demonstration and a guide for the permanent historic vehicle display. An informational "time capsule" will be developed and added with the truck as it goes into Yellowstone's historic vehicle collection.

14.

15. Date Prepared: December 15, 1994

16. Date Amended: March 27, 2003

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Pacific Northwest and Alaska
Regional Bioenergy Program
Montana Project Summary Sheet

1. **Title: Comprehensive emissions and chemical characterization of rapeseed oil-derived biodiesel in support of the *Truck in the Park Project***

2. **Description:** The project promotes commercial acceptance and development of rapeseed ethyl ester and rapeseed methyl ester as a biodiesel by providing definitive emissions and performance data from tests conducted by an industry-accepted laboratory. Of special interest are the results from the hydrocarbon speciation and air toxic emissions. The target audience includes regulators and heavy duty diesel users, especially in environmentally sensitive applications such as the tourism industry's buses and trucks. The Montana Department of Environmental Quality (**DEQ**) in cooperation with the U. S. Department of Energy (**DOE**) Regional Bioenergy Program, Cummins Engine Company and Dodge Truck Division of the Chrysler Corporation are developing data needed by potential markets and producers of rapeseed-based ethyl or methyl esters now produced by the University of Idaho (**UI**) and private cooperators. DEQ coordinated the testing, industrial participation, selection of vegetable oil derivatives and blends for testing, and contracted with Southwest Research Institute for the EPA heavy duty emissions tests using a Cummins B Series (5.9 liter) diesel engine. The biodiesel products also were evaluated for their lubrication qualities. The results of this testing will assist the **Truck in the Park Project** in identifying a niche market for biodiesel in the tourism industry. If successful, the project will provide data to support an initial market for a new value-added industry that uses agricultural products and wastes for feedstocks.

3. **Grantee:** Montana Department of Environmental Quality, Energy Division
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Identification No: EDG-93-7549, DE-FG79-82BP35776MOD08

5. **Regional Program Funds: $ 90,000**
Estimated total cost: 270,000

6. **Cost Sharing and Project Participants:**
Montana Department of Environmental Quality 135,000
Dodge Truck Division of Chrysler Corporation [technical oversight]
Cummins Engine Company [test engine, technical oversight] 10,000
J.R. Simplot Company, Boise, ID [ethanol and catalyst for biodiesel] 10,000
Koch Agricultural Services Company, Great Falls, MT
[rapeseed oil feedstock]
University of Idaho, Agricultural Engineering Department (UI),
technical support, fuel production and analysis 15,000
Southwest Research Institute [vapor phase PAH
investigations, technical assistance] 10,000

7. **Needs Addressed:** To increase commercial acceptance of rapeseed-based biodiesel, DEQ is developing detailed data needed by regulators, potential fuel producers, diesel engine manufacturers, and consumers to support the marketing and use of bio-based petroleum substitutes.

The petroleum substitute being investigated is a locally produced rapeseed ethyl ester (REE) used as a diesel fuel additive to reduce emissions, odors, and smoke from diesel engines. Demonstrations show that REE used in a Cummins 5.9 liter diesel engine pickup reduces smoke, CO, HC, and NO_x, with a slight increase in particulates (PM). The cost of REE can become more competitive with other emissions reduction options if biodiesel can also be shown to reduce toxic air emissions and improve other aspects of conventional diesel fuel. Preliminary test results indicate that blends of biodiesel with conventional diesel can reduce lubricity problems observed with low sulfur diesel fuels. Also, data from Austria suggest that toxic air contaminants are reduced by using these oils blended with conventional diesel fuel. To assist commercialization of RME and REE in the United States, tests needed to be conducted using scientific and engineering practices accepted by American regulators and industry.

8. Project Objectives: The project objective is to obtain definitive data on emissions and other aspects of rapeseed-derived biodiesel needed for development. Commercial developers are interested in data that show biodiesel's abilities to:

reduce the amount and type of emissions, particularly PAH and toxic air contaminants
produce or prevent deposits on fuel injectors (detergent properties)
increase cetane number and oxygen content in the diesel fuel
improve the performance of lubrication oil's oxidation resistance and neutralization capacity, and
increase the lubricity of low sulphur diesel fuel

The tests were designed to determine:

the biodiesel blends that best reduce emissions of carbon monoxide (CO), particulate matter (PM), oxides of nitrogen (NO_X), sulfates, and hydrocarbons (HC), including polycyclic aromatic hydrocarbons (PAH) and toxic air contaminants

the effects of these biomass fuels on engine lubrication, injector carboning, engine lubrication oil and other reliability factors

how the effects of these fuel blends apply to other heavy duty diesel engines used in buses and trucks, important if these blends are to be used in other engines.

9. Approach: This information was sought through comprehensive environmental and chemical testing that detects the effects of bio-based fuels on emissions, lubrication oil and engine endurance. Testing is progressing in three phases, but only Phase I is complete at this time.

Phase I: **Engine Dynamometer Testing**: Phase one consisted of EPA heavy duty engine dynamometer tests using a Cummins B Series (5.9 liter) diesel engine. This engine was selected because of past emissions tests using rapeseed-based biodiesel fuels Also, it is the same engine type used in the Truck in the Park Project. Seven fuels were evaluated: 1) Phillips low sulfur 2-D diesel fuel, 2) 100 percent rapeseed ethyl ester (REE), 3) 100 percent rapeseed methyl ester (RME), 4 and 5) 50 percent blends of REE and RME with diesel, and 6 and 7) 20 percent blends of REE and RME with 2-D diesel fuel. Besides the emissions tests, fuel analyses and a modified ball-on-cylinder or BOECLE lubricity tests were conducted on all fuels.

All heavy duty transient tests include fuel chemistry characterization of the fuel (such as cetane, density, viscosity, etc. with percent H, C and O) and analyses on regulated emissions (NO_X, CO, HC, and PM), soluble organic fraction (SOF) and sulfates. Other chemical analyses will be run on selected samples including:

a) Polycyclic aromatic hydrocarbons (PAH) analyses to identify aromatic compounds.
b) Direct filter injection gas chromatography (DFI/GC) analysis to provide volatile organic fraction (VOF) and identify the source of emissions
c) Hydrocarbon speciation, aldehydes and ketone analyses: A CARB protocol provides data for compounds in the C1-C12 range. A speciation protocol for C13-22 was developed by SwRI to analyze diesel type fuels. This procedure provides results that are not as definitive as the C1-12 analyses partly because it is not yet a certified protocol. This testing best evaluates fuel additives, such as a blend of biodiesel with conventional diesel. Each fuel was run for one cold and two hot starts with and without the catalytic converter. Baseline fuels of low-sulfur diesel fuel and 100 percent REE (fuels A and B) were run for two consecutive days. The following emissions were collected during this testing:
Data on NO_X, CO, CO_2, HC, and PM, soluble organic fraction (SOF) and sulfates

Solid and volatile fraction PAH, ketones and aldehydes were analyzed for the first cold and hot starts of each fuel
Solid and volatile fraction emissions had a bioassay and PAH analyses for the second hot start of each fuel
A Volatile Organic Fraction (VOF via DFI/GC) test was run on the first cold and hot starts of each fuel
Hydrocarbon speciation C1-22 (proposed diesel protocol) analyses were run on the first hot and cold start of each fuel

Phase II: California Air Resource Board (CARB) Certification tests using a Detroit Diesel Series 60 diesel engine (or equivalent): Based on the results of Phase I testing, the most promising fuels will proceed to Phase II, that will screen the fuel for compliance with the California Air Resource Board (CARB) regulations. These tests use a Detroit Diesel Series 60 diesel engine. This test would follow 2 of 10 days of the CARB Alternative 1 Certification Test using a pseudo California diesel for the reference fuel to compare two candidate fuels. The screening test would evaluate one reference and two candidate fuels. Samples would be analyzed for regulated emissions, CO_2, SOF, sulfates, PAH, and DFI/GC (VOF). Hydrocarbon speciation (C1-22) analyses would be performed only on the first run of each fuel. This would supply the hydrocarbon speciation data needed for EPA's fuel certification requirements.

Results of these screening tests will determine the value in conducting the complete and very expensive CARB test that runs for 10 days for each fuel with a control fuel that costs more than $100 per gallon.

Phase III. Based on the results of Phase II testing, the most promising fuels will proceed to Phase III, which will include standard reference tests such as a Cummins L-10 injector carboning analyses and the 1K (lube oil durability test) if need and funding permit.

10. Major Milestones:

Project management and development of detailed test plan (completed 5/20/95)
Conduct Phase I testing using a Cummins B diesel engine (completed 12/4/95)
Review report and decide on fuels to continue testing (in progress)
Conduct Phase II testing using a Detroit Diesel Series 60 or similar engine
Conduct Phase III testing using the candidate biodiesel fuel in a Cummins L-10 or Caterpillar 3304 engine
Reporting, information transfer, presentations (on-going)

11. Results:

DEQ obtained private industry match for fuel and a 160 HP Cummins B5.9L engine which was delivered to Southwest Research Institute on June 12, 1995.
The final test plan addressed problems found in other reported testing. Two analyses were used to clarify the carbon source (fuel or lube) and type of compounds. First, particulate samples were analyzed with a mass spectrogram performed to identify the compounds--a qualitative measure used to calibrate gas chromatographies (GCs) to monitor those compounds quantitatively. Second, a direct filter injection gas chromatograph (DFI/GC) analysis identified the source of hydrocarbon compounds: either the lubrication oil or fuel. A DFI/GC is neither a gas chromatograph nor mass spectrogram, but identifies compounds from unburned or partly burned lube oil. These tests, coupled with hydrocarbon speciation of C1-22, provide a detailed look at emissions from rapeseed-based biodiesels.
In September 1995, four barrels each of REE and RME were shipped to SwRI. Jeff Taberski, of the University of Idaho, monitored the blending and test cell set up at SwRI. The fuels were blended, and fuel characterization data completed.
A Cummins B5.9L diesel engine was installed for Phase I tests which started October 23 and were completed on December 4, 1995.
The original test plan assumed that hydrocarbon speciation (C1-C22) would yield data adequate to report part results. However, the sampling temperatures for hydrocarbon speciation and volatile PAH were different requiring a separate sample and analysis. The changes were made before any tests were run. Also, at this time, another set of samples was collected for bioassay analyses by the

University of California at Davis using 16 "cleaned" EPA poly-urethane foam air filters or PUF samples were taken on the second hot run of each fuel.

On March 14, 1996, DEQ distributed for review a draft final report regarding the work at SwRI. The final printing of the report was ordered December 6, 1996.

EXECUTIVE SUMMARY

Two different biodiesel fuels derived from rapeseed oil were tested at Southwest Research Institute (SwRI) to characterize heavy-duty engine exhaust emissions and biodiesel effects on lubricity. The objective of the program was to compare results for the biodiesel fuels to results obtained with diesel fuel. The two biodiesel fuels were a rapeseed ethyl ester (REE) and a rapeseed methyl ester (RME). Each fuel was tested both neat and in two blend levels, 50 percent and 20 percent by volume with the base diesel fuel. Fuel properties were measured, Table 2. The transient emissions characterization was performed using a 1995 Cummins B5.9L diesel engine, both with and without a catalytic converter (catalyst).

Composite transient emissions data for the four primary pollutants, regulated by the EPA for on-highway engines, is given in the table below. Emissions data are given for all seven test fuels, both with and without catalyst. Transient cycle work and fuel consumption data (BSFC) were also included. In general, the biodiesel fuels reduced transient emissions levels of HC, CO, and total particulate, but had no significant effect on NO_x levels, as compared to levels obtained with diesel fuel.

Particulate samples from all transient emission tests were analyzed to determine the composition of the particulate. These data indicated that the reductions observed in particulate emissions when biodiesel fuels were used were due primarily to reduction in the level of carbon soot. Reduced carbon soot probably resulted from improved oxidation of soot in the engine due to the oxygen present in biodiesel. However, the mass of volatile organic material in the particulate, referred to as the volatile organic fraction (VOF), increased when using biodiesel. The net decrease in total particulate using biodiesel fuels would have been larger but the increase in VOF partially offset the reduction in soot. An exhaust catalyst typically reduces the VOF of the particulates. Using biodiesel, the catalyst was able to control the increase in VOF, so that the combined use of biodiesel and a catalyst proved more effective in controlling particulate than either of the two alone. RME had slightly lower levels of regulated emissions than REE.

TABLE 1. COMPOSITE EMISSIONS FROM A CUMMINS B5.9L ENGINE WITH BIODIESEL FUELS

Fuel	Catalyst	Transient Emissions, g/hp-hr					BSFC, lb/hp-hr	Work, hp-hr
		HC	CO	NO_x	CO_2	PM		
2-D	No	0.30	1.47	4.37	609	0.106	0.424	12.5
	Yes	0.25	1.42	4.25	606	0.073	0.422	12.4
REE	No	0.11	0.95	4.26	645	0.091	0.500	11.7
	Yes	0.07	0.64	4.27	651	0.047	0.505	11.7
RME	No	0.09	0.90	4.52	642	0.080	0.498	11.8
	Yes	0.06	0.61	4.48	640	0.042	0.494	11.8
REE50	No	0.17	1.03	4.26	621	0.092	0.458	12.2
	Yes	0.12	0.74	4.37	637	0.058	0.470	12.1
RME50	No	0.16	0.97	4.30	625	0.087	0.460	12.2
	Yes	0.11	0.70	4.30	633	0.055	0.458	12.2
REE20	No	0.23	1.24	4.31	623	0.100	0.444	12.2
	Yes	0.16	0.94	4.30	645	0.067	0.459	12.2
RME20	No	0.22	1.14	4.39	618	0.093	0.444	12.2
	Yes	0.15	0.97	4.33	616	0.064	0.442	12.2

A disadvantage of the biodiesel fuels was noted in terms of engine performance and fuel economy (BSFC). The engine produced about 6 percent less power when fueled on either of the neat biodiesel fuels, and had significantly higher fuel consumption during the transient cycle. This change was less pronounced with the biodiesel/diesel fuel blends. The performance and fuel economy of the 20 percent blends were nearly identical to that of diesel fuel, whereas the 50 percent blends fell about halfway between the neat biodiesels and diesel fuel. These changes in performance and fuel economy were essentially due to the lower energy content per unit volume of biodiesel as compared to diesel fuel.

Sampling and analysis were also performed on all of the transient tests to try to characterize the compounds present in the gaseous hydrocarbon emissions in more detail. This data indicated that the neat biodiesel fuels appeared to reduce both the total mass and the reactivity, in terms of ozone formation potential, of the gaseous hydrocarbon emissions. It also indicated that the gaseous hydrocarbon emissions associated with using the neat biodiesel fuels were composed of a much narrower range of compounds than was the case for diesel fuel, and that apparently these compounds were more easily oxidized by the catalyst. The results for blended fuels generally followed a pattern similar to that observed for the neat biodiesel fuels, but to a lesser degree as the amount of biodiesel in the blend decreased. The hydrocarbon speciation data for the blends also indicated that the combination of diesel fuel and biodiesel did not produce any unusual toxic compounds not already found in the exhaust of either fuel when run separately.

Detailed analyses of both gaseous and particulate emissions were also made to determine the levels of polycyclic aromatic hydrocarbons (PAH). Gas-phase PAH levels significantly decreased with neat biodiesel fuels as compared to diesel fuel. Some of the particulate-phase PAH compounds also decreased, but several others increased. These same trends were present with the blended fuels, but less strongly than with neat biodiesel fuels. In the case of PAH emissions, the 20 percent blends gave results essentially identical to the diesel fuel. It should be noted that the mass of gas-phase PAH compounds was several orders of magnitude higher than the mass of particulate-phase PAH compounds. The catalyst appeared to be effective in reducing PAH emissions from all fuels, but it was somewhat more efficient in doing so when the biodiesel fuels were used. The catalyst was also able to control any increases in particulate-phase PAH compounds that occurred when biodiesel was used.

ɔricity testing of the biodiesel fuels was performed on laboratory scale wear testing machines, using two different ..ethods. The test results indicated that both neat RME and REE had excellent lubricating characteristics, superior to any known commercially available diesel fuel. Tests also indicated that blending biodiesel with conventional diesel fuel resulted in a significant improvement in lubricity as compared to the diesel fuel alone.

12. Reports

Sharp, Christopher A., Howard E. Haines. November 1996. **Emissions and Lubricants Evaluation of Rapeseed Derived Biodiesel Fuels.** EDG-93-7549, SwRI 7507. Montana Department of Environmental Quality. Helena, Montana.

13. Future Activities: The data has been presented at a November 1996 meeting in Seattle. Results were incorporated into other projects prioritized by the National Biodiesel Board. A report is being developed by the University of California, Davis, to summarize the bioassay analysis and confirmation of PAH data.

14. Date Prepared: April 17, 1995
Date Amended: 10/7/2003

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Fuel	2-D	REE	RME	REE50	RME50	REE20	RME20
Description	Diesel	Neat REE	Neat RME	50% REE 50% 2-D	50% RME 50% 2-D	20% REE 80% 2-D	20% RME 80% 2-D
Fuel Code	EM-2045-F	EM-2126-F	EM-2130-F	EM-2134-F	EM-2136-F	EM-2135-F	EM-2137-F
Cetane Number, D-613	43.3	60.7	58.7	50.8	51.0	48.2	48.2
Distillation, F, D-86:							
IBP	343	643	462	370	373	341	347
0.1	433	681	569	477	475	443	442
0.5	501	705	696	615	613	525	525
0.9	591	747	725	694	698	676	662
EP	633	763	761	714	709	687	696
API Gravity, D-4052	36	30.2	29.4	33.1	32.7	34.9	34.7
Total Sulfur, wt%, D-2622	0.03	<0.001	<0.001	0.013	0.012	0.022	0.021
Flashpoint, F, D-1319	157	406	392	187	183	157	172
Viscosity, cSt, D-445	2.63	6.07	5.51	4.05	3.80	3.13	3.02
Carbon, wt%, D-5291	86.9	78.2	77.7	81.9	82.1	84.8	84.2
Hydrogen, wt%, D-5191	13.1	12.6	12.4	12.6	12.8	13.2	13.1
Oxygen, wt%, remainder	00.0	9.2	9.9	5.5	5.1	2.0	2.7
Heat of Combustion, Btu/lb, D-240							
Gross	19572	17483	17362	18516	18459	19131	19131
Net	18351	16336	16229	17365	17288	17930	17936
Ash Content, D-482	0.001	0.001	0.003	0.005	0.005	0.002	0.003
Carbon Residue, Ramsbottom, D-524	0.1	a	0.458	a	0.107	0.077	0.056
Cloud Point, C, D-2500	-15	-4	-6	-8	-8	-14	-18
Pour Point, C, D-97	-21	-18	-12	-21	-21	-21	-21

[a] Duplicate analyses on three different samples provided inconsistent results. No value is reported.