# THE FEASIBILITY OF FUELING THE RESEARCH VESSELS D.J. ANGUS AND W.G. JACKSON WITH BIODIESEL

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By: Robert F. Udell

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**Executive Summary:** The Annis Water Resources Institute (AWRI) at Grand Valley State University operates two diesel powered research vessels on Lake Michigan and connecting waters. The exhaust from these boats exposes the passengers and crew to a variety of air pollutants and contributes to the degradation of water quality, as much of the particulate matter, nitrogen oxides, and unburned fuel can be dissolved or suspended in the exhaust cooling water. Literature research was completed to determine the feasibility of operating the R/Vs W.G. Jackson and D.J Angus on biodiesel, a renewable and EPA approved alternative diesel fuel. Conclusions reached from the research are: 1) The D.J. Angus can complete the normal education, outreach, and research activities without significant risk to the vessel's engines or schedule when fueled with biodiesel, 2) Operation of the W.G Jackson on biodiesel is not feasible at this time because of operating cost and potential risk to the vessel engines and scheduled activities. However, this report recommends that the W.G. Jackson should initially be fueled with a blend of 20% biodiesel and 80 % petroleum based diesel fuel and that the D.J Angus should begin using the same blend at a later date. This conservative approach is recommended as there are unexpected results reported from a demonstration project completed by the University of Missouri that involved the same engine model as the Jackson's main drive engines.

No mechanical damage to any engine took place in any of the demonstration projects or research referenced or read by the author The AWRI goal should be to operate both vessels on biodiesel following a period of familiarization with the fuel, determination of the impact on vessel operation, and additional research performed on the W.G Jackson to determine the actual cost and impact on the environment and vessel outreach activities.

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#### I. INTRODUCTION:

a. **Background:** When Rudolf Diesel first conceived the compression-ignition engine, commonly called the diesel engine, coal dust was his fuel of choice. It wasn't until later that a by-product of gasoline production became the primary fuel for diesel engines. However, diesel exhaust emissions from petroleum-based fuels make significant contributions to environmental pollution and recently have been designated a health risk by the Environmental Protection Agency (EPA) (5).

The most promising approach to reducing the harmful emissions from diesel engines is a vegetable oil based fuel called biodiesel. Biodiesel, chemically described as a mono alkyl ester, is recognized by the EPA as an alternative fuel. Biodiesel is biodegradable, non-toxic, and has been the focus of research for over twelve years. Biodiesel is available and being used by many municipalities and government fleets, not as an object of research or in demonstration projects, but as a mature and environmentally beneficial alternative fuel to petroleum diesel (petrodiesel).

The terms "biodiesel" and "B100" (100% biodiesel) are used interchangeably and mean a pure, unblended fuel derived from a vegetable oil feedstock.

b. **Project Goals:** The research documented here has focused on the potential operational, cost, and mission impacts of operating the Annis Water Resources Institute's (AWRI) research vessels, the D.J. Angus (Angus) and the W.G. Jackson (Jackson), on commercially available biodiesel.

A secondary project objective was to quantify the current marine diesel fuel market in west Michigan and form a preliminary assessment of the potential biodiesel market and long-term availability for fueling the Angus and Jackson. The market study is attached as an appendix to this report (Appendix IX).

c. Project Summary: The underlying assumption in this report is that the over-the-road (i.e. terrestrial) experience documented in the referenced research is applicable to the marine application under consideration. As the over-the-road and marine applications may have different duty cycles and environments, a careful consideration of the differences was made to ensure that the referenced research can be used as an indication of the impact of the use of biodiesel on the various engines used on the two vessels. All the various engines on both of the AWRI vessels are rated as Medium, Continuous Duty applications.

The conclusions reached from this research are:

- The duty cycles and environments of the referenced research were equal to or more severe than the duty cycles and environments experienced by the AWRI research vessels.
- There is an acceptably low risk to the Angus's educational and outreach mission in fueling with biodiesel.

- The risk to the mechanical integrity of the Angus's main drive engine is no greater than fueling with petrodiesel.
- The Angus's power generator package diesel engine (genset) has a slightly higher risk to the mechanical integrity as there are no supporting data found during the research for the use of biodiesel in the specific engine model.
- Blends of biodiesel and petrodiesel are also acceptable for use in the Angus's engine and genset but at slightly higher levels of risk than the use of biodiesel.
- The risk to the Jackson's educational and outreach mission is determined to be unacceptable for the use of biodiesel due to lack of experience with the fuel in the specific engine model.
- The Jackson's educational and outreach mission can be completed with an acceptable level of risk if a blend containing 20% biodiesel and 80% petrodiesel (B20) is used as the fuel.
- The risk to the mechanical integrity of the Jackson's main drive engines when fueling with B20 is no greater than fueling with petrodiesel.
- The Jackson's gensets may be fueled with B20 with a slightly higher risk to the mechanical integrity as there are no supporting data found during the research for the use of biodiesel in the specific engine model.

The recommendation to use of B20, initially in the Jackson, to gain experience with the fuel, complies with the manufacturer's recommendations and utilizes the redundancy of main drive engines and gensets to minimize the risk of a mission problem associated with the fuel.

The various blends of biodiesel and petrodiesel discussed in this report are identified by a capital "B" followed by a number. B20 is a blend of 20% biodiesel and 80% petrodiesel while B5 is 5% biodiesel and 95% petrodiesel and B100 is 100% biodiesel.

#### II. THE MISSION:

AWRI's two diesel-powered vessels are engaged in educational, outreach, and research activities on Lake Michigan and connecting waters. These vessels have carried over 84,000 students (elementary, secondary, and university) and adults since 1986. These cruises have tremendous educational value, as they introduce passengers to the main issues facing Lake Michigan and provide a hands-on floating laboratory where students of all ages can analyze the quality of the water and examine the different life forms in the water and sediments.

Both the Angus and the Jackson are scheduled for twice-daily cruises during regular school operating hours and for organizations, research, and outreach activities during the summer months when schools are in recess. During May, the Jackson is often scheduled for an additional cruise after normal school hours to accommodate all the schools wanting to take advantage of the educational opportunity.

Any operational problem related to the use of biodiesel or a blend causing either vessel to cancel or curtail a scheduled cruise would be unacceptable.

#### III. RELATED LITERATURE:

Schumacher (38, 40, 42) and Peterson (35) reported results from an extensive 10 year study of the operation of 12 Dodge pickup trucks with diesel engines fueled with biodiesel, blends of biodiesel and petrodiesel, and petrodiesel. Periodic engine oil analyses were made to determine the wear rate of the engines. Engine wear metals reported for the biodiesel-fueled engines were no different than those reported for petrodiesel-fueled engines. The Cummins 5.9L engine in 11 of these test vehicles is the over-the-road version of the marine engine used in the Angus.

Schumacher (39, 41) reported on a 26-month test of 10 Detroit Diesel 6V92 diesel engines mounted in urban buses. Five buses were fueled with B20 and five were fueled with 100 % low sulfur petrodiesel. Engine maintenance, exhaust emissions, operational performance, and fuel consumption were recorded. Periodic engine oil analyses were made to determine the wear rate of the engines. The bus engines in this test are the overthe-road equivalent of the engines powering the Jackson.

Graboski (21), Koo-Oshima (26), Womac (59), and the National Biodiesel Board (51), investigated emissions from various small diesel engines fueled with biodiesel and biodiesel blends. Emissions measured from engines fueled with biodiesel and blends were significantly reduced from emissions from the same engines fueled with petrodiesel. The oxides of nitrogen (NOx) measurements indicated an increased emission of NOx of approximately 8 % for biodiesel over petrodiesel.

Peterson (34), Cytoculture (5), and von Wendel (58) reported on the impact of marine diesel engines on aquatic environments. Womac (59) and Nine (33) tested marine diesel engines in a laboratory simulation of a marine environment and reported on the impact of the engine exhaust on the water quality. The impact to the environment was reported to be less than the impact of petrodiesel with lower emissions, improved biodegradability, and lower toxicity for biodiesel.

#### IV. MANUFACTURING AND AGRICULTURAL ISSUES:

d. Manufacturing biodiesel: A diesel engine can utilize any number of oils as a fuel, petroleum or vegetable oil based. Many of the vegetable oils can fuel a diesel engine without further processing including used fryer oil (after filtering out the pieces of french fries, chicken, etc.). A diesel engine using one of these oils will perform poorly and not meet emissions standards. However, the esters formed from vegetable oils produce a clean burning fuel giving good performance while reducing harmful emissions. The process by which a vegetable oil based diesel fuel is made is the transesterification process. The process is well known with the by-products being

water, alcohol, and, glycerol (8, 53). Transesterification is widely used in the oleochemical industry as the first step in the manufacture of soaps, detergents, and cosmetics. Transesterification uses either ethanol or methanol in conjunction with a catalyst to produce ethyl or methyl esters.

The biodiesel manufacturing capacity was estimated at approximately 12.5 million gallons per year in 2000. The American Soybean Association (ASA) reported 12.5 million gallons of biodiesel produced in 2001 and estimated production of 17.5 million gallons in 2002 (50). The growth in biodiesel production has been nearly linear since 1999 and is apparently limited by the capacity of available transesterification facilities for biodiesel production. The majority of the transesterification capacity is in the oleochemical industry where one manufacturer claims a 40 million gallon annual capacity (32).

All by-products of the transesterification process are less detrimental to the environment than the by-products of the distillation process for manufacturing petroleum based diesel fuel (49). Excess glycerol has caused some problems in Europe where glycerol from the manufacture of biodiesel has been incinerated because the excess can not be absorbed by the soap and cosmetic market.

Dr. Harvey Nikkel, professor and chair of the GVSU Chemistry Department, has suggested that the glycerol might be changed into ethanol through a biological process, which then could be used in the transesterification process (Appendix VII). The feasibility of this process requires research before it could be put into practice.

The use of glycerol as a fertilizer has been discussed to a limited degree but the practicality of the use of glycerol or a derivative as a fertilizer has yet to be determined.

e. **Agricultural Component:** In 2002, Michigan grew approximately 78 million bushels of soybeans on 2.0 million acres (31). The counties of Kent, Muskegon, and Ottawa, together, grew approximately 2.0 million bushels of the total (31). Soy oil is a byproduct of the processing of the soy beans to obtain soy meal which is used for livestock feed. The soy meal processors have been successful in building a secondary market for the soy oil.

The largest producer of soy meal in Michigan, Zeeland Farm Services, is located in Zeeland, Michigan. The location is convenient to the users of soy meal in Kent, Ottawa, and Allegan Counties but in an area that is not a large grower of soybeans. Kent, Ottawa, and Muskegon counties together grow fewer bushels of soy beans than Ingham County, the seventeenth largest (county) grower of soybeans (31). Zeeland Farm Services produces 12 to 15 million gallons of soy oil annually and in the summer of 2003 will have the capacity to store 60,000 gallons of biodiesel for distribution in western Michigan (anecdotal information from Keith Reinholt of the Michigan Soybean Association).

The soy oil produced from the United States soybean crop has an established market for (human) food. If all the soy oil was diverted to diesel fuel production, an estimated 2.6 billion gallons of biodiesel could be produced – only 6% of the total, domestic demand (40 billion gallons annually). It has been estimated that 130 million gallons of biodiesel (only 0.3% of annual demand) could be produced from available soy oil without affecting the short term selling price of the oil and adversely affecting biodiesel sales (32). The primary issue is whether food production would take a secondary position to fuel production.

Other feedstocks, such as castor bean, may not compete with feedstocks used for food and would produce more biodiesel per acre than soy beans (4). Used fryer oil recycled into biodiesel would reduce the volume of used oil discarded into landfills and processed by wastewater treatment systems. The volume of used oil going into our land fills in the U.S. has been estimated to be 4 billion gallons (anecdotal information from Cortland Overmyer, Director of Grand Rapids Environmental Services Department). If accurate, this used oil would produce 3.4 billion gallons of biodiesel, 8.5% of our annual demand for diesel fuel.

Clearly biodiesel from soy oil alone is not the complete answer to reduction of our dependency on foreign oil or improvements to the exhaust emissions from diesel engines. But used as a blend agent in petroleum diesel and used in the unblended form in some environments it could significantly reduce the adverse impact of diesel engines on the environment (45).

#### V. REGULATORY ISSUES:

There are a number of regulatory considerations for new diesel engines, but engines manufactured before January 1, 2000 are accepted as meeting the emission standards in place at the time of manufacture. Only engines manufactured after January 1, 2000 or engines that are modified from the standard configuration are affected by new EPA regulation. When biodiesel fuel is used by a diesel engine, the manufacturer's certification for compliance to the International Marine Organization (IMO) NOx standard may no longer be valid.

Once the question of NOx emission compliance is raised, the engine owner must either supply sufficient data to the EPA to gain certification of compliance, interpret the regulation to mean that since no engine modification was made the certificate is valid, add an after-treatment to reduce the NOx emissions, or ignore the situation. There have been demonstrations that measured reduced emissions of NOx from marine engines where the exhaust gases and engine cooling water are mixed (33). The Total Hydrocarbons (THC), Particulate Matter (PM), and NOx dissolved or suspended in the exhaust water then may become a water quality issue.

This report is not intended to be exhaustive in regard to applicable regulations but is concerned only with any potential cost or violation of emissions standards that would

result from the use of biodiesel or a blend. The applicable regulations are found in Appendix II.

#### VI. MECHANICAL ISSUES:

f. Four-Cycle vs. Two-Cycle Engine operation: There are two mechanical cycles utilized by the various diesel engines on the Angus and Jackson. All engines on the Angus are four-cycle while the two, main drive engines on the Jackson are two-cycle. The Jackson's two gensets are driven by four-cycle engines. Typically, four-cycle engines have cleaner emissions while two-cycle engines have higher power densities (horsepower per pound) but have higher emissions and tend to carry raw fuel out with the exhaust gases.

The primary consideration in regard to the Angus and Jackson is how the different cycles impact the operation of the various engines.

The two mechanical cycles are detailed in Appendix III.

g. **Engine aspiration:** The various engines on the Angus and Jackson incorporate two types of aspiration or approaches to introducing combustion air into the engines. The main drive engines on both the Angus and Jackson are turbo-charged, while the three gensets are all naturally aspirated. Turbo-charged engines have higher power densities than naturally aspirated engines and the use of a turbo-charger is a consideration in meeting emissions standards.

The primary types of aspiration are detailed in Appendix III.

h. **Fuel Injection:** All diesel engines on both vessels are fuel injected from engine mounted injector pumps. Fuel injection and the point in the engine cycle at which the fuel is injected into the combustion chamber can affect the engine combustion and emissions. Retarded injection has been shown to reduce NOx emissions from engines fueled with biodiesel and in some cases brought the engines into compliance with the emissions regulations with a minor increase in fuel consumption.

Fuel injection can be used to reduce the amount of unburned fuel in the exhaust gases of two-cycle engines by injecting fuel into the cylinders only after the exhaust valves are closed, which cannot be done with naturally aspirated engines.

- i. **Engine Warranty Coverage:** (See Appendix III for engine specifications and other detail.)
  - i. **D.J. Angus:** The Angus is powered by a Cummins 5.9 Liter engine and generates electrical power for the vessel with a Westerbeke generator.

- 1. **Cummins:** The Angus main drive engine (MDE) was manufactured by Cummins on January 28, 2002 and installed in the following months prior to launching for the 2002 season. There was a twelve month warranty on this engine, which expired prior to the 2003 season (See Appendix IV).
- 2. **Electrical Power Generator:** The electrical power for the Angus is generated by a Westerbeke diesel engine driving a generator and draws fuel from the Angus's twin fuel tanks. The Westerbeke generator on the Angus was installed at the same time the MDE was installed but has a warranty that remains in effect until 2007.
- ii. **W.G. Jackson:** The Jackson is powered with twin Detroit Diesel engines and utilizes two generators to provide electrical power for the vessel.
  - 1. **Detroit Diesel:** Both main drive engines were manufactured in March of 1996 and have no warranty coverage remaining.
  - 2. **Small Electrical Power Generator:** The electrical power generation on the Jackson is provided by two self-contained generator packages (gensets). The smaller genset is a Northern Lights model M843N. Warranty coverage on the small genset has expired.
  - 3. **Large Electrical Power Generator:** The larger of the Jackson's gensets is rated at 30kW and is manufactured by Northern Lights as model M30C. Warranty coverage for the large genset has expired.

#### j. Engine Maintenance

- i. Angus Petrodiesel History:
  - 1. Main Drive Engine: The Angus follows a standard practice for scheduled engine maintenance. The oil filters are changed at each oil change, at 200 hour intervals, and a sample of engine lubricating oil is sent to an outside laboratory for oil analysis. This is a standard practice among operators and provides a picture of engine health and can forecast some engine problems. The Angus has a history of low engine wear and few maintenance issues. This engine is rated at medium continuous duty.
  - 2. Electrical Power Generator: Lubricating oil and oil filter are changed at 100 hour intervals. No engine oil analysis for a test or demonstration project has been found in the literature to allow a direct comparison to the Angus genset oil analysis or to establish acceptable rate of wear. There have been no performance or maintenance issues with the Angus genset. Generators are generally rated as Medium, Continuous Duty applications.
- i. Angus Biodiesel Expectations:

1. Main Drive Engine: Schumacher (38) included an evaluation of four different Dodge trucks having the same model 5.9L Cummins engine but fueled with B100, 100% biodiesel. Table 1 compares the average levels of engine wear metals from the University of Missouri testing and the Angus for petrodiesel and adds the data gathered for Dodge trucks fueled with B100. The table also provides estimates of the ranges the wear metals resulting from fueling the Angus with B100. The estimates are simple extrapolations of the means and utilize the standard deviations to estimate the expected ranges of the engine wear metals for the Angus if fueled with biodiesel. (see Appendix I for details of calculation and Appendix III for further discussion of engine wear metals)

Table 1

240.14 2										
Cummins BT5.9L Engine Oil Analysis -ppm										
Iron Copper Lead Aluminum Silicon C										
Angus B100*	4-27	1 – 12	0-4	0-2	3-27	0-2				
Angus Petro	20.0	4.0	3.0	2.7	14.0	1.7				
Standard Dev	7.81	3.46	1.00	0.58	7.81	0.58				
U. Mo B100**	10.86	3.25	2.15	1.72	3.10	0.95				
Standard Dev	6.65	4.42	1.82	0.87	3.08	2.57				
U. Mo Petro	13.79	1.86	2.89	4.33	2.86	1.48				
Standard Dev	5.34	1.05	2.57	1.77	0.95	0.90				

<sup>\*</sup>Projected values; not based on actual measurements – See Appendix I for calculations.

Silicon in the lubricating oil is a concern as this is a measure of the abrasive material entrained in the combustion air during engine operation. None of the wear metals measured in the Dodge truck oil samples (iron, lead, aluminum, chromium) that would be affected by the ingestion of the silicon was reported as excessive (38).

The predicted ranges of wear metals for the Angus are not excessive. If the silicon remains in the range of the petrodiesel data, then the wear metals may not be reduced as the University of Missouri data would lead us to believe but would revert to values closer to the Angus petrodiesel data. In either case, the values are acceptable.

2. Electrical Power Generator: No engine test or demonstration project has been found in the literature for the Angus genset when fueled with petrodiesel or biodiesel. No acceptable wear rate has been established for this particular engine. However, the petrodiesel wear metals are comparable to those in the Angus MDE and, based on similar duty cycle descriptions, similar changes in wear metals should result. Table 2 provides estimates of the ranges the wear metals resulting from fueling the genset with B100.

<sup>\*\*</sup>The Univ. of Missouri trucks operating on petrodiesel and those on B100 are different trucks. Some trucks operated in Idaho and others in Missouri; some in National Parks.

Table 2

Westerbeke 20.0BEDA Genset Engine Oil Analysis - ppm										
Iron Copper Lead Aluminum Silicon Chromium										
B100*	25-28	2-10	1-4	0-3	0-31	0-3				
Petrodiesel	33.5	3.5	3.5	3.5	13.5	1.5				
Standard Dev	0.71	2.12	0.71	0.71	9.19	0.71				

<sup>\*</sup>Projected values; not based on actual measurements – See Appendix I for calculations.

If the silicon remains in the range of the petrodiesel data, then the wear metals may not be reduced as the University of Missouri data would lead us to believe but then would revert to values closer to the Angus petrodiesel data. In either case, the predicted ranges of wear metals are acceptable.

- ii. Angus B20 Expectations: The Dodge truck testing at the University of Missouri included evaluation of the operation of the Cummins engine on B20 (38, 42).
  - **1. Main Drive Engine:** Fueling the Angus on B20 is also a viable approach. The Dodge truck testing included data from one B20 fueled truck (38).

Table 3 compares the University of Missouri data with the Angus experience and predicts an oil analysis for the Angus fueled with B20. The underlying assumption is that the duty cycles are similar.

The data from the Dodge truck testing for B20 are less compelling as they were taken from a single truck fueled on B20 (from Rapeseed) but ran over 100,000 miles in Idaho.

Table 3

Cummins BT5.9L Engine B20 Oil Analysis - ppm										
	Iron	Copper	Lead	Aluminum	Silicon	Chromium				
Angus B20*	0-21	2-12	0-3	0-2	0-14	0-2				
Angus Petro	20.0	4.0	3.0	2.7	14.0	1.7				
Standard Dev	7.81	3.46	1.00	0.58	7.81	0.58				
U. Mo B20#	6.23	4.07	1.53	1.67	2.43	0.73				
Standard Dev	2.26	6.16	0.63	0.84	1.14	0.45				
U. Mo Petro	13.79	1.86	2.89	4.33	2.86	1.48				
Standard Dev	5.34	1.05	2.57	1.77	0.95	0.90				

<sup>\*</sup>Projected values; not based on actual measurements. See Appendix I for calculations.

The ranges for wear metals estimated for Angus fueled with B20 are within acceptable ranges.

**2. Electrical Power Generator**: No engine test or demonstration project was found in the research for the Angus genset fueled with B20. Anecdotal information on the operation of diesel engines on biodiesel and blends, in general, indicates that that the risk of damage to the engine is negligible.

<sup>\*</sup>The Univ. of Missouri trucks operating on petrodiesel and those on B20 are different trucks operating in different environments.

However, there is still warranty coverage on this engine and the manufacturer could deny coverage should a problem result from the use of B20.

Westerbeke diesel generators fueled with biodiesel are driving in the Channel Islands National Park, CA but no documentation of the experience is available (Anecdotal information from Kent Bullard of Channel Islands National Park). Similar engines have been operated on B20 and biodiesel without mechanical problems (33).

Over all, the risk to the vessel and mission if operated on B20 would seem acceptable without further investigation.

#### iii. Jackson Petrodiesel History:

- 1. Main Drive Engines: The Jackson follows a standard practice for scheduled engine maintenance. The oil filters are changed at each oil change, at 200 hour intervals, and a sample of engine lubricating oil is sent to an outside laboratory for oil analysis. This is a standard practice among operators and provides a picture of engine health and can forecast some engine problems. The engine duty cycle rating for the Jackson application is Medium, Continuous Duty. The Jackson has a history of low engine wear and few maintenance issues.
- 2. Small Electrical Power Generator: Regular oil analysis has not been performed for the small Jackson genset. Reference data for a Lugger engine of the same model has not been found in the research to allow a comparison or establish an acceptable wear rate. Lubricating oil and filter are changed at 100 hour intervals. The small genset has a history of few maintenance issues.
- 3. Large Electrical Power Generator: No engine oil analysis for a test or demonstration project has been found in the literature to allow a direct comparison to the large Jackson genset oil analysis or establish acceptable rates of wear. Lubricating oil and filter are changed at 100 hour intervals. The large genset has a history of low engine wear and few maintenance issues.

#### iv. Jackson - Biodiesel Expectations:

**1. Biodiesel:** No precedent for the use of biodiesel in the Detroit Diesel engines was found in the research.

#### v. Jackson – B20 Expectations:

1. Main Drive Engines: Schumacher (44) reported on urban transit buses operating over a two year period in St. Louis, MO having the same model engines as the W.G. Jackson using both low sulfur petrodiesel and B20. The duty cycle rating for the bus diesel engine application is Intermediate, Severe Duty – more severe and demanding than the Jackson engine application.

Table 4 lists engine wear metals from the Jackson oil analysis during the 2002 season and the data from St. Louis bus demonstration project. The table also provides estimates of the ranges the wear metals that might result from fueling the Jackson with B20. This prediction assumes that the changes in wear metals that occurred in the St. Louis bus demonstration represents a worst case scenario – wear metal measurements from the Jackson using B20 should be lower (See Appendix III for further discussion of wear metals from the Jackson and St. Louis bus test.).

The iron wear metal listed in Table 4 is the only wear metal with a high probability of being statistically different (39). Detroit Diesel Corporation (DDC) recommends that a single oil analysis metal content should be less than: 150ppm of Iron, 25ppm of Copper, and 10ppm of Lead for over the road application. The St. Louis bus test data lists two metals exceeding the recommended limits raising a concern regarding the engine condition. DDC recommendations for marine limits are different only in the iron content, which is limited to 250ppm (28). The Jackson means and every single data point is within the recommended limit (See Appendices I, III & VII).

Detroit Diesel 6V92TA Engine Oil Analysis - ppm Copper Lead Aluminum **Silicon** Chromium Iron Jackson B20\* 13-19 2-5 3-8 1-3 2-9 0 - 112.2 **Jackson Petro** 2.5 5.0 1.5 6.1 0.6 2.31 3.98 Standard Dev 3.16 1.27 0.53 0.52 U. of Mo B20\*\* 115.8 42.5 13.2  $17.4^{\#}$ 0.8 3.3 157.24 Standard Dev 57.75 104.59 1.98 NA 1.87 U Mo Petro\*\*  $19.0^{\dagger}$ 89.7 27.8 11.6 0.5 2.7 Standard Dev 57.72 157.24 104.59 1.98 NA 1.87

Table 4

The silicon in the Jackson lubricating oil analyses is low compared to that measured in the bus demonstration and is not considered an issue. Based on duty cycle descriptions, using the bus data to estimate the worst case changes to the Jackson wear metals should be conservative - i.e. actual changes should be less than those estimated based on the bus data. The ranges of wear metals estimated for the Jackson are not excessive and are predicted to remain below the Detroit Diesel Corporation (DDC) recommended limits for the scenario considered.

If the silicon in the Jackson oil remains in the range of the petrodiesel data when B20 is used, then the other wear metals may not vary in the same manner as it does in the buses. The expectation derived from biodiesel research is that the

<sup>\*</sup>Projected values; not based on actual measurements – see Appendix I for calculations.

<sup>\*\*</sup>The Univ. of Missouri buses operating on petrodiesel and those on B20 were different buses on different routes introducing a set of uncontrolled variables into the data.

<sup>&</sup>lt;sup>#</sup> Silicon data is from the same test but from a different reference (7) and a shorter test period.

introduction of biodiesel (either B100 or in a blend) increases the lubricity of the fuel and reduces engine wear, increasing life. The University of Missouri data are contrary to this premise and other research regarding the lubricity effects of biodiesel (40, 58).

There are other concerns with the bus testing in St. Louis. The fuel was not mixed properly for the first 18 months of the testing and the blend was estimated to vary from B89 to B7 for this period – the actual blend at the engine is unknown. The final 8 months of the test had improved controls on the blend but data for the two periods were merged for the final report (39).

There were increased cooling system failures in the B20 fueled group. No root cause for the failures was identified but, in general, increased combustion temperature has been identified as a possible problem with biodiesel. However, B20 should not be an issue in increased engine cooling system load. Also, marine engine cooling systems have excess capacity in that the heat sink for the waste heat is nearly infinite – the water surrounding the boat. Only the design of the engine heat exchanger would limit the heat transferred to the raw water. The fixed air flow and limited heat transfer area of the bus radiator would mean that increased heat load would raise the average temperature of the circulated cooling fluid and engine operating temperature.

The wear levels experienced by the St. Louis buses exceeded the DDC recommendations and may indicate an engine problem as the root cause for the increased wear metals in the oil (see Appendix III). All the bus engines were rebuilt prior to the start of the St. Louis test but had between 12,000 and 59,000 miles on the rebuilt engines at the start of the test.

The B20 fueled buses maintained their scheduled routes with no more fuel related maintenance issues than the petrodiesel fueled buses. However, a better understanding of the effects of fueling the Jackson's engines with the B20 blend must be gained and well understood before committing to the use of B100.

- 2. Small Electrical Power Generator: Regular oil analysis has not been performed for the small Jackson genset nor have reference data for a Lugger engine of the same model been found in the research. Also, no data were found in the research for the specific engine model operation with biodiesel or blends.
- 3. Large Electrical Power Generator: No engine oil analysis for a test or demonstration project has been found in the literature to allow a direct comparison to the large Jackson genset oil analysis or establish acceptable rates of wear for the engine when fueled with biodiesel or blends.

Table 5 lists engine wear metals for the Jackson large genset and estimates the wear metals for the large genset if fueled with B20.

Table 5

Northern Lights M30C Genset Engine Oil Analysis - ppm										
	Iron	Copper	Lead	Aluminum	Silicon	Chromium				
B20*	1-5	4-7	0-5	0-3	3-9	0-0				
Petrodiesel	6.5	2.5	1.5	2.5	7.0	0.0				
Standard Dev <sup>#</sup>	0.71	0.71	2.12	0.71	1.41	0.00				
U. Mo B100**	10.86	3.25	2.15	1.72	3.10	0.95				
Standard Dev**	6.65	4.42	1.82	0.87	3.08	2.57				
U. Mo Petro**	13.79	1.86	2.89	4.33	2.86	1.48				
Standard Dev**	5.34	1.05	2.57	1.77	0.95	0.90				

<sup>\*</sup>Projected values; not based on actual measurements. See Appendix I for calculations

The estimates of the wear metals in an oil analysis sample for this engine are not excessive but are the most speculative of any of the engines of concern. The estimates are based on the changes that occurred in the Dodge truck testing for a truck fueled with B20 (38, 42). The underlying assumption is that four-cycle engines with similar duty cycles should react to the fuel in the same manner.

#### VII. EMISSIONS:

k. **Angus:** Emissions from the Angus will include gaseous and exhaust gas cooling water discharge.

#### i. Gaseous:

1. **Main Drive Engine:** Table 6 data are taken from a 1991 Cummins 5.9L diesel engine similar to the Angus's main drive engine (42). These data are for operation on B100 and petrodiesel. Note that the data for carbon monoxide (CO) are a volumetric percentage while the oxides of nitrogen (NOx) and total hydrocarbons (THC) components are parts per million (ppm). No data are available for particulate matter (PM) from the test.

Table 6

Cummins 5.9L Exhaust Emissions*									
CO % NOx ppm THC ppm PM									
B100	.013	768.6	5.4	ND					
Petrodiesel	.025	639.7	6.6	ND					

<sup>\*</sup>Engine not equipped with an aftercooler, No standard deviation data available.

The data in Table 6 represent the changes that are expected in emissions when changing to biodiesel. There were some issues with the Dodge truck data, however, as the results were not duplicated in a measurement a year later. The report attributed the lack of repetition to an equipment problem (42).

<sup>\*\*</sup> Data repeated from Table 3

<sup>\*</sup>Based on samples from two oil changes.

The same data taken from a 1992 Cummins 5.9L diesel engine with an aftercooler have significantly different results. For example, the NOx measurement for B100 is larger than for petrodiesel in two consecutive years, as expected, but CO also increased, by as much as 25%, contrary to expectations (42). The reason for the aftercooler influence on the exhaust emissions is not addressed in the literature.

The emissions at the exhaust manifolds of the Angus and the trucks should be similar but the measured emissions from the Angus will be different from those in Table 5 due to the catalytic converters in the trucks, unique characteristics of the marine exhaust system, contributions from the genset, and actual duty cycle. Down stream of the water injection point the cool exhaust gases will be altered further because a portion of the PM, NOx, THC, and CO components can be suspended or dissolved in the cooling water (33). Tests have shown that the suspended and dissolved components vary by engine and installation.

The final products of combustion measured in the exhaust gases and discharge water quality will have to be determined by test on the Angus.

Although not controlled by the EPA as an emission, sulfur oxides, present in the petrodiesel exhaust which contributes to acid rain, would be eliminated by using biodiesel. Sulfur oxides are controlled indirectly by EPA fuel quality standards which control sulfur content in the fuel.

- 2. **Electrical Power Generator:** No emissions data were found for the Westerbeke engine in the literature during the research. The engine is certified to comply with the IMO standards when fueled with petrodiesel.
- 3. **Cummins Emissions B20:** There were no gaseous or water emissions data found in the research for the Cummins engine operating on B20. However, the gaseous emissions are expected to be reduced from the petrodiesel emissions in linear proportion to the blend ratio (33).

Table 7 estimates the gaseous emission from the Angus main drive engine using B20 fuel. The estimate is for dry exhaust, upstream from the point where the gases are mixed with cooling water. Downstream from the water mixing point the gaseous exhaust will have a different composition with NOx being nearer the petrodiesel level.

Table 7

<b>Cummins 5.9L B20 Exhaust Emissions</b>									
CO % NOx ppm THC ppm PM									
$B20^{\#}$	.023	665.5	6.4	ND					
B100	.013	768.6	5.4	ND					
Petrodiesel	.025	639.7	6.6	ND					

<sup>#</sup>Estimated mean values proportional to biodiesel content in the fuel (33); not based on actual measurements, no standard deviation data available.

- 4. **Electrical Power Generator:** Gaseous emissions from the Westerbeke engine will be reduced in proportion to the blend ratio as in Angus main drive engine.
- ii. **Water:** No exhaust discharge water quality data are available for the Angus main drive engine. Marine exhaust system installation normally falls outside the engine manufacturer's responsibility, as it is part of the vessel rather than the engine. The impact on the discharge water will vary from the influences of the installation. Data from some tests have shown that higher NOx emissions from biodiesel can be washed out of the exhaust gases by the exhaust cooling water along with PM, CO, and THC and become dissolved or suspended in the cooling water (33). Unburned fuel in the exhaust and cooling water is also expected and is part of the THC component.

Water borne engine exhaust contaminants have been researched to a limited ent and some data are available for lethal doses (LD<sub>50</sub>) and lethal concentrations (LC<sub>50</sub>), but no research was found for exhaust components suspended or dissolved in normal exhaust cooling water (58, 59, 60).

No information or data regarding the exhaust cooling water quality for the Angus's genset was found in the research.

1. **Jackson:** Emissions from the Jackson will include gaseous and exhaust gas cooling water discharge.

#### i. Gaseous:

1. **Main Drive Engine:** Table 8 data are taken from a laboratory test of a Detroit Diesel 6V92 diesel engine similar to the Jackson's main drive engines (44). These data are for operation on a B20 blend only. No data were gathered for operation on B100.

The data indicate that exhaust emissions are reduced in relation to the biodiesel content in the blend as expected. The data also illustrate that the NOx in the exhaust can be affected by the timing of the injection of the fuel, which can be easily handled through the Electronic Control Module (ECM) should that become necessary. Higher blend ratios (higher biodiesel content in the fuel) will cause the NOx to increase while reducing the other measured emissions.

Table 8

Detroit Diesel 6V92 St. Louis Bus Exhaust Emissions* -g/bhp-Hr										
	CO	NOx	THC	PM						
B20 <sup>#</sup>	1.32	4.46	0.56	0.18						
B20 <sup>@</sup>	1.50	4.25	0.38	0.22						
Petrodiesel*	1.67	4.40	0.42	0.28						

<sup>&</sup>lt;sup>#</sup> B20 blended with #1 petrodiesel

<sup>&</sup>lt;sup>®</sup> B20 blended with #2 diesel and a retarded fuel injection point of 3 deg.

<sup>\*</sup>No standard deviation data are available. The bus engine installation included a catalytic converter

The emissions at the exhaust manifolds of the Jackson and the buses should be similar but the measured emissions from the Jackson will be different from those in the above table due to the catalytic converter in the bus installation, unique characteristics of the marine exhaust system in the Jackson, contributions from the gensets, and actual duty cycle. Down stream of the water injection point the cool exhaust gases will be altered further because a portion of the PM, NOx, and CO components can be suspended or dissolved in the cooling water (33). Tests have shown that the suspended and dissolved components vary by engine and installation.

The final products of combustion measured in the exhaust gases and discharge water quality will have to be determined by test on the Jackson.

Although not an EPA controlled emission, it is expected that the sulfur oxides (SOx), which contribute to acid rain, will be reduced by 20% by using the B20 blend.

- 2. **Electrical Power Generators:** No emissions data were found in the literature during the research for either the Lugger or Toyota engines driving the power generators.
- m. Water: No exhaust discharge water quality data were found as a result of the research for the Jackson main drive or genset engines. The exhaust system installation normally falls outside the engine manufacturer's responsibility, as it is part of the vessel rather than the engine. The impact on the discharge water will vary from the influences of the installation.

Waterborne engine exhaust contaminants have been researched to the extent that some data are available for lethal doses ( $LD_{50}$ ) and lethal concentrations ( $LC_{50}$ ), but no research has been found regarding exhaust component concentrations in normal exhaust cooling water (58, 59, 60).

n. **Health:** The EPA has announced that long term exposure to petrodiesel exhaust emissions can cause lung cancer (5). Biodiesel is the only alternative fuel which has completed Clean Air Act Health Effects Testing (26, 51). Biodiesel does not threaten human life and B100 reduces cancer-causing compounds in diesel exhaust by 90 % as compared to petrodiesel.

Blends of petrodiesel and biodiesel are not as effective at reducing carcinogenic compounds as B100 but will reduce them approximately in the biodiesel/petrodiesel ratio. A B20 blend will have 82 % (approximately) of the carcinogens of 100% petrodiesel exhaust (9).

As diesel engines tend to be long lived, engines currently in service could remain in service for 20 years or more. Engines built after 2000 will discharge fewer carcinogens, greenhouse gases, and will pollute less by regulation. Engines built

before 2000 will continue to generate harmful material that could only be affected by the fuel used or by extensive modification at high cost. Biodiesel would effectively reduce the emissions of harmful pollutants of older engines. From a health point of view, more biodiesel content and use is better for all people exposed to diesel exhaust fumes.

o. **Spills:** Spills of biodiesel or blends are less detrimental to the environment than are petrodiesel spills. Biodiesel and blends are both more biodegradable than petrodiesel (33, 60). However, spills are still a serious matter and need to be approached as if they were petrodiesel spills, as that is how they are treated from a legal point of view (58).

Incidental spills of biodiesel on painted surfaces, if not wiped up, will eventually lift the paint from the surface.

p. **Spontaneous Combustion:** Biodiesel-soaked rags will support spontaneous combustion if not handled properly.

#### VIII. OPERATIONAL ISSUES:

q. **Logistics:** The logistics of fueling the Angus and Jackson will be a pivotal issue. Currently there is limited regional availability of biodiesel or B20. Crystal Flash in Grand Rapids, MI, is currently selling B20 to the Zeeland, MI public schools. No mechanical (engine) alterations were made to the approximately 50 vehicles using B20 – 12 of these vehicles have the same model engine as the Angus. The Zeeland School system converted one storage tank and pump to dispense B20. The buses (and other vehicles) fueled at this pump as required. The Zeeland public school system used approximately 50,000 gallons of B20 prior to March 31, 2003 and through the winter of 2002-2003 no cold weather problems were reported.

The favored approach to fueling is to have it delivered to the Angus at the Grand Haven Coast Guard Station and to the Jackson at the Lake Michigan Center, as is the current practice for petrodiesel. This approach minimizes cost and the expenditure of time by the crews to fuel the boats.

There are six optional approaches to fueling considered in this report:

- 1) NOAA, at the Great Lakes Environmental Research Laboratory field station, is considering having a B100 tank and fuel pump at their Muskegon field station for their use and would allow AWRI to fuel there as well. AWRI vessels would have to travel to the NOAA (Muskegon) field station to take on fuel. (Assumes that NOAA is the only or optimal source.)
- 2) NOAA is also considering establishing a local, independent B100 supplier to deliver fuel to their dock in a tank truck when required by the Shenehon. This would require AWRI vessels to travel to the NOAA field station to add fuel

- when fuel was required by the Shenehon. (Assumes that NOAA is the only or optimal source.)
- 3) AWRI could develop a new B100 source for dockside delivery at our convenience. (Currently, the Jackson takes on fuel at dockside in Muskegon while the Angus motors to the Grand Haven Coast Guard Station to take on fuel from a tank truck at dockside.)
- 4) AWRI could develop a new B100 source and install a storage tank in the AWRI field station for fuel delivery at regularly scheduled times. The Angus would have to travel to Muskegon to take on fuel.
- 5) It is possible to make B100 from the used fryer oil from the Grand Valley State University's food services and store it in the AWRI field station in Muskegon until needed, requiring a storage tank. The Angus would have to motor to the AWRI field station to take on fuel.
- 6) Develop a B20 source for dockside delivery per our current practice.

Fueling during a normal cruise was not considered because it was assumed to impact the effectiveness of the educational experience. (See Tables 9 and 12 for times to fuel)

#### r. Fuel Consumption

i. **Angus:** During 2002 the Angus used 1144 gallons of petrodiesel. Biodiesel fuel consumption has tended to be higher than when using petrodiesel. Data from the Dodge truck testing indicate that fuel consumption for the Angus could increase by 5% - 7% when fueled with B100 to approximately 1201 gallons per year (42).

Also, the Angus fuel consumption of B20 could be expected to be on the order of 1% to 2% greater or 1155 gallons per year based on 2002 usage (42).

The change in fuel consumption with B20 is approximately one fifth the increase in fuel consumption with B100 (using 1% for B20 and 5% for B100), or approximately proportional to the change in biodiesel content of the fuel.

ii. **Jackson:** The Jackson consumed 4627 gallons of petrodiesel in 2002. Mileage from the bus testing in St. Louis was reported to be 3.87 miles per gallon of low sulfur diesel. The same model buses experienced a 5.6% increase in fuel consumption (3.65 mpg) when fueled with B20 (41). Although the data are not directly applicable to the Jackson, they do give an indication of the potential change in fuel consumption. In the worst case scenario, the Jackson could experience a 5% to 6% increase in fuel consumption when fueled with B20 (4627 + 4627 x 0.056) or approximately 4886 gallons based on 2002 usage. This increase is high in light of Dodge truck data and is contrary to experience of other researchers when fueling with B20 (39).

Using the Dodge truck data to estimate the increase in fuel consumption for the Jackson (the change in fuel consumption from B0 to B20 is approximately one fifth the change in fuel consumption from B0 to B100) yields an estimate of 28% (5.6%)

x 5) and increased fuel consumption for the Jackson engines of  $5922 (4627 + 4627 \times 0.056 \times 5)$  gallons per year.

Either an engine problem, indicated by the wear metals exceeding the Detroit Diesel Corporation recommended limits, or the bus duty cycle could be the root cause for the high fuel consumption during the St. Louis demonstration. In either case, it is expected that the Jackson will experience a smaller increase in fuel consumption than estimated.

#### s. Engine Performance:

- i. **Angus:** At 1700 RPM the Dodge trucks without aftercoolers developed an additional 2 horsepower when fueled with B100. Trucks with aftercoolers lost approximately 7 horsepower when fueled with B100. The change in output of +2%/-5% should carry over to the Angus (42). In general, low RPM horsepower is expected to increase while high RPM horsepower will decrease when using biodiesel.
- ii. **Jackson:** No data are available from the St. Louis bus test for engine performance change when fueled with biodiesel. Based on the energy content of the fuel, a 3% decrease in horsepower should be expected, but the impact of the two-cycle engine is unknown (58). Engine power decreased by approximately 9% in laboratory testing of the 6V92 engine (44).

## t. Cold Weather/storage

- i. **NOAA Experience:** Cold weather operation was accommodated by the R/V Shenehon in 2002 in the same way as it is with petrodiesel, i.e. blending. B100 is acceptable for the warmer weather months of April thru October but B50 was used for operation from November through March.
- ii. **Angus/Jackson**: The Angus and Jackson are not used during the cold months, November to April, but are laid up. Storage of the higher blend ratios or B100 biodiesel can result in the fuel breaking down and in adverse interactions with copper or copper alloys (brass & bronze) during the storage period. Lower blend ratios (less than B20) result in better storage experiences.

Any copper piping or copper alloys in contact with high blends or B100 causes black sludge to form that will plug fuel filters when the engines are first started in the spring. (Anecdotal information from Steve Westbrook of the Southwest Research Institute and Dr. Alvin Womac of the University of Tennessee)

u. **Operational Fuel Blend:** If the vessels are stored with petrodiesel or a low blend in the fuel tanks, and B20 is the desired operating fuel, the ratio of biodiesel to petrodiesel of the fuel in the vessel fuel tank will vary as fuel is added. The issue will be the effectiveness of mixing the fuel in the tank and the fuel added. The mixing will not

affect the operation of the engines but will be of concern at the end of the season just before lay-up. Petrodiesel could be added in place of B20 the last time the fuel tank is filled at the end of the season to reach a lower blend in the tank if desired.

v. **Mixing:** There are mixing issues that have been ignored in the foregoing discussions. Incomplete mixing will not harm the engines but would be concern only in the fall prior to lay-up or in the Jackson main drive engines where operation on biodiesel is considered a higher risk. However, this situation arose early in the St. Louis test without any consequences to the mechanical integrity to the test buses or abnormal route delays (39).

If not properly mixed, the biodiesel and petrodiesel can stratify. There are concerns with component temperature differences when mixing is assumed to take place due to vehicle motion. "Splash blending" is the practice of partially filling a tanker with one component and then topping off with the second. Mixing is assumed to take place during transport to the user. This is often the approach for winter blending of petrodiesel. A knowledgeable supplier will deliver well mixed fuel.

w. Appendix VIII contains National Renewable Energy Laboratory guidelines for handling and use of biodiesel.

#### IX. COST:

# x. Angus 2002 Operating Cost: Table 9 summarizes the

Angus baseline operating cost for the 2002 season.

Petrodiesel was dispensed from a tanker into the Angus at the Coast Guard Station in Grand Haven approximately one nautical mile from the Municipal Marina where the Angus is normally docked. This required that both the captain and a deck hand be aboard for fueling.

The table breaks out those items that may be affected by the use of biodiesel or a blend (below the subtotal line).

Fuel cost alone is 1.3% of the total cost of operation of the Angus.

# y. Angus - Operating Cost for **Biodiesel Options:**

Differences from the baseline for any of the options from Section VIII.a are assumed to result only from fuel cost differences and any cost associated with fueling.

Each option has unique logistics issues such as requiring a captain and deck hand on the boat to fuel at a remote location (\$110.12 per

hour - \$150.11 less instructor cost).

Table 9

10 4 200								
Angus Annual Operating Costs –2002 Petrodiesel Baseline								
<b>Operating Hours</b>	560							
Fuel Filters Used:								
Main Drive Engine	8							
Power Generator	6							
<b>Fuel Filter Cost Each</b>								
Main Drive Engine	\$9.37	\$74.96						
Power Generator	\$9.37	\$56.22						
Total Oil Used								
Main Drive Engine	60							
Power Generator	20							
Oil Cost								
Main Drive Engine	\$1.77	\$106.20						
Power Generator	\$1.77	\$36.11						
Oil Filters Used								
Main Drive Engine	4							
Power Generator	3							
Oil Filter Cost Each								
Main Drive Engine	\$7.36	\$29.44						
Power Generator	\$35.77	\$109.11						
Normal Main't Labor								
Main Engine		\$193.00						
Power Generator		\$158.40						
Labor rate	\$13.00							
Other Main't Cost		\$425.00						
Major Main't expense		\$2,676.60						
Total Labor (crew)		\$49,449.75						
Instructor expense		\$22,394.57						
Misc. Expense		\$4,113.77						
Sub Total		\$81,902.30						
Total Fuel used	1144	\$1,101.70						
Fuel Cost per Gallon	\$0.963							
Man-hours to fuel (6x/yr)	.6	\$396.42						
Distance to Fuel (6x/yr)	2 nm*							
Travel – Hours (6x/yr)	1	\$660.71						
Op Cost less Instructors	\$110.12/hr							
	<b>Total Cost</b>	\$84,061.13						
Operating Cost/Hr \$150.11								
* Nautical Miles – nm								

Table 10 summarizes the changes to the annual cost components that would be affected by utilizing biodiesel or B20 for the six options considered. The data do not consider any modification to the current configuration of the vessel.

Fuel prices are from quotes on January 23, 2003 and will change with time. However, the changes in the values for "Increase in operating cost per season" due to a change in the "Fuel Cost per Gallon" value will only be the change in fuel cost per gallon times the fuel used. A ten cent per gallon change in fuel cost will impact Table 10 results by approximately 0.1 %.

Table 10

	Angus - Biodiesel Options Steady State Operation											
	Optio	on 1 B100	Optio	on 2 B100	Optio	on 3 B100	Optio	on 4 B100	Optio	on 5 B100	Op	tion 6 B20
Operating Hours		560		560		560		560		560		560
<b>Total Fuel used</b>	1201	Extended	1201	Extended	1201	Extended	1201	Extended	1201	Extended	1155	Extended
Fuel Cost per Gallon	\$1.80	\$2,161.80	\$1.80	\$2,161.80	\$1.90	\$2,281.90	\$1.90	\$2,281.90	\$1.00	\$1,201.00	\$1.25	\$1,441.75
Man-hours to fuel (6x/yr)	.6	\$396.42	.6	\$396.42	.6	\$396.42	.6	\$396.42	.6	\$396.42	.6	\$396.42
Distance to Fuel Dock	12nm		12nm		2nm		20nm		2nm		2nm	
Travel time – Hours (6x/yr)	4	\$2,642.88	4	\$2,642.88	1	\$660.71	6	\$3,964.32	1	\$660.71	1	\$660.71
Boat cost per hour less Instructors Exp.	\$110.12		\$110.12		\$110.12		\$110.12		\$110.12		\$110.12	
Option subtotal		\$5,201.10		\$5,201.10		\$3,339.03		\$4,880.72		\$2,258.13		\$2.498.88
Petrodiesel sub total		\$81,902.30		\$81,902.30		\$81,902.30		\$81,902.30		\$81,902.30		\$81,902.30
Option Total Cost		\$87,103.40		\$87,103.40		\$85,241.33		\$88,544.94		\$84,160.43		\$84,401.18
Operating Cost/Hr		\$155.54		\$155.54		\$152.22		\$158.11		\$150.28		\$150.72
Percent Change from Baseline (\$150.11/Hr)		3.6%		3.6%		1.4%		5.3%		0.12%		0.4%
Increase in operating cost per season		\$3,040.80		\$3,040.80		\$1,182.60		\$4,480.00		\$95.20		\$341.60

z. **Angus Biodiesel Options - Discussion:** The lowest cost option, involving the least risk to equipment and mission is Option 6. None of the options is a clear leader in that fueling logistics continue to be a concern. Under current conditions, the Angus fuels from a tanker at the Grand Haven Coast Guard station. The new (or existing) supplier will have to be willing to transport a small quantity of fuel, approximately 200 gallons six times per season, from Grand Rapids, Grand Haven, or Holland.

Options one and two differ only in when fueling could take place. Option two requires the Angus to fuel when the Shenehon requires fuel and is unlikely to be practical.

The cost analysis above does not consider any capital investment to support the procurement of a storage tank or pumping equipment. Options four and five also carry the overhead of liability and spill containment that lie outside the current scope of the facility (See paragraph IX.i).

aa. **Angus Initial Season Cost:** Operational costs for steady state operation are detailed in Tables 9 and 10. Additional start—up costs would be required during the first season The Angus will require some abnormal maintenance costs as fuel filters and oil filters will need to be changed more frequently. Table 11 estimates additional, first year, operating costs.

Table 11

1 WAY 11							
Angus start-up Costs 2003 dollars							
Fuel Filters Used:							
Main Drive Engine	3	\$9.37	\$28.11				
Generator	3	\$9.37	\$28.11				
Total Oil Used							
Main Drive Engine	12	\$1.77	\$21.24				
Power Generator	4	\$1.77	\$7.08				
Oil Filters Used							
Main Drive Engine	1	\$7.36	\$7.36				
Generator	1	\$35.37	\$35.37				
Labor							
Main Engine	5	\$31.00	\$155.00				
Power Generator	3	\$31.00	\$93.00				
Oil Analyses (2 additional)	2	\$25.00	\$50.00				
Total Cost	Total Cost \$425.27						

#### bb. Jackson 2002 Operating

**Cost:** Table 12 summarizes the petrodiesel baseline operating cost for the Jackson for 2002.

Petrodiesel was delivered to the Jackson at dockside and required only that a person be present to sign for the fuel delivery.

Fuel cost alone is 3.7% of the total cost of operation of the Jackson.

The table breaks out those items that may be affected by the use of biodiesel or a blend (below the subtotal line).

# cc. Jackson - Operating Cost for Biodiesel Options:

Differences from the baseline for any of the options from Section VIII.a are assumed to result only from cost differences and any cost associated with fueling other than at dockside. Each option has unique logistics issues such as having to travel to a remote location necessitating a full crew on the boat for the duration of the fueling process. Distance traveled and travel time is assumed to be round trip.

The Jackson has a much higher fuel component in the biodiesel operating cost because of the assumption of a linear extrapolation of fuel consumption from the St. Louis bus testing (which may not be valid).

Table 12

Table 12						
Jackson Annual Operating Costs – 2002 Petrodiesel Baseline						
<b>Operating Hours</b>	543					
<b>Fuel Filters Used:</b>						
Main Drive Engine	12					
Lg. Generator	6					
Sm. Generator	2					
<b>Fuel Filter Cost Each</b>						
Main Drive Engine	\$18.35	\$220.20				
Lg. Generator	\$8.50	\$51.00				
Sm. Generator	\$8.50	\$17.00				
Total Oil Used						
Main Drive Engine	144					
Lg. Generator	60					
Sm. Generator	12					
Oil Cost						
Main Drive Engine	\$1.76	\$253.44				
Lg. Generator	\$1.77	\$106.20				
Sm. Generator	\$1.77	\$21.24				
Oil Filters Used						
Main Drive Engine	6					
Lg. Generator	6					
Sm. Generator	2					
Oil Filter Cost Each						
Main Drive Engine	\$19.93	\$119.58				
Lg. Generator	\$5.01	\$30.06				
Sm. Generator	\$5.49	\$10.98				
Normal Main't Labor						
Main Engine		\$143.29				
Power Generator	*	\$125.71				
Labor rate	\$11.64	\$34.92				
Other Main't. Cost		\$330.00				
Major Main't. expense		\$6.442.00				
Total Labor(crew)		\$74,164.44				
Instructor expense		\$30,201.27				
Misc. Expense		\$7,915.40				
Sub Total		\$120,210.68				
Total Fuel used	4627	\$4,664.13				
Fuel Cost per Gallon	\$1.004	42.10.77				
Labor to fuel (9x/yr)	1.5	\$249.75				
Distance to Fuel (9x/yr)	0	0				
Travel – Hours (9x/yr)	0	0				
Labor rate	\$18.50  Total Cost	0				
	\$125,124.56					
Opera	\$230.43					

#### The Feasibility of Fueling the Research Vessels W.G. Jackson and D.J Angus with Biodiesel

In this analysis, no storage facility capital investment, liability, or operating cost for any tank or manufacturing facility has been included or considered for any option (See paragraph IX.i).

Table 13 summarizes the changes to the annual cost components that would be affected by utilizing biodiesel or B20. The data do not consider any modification to the current configuration of the vessel.

Fuel prices are from quotes on January 23, 2003 and will change with time. However, the changes in the values for "Increase in operating cost per season" due to a change in the "Fuel Cost per Gallon" value will only be the change in fuel cost per gallon times the fuel used. A ten cent per gallon change in fuel cost will impact Table 13 results by approximately 0.5 %.

Table 13

Jackson - Biodiesel Options Steady State Operation												
	Optio	on 1 B100	Optio	on 2 B100	Optio	on 3 B100	Optio	on 4 B100	Optio	on 5 B100	Ор	tion 6 B20
Operating Hours		543		543		543	543		543		543	
<b>Total Fuel used</b>	5922	Extended	5922	Extended	5922	Extended	5922	Extended	5922	Extended	4886	Extended
Fuel Cost per Gallon	\$1.80	\$10,659.96	\$1.80	\$10,659.96	\$1.90	\$11,251.80	\$1.90	\$11,251.18	\$1.00	\$5,922.00	\$1.25	\$6,107.50
Man-hours to fuel (9x/yr)	1.5	\$2,359.94	1.5	\$2,359.94	1.5	\$249.75	1.5	\$249.75	1.5	\$249.75	1.5	\$249.75
Distance to Fuel Dock (9x/yr)	4.3 nm		4.3 nm		0		0		0		0	
Travel time – Hours (9x/yr)	2	\$3,146.58	2	\$3,146.58	0	0	0	0	0	0	0	0
Boat cost per hour less Instructors Exp.	\$174.81		\$174.81		\$18.50*		\$18.50		\$18.50		\$18.50	
Option subtotal		\$16,225.52		\$16,225.52		\$11,564.25		\$11,564.25		\$6,204.75		\$6,357.25
Petrodiesel sub total		\$120,210.68		\$120,210.68		\$120,210.68		\$120,210.68		\$120,210.68		\$120,210.68
<b>Total Cost</b>		\$136,337.16		\$136,337.16		\$131,711.61		\$131,711.61		\$126,382.43		\$126,567.93
Operating Cost/Hr		\$251.15		\$251.15		\$242.56		\$242.56		\$232.74		\$233.09
Percent Change from Baseline (\$230.43/Hr)		9.0%		9.0%		5.3%		5.3%		1.0%		1.2%
Increase in operating cost per season		\$11,250.96		\$11,250.96		\$6,586.59		\$6,586.59		\$1,254.33		\$1,444.38

<sup>\*</sup> Only a single attendant (\$18.50/hr) is required for fueling at the Lake Michigan Center - not a crew and travel (\$174.81)

dd. **Jackson Biodiesel Options - Discussion:** The lowest cost and risk scenario is Option 6. However, all the above options have operational concerns and cost issues that would seem to limit their viability. Adding nine percent to the annual operating cost and operating the Jackson on 100% biodiesel knowing the experience with the Detroit Diesel engine in the St. Louis testing seems adventurous at best and affects Options one through five.

Options one and two add travel time for a crewed boat to get fuel. Options three and six require AWRI to develop a new and/or independent (from NOAA) source for biodiesel or B20. Options four and five require additional capital outlays to store and dispense fuel from the AWRI Field Station building. Options four and five also carry the overhead of liability and containment that lie outside the current scope of the facility.

ee. **Jackson Initial Season Cost:** First year operation of the Jackson will require some abnormal maintenance costs as fuel filters and oil filters will need to be changed more frequently. Table 14 estimates additional, first year, operating costs.

Table 14

AUNIV II							
Jackson start-up Costs 2003 dollars							
	Qty	Unit Cost	Extended				
Fuel Filters Used:							
Main Drive Engine	6	\$18.35	\$110.10				
Lg. Generator	3	\$8.50	\$25.50				
Sm. Generator	3	\$8.50	\$25.50				
Total Oil Used							
Main Drive Engine	24	\$1.77	\$42.48				
Lg. Generator	4	\$1.77	\$7.08				
Sm. Generator	4	\$1.77	\$7.08				
Oil Filters Used							
Main Drive Engine	1	\$19.93	\$19.93				
Lg. Generator	1	\$5.01	\$5.01				
Sm. Generator	1	\$5.49	\$5.49				
Normal Main't. Labor							
Main Engine	10	\$11.64	\$116.40				
Lg Generator	3	\$11.64	\$34.92				
Sm Generator	3	\$11.64	\$34.92				
Oil Analyses (2 Additional)			\$50.00				
Total Cost			\$484.41				

ff. **Capital Costs for Fuel Storage and Pump:** Fueling options 4 and 5 would require AWRI to invest in some fuel storage and dispensing equipment. In addition, further research into the required spill containment, safety requirements, and licensing would have to be completed. However, once these issues were understood and met, fuel could be stored in the AWRI Field Station during the months when the Jackson

operated – April thru October. Storage and dispensing equipment would cost approximately:

3 - 275 gallon totes @ \$100.00 ea. \$300.00 1 - Pump/hose \$800.00 \$1,100.00

Storage of 825 gallons of diesel fuel should not require a formal Michigan Pollution Incident and Prevention Plan (PIPP) as the requirement pertains to 660 or more gallons stored in a single container or 1320 gallons or more stored at a single site. There are pallet mounted storage totes with integral spill containment barriers that should be considered but will add cost. A formal plan for reacting to a spill is not required but should be considered as it is good practice.

#### X. FOLLOW-ON ACTIVITIES:

There are a number of activities that could be undertaken to both encourage the use of alternative fuels, like biodiesel or blends, and to improve the environment. There has been a great deal of research completed on the effects of the use of biodiesel on diesel engines and their emissions, however, education of potential users and creating a base of support (a market) among users is required.

- Legislation to mandate the use of alternative fuels would help preserve Michigan's water resources and to support continued tourism in the State should be encouraged. For example:
  - Legislation similar to that enacted by Minnesota requiring a minimum B2 blend for all diesel fuel sold in Michigan would be a first step.
  - Legislation to mandate that B20 be sold for marine applications in all Michigan waters. This would reduce the impact of diesel engines on the air and water quality for recreation boaters.
- AWRI should continue to research the application of biodiesel or B20 to their two vessels and research the use of the by-products and transesterification process.
  - Monitor discharged water quality to research the impact of low concentrations of exhaust components and long term effect on aquatic plant and animal life.
  - Continue to educate the potential users on the benefits of biodiesel. The current grant funded by the Michigan Biomass Energy Program Grant should be considered only a first step.
  - o Investigate the possibility of producing ethanol from glycerol.
  - o Investigate the possibility of using glycerol for a fertilizer.
  - Investigate the use of glycerol to accelerate the transesterification reaction by burning it to raise the temperature of the reaction vessel.

#### **XI. CONCLUSIONS:**

The conservative approach assumed in this report is that the over-the-road data are indicative of the types of changes that take place and can give indications as to the order of magnitude of changes in the marine application. The over-the-road data were used to bracket potential oil analysis wear metals under the assumption that the duty cycles are equivalent or more severe than duty cycles of the AWRI research vessels. The duty cycles assumed, Medium, Continuous Duty, for the various engines on the two vessels fall under the ISO 3046 duty cycle definitions (See Appendix III).

The duty cycle description for the St. Louis transit buses, Intermediate, Severe, is anecdotal information from Van Eck Diesel Service, Inc. The duty cycle assessment, Medium, Continuous Duty, for the gensets and over-the-road Dodge truck application is anecdotal information from Cummins Michigan Power.

The total experience base of the use of biodiesel or B20 indicates that there are no risks to the mechanical integrity of well maintained diesel engines in the use of either fuel (7, 13, 15, 33, 34, 37, 59).

gg. **Fuel of Choice:** In general, the preponderance of data and previous research indicates that the use of biodiesel in the Angus is without significant risk to the vessel or mission.

There was no supporting data found in the research for the use of biodiesel in the Jackson's main drive engines. Sufficient data was found to support the use of B20 with low risk to the vessel and mission.

However, operating the two vessels on different fuels will likely place an additional cost burden on the Angus due to the required delivery of a small quantity of biodiesel to the Coast Guard Station in Grand Haven and being the only AWRI use of the fuel.

B20 has been proven feasible in both main drive engine models utilized by the two research vessels. Therefore, B20 should be used by both vessels until further research into the impact of higher blends (>B20) or biodiesel on the operation of the Jackson can be completed.

hh. **Redundancy:** A fuel related problem with either the Angus's single main drive engine or single genset could result in cancellation or curtailing a scheduled cruise. The Jackson has two main engines and would require two simultaneous fuel related problems, one associated with each main drive engine or one associated with each

genset to cause a cancellation or curtailing a scheduled cruise. The Angus could not tolerate a single fuel related problem without cancellation or curtailing a scheduled cruise. This consideration favors the Jackson for initial use of B20.

ii. Non-ASTM Fuel: Operation of the Angus or the Jackson on biodiesel or a blend using biodiesel not meeting the ASTM standard, as might be the case in Option 5 in Section VIII.a, would be a high risk but may be manageable if the total glycerol, alcohol, and water content of the end product are controlled to acceptable levels – i.e. create an AWRI specification for biodiesel. Determining the acceptable levels of glycerin and water could only be determined by test in one or both of the vessels and/or a land based engine. The GVSU Combustion Engineering Laboratory has a Cummins diesel engine (different model than the Angus), which could be used to determine the impact of glycerol, alcohol, and water levels in biodiesel fuel and might form the basis for a student project.

#### XII. RECOMMENDATIONS:

This research determined that the risk to the AWRI's educational and outreach mission in fueling the Jackson with B20 or the Angus with biodiesel or B20 is low. The risk to the main drive engines is also low. The genset is considered to have slightly higher risk because there is little supporting data for the use of biodiesel in the specific engine models.

Fueling the Angus with B20 would have a slightly higher risk than fueling with biodiesel as the supporting data are based on less total experience with the fuel. The use of biodiesel could easily follow any change in fuel used by the Coast Guard assuming a mutually satisfactory agreement could be reached.

The Detroit Diesel 6V92 engine testing in St. Louis, MO had unexpected results that indicate that the approach in fueling the Jackson with B20 should be to gain experience with the fuel, establish a good understanding of the interaction with the engines, ensure no untoward incidents occur, and then consider the use of biodiesel for the future. A plan to examine the economics of fueling the Jackson with biodiesel should be established once B20 has been used successfully.

Recommendations for increased monitoring of maintenance items the first season are found in Appendix V.

- jj. **D.J. Angus:** The Angus should not initiate the use of biodiesel or a blend but should follow the Jackson by a few months or a season.
  - i. **Lack of Redundancy:** The Angus has a single main drive engine and a single genset. Any fuel related problem with either engine would be cause for cancellation or curtailing a cruise.

- ii. **Logistics:** The logistics of getting biodiesel or a blend to the Angus may be prohibitive if a new supplier is required.
- iii. **Experience:** Because AWRI operates two vessels, it is the conservative approach to initiate the fuel change on the vessel with the lower risk and gain experience with the fuel. This approach may uncover issues that have not been realized in this research or in the assumptions on the applicability of over-the-road testing to marine use.
- kk. **W.G. Jackson:** The Jackson should take the lead in the conversion of the fleet to biodiesel. The Jackson should be fueled with B20 initially.
  - i. **Redundancy:** The Jackson has two main drive engines and two gensets. A fuel related problem would have to impact two engines before a cruise would have to be cancelled or curtailed. Redundancy creates a fault tolerant situation, i.e. a plugged fuel filter on one engine would initiate preventative action against a second occurrence.
  - ii. **Engine Manufacturer Endorsement:** Detroit Diesel currently endorses the use of B20 in their engines.
  - iii. **Logistics:** The logistics of getting fuel to the Jackson are less troublesome than to the Angus. A supplier of B20 fuel should be found (or the current supplier willing to deliver B20 to our dock). The quantity of fuel is higher than for the Angus, making the delivery to our dock more attractive to a supplier. Once the supplier is in place, AWRI would be in a better bargaining position to arrange for fuel delivery to the Angus. Possible suppliers are Merl Boes and Crystal Flash.

#### **XIII. ACKNOWLEDGEMENTS:**

- ll. **Project Sponsor:** Dr. William G. (Bill) Jackson funded this feasibility study with the intent of reducing the emissions of the AWRI's research vessels and providing a role model for other commercial and recreational vessels powered by diesel engines and operating on Muskegon Lake and the Great Lakes.
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# APPENDIX I

# STANDARD DEVIATION

and

# **EXTRAPOLATIONS**

					REF	ERENCE	DATA S	UMMARY	
			Iron	Copper	Lead	Aluminum	Silicon	Chromium	
									Rreference (38) Data k=3
		95 Truck - data	21.20	2.20	3.40	2.16	4.40	2.40	Average Values Nn=5
		St Dev	4.54	1.64	1.67	1.07	0.55	1.34	
	_	Pepsi Truck - data	8.94	1.47	1.29	5.71	2.06	1.00	Average Values Nn=17
	ese	St Dev	4.14	0.80	0.58	2.13	0.97	0.00	
Ð	ibc	McG Truck - data	20.28	2.57	6.42	2.53	3.71	2.00	Average Values Nn=7
gin	Petrodiesel	St Dev	8.01	1.13	5.09	0.87	1.11	1.53	
- En	ď	Wtd Average	13.79	1.86	2.89	4.33	2.86	1.48	From Equation (1) using Nn values from above
Dodge Trucks - BT5.9 L Engine		St Dev	5.34	1.05	2.57	1.77	0.95	0.90	From Equation (3)
- 81	,,,,,,								Rreference (38) Data k=4
ks		92 Truck - data	6.79	3.25	1.46	0.46	2.58	1.42	Average values with Nn=24
n n		St Dev	4.03	3.70	1.84	0.64	2.08	4.23	1 11 N 46
Ī		91 Truck - data	9.00	3.23	2.00	0.23	2.15	1.85	Average values with Nn=13
βğρ	<u></u>	St Dev	12.59	3.32	3.16	0.44	1.86	2.91	A
Õ	ese	94 Truck- data St Dev	15.50 3.88	2.39	2.17 1.15	3.20 0.84	3.05 1.80	0.67 0.59	Average values with Nn=18
_	Biodiese	95 Truck - data	12.40	3.88	2.88	2.65	4.12	0.59	Average values with Nn=25
	Bi	St Dev	6.32	6.45	1.30	1.22	4.81	0.44	Average values with NH=25
		0.501	0.02	0.10	1.00	1.22	1.01	0.11	
		Wtd Average	10.86	3.25	2.15	1.72	3.10	0.95	From Equation (1) using Nn values from above
		St Dev	6.78	4.50	1.85	0.88	3.14	2.63	From Equation (3)
و ر									Data from AWRI oil analysis
5.9 7ri	ø		15.0	8.0	4.0	3.0	23.0	1.0	
aT.	Data		29.0	2.0	3.0	2.0	10.0	2.0	
nins BT s Main E Engine			16.0	2.0	2.0	3.0	9.0	2.0	
us l		Average	20.0	4.0	3.0	2.7	14.0	1.7	Simple average calculation
Cummins BT5.9 L Angus Main Drive Engine		St Dev	7.81	3.46	1.00	0.58	7.81	0.58	From Equation (2) with n=3
		Extraplacted Mass	15.75	6.98	2.23	1.06	15.15	1.07	From equation (4)
ate	-	Extraploated Mean	15./5	<b>ს.9</b> 8	2.23	1.00	15.15	1.07	From equation (4)
<u>ä</u>		St Dev	7.81	3.46	1.00	0.58	7.81	0.58	Assumed equal to the Cummins on petrodiesel
est	$\vdash$	Ot Dev	7.01	J. <del>+</del> U	1.00	0.00	7.01	0.50	n localitod equal to the outlithing off petrodiesel
Angus B100 estimate		Margin of error	11.27	5.00	1.44	0.83	11.27	0.83	From equation (5) and n=3
, B,		High Prediction	27.03	11.98	3.67	1.89	26.42	1.90	
šnb		. light rodiotion	27.00	12.00	4.00	2.00	27.00	2.00	Table 1 (or Appendix III Table 3) values
Ang	Ang	Low Prediction	4.48	1.98	0.79	0.23	3.88	0.24	rabio i (oi rippoliaix ili rabio o) valuos
		2011 1 1001011011	4.00	1.00	0.00	0.00	3.00	0.00	Table 1 (or Appendix III Table 3) values

	REFERENCE DATA SUMMARY											
	Iron Copper Lead Aluminum Silicon Chromium											
0;								Reference (38) data				
odge ck B2	Mean	6.23	4.07	1.53	1.67	2.43	0.73					
Dodę Truck	St. Dev	2.26	6.16	0.63	0.84	1.14	0.45					
e	Extraploated Mean	9.03	7.11	1.14	0.66	2.63	0.47	From equation (4)				
estimate	St. Dev	7.81	3.46	1.00	0.58	7.81	0.58	Assumed equal to the Cummins on petrodiesel				
	Margin of error	11.27	5.00	1.44	0.83	11.27	0.83	From equation (5) n=3				
, B20	11:15 1:0	00.04	10.11	0.50	4.50	10.00	4.00					
Angus	High Prediction	20.31	12.11 12.00	2.58 3.00	1.50	13.90	1.30 2.00	Table 2 (Appendix Table 5) values				
	Low Prediction	21.00 -2.24	2.11	-0.31	2.00 -0.17	14.00 -8.64	-0.36	Table 3 (Appendix Table 5) values				
	Low Frediction	0.00	2.00	0.00	0.00	0.00	0.00	Table 3 (Appendix Table 5) values				

					REF	ERENCE	DATA S	UMMARY	
	********		Iron	Copper	Lead	Aluminum	Silicon	Chromium	
									Data from AWRI oil analysis
sel	data		33.00	5.00	4.00	4.00	20.00	2.00	
ar Pe	ဗ		34.00	2.00	3.00	3.00	7.00	1.00	
Westerbeke 20.0BEDA Petrodiesel		Average	33.50	3.50	3.50	3.50	13.50	1.50	Simple average calculation
We 20 Pe		St Dev	0.71	2.12	0.71	0.71	9.19	0.71	From equation (2) and n=2
0									
B100		Extraploated Mean	26.39	6.11	2.60	1.39	14.61	0.96	From equation (4)
EDA		St Dev	0.71	2.12	0.71	0.71	9.19	0.71	Assumed equal to the Westerbeke on petrodiesel
ke 20.0BE Estimate		Margin of error	1.25	3.75	1.25	1.25	16.25	1.25	From equation (5) and n=2
ke :		High Prediction	27.64	9.86	3.85	2.64	30.86	2.21	
Westerbeke		riigiri rediction	28.00	10.00	4.00	3.00	31.00	3.00	Table 2 (or Appendix Table 4) values
ste		Low Prediction	25.14	2.36	1.35	0.14	-1.64	-0.29	, , , , , , , , , , , , , , , , , , , ,
We			25.00	2.00	1.00	0.00	0.00	0.00	Table 2 (or Appendix Table 4) values
B20		Extraploated Mean	15.13	7.65	1.85	1.35	11.46	0.74	From equation (4)
		0: 0		2.12	. = .		0.10		
BE		St Dev	0.71	2.12	0.71	0.71	9.19	0.71	Assumed equal to the Westerbeke on petrodiesel
ke 20.0BEDA Estimate		Margin of error	1.25	3.75	1.25	1.25	16.25	1.25	From equation (5) and n=2
Westerbeke Est		High Prediction	16.38	11.40	3.10	2.60	27.71	1.99	
erb		<u> </u>	17.00	12.00	3.00	3.00	28.00	2.00	
est		Low Prediction	13.88	3.90	0.60	0.10	-4.79	-0.51	
>			13.00	3.00	0.00	0.00	0.00	0.00	

					REF	ERENCE	DATA S	UMMARY	
	w		Iron	Copper	Lead	Aluminum	Silicon	Chromium	
									Reference (39) data [Si data from reference (7)]
-t 6		Biodiesel	115.8	42.5	13.2	0.8	17.4	3.3	Average data with na=61
§ §		St Dev	57.72	157.24	104.59	1.98	NA	1.87	From Equation (7) and "t" value
e <u>e</u> s									
iis Bus t Diese engine		Petrodiesel	89.7	27.8	11.6	0.5	19	2.7	Average data with nb=80
uis t D		St Dev	57.72	157.24	104.59	1.98	NA	1.87	From Equation (7) and "t" value
St. Louis Bus Test - Detroit Diesel 6V92 engine		4	0.00	0.55	0.00	0.00	NIA	4.00	
et ::		Doob ob 386 c	2.66	0.55	0.09	0.89	NA	1.89	000 000 in mat (00)
0, 1		Probability	0.009	0.578	0.928	0.378	NA	0.06	.928 was .368 in ref (38) - assumed error
_									Data from AWRI oil analysis
air		0	14.0	2.0	5.0	2.0	8.0	1.0	,
Σ	m	ide	12.0	2.0	4.0	1.0	8.0	1.0	
jo.	Data Port Side		12.0	2.0	6.0	2.0	7.0	1.0	
	Į o	12.0	2.0	5.0	1.0	12.0	0.0		
Ja		_	7.0	6.0	5.0	2.0	1.0	0.0	
sel 6V92 - Jac Drive Engines		0	16.0	2.0	9.0	2.0	8.0	1.0	
§ <u>□</u>	ä	e e	16.0	2.0	7.0	2.0	8.0	1.0	
ive	Data	Starboard	12.0	2.0	4.0	1.0	8.0	1.0	
es D	_	Sta	14.0	3.0	0.0	1.0	0.0	0.0	
ă			7.0	2.0	5.0	1.0	1.0	0.0	
ej G		Average	12.2	2.5	5.0	1.5	6.1	0.6	Simple average calculation
Detroit Diesel 6V92 Drive Eng		St Dev	3.16	1.27	2.31	0.53	3.98	0.52	From Equation (2) n=10
		Ot Bev	0.10	1.21	2.01	0.00	0.00	0.02	110111 Equation (2) 11=10
		Extraploated Mean	15.75	3.82	5.69	2.40	5.59	0.73	From Equation (4)
ate		St Dev	3.16	1.27	0.04	0.53	2.00	0.52	Assumed agual to the Detroit Dissal on Detrodicael
JAX B20 estimate	-	St Dev	3.10	1.21	2.31	0.53	3.98	0.5∠	Assumed equal to the Detroit Diesel on Petrodiesel
est		Margin of error	2.49	1.00	1.83	0.42	3.15	0.41	From Equation (5) and n=10
20		3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	-			-		-	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
B		High Prediction	18.24	4.83	7.52	2.82	8.74	1.14	
₹		-	19.00	5.00	8.00	3.00	9.00	1.00	Table 4 (or Appendix III Table 9) values
7		Low Prediction	13.26	2.82	3.86	1.98	2.44	0.33	
			13.00	2.00	33.00	1.00	2.00	0.00	Table 4 (or Appendix III Table 9) values
			70.00	2.00		1.00	2.00	0.00	Table 1 (of Appendix III Table 6) values

	REFERENCE DATA SUMMARY											
			Iron	Copper	Lead	Aluminum	Silicon	Chromium				
ts									Data from AWRI oil analysis			
Lights C esel	; ;	200	7.00	3.00	3.00	3.00	6.00	0.00				
	3	S S	6.00	2.00	0.00	2.00	8.00	0.00				
ern L M30C		Average	6.50	2.50	1.50	2.50	7.00	0.00	Simple average calculation			
Northern Ligh M30C Petrodiesel	-	St Dev	0.71	0.71	2.12	0.71	1.41	0.00	From equation (2) and n=2			
0												
B20		Extraploated Mean	2.94	5.47	0.79	0.96	5.94	0.00	From equation (4)			
M30C e	_	St Dev	0.71	0.71	2.12	0.71	1.41	0.00	Assumed equal to the Northern Lights on Petrodiesel			
Lights N Estimate		Margin of error	1.25	1.25	3.75	1.25	2.50	0.00	From equation (5) and n=2			
n Lig Est	E	High Prediction	4.19	6.72	4.54	2.21	8.44	0.00				
her			5.00	7.00	5.00	3.00	9.00	0.00	Table 5 (or Appendix III Table 10) values			
Northern		Low Prediction	1.69	4.22	-2.96	-0.29	3.44	0.00				
ž			1.00	4.00	0.00	0.00	3.00	0.00	Table 5 (or Appendix III Table 10) values			

# APPENDIX II

# REGULATORY CONSIDERATIONS

#### I. EPA:

The controlling legislation is the Environmental Protection Act of 1992 and the Environmental Protection Act Amendments of 1997. This legislation has not applied to off-road or marine diesel emissions except Section 203 clarifies the definition of off road vehicles to include marine engines and provides for studies of the impact of alternative fuels in off road vehicles at 6 and 10 years after the Act is enacted (2003 and 2007) (51).

The EPA emission standards for new marine engines built after January 2006 will regulate engine emissions of particulate matter (PM), total hydrocarbons (THC), carbon monoxide (CO), and oxides of nitrogen (NOx) for marine diesel engines over 50 Hp.(47) The primary regulation on marine emissions has been oxides of nitrogen and sulfur oxide through IMO (MARPOL 73/78 Annex VI) standards which will be superceded by new legislation.(50)

Both the Angus and Jackson main drive engines are exempted from compliance to the new EPA regulation and will remain regulated by the older IMO standards because of the manufacture date.

The power generator engines on both the Angus and Jackson fall beneath the Hp threshold (50 Hp) required by the new regulation and are also grandfathered into compliance to the older IMO standard

Emissions of carbon dioxide (CO2) have not been a focus of the EPA as an engine emission but do contribute to global warming. CO2 has not been regulated but greenhouse gas emissions are a concern.

#### **II. Coast Guard:**

The Coast Guard has had little input to the regulation of diesel engine emission but has included MARPOL 73/78 language as a pass though communication rather than real regulation. The MARPOL Annex VI, "Prevention of Air Pollution from Ships", is the current standard that is driving the development of reduced diesel emissions. Annex VI is not currently accepted by the participating countries but carries retroactive requirements for engines produced after 2000 once ratified by 15 states which constitute 50 % of the world fleet (50).

#### III. Pending Legislation.

a. Federal. In March of 2002 the United States Senate unanimously passed an energy bill that would lift a restriction on the government's use of biodiesel. The restriction had been placed on biodiesel fuel use by the Energy Policy Act of 1992 (EPAct) wherein alternative fuel vehicles (AFV) were mandated to constitute 10 % of state, federal and public utility fleets. Since biodiesel works in all diesel engines with few or no modifications AFV credits were created to account for biodiesel use

#### APPENDIX II - Regulatory Issues

in existing vehicles by a 1998 amendment to the EPAct. For every 450 gallons of biodiesel fuel consumed one AFV credit was earned but affected fleets were limited to using biodiesel for 50 % of their credits. The new Senate bill would eliminate that restriction and could result in a doubling of the demand for biodiesel in some affected fleets.

**b. State.** Michigan Senate Bill SB1357 was considered in 2003 but died in the Committee on Transportation and Tourism. This bill would have required every gallon of diesel fuel sold in the state over-the-road, off-road, and marine diesel fuel to have 2% biodiesel content beginning January 1, 2004. This mirrors a state law enacted in Minnesota in 2002 which takes effect in January 2005.

Michigan Senate Bill SB1362 also died in the Committee on Transportation and Tourism. This bill would have exempted diesel fuel that is a blend of (at least) 20% biodiesel and 80% petrodiesel from motor fuel taxes imposed by 2000 PA 403.

Michigan House Bill HB6149 was also been referred to the Committee on Transportation and Tourism where it died. This bill would have required a study on the feasibility of the state purchasing and using alternate fuel vehicles.

The two Senate bills would have provided incentives for the use of biodiesel and encourage establishment of the infrastructure necessary to reduce the cost of biodiesel.

The House bill may have been redundant in that the use of alternate fuel vehicles has already been mandated by the Energy Policy Act Amendments of 1997 albeit an unfunded mandate. Biodiesel or a biodiesel blend could be used in state owned diesel vehicles now simply by buying the biodiesel (or blend) and pumping it from existing state owned storage tanks and alternate fuel vehicle credits could be earned.

# **APPENDIX III**

# **MECHANICAL CONSIDERATIONS:**

### I. MECHANICAL ISSUES:

# a. Four-Cycle vs. Two-Cycle Engine operation:

The operation of internal combustion engines, including compression ignition (diesel) engines are described as either two-cycle and four-cycle engines.

- **i. Four-Cycle:** Four-cycle engines are most common and are found in all production automotive applications. The-four cycle engine has four distinct steps for each cylinder (piston) in each 720 degree (two revolutions) rotation of the engine:
  - 1) Intake Stroke (0 to 180 degrees of engine rotation) piston moves down from top dead center to bottom dead center while drawing in a mixed charge of fuel and air through the open intake valves. In engines with fuel injection, the combustion air only is drawn in during this stroke.
  - 2) Compression Stroke (180 to 360 degrees of engine rotation) piston moves up from bottom dead center to top dead center with intake and exhaust valves closed, compressing the fuel/air mixture. In engines with fuel injection, the fuel forced in as the piston nears top dead center. In compression ignition engines the pressure/temperature increase caused by the compression causes the mixture to ignite.
  - 3) Power stroke (360 to 540 degrees of engine rotation) piston moves down from top dead center to bottom dead center from expansion of ignited fuel/air mixture causing a rotation of the crankshaft and output shaft of the engine.
  - 4) Exhaust stroke (540 to 720 degrees of engine rotation) piston moves up from bottom dead center to top dead center exhausting the burn gases out of the cylinder through the open exhaust valves.

The cycle then repeats for as long as fuel and air are introduced into the engine.

- ii. Two-Cycle: Two-cycle engines are found primarily in lower power applications like motor cycles, lawn mowers, model airplane engines and in some older larger engines. The two cycle applications are becoming fewer as there are inherent emission disadvantages from the mixing of the intake fuel/air mixture and exhaust gases. The advantage to the two cycle engine is the engine delivers twice as many power strokes per engine rotation as does the four cycle engine. The two cycle engine has the following operational steps per engine revolution (360 degrees):
  - 1) Power/Exhaust stroke (0 to 180 degrees of engine rotation) piston moves down from top dead center to bottom dead center causing a rotation of the crankshaft and output shaft of the engine. The cylinder exhaust valves are opened prior to the bottom dead center point to allow the burned gases to

flow out through the exhaust valves. Near the end of this stroke, the piston uncovers an opening in the side wall of the cylinder through which the new air/fuel charge enters the cylinder.

2) Intake/Compression stroke (180 to 360 degrees of rotation) – after sufficient upward movement, the piston closes the cylinder side wall opening and has exhausted most of the burned gases, the exhaust valve are closed. The piston continues to travel upward compressing the air/fuel mixture (causing ignition in compression ignition engines).

The cycle then repeats for as long as fuel and air are introduced into the engine.

The exhaust gases and the fuel air mixture are mixed during the intake/compression portion of the cycle and a significant amount of unburned fuel can be exhausted with the products of combustion. The two cycle gasoline engines used in motorcycle and many other applications are being replaced by four cycle engines simply to reduce the unburned hydrocarbons released during operation and meet the clean air environmental requirements of current and future legislation.

- b. Engine aspiration: Internal combustion engines require both fuel and air to function. There are three main approaches to introducing combustion air into an internal combustion engine: supercharging, turbo-charging, or natural aspiration. Fuel injection is generally used for diesel engines wherein fuel is injected directly into the cylinder. Fuel injection allows the initiation of combustion to be timed by selecting the point in the compression stroke when the fuel is injected into the cylinder. Timing has been shown to affect the performance and emissions of engines and is used to assist in meeting emissions standards
  - i. Supercharged: Supercharged engines have an air pump that forces combustion air into the cylinder. This high pressure air improves engine performance over air introduced at atmospheric pressure (natural aspiration). Supercharges are driven from the engine output shaft with a mechanical connection and commonly belt driven. Supercharged engines have superior performance to naturally aspirated engines but utilize shaft horsepower to operate the air pump decreasing the engine output.
  - **ii. Turbo-charged:** Turbocharged engines are similar to supercharged engines except that the combustion air is pumped into the cylinders by a pump that is driven by a turbine in the engine exhaust system similar to the way a jet engine compressor is driven. Turbocharged engines have superior performance to both naturally aspirated engines and supercharged engines as the energy to drive the combustion air pump comes from waste energy in the exhaust stream. The use of the exhaust energy to drive the air pump is still a parasitic influence on

engine performance as exhaust back pressure is increased which affects the ability to force air and fuel into the cylinders.

iii. Natural Aspiration: Naturally aspirated engines are engines that breathe from the natural action of the engine, i.e. when the piston of a four cycle engine moves from top dead center to bottom dead center the pressure within the cylinder decreases drawing air into the cylinder. Naturally aspirated engines do not require fuel injection but can use this natural air flow to draw fuel into the air flow as in a carburetor using the Bernouli principal. Fuel injection is still used in many engines that are naturally aspirated to allow timing of the combustion within the engine which can affect emissions.

### c. Engine Warranty Coverage:

### i. D.J. Angus:

1. Main Drive Engine: The Angus Main Drive Engine (MDE) is a Cummins model 6BT5.9 M180. This is a 5.9 liter displacement, turbo-charged, six cylinder, four-cycle, compression-ignition engine, rated at 180 HP at 2500 RPM. This engine has been fueled with premium diesel since it was installed in the Angus.

The warranty position of Cummins on the use of biodiesel or blends in their products is a consideration for AWRI only to the extent that it provides some information on manufacturer's experience with the fuel. Cummins states that it is the user's responsibility to obtain any local, regional, or national exemptions necessary to fuel any Cummins emission regulated engine with biodiesel or blends. They state that oxides of nitrogen emissions (NOx) from their engines will increase by 2% with B20 fuel (61).

**2. Electrical Power Generator:** The generator is a self-contained package (genset) Westerbeke model 20.0BEDA. This package includes a Westerbeke four cylinder, four-cycle, naturally aspirated, compressionignition engine. The genset package is rated at 20 kW at 1800 RPM (60 hertz).

The Westerbeke position on the use of biodiesel is not well communicated. Their website customer assistance contact would provide only a section of the Westerbeke Engines & Generators Manual that describes the fuel system and general operational requirements. No mention of the use of biodiesel is contained in the material (See Appendix IV).

A formal request for a position on the use of biodiesel in Westerbeke Diesel engines of the specific model used on the Angus was made to the sales and marketing department of the Westerbeke corporate headquarters on

December 3, 2002. The Westerbeke response is typical of diesel engine manufacturer's position (See Appendix IV).

"The Westerbeke Corporation does not approve, nor does it disapprove, of the use of biodiesel as a fuel in its diesel engines. However, if a failure occurs as a result of the use of biodiesel, warranty will be denied."

#### ii. W.G. Jackson

- 1. **Detroit Diesel:** Twin Detroit Diesel Engines drive the Jackson. Both the port side main drive engine (PMDE) and the starboard main drive engine (SMDE) are Model 6V92, turbo charged, two-cycle, eight cylinder, compression-ignition engines, rated at 325 HP at 1800 RPM. Detroit Diesel Corporation recommends that the use of biodiesel be limited to B20 blend. No comments are made on emissions or need to obtain exemptions for emissions regulated engines (28) (See Appendix IV).
- 2. Small Electrical Power Generator: The small genset is rated at 12kW and is powered by a Lugger model 843 diesel engine. This engine is a three cylinder, four-cycle, naturally aspirated, compression-ignition engine. Lugger is a brand name of Alaska Diesel Electric, Inc. as is Northern Lights. Warranty coverage on the small genset has expired.

Alaska Diesel Electric, Inc. utilizes several different brands of diesel engines on their gensets and is not limited to those of concern in operation of the Angus or the Jackson. Their position on the use of biodiesel is the most restrictive of any of the manufacturers whose engines are used on their gensets. When a request was made for their position on the use of biodiesel in the Lugger engine, Alaska Diesel Electric, Inc. provided the statement from John Deere (24) dated December 3, 2001 with the (verbal) comment that a maximum of a B5 blend was the position of John Deere and hence Alaska Diesel Electric, Inc. (See Appendix IV).

The John Deere position statement is not clear. While stating that "John Deere has approved the use of soy-based Biodiesel in all of its diesel-powered products", their guidelines state that "While rapeseed methyl ester concentrations of up to 100% have been run successfully, concentrations of up to 5% Biodiesel have shown improvement in fuel lubricity while minimizing the potential problems associated with fuel degradation" (24) – a statement concerned with fuel quality.

Alaska Diesel Electric, Inc. has elected to take the conservative approach of the use of the B5 blend as a maximum, which does not appear to be the intention of John Deere. The real issue may be the statement that "Users of

John Deere Emission Certified Engines are responsible for obtaining any appropriate local, state, and national certifications for the use of Biodiesel" (24). Diesel engines fueled with B100 do not meet marine standards for NOx emissions and may be the basis for the statements of approval of the use of B5 as well as a fuel quality concern.

**3.** Large Electrical Power Generator: The model M30C is powered by a Toyota diesel engine model 1Z. The engine is a four cylinder, four-cycle, naturally aspirated, compression-ignition engine.

The previous comments regarding the position of Northern Lights on the use of biodiesel also apply to the large genset.

Toyota does not have a position on the use of biodiesel in their engines that they are willing to share. The engine is produced for sale primarily in Japan and Europe. A number of attempts were made to find some statement or position but Toyota America was unwilling to provide any statement other than the verbal statement that the engine is not produced for use in North America and no written position will be made available.

Anecdotal information supporting the use of B100 in the engine has come indirectly from a Toyota Technical Representative through the Grand Rapids Dealership, Kool Toyota. Although not a rigorous endorsement, the fact that the statement was made at all lends some (minor) degree of credibility.

#### d. Engine Maintenance:

#### i. Angus Petrodiesel History:

**1. Main Drive Engine:** The Angus oil analysis focuses on those engine materials indicate potential engine components that will wear over time.

The wear metals of primary concern are:

- 1. Iron. Iron in the lubricating oil can reflect cylinder wall/liner, valve, and/or gear wear.
- 2. Copper. Copper in the lubricating oil can reflect wear in bearings, bushings, and degradation to oil coolers if the engine is equipped with one.
- 3. Lead. Lead is indicative of journal bearing wear as found in the crankshaft and piston rod bearings.
- 4. Aluminum. Aluminum wear particles in the lubricating oil indicate wear to pistons.

- 5. Silicon. Silicon particles in the lubricating oil would indicate wear material that has been carried into the engine through the combustion air filters.
- 6. Chromium. Chromium is primarily used in the manufacture of piston rings and is a measure of the rate of wear of the rings.

Schumacher (38) reported on testing of eleven Dodge trucks having the same model engine as the D.J. Angus in a ten-year test using petrodiesel, biodiesel, and blends. Table 1 compares the average (mean) levels of engine wear metals from the University of Missouri testing of three trucks and the average levels reported for the Angus oil analysis during the 2002 season for operation on petrodiesel.

The Dodge trucks were of various model years, and not uniformly equipped. The trucks were fueled with standard number 2 over-the-road fuel while the Angus was fueled with premium diesel fuel.

Cummins BT5.9L Engine Oil Analysis - Parts per Million (ppm) Chromium Iron Copper Lead Aluminum **Silicon** 20.0 4.0 2.7 14.0 1.7 Angus Petro\* 3.0 Standard Dev 7.81 3.46 1.00 0.58 7.81 0.58 U. of Mo Petro 13.79 1.86 2.89 4.33 2.86 1.48 Standard Dev 5.34 2.57 1.77 0.90 1.05 0.95

Table 1

The means of the data gathered from the Angus oil samples are comparable to the means of the data from the University of Missouri Dodge truck testing with the exception of silicon. Consideration of the standard deviations of the means support this conclusion.

The high silicon in the lubricating oil is a concern as this is a measure of the abrasive material entrained in the combustion air during engine operation. None of the wear metals (iron, lead, aluminum, chromium) that would be affected by the ingestion of the silicon was reported as excessive (38). The Angus is moored in an area prone to dust and dirt, which supports the belief that the silicon is an environmental factor.

Cummins rates the truck application as Medium, Continuous duty – the same as the Angus duty cycle (Anecdotal information from Ed Hyslop of Cummins Michigan Power).

Cummins, Inc has no recommendations for engine wear contaminant levels in lubricating oil (See Appendix IV).

<sup>\*</sup> Based on samples from three oil changes - see Appendix I for calculations

2. Electrical Power Generator: No engine oil analysis for a test or demonstration project has been found in the literature to allow a direct comparison to the Angus genset oil analysis or to establish acceptable rate of wear. Lubricating oil and filters are changed at 100 hour intervals. Table 2 reports the mean of the engine-wear metals for the 2002 season.

Table 2

Westerbeke 20.0BEDA Engine Oil Analysis - ppm										
Iron Copper Lead Aluminum Silicon Chromium										
Petrodiesel*	33.5	3.5	3.5	3.5	13.5	1.5				
Standard Dev   0.71   2.12   0.71   0.71   9.19   0.71										

<sup>\*</sup> Based on samples from two oil changes. See Appendix I for calculations.

The wear metals are of the same order of magnitude as in the main drive engine, which would lead one to believe that the engine wear would be acceptable. Also, there have been no performance or maintenance issues with the Angus genset. Generators are generally rated as Medium, Continuous Duty applications. (Anecdotal information from Ed Hyslop of Cummins Michigan Power)

It is interesting to compare the genset silicon ingestion to the Angus MDE silicon ingestion and note that the only filtration of combustion air on this genset is a simple, coarse screen intended to limit ingestion of rags or similar debris.

The genset and the Angus MDE may benefit from improved air filtration. The lack of any real air filtration on the genset resulting in levels similar to the Angus main drive engine with a standard combustion air filter calls into question the effectiveness of the MDE air filter.

#### ii. Angus - Biodiesel Expectations:

1. Main Drive Engine: Schumacher (38) included an evaluation of four different Dodge trucks having the same 5.9L Cummins engine but fueled with B100, 100% biodiesel. Table 3 (This is the same table that appears in the main body of this report as Table 1) compares the average levels of engine wear metals from the University of Missouri testing and the Angus for petrodiesel and adds the data gathered for Dodge trucks fueled with B100. The table also provides estimates of the ranges the wear metals that might result from fueling the Angus with B100.

The expectation is that the wear levels experienced by the Angus MDE would fall into the ranges specified in the italicized line of the table.

Table 3

	Cummins BT5.9L Engine Oil Analysis -ppm											
Iron Copper Lead Aluminum Silicon Chromium												
Angus B100*	4-27	1 – 12	0-4	0-2	3-27	0-2						
Angus Petro	20.0	4.0	3.0	2.7	14.0	1.7						
Standard Dev	7.81	3.46	1.00	0.58	7.81	0.58						
U. Mo B100**	10.86	3.25	2.15	1.72	3.10	0.95						
Standard Dev	6.65	4.42	1.82	0.87	3.08	2.57						
U. Mo Petro	13.79	1.86	2.89	4.33	2.86	1.48						
Standard Dev	5.34	1.05	2.57	1.77	0.95	0.90						

<sup>\*</sup>Projected values; not based on actual measurements – See Appendix I for calculations.

2. Electrical Power Generator: No engine test or demonstration project has been found in the literature for the Angus genset when fueled with petrodiesel or biodiesel. No acceptable wear rate has been established for this particular engine. However, the petrodiesel wear metals are comparable to those in the Angus MDE and, based on similar duty cycle descriptions, similar changes in wear metals should result. Table 4 provides estimates of the ranges the wear metals that might result from fueling the genset with B100.

Table 4

Westerbeke 20.0BEDA Genset Engine Oil Analysis - ppm										
Iron Copper Lead Aluminum Silicon Chromium										
B100*	25-28	2-10	1-4	0-3	0-31	0-3				
<b>Petrodiesel</b> 33.5 3.5 3.5 13.5 1.5										
Standard Dev 0.71 2.12 0.71 0.71 9.19						0.71				

<sup>\*</sup>Projected values; not based on actual measurements – See Appendix I for calculations.

The expectation is that the wear levels experienced by the Angus genset would fall into the ranges specified in the table.

The predicted ranges of wear metals for the Angus genset are not excessive.

- iii. **D.J. Angus Operation B20:** The Dodge truck testing at the University of Missouri included evaluation of the operation of the Cummins engine on B20.
  - 1. Main Drive Engine: There is significant over the road experience at the University of Missouri Columbia (38, 42), supporting the operation of the Angus MDE on B100. However, operating on B20 is also a viable approach. The Dodge truck testing included data from one B20 fueled truck (38). Table 5 compares the University of Missouri data with the Angus experience and predicts an oil analysis for the Angus fueled with B20. The underlying assumption is that the duty cycles are similar.

<sup>\*\*</sup>The Univ. of Missouri trucks operating on petrodiesel and those on B100 are different trucks.

Some trucks operated in Idaho and others in Missouri; some in National Parks.

The data from the Dodge truck testing for B20 is less compelling as it was taken from a single truck fueled on B20 (from Rapeseed) but ran over 100,000 miles in Idaho.

Table 5

Cummins BT5.9L Engine B20 Oil Analysis - ppm											
Iron Copper Lead Aluminum Silicon Chromiun											
Angus B20*	0-21	2-12	0-3	0-2	0-14	0-2					
Angus Petro	20.0	4.0	3.0	2.7	14.0	1.7					
Standard Dev	7.81	3.46	1.00	0.58	7.81	0.58					
U. Mo B20#	6.23	4.07	1.53	1.67	2.43	0.73					
Standard Dev	2.26	6.16	0.63	0.84	1.14	0.45					
U. Mo Petro	13.79	1.86	2.89	4.33	2.86	1.48					
Standard Dev	5.34	1.05	2.57	1.77	0.95	0.90					

<sup>\*</sup>Projected values; not based on actual measurements. See Appendix I for calculations.

### iv. Jackson Petrodiesel History:

**1. Main Drive Engines:** The wear materials of concern are the same as for the Angus, Section I.d.i.1, and relate to the same engine components.

Table 6 compares the average levels of engine wear metals from the University of Missouri testing for low sulfur petrodiesel and the average levels from the Jackson 2002 season using low sulfur, premium petrodiesel. No data for the Jackson's engine operating on biodiesel was found in the research.

The duty cycle rating for the Jackson application is Medium, Continuous while the rating for the transit bus application is Intermediate, Severe – a more severe and demanding application.

Table 6

	Detroit Diesel 6V92TA Engine Oil Analysis - ppm											
Iron Copper Lead Aluminum Silicon Chromium												
Jackson Petro	12.2	2.5	5.0	1.5	6.1	0.6						
Standard Dev	3.16	1.27	2.31	0.53	3.98	0.52						
U. of Mo Petro	89.7	27.8	11.6	0.5	19.0*	2.7						
Standard Dev	57.72	157.24	104.59	1.98	NA	1.87						

<sup>\*</sup> Silicon data is from a different reference (7) for the same test but a shorter test period and as no silicon data were reported in the final report.

The silicon in the lubricating oil is a concern as this is a measure of the abrasive material that can enter the combustion air during engine operation.

<sup>\*</sup>The Univ. of Missouri trucks operating on petrodiesel and those on B20 are different trucks operating in different environments.

See Appendix I for calculations.

The silicon in the bus oil is over five times the silicon content for the Dodge trucks from the long term University of Missouri test (See Table 3 – U. of MO petro) but is of the same order of magnitude as the Angus oil silicon content. The iron content in the bus oil samples is also approximately five times that of the Dodge truck testing (Table 3).

The data in Table 6 are of concern only in that the oil sampling wear metals from the bus tests seems high when compared to the Jackson average wear metals, the Angus data, and the other data available.

Detroit Diesel Corporation recommends that a single oil analysis metal content should be less than: 150ppm of Iron, 25ppm of Copper, and 10ppm of Lead for over the road application. Recommendations for marine limits are different only in the iron content, which is limited to 250ppm (28). The St. Louis bus test data lists two metals exceeding the recommended limits while the Jackson average and every single data point is within the recommended limit (See Appendix I & IV).

The lower mean value of silicon in the Jackson oil samples compared to the Angus (Table 7) suggest that the Jackson air filters may be more effective in preventing environmental wear materials from entering the engines.

Table 7

Jackson and Angus Oil Analysis Comparison - ppm										
Iron Copper Lead Aluminum Silicon Chromium										
Jackson Petro	6.1	0.6								
Standard Dev*	3.16	1.27	2.31	0.53	3.98	0.52				
Angus Petro	2.7	14.0	1.7							
Standard Dev	7.81	3.46	1.00	0.58	7.81	0.58				

<sup>\*</sup>See Appendix I for calculations

2. Large Electrical Power Generator: No engine oil analysis for a test or demonstration project has been found in the literature to allow a direct comparison to the large Jackson genset oil analysis or establish acceptable rates of wear. Table 8 is the average engine wear metals for the 2002 season. Lubricating oil and filters are changed at 100-hour intervals.

Table 8

Nor	Northern Lights M30C Genset Engine Oil Analysis - ppm											
Iron Copper Lead Aluminum Silicon Chromium												
Petrodiesel	6.5	2.0	1.5	2.5	7.0	0.0						
Standard Dev* 0.71 0.00 2.12 0.71 1.41 0.00												

<sup>\*</sup> Based on samples from two oil changes. See Appendix I for calculations.

Northern Lights does not have any recommendations regarding acceptable level of wear metals in engine oil from their engines (Appendix IV).

The wear metals and silicon measurements from the Toyota engine mounted on the large Jackson genset are comparable to the other engine oil analysis of the Angus's and Jackson's engines.

### v. Jackson – B20 Expectations:

1. Main Drive Engines: Table 9 (same as Table 4 in main text of report) provides estimates of the ranges the wear metals that might result from fueling the Jackson with B20. The iron wear metal for B20 usage compared to petrodiesel measurements is the most disconcerting as this is the only wear metal with a high probability of being statistically different (39).

Detroit Diesel 6V92TA Engine Oil Analysis - ppm						
	Iron	Copper	Lead	Aluminum	Silicon	Chromium
Jackson B20*	13-19	2-5	3-8	1-3	2-9	0 – 1
Jackson Petro	12.2	2.5	5.0	1.5	6.1	0.6
Standard Dev	3.16	1.27	2.31	0.53	3.98	0.52
U. of Mo B20**	115.8	42.5	13.2	0.8	17.4#	3.3
Standard Dev	57.75	157.24	104.59	1.98	NA	1.87
U Mo Petro**	89.7	27.8	11.6	0.5	19.0#	2.7
Standard Dev	57.72	157.24	104.59	1.98	NA	1.87

Table 9

The silicon in the Jackson lubricating oil analyses is low compared to that measured in the bus demonstration and is not considered an issue. Based on duty cycle descriptions, using the bus data to estimate the worst case changes to the Jackson wear metals should be conservative. The ranges of wear metals estimated for the Jackson are not excessive and are predicted to remain below the Detroit Diesel Corporation (DDC) recommended limits.

If the silicon in the Jackson oil remains in the range of the petrodiesel data when B20 is used, then the other wear metals should not vary in the same manner as it does in the buses. The expectation derived from the majority of biodiesel research is that the introduction of biodiesel (either B100 or in a blend) increases the lubricity of the fuel and reduces engine wear, increasing life. The University of Missouri data are contrary to this premise and other research (40, 58) regarding the lubricity effects of biodiesel.

Clearly, a better understanding of the effects of fueling the Jackson's engines with the B20 blend must be gained and well understood before committing to the use of B100.

<sup>\*</sup>Projected values; not based on actual measurements – see Appendix I for calculations.

<sup>\*\*</sup>The Univ. of Missouri buses operating on petrodiesel and those on B20 were different buses on different routes introducing a set of uncontrolled variables into the data.

<sup>#</sup> Silicon data is from the same test but from a different reference (7) and a shorter test period.

**2. Large Electrical Power Generator:** Table 10 introduces estimates for the wear metals for the genset if fueled with B20.

Table 10

Northern Lights M30C Genset Engine Oil Analysis - ppm						
	Iron	Copper	Lead	Aluminum	Silicon	Chromium
B20*	1-5	4-7	0-5	0-3	3-9	0-0
Petrodiesel	6.5	2.5	1.5	2.5	7.0	0.0
Standard Dev <sup>#</sup>	0.71	0.71	2.12	0.71	1.41	0.00
U. Mo B100**	10.86	3.25	2.15	1.72	3.10	0.95
Standard Dev**	6.65	4.42	1.82	0.87	3.08	2.57
U. Mo Petro**	13.79	1.86	2.89	4.33	2.86	1.48
Standard Dev**	5.34	1.05	2.57	1.77	0.95	0.90

<sup>\*</sup>Projected values; not based on actual measurements. See Appendix I for calculations

The risk of engine damage to the large genset when fueled with B20 blend should be small but risk to the mission would be slightly higher.

<sup>\*\*</sup> Data repeated from Table 3

<sup>\*</sup>Based on samples from two oil changes.

# APPENDIX IV – Operational Issues

# APPENDIX IV

# **OPERATIONAL CONSIDERATIONS:**

#### I. OPERATIONAL ISSUES:

a. Operational Fuel Blend: If the vessels are stored with petrodiesel or a low blend in the fuel tanks, and a much higher blend or biodiesel is the desired operating fuel, the ratio of biodiesel to petrodiesel of the fuel in the vessel fuel tank will vary as fuel is added. Table 1 below provides fuel data and the resulting blend ratio for an assumed fueling schedule. The issue will be the effectiveness of the mixing of the tank fuel and fuel added. The mixing will not affect the operation of the engines but will be of concern at the end of the season just before lay-up.

For 100% of tank capacity drawn down to 33% of capacity for the initial spring fueling, an effective B13 blend is predicted for the fuel in the tank after an initial fueling with B20. B20 in the fuel tank would be reached with only 4 fuel stops the first season and three the second season (fuel stop 14). Drawing the fuel tank down to near empty will shorten the time to reach B100 and reduce total emissions from the vessel. In the fall, a single fill-up with petrodiesel would result in a B7 blend for storage (fuel stop 11).

A simple Excel spreadsheet similar to Table 1 will predict the fuel-tank blend ratio automatically when the fuel added to the tank is entered.

A similar situation would arise if B100 were the fuel of choice but the resulting fuel tank blend would take much longer to reach B100 and more petrodiesel would have to be run through the tank to reach a blend of b20 or less for winter storage.

Table 1

Fuel Blend in Vessel Fuel Tank						
Fuel stop	Fuel in Tank - Percent of Tank Capacity	Amount of Fuel Added - Percent of Capacity	Type of Fuel Added	Resulting Tank Blend		
1	33%	67%	B20	B13		
2	33%	67%	B20	B18		
3	33%	67%	B20	B19		
4	33%	67%	B20	B20		
5	33%	67%	B20	B20		
6	33%	67%	B20	B20		
7	33%	67%	B20	B20		
8	33%	67%	B20	B20		
9	33%	67%	B20	B20		
10	33%	67%	B20	B20		
11	33%	67%	Petrodiesel	B7		
12	33%	67%	B20	B16		
13	33%	67%	B20	B19		
14	33%	67%	B20	B20		

**Mixing:** There are mixing issues that have been ignored in the foregoing discussions. Incomplete mixing will not harm the engines but would be concern only in the fall prior to lay-up or in the Jackson main drive engines where operation on biodiesel is considered a high risk. However, this situation arose early in the St. Louis test without any consequences to the mechanical integrity of the test buses or abnormal route delays (39).

# APPENDIX V

# FIRST SEASON RECOMMENDATIONS:

#### I. INITIAL SEASON CONSIDERATIONS:

**a. Preparatory work:** Prior to making any changes in the fuel used in either vessel, measurements of exhaust gas emissions and an analysis of exhaust gas cooling water should be completed. These measurements will form a baseline of operation for comparison to the same measurements made after the vessels change to biodiesel or B20. As AWRI is focused on research and water quality, we should understand the impact of operating our vessels and contribution to the environmental.

Both vessels should have sampling ports added to the exhaust systems on all engines so that exhaust gas samples at the exhaust manifolds and downstream of the point where the exhaust cooling water in injected. Exhaust gas cooling water should also be sampled and appropriate sampling ports to access the cooling water should be added to both vessels.

**b. Funding:** The grant under which this feasibility study was completed did not provide funding to support exhaust gas or exhaust gas cooling water analysis. Attempts to win a grant to support an organized and more enlightening approach to understanding the impact on the environment by using biodiesel or B20 in the two vessels were unsuccessful.

Alternatively, the current grant could support the preparatory work if the feasibility study and market study were completed early or the scope changed to allow the funding of the preparatory work on both vessels. This would result in a shorted schedule but more effective use of the available funds and a better understanding of the impact of the fuel on the environment.

Lacking funding, a change to biodiesel or B20 can be made without the baseline and measurements made at a later date to assess the environmental impact without knowledge of the improvement (or lack thereof). Research completed for this study indicates that there will be a positive change.

- **c. Angus Start-up:** A number of considerations are necessary once the decision is made to fuel with biodiesel or a blend.
  - **i. Fuel:** The choice of fuel for the Angus initially should be B20.
    - 1. Follow the Jackson: If the Jackson is fueled with B20 then fueling the Angus with the same fuel has the benefit of increasing the quantity of fuel bought and may bring a cost reduction to the Jackson. This is low risk for the Angus but higher than if B100 were used because less supporting data are available.

- 2. Follow the Coast Guard: If the Coast Guard station in Grand Haven converts to biodiesel then the Angus should use that fuel when it becomes available, assuming the conflict of interest between the inspection and fuel supplier roles of the Coast Guard could be resolved. The fuel of choice for the Coast Guard is likely to be biodiesel with a B50 Blend being used in the cold months. The issue then would be replacing the fuel blend in the fuel tank with a blend appropriate for winter lay-up B20 or less.
- ii. Monitor fuel filters: Biodiesel or B20 is expected to clean the Angus fuel tank of microbial growth that has accumulated. This will be deposited in the fuel filters and twice daily inspection of the main drive and genset engines fuel filters is recommended for the first week of operation. Continued, increased, periodic filter inspection of the MDE and genset filters should be carried out until the system is clean and the current interval can be reached. The crew can best determine the interval through experience. Changing the filters more frequently will be required initially but only real time experience will determine the necessary interval. Three additional filter changes are included in the start-up cost estimate of Table 26.
- **iii.** Change the Lubricating oil: The start-up cost estimate includes cost for one added oil change in the first season of operation on biodiesel. This is precautionary only and may not be required. The determining factor in the need for an oil change is fuel in the lubricating oil. Biodiesel fuel in the oil will cause the oil to sludge. Fuel in the oil can only be determined by oil analysis. The Cummins engine has not experienced these problems but piston ring condition will play a role in fuel getting into the oil.

No information regarding the Westerbeke engine and fuel/oil contamination was found in the research.

iv. Monitor Injectors: Some problems have been experienced with injector cavitation during operation with biodiesel and accumulating deposits from the fuel. These have been minor occurrences that appear to be engine specific, i.e. occur only in some engines but inspection at the end of the season should be considered. The Cummins engine has had no reported injector problems.

There is no information regarding injector problems with the Westerbeke engine.

v. Monitor Elastomeric Components: Periodic inspection of flexible hoses and elastomer seals and gaskets is recommended. Even low blend fuels can attack some components resulting in drips or worse leaks. This is not expected to affect the Cummins or Westerbeke engine or accessories.

- vi. Analysis of lubricating oil: Establish an increased frequency of oil analysis. Draw a sample of oil for analysis every 100 hours from both the main drive engine and genset for the first 400 hours of operation. Monitor the samples for changes and trends in metals and fuel content. The wear metal measured should be significantly less than the existing samples as the time between samples is shorter providing less time for engine wear metals to accumulate. The additional cost for two additional oil analyses is included in the Start-up costs summary of Table 26.
- **vii. Engine Performance:** Engine performance for the Cummins engine on biodiesel has been reported as both higher and lower than petrodiesel-fueled engines. Engines with aftercoolers tend to be 7% lower, while engines without report a 5% increase in power. In general, increased power will be experienced at low RPM and lower power at high RPM.

The Westerbeke engine will also experience a decrease in performance of the same order of magnitude as the main drive engine.

**Fuel Consumption:** Fuel consumption will increase by 5% for B100 and 1% for B20 based on over-the-road test experience.

Fuel consumption for the Westerbeke engine should also increase by 5% for biodiesel and 1% for B20. Fuel data used in Table 25 apply to the vessel as a whole so neither the main drive engine nor the genset fuel consumption can be broken out from total fuel used.

ix. Cold Weather: Cold weather storage with biodiesel or a high blend (above B20) in the fuel tank is not recommended. Copper and copper alloys will cause a black sludge to form in storage and plug fuel filters. Long-term storage should take place with B20 or less in the fuel tanks.

The no risk situation would be to negotiate a buy-back arrangement with the fuel supplier to reduce the risk of using old fuel in the spring. The supplier would accept excess B20 or biodiesel and provide a credit. The boat could then be stored with a good storage blend or 100% petrodiesel in the tanks and engine.

#### d. Jackson Start-up:

i. Fuel: The Jackson should proceed with establishing a budget and process to utilize a B20 blend for the 2003 season, if possible, and following seasons. Once the behavior of the Detroit Diesel engines is well understood, the blend ratio could then be increased. Detroit Diesel Corporation does not recommend a blend higher than B20 at this time but as there is no warranty coverage this should not be a consideration and only mechanical risk and mission risk should be considered. Further experience with B20 and

incremental increases to B100, while monitoring oil wear metals, will minimize risk to the engines. The main issue may be NOx emissions.

The use of B20 will allow AWRI to gain some experience with the Lugger and Toyota engines operating on the fuel. This should be low risk but the lack of experience with the specific engine models represents an unknown.

- **ii. Monitor fuel filters:** The fuel is expected to clean the Jackson fuel tank of microbial growth that has accumulated. This will be deposited in the fuel filters of both main engines and both gensets and twice daily inspection is recommended for the first week of operation. Changing of the filters often is recommended but only real time experience will determine the necessary interval. Three additional filter changes are included in the start-up cost estimate of Table 29.
- **iii. Monitor Elastomeric Components:** Periodic inspection of flexible hoses and elastomer seal and gaskets is recommended. Even low blend fuels can attack these components resulting in drips or worse leaks.
- iv. Change the Lubricating oil: The start-up cost estimate includes cost for one added oil change in the first season of operation on biodiesel. This is precautionary only and may not be required. The determining factor in the need for an oil change is fuel is the lubricating oil. Fuel in the oil can only be determined by oil analysis. Fuel in the oil should not be a problem but in some demonstrations excessive fuel was found in the lubrication oil and will cause sludging. The Detroit Diesel engines has not experienced these problems but piston ring condition will play a role in fuel getting into the oil.

No information regarding fuel/oil problems was found for the Lugger or Toyota engines.

v. Monitor Injectors: Some problems have been experienced with Detroit Diesel 6V92 injector cavitation and accumulating fuel deposits during operation with B20. These have been minor occurrences that appear to be engine or application specific, i.e. occur only in some engines. Inspection of injectors at the end of the season is recommended.

No information regarding injector problems was found for the Lugger or Toyota engines.

vi. Analysis of lubricating oil: Establish an increased frequency of oil analysis. Draw a sample of oil for analysis every 100 hours for both main engines and both gensets the first 400 hours of operation. Monitor the samples for changes and trends in metals and fuel content. The wear metal measured should be significantly less than the existing samples as the time

between samples is shorter providing less time for engine wear metals to accumulate. The additional cost for oil analysis is included in the start-up costs summary of Table 29.

The small genset should be added to the oil sampling program and increased running time should be considered so that an adequate database of operation on the fuel is established.

**vii. Engine Performance:** No engine performance data for the 6V92 Detroit Diesel engine on B20 were reported. In general, B20 is expected to have a minor affect on engine performance and a reduction on the order of 3 to 9% should be expected.

Both gensets will experience a change in output power on the order of +2% or -5%.

**viii. Fuel Consumption:** Fuel consumption will increase. The St. Louis buses experienced a 5.6% increase in fuel consumption when using B20. This is considerably higher than expected but may be an attribute of the two-cycle diesel engine, the bus duty cycle, or the engine condition. The 5.6% value and the extrapolated value of 28.7% were used to calculate fuel consumption in Table 28 and are believed to be a worst case. Both of these values are suspect and need to be verified or disputed by data from the Jackson. The high value impacts hourly operational costs heavily and, if accurate, will seriously restrict the blend level useable in the Jackson.

The Lugger and Toyota engines should experience no more than a 2% increase in fuel consumption when fueled with B20. However, since the fuel data used in Table 26 apply to the vessel as a whole, two main engines and two gensets, fuel usage estimated will be overstated to a minor degree.

ix. Cold Weather: Cold weather storage with biodiesel or a high blend (above B20) in the fuel tank is not recommended. Copper and copper alloys will cause a black sludge to form in storage and plug fuel filters. Long-term storage should take place with a B20 or lower blend in the fuel tanks. Petrodiesel in the engine and fuel lines is the lowest risk situation for winter lay-up, but only slightly better than B20.

The no-risk situation would be to negotiate a buy-back arrangement with the fuel supplier to reduce the risk of using old fuel in the spring. The supplier would accept excess B20 or biodiesel and provide a credit. The boat could then be stored with a good storage blend or 100% petrodiesel in the tanks and engine.

**x. Air Filtration:** Improvements to combustion air filtration should not be a consideration for the Jackson.

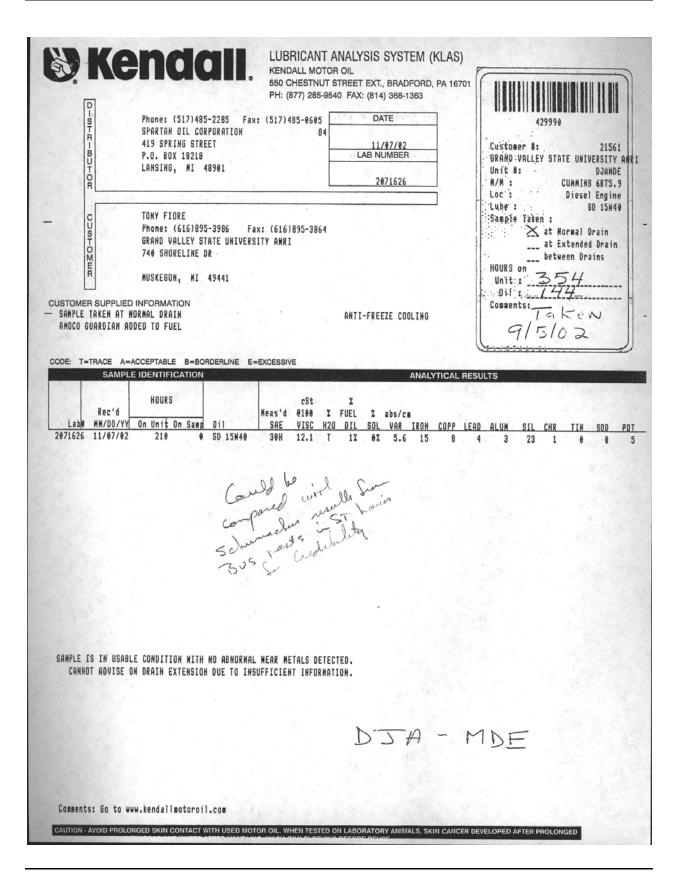
## APPENDIX VI

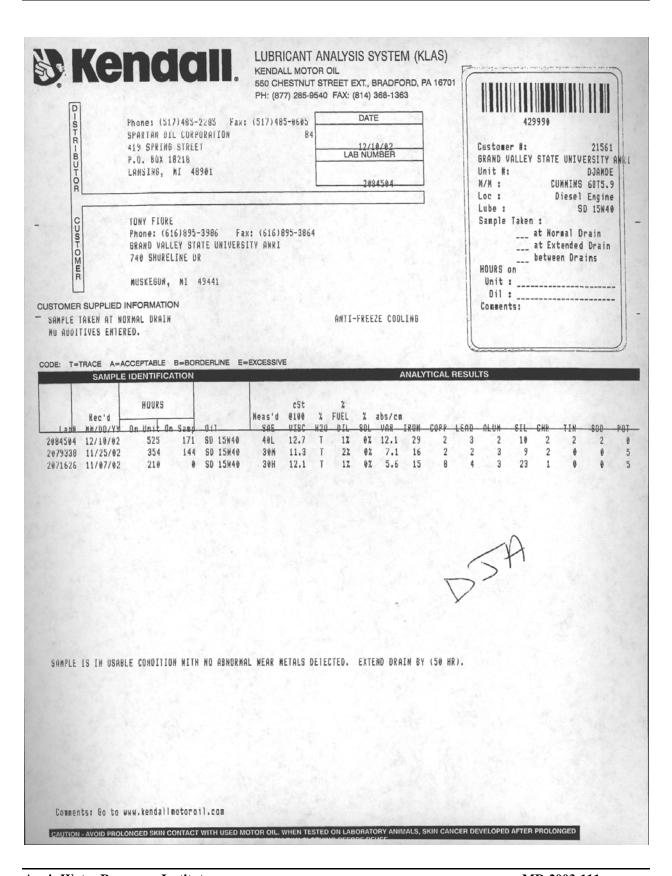
ENGINE MANUFACTURERS DATA
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**CUMMINS, INC** 

**Engine Data** 





## Marine Products Page 2 of 4 Continuous Duty (CON) Intended for continuous use in applications requiring uninterrupted service at full power. This rating is an ISO 3046 standard power rating. Typical vessel applications include: oceangoing displacement hulls such as fishing trawlers, freighters, tugboats, bottom drag trawlers, and towboats. Heavy Duty (HD) Intended for continuous use in variable load applications where full power is limited to eight (8) hours out of every ten (10) hours of operation. Also, reduced power operations must be at or below 200 rpm of the maximum rated rpm. This is an ISO 3046 fuel stop power rating and is for applications that operate 5,000 hours per year or less. Typical vessel applications include: displacement hull vessels such as mid-water trawlers, purse seiners, and towboats where frequent slowing is common and engine speed and load is stable. Also used in high speed vessels such as ferries and crewboats. Medium Continuous Duty (MCD) Intended for continuous use in variable load applications where full power is limited to six hours out of every twelve hours of operation. Also, reduced power operations must be at or below 200 rpm of the maximum rated rpm. This rating is an ISO 3046 fuel stop power rating and is for applications that operate less than 3,000 hours per year. Typical vessel applications include: planing hull ferries, fishing boats designed for high speeds to and from fishing grounds, offshore service boats, and also (non-cargo) displacement hull yachts and short trip coastal freighters where engine load and speed are cyclical. Intermittent Duty (INT) Intended for intermittent use in variable load application where full power is limited to two hours out of every eight hours of operation. Also, reduced power operations must be at or below 200 rpm of the maximum rated rpm. This rating is an ISO 3046 fuel stop power rating and is for applications that operate less than 1,500 hours per year. Typical vessel applications include: planing hulls such as customs, military and police vessels, charter and some fishing vessel applications. High Output (HO) Intended for use in variable load applications where full http://www.gce.cummins.com/mce/mce pages/productpage.htm 3/19/2003

# Marine Products Page 3 of 4 power is limited to 1 hour out of every 8 hours of operation. Also, reduced power must be at or below 200 rpm of the maximum rated rpm. This power rating is for pleasure / nonrevenue generating applications that operate 300 hours per year or less. Typical vessel applications include pleasure craft such as sportfishers, motoryachts, and cruisers. BHP - ISO 8665 fuel stop power rating. Fuel 40 C (104 F). Metric Horsepower - ISO 3046 fuel stop power rating. Fuel 25 C (77 F) Top of page **Marine Emissions Certifications** On January 1, 2000, emissions standards set forth by the International Maritime Organization (IMO) entered into effect in many areas of the world for marine diesel engines above 130 kW (174hp). This is the first time in history that diesel emissions from vessels have been subjected to a control standard, however it will not be the last. Cummins is making the investment now to ensure our products not only meet the standards of today, but are ready to meet the challenges of Cummins Marine offers a full line of certified emissions compliant engines, with certificates available from the U.S. Environment Protection Agency (EPA) and Lloyd's Register of Shipping. The emissions status of each Cummins engine is indicated in the Marine Products table. **Onan Generators** At Onan, we've spent decades focused on one goal developing the best-designed and most innovative marine generator sets in the industry...which is why we are the global leader in marine genset production. More than 60 years of marine experience, gained by supplying generators to the U.S. Coast Guard, Navy, recreational boaters, and some of the finest yacht builders in the world, is built into every Onan marine generator. Our extensive line of marine generator sets from 4-95 kW provide state-of-the-art reliability and smooth, quiet operation. Top of page Marine Product Line You can also click the "marine products" button at the top of the page (left). http://www.gce.cummins.com/mce/mce pages/productpage.htm 3/19/2003



## Service Bulletin

Subject

**Fuels for Cummins Engines** 

Bulletin No. Date: 3379001-07 01-Oct-2002

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## Introduction

This bulletin covers information about fuels for Cummins engines. The purpose of this bulletin is to help the user understand proper fuel selection, and problems associated with fuel.

## **Diesel Fuel**

Diesel fuel performs three major functions in a Cummins diesel engine.

- 1. It supplies all the energy for the engine.
- 2. It cools and lubricates the precision parts of the engine's fuel pump and injectors.
- 3. It enables emissions controlled engines to meet regulated emissions levels.

## **Premium Diesel Fuel**

Cummins diesel engines will run on a great variety of fuels, but some fuels will give better performance, higher efficiency, improved reliability, or lower maintenance costs than others. Fuel must be selected based on overall operating costs, not just on the purchase price. Cummins recommends the use of premium fuels meeting the requirements of Category 1 through 4 as outlined in the Worldwide Fuel Charter (www.engine-manufacturers.org/about/guidelines.cfm). Operators must select fuels from these categories to optimize performance and emissions.

## Category 1:

Markets with no or minimal requirements for emission controls.

## Category 2:

Markets with stringent requirements for emission controls that requires the use of low sulfur fuel, for example, vehicles meeting United States and European on-highway standards. The maximum is 0.05 percent sulfur.

Cummins Inc., Columbus, Indiana 47202-3005
Cummins Engine Company Ltd., Daventry, Northants, England NN11 5NU
Registered Office: 46-50 Coombe Road, New Malden, Surrey KT3 4QL
Registered No. 573951 England
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Markets with advanced requirements for emission controls that require ultra low sulfur fuel (less than 50 ppm) for after-treatment devices.

Category 4: Markets with further advanced requirements for emission control to enable sophisticated NOx and PM aftertreatment technologies. This normally requires no detectable sulfur in fuel.

Category 4:

Markets with further advanced requirements for emission control to enable sophisticated NOx and PM aftertreatment technologies. This normally requires no detectable sulfur in fuel.

## Required Diesel Fuel Specifications

This section presents the fuel specifications required by Cummins.

Fuels meeting national and international specifications can be used if they observe the specifications listed in Table 1: Required Diesel Fuel Specifications. Cummins engines will operate satisfactorily on fuels meeting all the properties listed in Table 1; however, fuels meeting only the required specifications may not give the same level of performance, efficiency, reliability or maintenance costs as premium fuels.

Table 1: Required Diesel Fuel Specifications					
Viscosity	1.3 to 5.8 centistokes (1.3 to 5.8 mm per second) at 40°C [104°F]				
Cetane Number	42 minimum above 0°C [32°F]; 45 minimum below 0°C [32°F]				
Sulfur Content	Not to exceed 0.5 mass-percent <sup>1</sup>				
Active Sulfur	Copper Strip Corrosion not to exceed Number 2 rating after 3 hours at 50°C [122°F]				
Water Sediment	Not to exceed 0.05 volume-percent				
Carbon Residue	Not to exceed 0.35 mass-percent on 10 volume-percent residuum				
Density	0.816 to 0.876 grams per cubic centimeter (g/cc) at 15°C [60°F]				
Cloud Point	6°C [10°F] below lowest ambient temperature at which the fuel is expected to operate				
Ash	Not to exceed 0.02 mass-percent (0.05 mass-percent with lubricating oil blending)				
Distillation	The distillation curve must be smooth and continuous				
Lubricity SLBOCLE, or HFRR	3100 grams or greater SLBOCLE, or 0.45 mm maximum: Wear Scar Diameter (WSD) at 60°C [140°F] HFRR				

<sup>1.</sup> Regional, national, or international regulations can require a lower sulfur content than 0.5 percent. Consult all applicable regulations before selecting a fuel for a given engine application. Fuel with sulfur higher than 0.5 percent is not allowed without prior approval by Cummins. Fuel system corrosion, heightened emissions, and reduced oil drain intervals are just some of the possible adverse effects of fuels with very high sulfur. Fuel must observe proper flash point requirements to satisfy local safety regulations.

## Diesel Fuel Properties

- Viscosity
  - General Description Proper viscosity provides adequate pumping and lubricating characteristics to fuel system components.
  - Test Method ASTM D445, ISO 3104
- Cetane Number
  - General Description Cetane number is a measure of the starting and warm-up characteristics of a fuel. In cold weather or in service with prolonged low loads, a higher cetane number is desirable.

- Test Method - ASTM D613, ISO 5165

- Fuel with a cetane number greater than 55 may cause increased torque peak smoke. Reference ASTM D613, ISO 5165.
- Sulfur Content
  - General Description Diesel fuels contain varying amounts of various sulfur compounds. Fuel sulfur contributes to acid formation and exhaust particulates. Reduced sulfur is required to meet particulate

emissions and to avoid poisoning after-treatment devices. Higher sulfur fuel also needs higher total base number (TBN) lubricants to compensate for acid corrosion.

NOTE: Catalyst failures caused by the use of fuels with higher than recommended sulfur levels are not warrantable. High sulfur fuel will also shorten the life of certain components in the exhaust system, including the oxidation catalyst.

- Test Method ASTM D2622, ISO 4260
- Active Sulfur
  - General Description Some sulfur compounds in fuel are actively corrosive.
  - Test Method ASTM D130, ISO 2160
- · Water and Sediment
  - General Description The amount of water and solid debris in the fuel is generally classified as water and sediment. It is good practice to filter fuel while it is being put into the fuel tank. More water vapor condenses in partially filled tanks due to tank breathing caused by temperature changes. Filter elements, fuel screens in the fuel pump, and fuel inlet connections on injectors must be cleaned or replaced whenever they become dirty. These screens and filters, in performing their intended function, become clogged when using a poor or dirty fuel and will need to be changed more often.
  - Test Method ASTM DI796
- · Carbon Residue
  - General Description The tendency of a diesel fuel to form carbon deposits in an engine can be estimated by determining the Ramsbottom or Conradson carbon residue of the fuel after 90 percent of the fuel has been evaporated.
  - Test Method ASTM D524, ASTM D189, ISO 10370
- Density
  - General Description Density is an indication of the energy content of the fuel. Higher density indicates more thermal energy and better fuel economy.

    Test Method – ASTM D287, D4052, ISO 3675
- - General Description The cloud point of the fuel is the temperature at which crystals of paraffin wax first appear. Crystals can be detected by the cloudiness of the fuel.
  - Test Method ASTM D97, ISO 3015
- Cold Filter Plugging Point
  - General Description The cold filter plugging point of the fuel is the lowest temperature at which fuel can still flow through a 45 micron wire mesh. This test method can be directly related to a fuel's tendency to plug fuel filters at reduced temperatures due to the formation of paraffin wax crystals.
  - Test Method ASTM D6371
- - General Description The small amount of noncombustible metallic material found in almost all petroleum products commonly is called ash.
  - Test Method ASTM D482, ISO 6245
- Distillation
  - General Description At least 90 percent of the fuel must evaporate at less than 360°C [680°F]. All of the fuel must evaporate at less than 385°C [725°F].
  - Test Method ASTM D86, ISO 3405
- Lubricity (ball on cylinder evaluator) BOCLE
  - General Description Lubricity is the ability of a liquid to provide hydrodynamic and boundary lubrication to prevent wear between moving parts. Fuel with lower sulfur and viscosity tends to have lower lubricity. It can be measured by either one of two procedures.
  - - ASTM D6078, Scuffing Load Ball On Cylinder Evaluator (SLBOCLE), or ASTM D6079, ISO 12156, High Frequency Reciprocating Rig (HFRR)

## **Contingency Diesel Fuel Specifications**

This section presents the specifications for fuels which are only to be used when fuel meeting the required specifications are not available. In the case that fuels meeting the Required Specifications in Table 1 are not available, Cummins has prepared contingency specifications to aid the user in choosing the most acceptable contingency fuel.

## △ CAUTION △

Fuels outside the recommended fuel specifications, but within the contingency specifications, are only meant to be used for short periods of time when no other fuels are available. Use of contingency fuels can have an adverse effect on engine performance and durability. Cummins assumes no warranty responsibility for repairs or increased costs of operation resulting from the use of fuels that do not conform to the specifications listed in Table 1.

#### Guidelines for The Use of Contingency Fuels

- 1. A calibration change of the fuel pump or injectors is not recommended when changing to a contingency fuel that meets all the specifications shown in Contingency Diesel Fuel Specifications, although changing to a contingency fuel can cause a slight power loss and can result in higher than normal wear of certain components. See the sections in this bulletin on Power Loss and Component Wear and Durability for additional information.
- 2. Although it is not anticipated that smoke levels will increase when fuels meeting the contingency fuel specifications are used for short periods of time, the user must make sure that the use of such fuels does not result in a smoke level which exceeds legal limits applied to the owner or operator. Continued use of fuels meeting the contingency fuel specifications can result in increased smoke levels.
- 3. Some jet fuel lubricities can be too low to provide the necessary lubrication for the fuel system components. If (based on the fuel supplier's specifications) a fuel does not have the minimum lubricity listed for contingency fuels in Contingency Diesel Fuel Specifications, a fuel additive must be added to the fuel to increase the lubricity and specially enhanced fuel system components must be used. Refer to the section in this bulletin on fuel additives. Consult Cummins for available hardware options.

# ▲ WARNING ▲

Some contingency fuels, such as jet fuels and kerosene, are much more flammable than normal diesel fuel. Use extreme care to keep cigarettes, flames, pilot lights, sparks, arcing equipment and switches, and other sources of ignition away and out of areas sharing ventilation.

Additional maintenance can be required when using contingency fuels. Those using contingency fuels must consult with their fuel supplier to determine any problems which can result from using fuels meeting Contingency Diesel Fuel Specifications. If there is still a question, data on the fuel's physical properties must be submitted to Cummins Service Engineering Department for review before use in Cummins engines.

Table 2:	Contingency Diesel Fuel Specifications <sup>1</sup>
Viscosity	1.3 to 13.1 centistokes
Cetane Number	35 minimum above 0°C [32°F]; 40 minimum below 0°C [32°F]
Sulfur Content	Less than 2.0 mass-percent. Catalyst equipped engines may not be able to use high sulfur fuel even for a short period of time without permanent damage to the catalyst.
Active Sulfur	Copper Strip Corrosion not to exceed Number 2
Water and Sediment	Not to exceed 0.5 volume-percent
Carbon Residue	Not to exceed 5.0 mass-percent on 10 volume-percent residuum
Density	0.750 to 0.965 g/cc at 15°C
Cloud Point	Lowest temperature at which fuel can be maintained without forming paraffin wax crystals.
Pour Point	Lowest temperature at which fuel can still flow.
Ash	Not to exceed 0.05 mass-percent
Distillation	90 volume-percent at 395°C [743°F]
Lubricity (ball on cylinder evaluator) SLBOCLE	Minimum of 2300 grams SLBOCLE, maximum of 0.6 mm Wear Scal Diameter WSD at 60°C [140°F] HFRR
Vanadium	5 ppm, maximum
Aluminum	1 ppm, maximum
Silicon	1 ppm, maximum
Sodium	10 ppm, maximum

1. Reference test methods in Diesel Fuel Properties

## Effects of Contingency Diesel Fuels on Engine Operation

#### Viscosity

Low viscosity causes rapid wear of fuel pump and injectors. High viscosity causes hard starting, white smoke
when cold, injector cup cracking, and injector train failures. Governor wear on rotary fuel pumps can cause
loss of regulation.

#### Cetane Number

 Low cetane number can cause poor starting, excessive white smoke, and poor idling. Cetane number above 55 can increase torque peak smoke.

### Sulfur Content

High sulfur content increases wear in injectors, piston rings, and bearings. Use of fuels with sulfur content
above 0.5 mass-percent requires the use of higher total base number (TBN) lubricants (TBN greater than
10) and shorter oil drain intervals.

NOTE: Catalyst failures caused by the use of fuels with higher than recommended sulfur levels are **not** warrantable. High sulfur fuel will also shorten the life of certain components in the exhaust system, including the oxidation catalyst.

#### · Active Sulfur

 Excessive active sulfur increases the corrosive attack on the fuel pump, injectors, and other fuel system components.

### Water and Sediment

- Contaminated fuels reduce filter life, fuel system life, and cause on-road failures.

## · Carbon Residue

 High carbon residue causes increased combustion chamber carbon deposits, more exhaust smoke, and higher soot contamination of the lubricating oil.

#### Density

 Lighter fuels contain less thermal energy per gallon and result in somewhat lower fuel economy. A fuel with a density of 0.876 g/cc contains about 3.5 percent more energy per gallon than a fuel with a density of 0.815 g/cc.

## · Cloud Point

— Operating below the cloud point temperature can cause the fuel filter to clog with wax crystals, restrict fuel flow, and cause loss of power. It is suggested that if fuels with cloud points above the expected ambient temperatures are purchased, the consumer must consult the fuel supplier and Cummins Inc. concerning fuel handling techniques. For more information, refer to Common Issues With Winter Fuel.

## Pour Point

Operating near or below the pour point will cause start-up issues. It is doubtful that most fuel pumps could
operate at the pour point. In fact, it is recommended that systems be operated at 10 to 15 degrees F above
the pour point of a fuel.

## · Cold Filter Plugging Point

— Operating below the cold filter plugging point temperature will cause the fuel filter to clog with wax crystals, restrict fuel flow, and cause loss of power. If is suggested that if fuels with cold filter plugging points above the expected ambient temperatures are purchased, the consumer must consult the fuel supplier and Cummins Inc. concerning fuel handling techniques. For more information, refer to Common Issues with Winter Fuel.

## · Ash

 High ash content causes deposits of noncombustible metallic material in the combustion chamber and on the exhaust valves.

## · Distillation, Maximum

 Fuels with high distillation temperature can leave gummy deposits in the fuel system and result in poor fuel combustion.

## Lubricity

- Fuels with low lubricity can cause increased wear or seizure of fuel system components.

## Vanadiun

- Fuels with high vanadium content can cause valve burning.

## Aluminum

 Fuels with high levels of aluminum can cause premature ring and liner wear which can lead to excessive oil consumption.

- · Silicon
  - Fuels with high levels of silicon can cause premature ring and liner wear which can lead to excessive oil
    consumption.
- · Sodium
  - Fuels with high levels of sodium can cause premature ring and liner wear which can lead to excessive oil
    consumption. Sodium can combine with vanadium, if present, and catalyze, causing valve burning.
- · Zinc
  - Fuels with high levels of zinc can cause injector spray hole carboning. Do not use galvanized pipe or fittings
    in the fuel system plumbing. Diesel fuel will leach zinc galvanized material.

#### Power Loss

This section gives guidelines on power loss to be expected when using recommended or contingency fuels, or fuels that are above normal temperature.

**NOTE:** The values given concerning power loss due to the use of contingency fuels are intended **only** to help estimate power loss. Power loss can vary greatly, depending on operating conditions, engine type, fuel system type, fuel composition, and other factors. These guidelines can **not** be used to precisely calculate engine power loss.

The use of contingency fuels can cause a decrease in the power output of the engine due to differences in fuel density and viscosity. In addition, changes in fuel temperature also affect engine power output because temperature affects both viscosity and density.

#### Density

All engines will have a predictable variation in power output depending on the density of the fuel used. Engines using fuels with a high density will produce more power than those using fuels with a lower density because the thermal energy content of the fuel is higher. Since fuel is marketed by volume, lower density fuel carrying less thermal energy results in a proportional decrease in fuel economy or power output.

#### Viscosity

In general, lower viscosity results in lower power due to increased internal leakage in the fuel system. Also, lower viscosity fuels generally have lower thermal energy content. The effect viscosity has on power depends on the type of fuel system used.

## Temperature

Temperature causes changes in engine power because it affects both viscosity and density. An increase in fuel temperature will cause a decrease in viscosity, which will reduce power due to internal leakage in the fuel system as described above. The maximum recommended fuel pump inlet temperature for Cummins engines is 70°C [158°F].

An increase in fuel temperature will also cause a decrease in fuel density (increase in API gravity), which will reduce power due to lower energy content of the fuel. On Cummins engines using the PT®, Quantum, or HPI fuel systems, the power loss due to increasing temperature is less than that on engines using the in-line, distributor, or CELECT™ systems (less than 1 percent per 5°C [10°F]), due to the inherent viscosity compensating characteristics of these systems.

## Component Wear and Durability

This section shows the effects of contingency fuels on wear and durability of fuel systems components.

The use of contingency fuels can affect the wear and durability of both fuel pump and injector components within the fuel system. Many of these fuels are low in viscosity and lubricity as measured in the Ball On Cylinder Lubricity Evaluator (BOCLE) tests. Fuels with lubricity values below 2300 grams are considered to have poor lubricity and can cause failure of fuel system components. Other factors that affect wear and durability are sulfur, water, and sediment content. High sulfur content increases wear of the fuel system components. Abnormal quantities of water and sediment in the fuel will also cause excessive wear, as well as other engine problems.

## **Fuel Blending**

This section presents the effects of blending fuels with used and new lube oil, other fuels, and with gasoline, gasohol, or alcohol.

There are two different types of fuel blending processes referred to in this section. The first is the blending of used engine lubricating oil to reduce fuel costs and to aid in disposing of used engine oil. This section also discusses the blending of fuel and engine oil in on-highway applications. The second is the blending of heavier fuels with lighter fuels to lower the wax content, cloud point, and pour point, and thus improve cold weather operation. In addition, the effects and hazards of mixing alcohol with diesel fuel are discussed.

Blending Fuel and Lubricating Oil for On-Highway Applications



Some state and federal agencies have determined that used engine oil can be carcinogenic and can cause reproductive toxicity. Avoid inhalation of vapors, ingestion, and prolonged contact with used engine oil. If not reused, dispose of in accordance with local environmental regulations.

## △ CAUTION △

Engines equipped with an oxidation catalyst must not use fuel blended with lubricating oil. The lubricating oil causes deposits in the catalyst which will plug the catalyst and possibly cause higher emission levels and reduced engine performance.

## △ CAUTION △

Do not blend more than 5 percent used lubricating oil with the fuel. Do not blend other used oils with fuel, such as transmission fluid, gear case oil, and so forth.

Used engine lubricating oil can be blended with fuel using the Cummins Lube Oil Blender, Part Number 3376317 (110 volt, 60 Hz) or Part Number 3376362 (220 volt, 50 Hz). This process can be used to supplement fuel supply as well as provide a means of disposing of used lubricating oil.

To blend used engine oil with fuel, follow the instructions provided with the Cummins Lube Oil Blender.

Two rulings by the United States Environmental Protection Agency (EPA) affect the practice of blending lubricating oil with diesel fuel in the United States. First, on September 10, 1992, the Office of Solid Waste of the United States Environmental Protection Agency determined that used lubricating oil was not classified as hazardous waste. In addition, the blending of used lubricating oil with diesel fuel for burning in diesel powered vehicles was determined to be an acceptable method for disposing of used lubricating oil (57 Federal Register, R 41583, September 10, 1992). Second, beginning October 1, 1993, diesel fuel used in motor vehicles, as defined by the EPA, in on-highway applications must contain less than 0.055 percent sulfur by weight (Mandated in Section 211 of the 1990 Clean Air Amendments; 57 Federal Register, P. 19535, May 7,1992). Fuel blended with lubricating oil must also meet this specification.

Cummins allows the blending of lubricating oil with fuel used in their engines, except those equipped with an oxidation catalyst, often referred to as a catalytic converter (such as 1994 M11's and 1994 C8.3's used in urban transit buses, and 1994 B5.9's and C8.3's used in automotive applications). Cummins permits a maximum of 5 percent used lubricating oil to be blended with fuel. This helps to reduce operating costs and aids in the disposal of used engine oil. The blending of new lubricating oil to raise viscosity is also permissible. This helps to increase the viscosity of lighter fuels to acceptable levels. Cummins' recommendations for the blending of lubricating oil with fuel used in its engines have not changed; however, if blended fuel used in motor vehicles, as defined by the EPA, in on-highway applications exceeds the maximum sulfur content, United States federal law has been violated and penalties can be assessed. To be sure that blended fuel complies with the law, the following procedure must be followed. Both the diesel fuel and lubricating oil must have their sulfur content measured by a qualified laboratory using the testing method specified in ASTM D2622 (American Society of Testing and Materials Standard, or ISO 4260). Once the correct blend factor has been determined, multiply this by the volume of fuel to be blended. The result is the amount of this oil that can be blended with this fuel and remain within legal limits. Similar restrictions and processes must be followed worldwide where regional or national regulations can impose such sulfur limits.

As an example, consider 50,000 gallons of fuel with a sulfur content of 0.04 percent by weight and lubricating oil with a sulfur content of 0.5 percent by weight. Of this oil, 450 gallons can be blended with 50,000 gallons of this fuel and remain within legal limits for sulfur content in the United States. Margins must be allowed for measurement errors.

## Blending Fuel with Fuel

Cummins recommends the use of a premium diesel fuel during winter (ambient conditions at -7°C [20°F] or below) operating conditions. See Additives section of this bulletin.

In cold-weather operation, the most common method of preventing fuel waxing problems is to dilute heavier, higher wax content fuels such as U.S. Number 2-D diesel fuel with lighter, lower wax content fuels such as Number 1-D diesel or jet fuel. This reduces the concentration of wax, and thereby reduces both the cloud point and pour point. Blended fuels of this nature are more expensive to use both because they cost more and because they have a lower thermal energy content. A typical blended fuel contains 30 to 60 volume-percent light distillate fuel, usually yielding a 3 to 7°C [5 to 12°F] drop in cloud point, and a 5 to 11°C [9 to 20°F] drop in pour point. Lower wax content fuels must be added BEFORE wax forms to be effective.

Blending Fuel with Gasoline, Gasohol, and Alcohol

## A WARNING

Under no circumstances must gasoline or alcohol be used to dilute diesel fuel. This practice creates an extreme fire hazard and under certain circumstances an explosive hazard. Gasoline dilution is not an effective way to lower cloud point (20 volume-percent gasoline only lowers cloud point 4°C [7°F] and it lowers the fuel viscosity, cetane number, and flash-point). Alcohol dilution will increase the cloud point.

This section gives information on the use of fuel additives in Cummins engines including the use of bio-diesel and water emulsifiers.

Cummins Inc. neither approves nor disapproves of the use of any fuel additive, fuel extender, fuel system modification, or the use of any device not manufactured or sold by Cummins Inc. or its subsidiaries. Engine damage, service issues, or performance problems that occur due to the use of these products are not considered a defect in workmanship or material as supplied by Cummins Inc. and can not be compensated under the Cummins warranty.

Cummins engines are designed, developed, rated, and built to operate on commercially available diesel fuel as listed in Required Diesel Fuel Specifications; therefore, it is not our policy to recommend fuel additives.

In extreme situations, when available fuels are of poor quality or problems exist which are peculiar to certain operations, additives can be used. However, Cummins recommends consultation with the fuel supplier or Cummins Service Engineering Department prior to use of fuel additives.

Among the situations where additives can prove useful are the following:

- 1. A cetane improver additive can be used with low certain fuels.
- 2. A pour point depressant or flow improver additive can help with high pour point fuels.
- 3. A wax crystal modifier can help with fuels with high cold filter plugging points (CFPP).
- 4. An anti-icer can help prevent ice formation in wet fuel during cold weather.
- 5. Fleetquard's Fleet-tech™ Winter Conditioner (pint CC2591, quart CC2592, 2.5 gallon CC2595, 5 gallons -CC2593, 55 gallons - CC2594, and bulk - CC2590) can be used to improve the pour point and cold filter plugging point of diesel fuels in addition to preventing ice formation in wet fuels during cold storage. Although other additives are available that may provide some winter performance benefits, Fleet-tech™ Winter Conditioner is the only diesel fuel additive recommended by Cummins for winter performance improvements.

  6. An anti-oxidant or storage stability additive can help with fuel system deposits and poor storage stability.
- 7. A lubricity enhancer can be used to increase the lubricity of fuels so that they meet the requirements given in table
- 8. Cummins Premium Plus Diesel Fuel Additive or Fleetguard's Fleet-tech™ Asphaltene Conditioner (quart CC2597 and 2.5 gallon CC2596) can be used to clean carbon deposits from injectors and improve lubricity in fuels that fall below the recommended lubricity specification in Table 1. Although other additives may provide some performance benefits, Premium Plus and Fleet-tech™ Asphaltene Conditioner are the only diesel fuel additives recommended by Cummins for use with fuels that do not meed the lubricity specification in Table 1.
- 9. A blocide or fungicide can help when fuels are prone to contamination with bacteria or fungus. Although other additives may provide some performance benefits, Fleet-tech™ Microbicide (quart - CC2661 and gallon - CC2662) is the only product recommended by Cummins to treat fuels with biological contamination problems.

Premium diesel fuels can possibly contain several additives that can accomplish the same as buying additives and adding them to lower quality diesel fuel. A premium diesel fuel is defined by the Worldwide Fuel Charter as described on page 1.

Cummins recommends the use of a premium diesel fuel during winter (ambient conditions at -7°C [20°F] or below) operating conditions.

Great care must be exercised in the choice and use of additives. Some fuel additives can be harmful to the engine. Fuel additives containing ash forming materials will cause combustion chamber deposits. Most legitimate fuel additives perform only one function. Multifunctional fuel additives are mixtures of several additives. All fuel additives perform differently in different fuels; therefore, the additive used must be one to which the fuel will respond. There are no known additives that increase the power or improve the efficiency of a properly maintained engine.

NOTE: Cummins Inc. accepts no liability for engine damage resulting from the use of fuel additives which are not specifically recommended by Cummins.

With increased interest in emissions and reducing the use of petroleum distillate based fuels, many governments and regulating bodies encourage the use of bio-fuels. Bio-diesel fuels must be considered experimental at this time.

Bio-diesel fuels are methyl/ethyl ester-based oxygenates derived from a broad variety of renewable sources such as vegetable oils, animal fats, and cooking oils. Their properties are similar to diesel fuel, as opposed to gasoline or gaseous fuels, and thus are capable of being used in compression ignition engines. Soy Methyl Ester (SME) or some SME Diesel is the most common bio-diesel in the United States and is derived from soybean oil. Soy Diesel is a bio-diesel or petro-diesel blend based on SME. Rape Methyl Ester (RME) Diesel is the most common bio-diesel in Europe and is derived from rapeseed oil. These fuels are collectively known as Fatty Acid Methyl Esters (FAME).

Cummins test data on the operating effects of bio-diesel fuels indicates that typically smoke, power, and fuel economy are all reduced. However, as there are no firm industry standards on the content and properties for bio-fuels, consistency and predictability of bio-diesel operation is not well documented. There are provisional specifications for FAME issued in Germany under DIN V 51 606 and also recently through ASTM as PS121; however, these standards are under development and are subject to change.

Cummins certifies its engines using the prescribed EPA and European Certification Fuels. Cummins does **not** certify engines on any other fuel. It is the user's responsibility to use the correct fuel as recommended by the manufacturer and allowed by EPA or other local regulatory agencies. In the United States, the EPA allows use of **only** registered fuels for on-highway applications. The EPA has additional alternative fuel information at: <a href="http://www.epa.gov/otaq/consumer/fuels/altfuels/altfuels/altfuels/altfuels.htm">http://www.epa.gov/otaq/consumer/fuels/altfuels/altfuels.htm</a>.

It is the responsibility of the user to obtain the proper local, regional, or national exemptions required for the use of bio-diesel in any emissions regulated Cummins engine.

### Warranty and the Use of Bio-Diesel Fuel in Cummins Engines

Cummins neither approves nor disapproves of the use of bio-diesel fuel blends. There is a major difference between operating on pure (100 percent concentration) bio-diesel fuels and bio-diesel or petro-diesel fuel blends. Cummins is not in a position to evaluate the many variations of bio-diesel fuels, and the long-term effects on performance, durability or emissions compliance of Cummins products. The use of bio-diesel fuel does not affect Cummins materials and workmanship warranty. Failures caused by the use of bio-diesel fuels or other fuel additives are not defects of Cummins parts or workmanship and therefore would not be covered by Cummins warranty.

Given the current industry understanding of bio-fuels and blending with quality diesel fuel, it would be expected that blending up to a 5 percent volume-concentration should or most probably will **not** cause serious problems. This is consistent with the position taken by worldwide fuel system manufacturers.

For customers intent on blending bio-fuels above a 5 percent volume-concentration, the following concerns represent what is currently known in the industry. Concentrations beyond 5 percent by volume can have an adverse affect on the engine's performance and the fuel system integrity or durability. The affects are more serious with increasing concentration levels. Areas of concern when operating with bio-diesel fuels include low temperature operability (fuel gelation, filter plugging), heat content (poor fuel economy), and storage and thermal stability (filter plugging, injector deposits). In addition, from our fuel systems suppliers, the following issues are also noted:

- . Swelling and hardening or cracking of some elastomer seals within the fuel system or engine
- Corrosion of fuel system and engine hardware, especially aluminum and zinc
- · Solid particle blockage of fuel nozzles and passages
- Filter plugging
- Injector coking
- · Higher injection pressures due to physical flow properties, reduced fuel system life
- Added stress and heat to injection components, especially rotary fuel pumps
- Increased pump seizures and early life failures
- · Poor fuel spray atomization, reduced fuel economy
- Poor lubricity, reduced service life of fuel pump and fuel system.

Pure bio-diesel fuel is **not** stable and its acid content increases over time which can damage powdered metal components.

Operational Factors to Consider:

- The oil change interval can be affected by the use of bio-diesel fuel. End users are advised to use oil sampling to monitor the engine oil condition and to determine the optimum oil change interval. Pure bio-diesel fuel can cause a chemical reaction with lube oil resulting in oil sludging.
- Bio-diesel provides approximately 5-7 percent less energy per gallon of fuel when compared to distillate fuels. To avoid engine problems when the engine is converted back to 100 percent distillate diesel fuel, do not change the engine rating to compensate for the power loss when operated with bio-diesel fuels.
- Elastomer compatibility with bio-diesel is still being monitored. The condition of seals, hoses, gaskets, and wire coatings must be monitored regularly.
- Bio-diesel fuels can pose low ambient temperature problems for both storage and operation. At low ambient temperatures, fuel can possibly need to be stored in a heated building or a heated storage tank. The fuel system can require heated fuel lines, filters, and tanks. Filters can plug and fuel in the tank can solidify at

low ambient temperatures if precautions are **not** taken. Consult your bio-diesel supplier for assistance in the blending and attainment of the proper cloud point fuel.

- Bio-diesel has poor oxidation stability which can result in long term storage problems. The poor oxidation stability qualities can accelerate fuel oxidation in the fuel system. This is especially true in engines with electronic fuel systems because they operate at higher temperatures. Consult the fuel supplier for oxidation stability additives.
- Bio-diesel fuel is an excellent medium for microbial growth. Microbes cause fuel system corrosion and premature filter plugging. The effectiveness of conventional anti-microbial additives, when used in biodiesel, is not known. Consult your fuel and additive supplier for assistance.
- Care must be taken to remove water from fuel tanks. Water accelerates microbial growth. Water is naturally
  more prevalent in bio-diesel fuels than in distillate fuels.

#### Water-Emulsions

Water, up to 20 percent, can be blended into fuel with the use of some fuel additives such as detergents. The milk-like water emulsified diesel fuel is often referenced as an emission reducing fuel. The reduction of emissions normally range from 8 to 30 percent depending on engine type, operating conditions, and engine calibrations. Cummins engines are not tuned specifically to this kind of fuel, therefore can not warrant the reduction of emissions.

Since water is **not** combustible, the emulsified fuel usually results in fuel economy reduction of 15 percent or more. Other potential problems include water separation and water related problems like corrosion, change of ignition timing, and fuel system wear.

Cummins Inc. neither approves nor disapproves of the use of water emulsified fuels. Engine damage, service issues or performance problems that occur due to the use of these products are **not** considered a defect in workmanship or material as supplied by Cummins Inc. and can **not** be compensated under the Cummins warranty.

## Oxy-Diesel or E-Diesel



Do not mix gasoline, alcohol, or gasohol with diesel fuel. This mixture can cause an explosion.



Under no circumstances must gasoline or alcohol be used to dilute diesel fuel. This practice creates an extreme fire hazard and under certain circumstances an explosive hazard. Gasoline dilution is not an effective way to lower cloud point (20 volume-percent gasoline only lowers cloud point 4°C [7°F] and it lowers the fuel viscosity, cetane number, and flash-point). Alcohol dilution will increase the cloud point.

Alcohol is considered a renewable energy source. Some suppliers integrate up to 15 percent alcohol in diesel fuel to form oxy-diesel or e-diesel. While the use of special additives addresses some of the problems with alcohol blending in diesel fuel, Cummins recommends against the use of such blends due to safety reasons. This kind of fuel is considered experimental and is not covered by warranty. Engine damage, service issues or performance problems that occur due to the use of these products are not considered a defect in workmanship or material as supplied by Cummins Inc. and can not be compensated under the Cummins warranty.

## **Fuel Filters**

This section explains the types of fuel filters and their uses.

Fuel filters are standard equipment on all Cummins engines. They are designed to remove water and harmful particles from the fuel before they damage the fuel pump and other engine components.

Effective September 1, 1991, Cummins Inc. requires a fuel-water separator or fuel filter and water separator combination be installed in the fuel supply system. This requirement applies to all 1991 and later automotive certified engines and all future automotive engines. In addition to this requirement, Cummins Inc. recommends that a fuel-water separator or fuel filter and water separator combination be installed in the fuel supply system on all Cummins engines regardless of application.

NOTE: It is strongly recommended that the "N" and "L" series engines, built with CELECT™ and STC prior to September 1, 1991, be up-fitted with a fuel-water separator.

Water can be introduced to a diesel engine's fuel system in two ways. Water can be present in the fuel and enter the engine's supply tank at fill-up or water that is normally in the air above the fuel can condense on the walls of the fuel tank.

Water in diesel fuel is normally present as both free and emulsified water. Free water settles to the fuel tank bottom where it can be drained. Emulsified water stays in suspension where it can enter the fuel lines, fuel pump, and injectors. Once this suspended water is in the fuel system, it can cause corrosion and failure of key fuel system components.

## Throw Away Canister

The standard fuel filter is the spin-on element. These filters contain a porous, pleated, chemically treated paper element that will pass fuel freely but trap impurities and sediment.

When the element is serviced, it is simply detached from the fuel filter head assembly, discarded, and replaced with a new element. The element must be tightened to the manufacturer's specifications.

NOTE: Do not pour fuel from an old fuel filter into a new filter in an effort to prime the fuel system. Use only clean fuel to prime the fuel system. It is not necessary to add fuel to a new fuel filter if the engine is equipped with an electric fuel transfer pump. Fuel systems on these engines can be primed by turning the vehicle keyswitch on and off several times to activate the fuel transfer pump.

## A CAUTION A

Overtightening will distort the filter cartridge or crack the filter head. Do not use a filter element that has been dented or damaged prior to, or during, installation.

#### Replaceable Element Type

Another type of fuel filter used on Cummins engines has a replaceable pleated paper element.

#### Pre-Filters

Midrange B and C series engines require the use of a fuel pre-filter (150 micron maximum).

#### **Fuel-Water Separators**

Free and emulsified water can be removed from the fuel. Integral fuel filter and water separators are available that remove both free and emulsified water with varying degrees of efficiency. The standard fuel filter (FF105, FF202, FF213, FF5052) does remove some free and emulsified water, but with low efficiency. Due to the above facts and the requirement that a fuel-water separator or fuel filter and water separator be installed in the fuel supply system, Cummins has increased the requirements for free water and emulsified water removal. For engines with CELECT™ or HPI fuel systems, the fuel-water separator or fuel filter and water separator combination must remove a minimum of 95 percent of free water (per SAE J1839) and 95 percent of emulsified water (per SAE J1848). Fuel-water separator filters produced by Fleetguard® and most other major filter manufacturers meet or exceed these requirements.

Cummins engines with either CELECT™ or HPI fuel systems are factory fit with Fleetguard® fuel-water separators that utilize StrataPore™ filter media. These StrataPore™ filters provide high efficiency removal of harmful particles and both free and emulsified water.

The fuel-water separator requires daily draining. See Owner's Manual or Operation and Maintenance Manual for other regular service intervals of fuel filters.

NOTE: The drained fluids (mixture of water and fuel) must be properly disposed of according to regulations.

Table 1 lists the Cummins and Fleetguard® fuel filters that are available from Cummins Distributors and Dealers. Change or clean the fuel pre-filter, if so equipped.

## **Fuel Filter Maintenance**

Fuel filters must be changed periodically to prevent restriction of fuel flow from the fuel tank to the fuel pump. Change fuel filters as recommended by the appropriate Cummins Engine Operation and Maintenance Manual.

Check the fuel restriction when operating under severe conditions in order to determine if additional fuel filter changes are needed. These measurements must be taken at full load and peak power on engines with PT® and in-line fuel pumps or high idle with no load on Celect™ model engines. After checking the restriction a few times, a maintenance schedule for fuel filter changes can be established for each type of operation.

Table 3: Fuel Filter Part Numbers						
Fleetguard® Model Number	Cummins Part Number	Length mm [in]	Outside Diameter mm [in]	Used On		
FF-104	3315846*	107 [4.2]	94 [3.7]	L10, NT, Small Vee, Medium Vee, K19 fuel filter		
FF-105	3315844*	137 [5.4]	94 [3.7]	L10, NT, Small Vee, Medium Vee, K19 fuel filter		
FF-105-D (with drain)	3315847*	152 [6.0]	94 [3.7]	L10, NT, Small Vee, Medium Vee, K19 fuel filter		
FF-202	3313306*	286 [11.3]	118 [4.7]	V28, K38, K50 fuel filter		
FF-213	3300901*	174 [6.9]	94 [3.7]	NT fuel filter		
FF-5052	3931063*	116 [4.6]	77 [3.0]	Midrange fuel filter		

(Continued)

Fuels for Cummins Engines Page 12

Fleetguard®	Cummins Part	Table 3: Fuel Filter Length mm [in]	Outside Diameter	Used On
Model Number	Number	400 (0.4)	mm [in] 94 [3.7]	Mid
FS-1280	3930942	162 [6.4]		Midrange fuel-water separator
FS-1212	3315843	174 [6.9]	94 [3.7]	L10, NT, and K19 and QSK19 fuel-water separator
FS-1216	3313304	308 [12.1]	118 [4.7]	V28 and KV fuel-water sepa- rator
FS-1251	3286503	141 [5.6]	77 [3.0]	Midrange fuel-water separator
FS-1232	3834656	115 [4.5]	77 [3.0]	Fuel-water separator for B-Series in pre-1994 Dodge Ram (distributor fuel pumps only)
FS-1232V	3912104	170 [6.7]	77 [3.0]	Fuel water separator for B-Series in pre-1994 Dodge Ram (distributor fuel pumps only)
FS-1253	3923108	118 [4.6]	94 [3.7]	Fuel-water separator for B-Series in 1994 through 1996 Dodge Ram
FS-1253V	3865402	173 [6.8]	94 [3.7]	Fuel-water separator for B-Series in 1994 through 1996 Dodge Ram
FS-1000	3329289**	249 [9.8]	94 [3.7]	Fuel-water separator for M11, N14, ISM/QSM, and K19/QSM
FS-1001	3413084**	203 [8.0]	94 [3.7]	Short version of FS-1000
FS-1003	3406889**	250 [9.8]	94 [3.7]	ISM/QSM fuel-water separato
FS-1006	3089916**	310 [12.2]	120 [4.7]	QSK45/60/78 fuel-water sepa rator
FS-1007	4010650**	298 [11.7]	119 [4.7]	ISX/QSX fuel-water separator
FS-1022	3800394**	238 [9.4]	94 [3.7]	ISC/QSC fuel-water separator
FS-1040	4010651**	298 [11.7]	119 [4.7]	ISX/QSX fuel-water separator
FS-19519	3942533**	148 [5.8]	94 [3.7]	ISB/QSB fuel-water separator
FS-19519V	3894519**	148 [5.8]	94 [3.7]	ISB/QSB fuel-water separator
FS-19528	3931476	110 [4.4]	105 [4.1]	Fuel-water separator for B-Series in 1997 through 1999 Dodge Ram
FS-19579	3945213**	103 [4.1]	87 [3.4]	Fuel-water separator for 1996 through current midrange (2000 and 2001 Dodge Ram)

These filters are recommended only when using a standalone water separator.

\*\* These filter utilize StrataPore™ filter media.

Fuel restriction can be checked as follows. Refer to the appropriate troubleshooting and repair manual for more detailed instructions.

- 1. On the PT® fuel system, measure the restriction at the suction side (inlet) of the fuel gear pump. Change the filter element if the restriction is above 203 mm Hg [8 in Hg].
- 2. On in-line or distributor fuel systems, measure the restriction at the inlet of the fuel lift pump. Also measure the pressure drop across the fuel filter and the pressure at the inlet to the fuel injection pump. Change the filter element if the pressure drop across the filter is more than 34 kPa [5 psi].
- 3. On the CELECT™ system, measure the restriction at the suction side (inlet) of the fuel gear pump. Change the filter
- element if the restriction is above 254 mm Hg [10 in Hg].

  4. On the HPI-TP system (ISX/QSX/Signature) there are different test locations and limits depending on the engine option. See the engine Troubleshooting and Repair Manual for specific instructions.
- 5. On the CAPS system, measure the restriction at the inlet of the fuel gear pump. Change filter if restriction is above 254 mm Hg [10 in Hg].
- 6. On the Quantum system, there are different test locations and limits depending on the engine option. See the engine troubleshooting and repair manual for specific instructions.

NOTE: If the restriction exceeds these limits, the fuel flow to the pump will be reduced and engine power will decrease.

## **Hot Restarts**

This section shows how contingency fuels affect the ability of the engine to restart while still hot.

On Cummins engines which use a distributor type fuel system, the use of contingency fuels can cause difficulty restarting the engine while it is still hot. In addition, if excessive wear exists in the fuel pump, the same difficulty can occur even when using fuels within the range listed in Required Diesel Fuel Specifications. The problem is caused by excessive leakage of fuel around the internal components of the fuel pump. Fuel leakage becomes excessive due to the high temperatures and low viscosity of the fuel. Excessive wear of the fuel pump components will make the problem worse. The leakage can become so great that the pump will not produce the fuel rate necessary to restart the engine. If this problem is encountered, it can be corrected by using fuel which meets the specifications in the Required Diesel Fuel Specifications section of this bulletin. If this does not correct the problem, repair or replacement of worn fuel pump components is necessary.

Alternate or contingency fuels can cause difficulty restarting a hot engine. The hot restart complaint can be caused by fuel burning prematurely during the first compression stroke. Lighter alternate or contingency fuels can enter the cylinder through an open injector caused by the thermal expansion that occurs during the heat soak after engine shut down. The burning fuels increase the starting cylinder pressure and increase the amount of torque needed to start the engine. Lighter alternate or contingency fuels with lower flash points increase the probability of fuel entering and burning in the cylinder. This issue can, on occasion, occur when using fuels that meet the required properties listed in Table 1. Various Hot Restart kits (sometimes referred to as a Hot Start Knock kit) have been released by Cummins to address this issue.

If this complaint is encountered, it can be corrected by using fuels which meet the requirements in the Required Diesel Fuel Specifications section of this bulletin. If this does not correct the hot restart complaint or if the recommended fuel can **not** be used, refer to the Service Information Bulletin Number, 90SIB6-1.

#### Common Issues With Winter Fuel

This section presents the various winter fuel issues and methods of dealing with them.

Two winter fuel handling issues, wax and ice, have annoyed diesel operators for years. There is no solution to either of these problems that is ideal for all situations, but the better one understands the problem, the less difficult the process of finding a solution becomes. Determining whether a low power complaint is due to fuel filter plugging complaint is fairly simple: replace the fuel filter with a new filter. If this allows the vehicle to operate normally even for a short period of time, then obviously something in the fuel is plugging the filter and causing the complaint. A simple way of determining whether the filter plugging is caused by wax or ice is to bring the plugged filter into a warm shop, drain out the liquid fuel, place the filter upside down on a piece of paper or in a shallow pan, and allow the filter to warm to room temperature. If there is ice in the filter, it will melt and run out of the filter and the water on the paper or in the pan will be obvious. Most petroleum wax, on the other hand, will not melt at room temperature. To speed the analysis process, the filter can be cut open and spread out. Once the cause of the low power complaint is determined, then a logical solution can be chosen.

## Fuel Wax

All middle (or intermediate) distillate fuels, such as jet fuels, heating fuels, and diesel fuels, contain paraffin wax. Paraffin wax is a solid, crystalline mixture of straight-chain or normal hydrocarbons melting in the approximate range of 40 to 60°C [104 to 140°F]. This paraffin wax occurs naturally in the crude oil from which fuel oils are distilled. The wax content of a distillate fuel varies greatly, depending on the crude oil from which the fuel is produced and in the processing of the fuel. Generally, higher boiling distillate fuels, such as U.S. Number 2-D diesel fuel, have a higher concentration of paraffin wax than lower boiling distillate fuels, such as jet fuel.

Because of the strong relationship between temperature and solubility of wax, wax separation is a problem in handling and using diesel fuel during cold weather. As fuel cools, a temperature is reached at which the soluble paraffin wax in the fuel begins to come out of solution (Cloud Point); any further cooling will cause wax to separate out of solution. The temperature at which a certain fuel will become saturated with wax and causes filter plugging problems is termed the Cold Filter Plugging Point (ASTM D 6371). The temperature at which fuel will no longer flow is the Pour Point (ASTM D-97). At the pour point, most of the fuel is still liquid oil although it is very thick or viscous and trapped in a honeycomb-lick network of wax crystals.

Since diesel powered equipment is frequently used at temperatures low enough to cause wax to separate, a number of techniques have been devised to prevent the wax from causing problems by plugging fuel screens, lines, filter, and so on, and preventing fuel flow to the engine. Vehicles designed to operate at very low temperatures have provisions for heated fuel tanks, insulated fuel lines, heated fuel filters and other mechanisms to warm the fuel so that the wax does **not** separate. These more elaborate systems are usually **not** practical in more temperate climates where they are needed **only** a few days a year.

## **Fuel Filters**

Fuel filters have already been discussed in detail in the Fuel Filters section of this bulletin. The only additional consideration in terms of common issues with winter fuels is that using a large filter or multiple filters in parallel will allow more fuel wax to be filtered before a power loss occurs. Also, relocating the fuel lines and filter out of the

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## **Fuel Filters**

Fuel filters have already been discussed in detail in the Fuel Filters section of this bulletin. The only additional consideration in terms of common issues with winter fuels is that using a large filter or multiple filters in parallel will allow more fuel wax to be filtered before a power loss occurs. Also, relocating the fuel lines and filter out of the

wind-stream and wheel splash and into the engine compartment near the engine block will help keep them warm.

Engine Idling

## ▲ CAUTION ▲

Do not idle the engine for excessively long periods of time. Long periods of idling (more than 10 minutes) can damage an engine because combustion chamber temperatures drop so low the fuel may not burn completely. This will cause carbon to form in the injector spray holes and on the piston rings and can result in stuck valves.

#### Additives

There are a number of fuel additives available which reduce the pour point and cold filter plugging point (CFPP) of diesel fuel. These are commonly referred to as pour point depressant additives, cold flow improver additives, wax crystal modifiers, or fluidity improver additives (and can be collectively termed "Winter Additives"). Certain additives can reduce the Pour Point by as much as 70°F and the CFPP by as much as 30°F. A survey of winter blend fuels by the Bureau of Mines (now a part of the Energy Research and Development Administration) revealed that a large percentage of the commercially marketed diesel fuels had been treated with a winter additive. Before purchasing such an additive to treat fuel, ask the fuel supplier whether the fuel already contains a winter additive. Depending on the amount and type of additive already in the fuel, additional additization may or may not be necessary.

These additives alter the size and shape of wax crystals allowing pumping of fuel at lower temperatures. Although certain additives can be very effective, they are not a cure all. Their performance varies depending on the paraffin type and content of the fuel treated. Severe weather applications may require fuel warmers in addition to additives. Although other additives are available that may provide some benefits, Fleetguard's Fleet-tech\* Winter Conditioner is the only fuel additive recommended by Cummins to help prevent filter gelling in cold weather applications.

#### **Fuel Warmers**

Warming diesel fuel just prior to filtration is an excellent method of preventing fuel filter plugging. If cold fuel is warmed sufficiently, the wax crystals will dissolve in the fuel. The dissolving requires warming to a temperature of approximately 11 to 22°C [20 to 40°F] above the fuel's cold filter plugging point.

In order for a fuel warmer to reliably prevent fuel filter plugging due to wax, it must be capable of supplying enough heat to the fuel at the maximum fuel flow (not just fuel consumption) rate to raise the fuel temperature from the lowest expected fuel temperature (probably the lowest expected ambient temperature) to 11 to 22°C [20 to 40°F] above the fuel's cold filter plugging point. There are four different fuel warmers presently offered by Fleetguard® to raise the temperature of the inlet fuel.

 Fuel Filter Heater - The Fleetguard® Positive Temperature Coefficient (PTC) fuel filter heats the fuel before the fuel flows into the fuel filter. The heater is installed on the fuel filter head. Most complaints of fuel waxing occur in the fuel filter. The heater uses ceramic discs that sense the fuel temperature and heats the fuel to a temperature just above the cloud point.

The PTC heater is self-regulating. Depending on battery voltage, the heaters use from 6 to 25 amps at maximum output. When no heat is required, the heater uses less than 0.5 amp. The heater can be left on during engine operation or it can be turned off with the cab switch. The heater reaches full heating capacity in about two minutes. The PTC heater kit is available (see Table 4).

Table 4: Fuel Filter Heaters				
Watts	Fleetguard® Part Number			
300	3836029-S			

A Fleetguard® kit, Part Number 3837317-S, adapts the heater to most fuel filter heads with 1 in-14 threads. Refer to the following fuel filter list. The heater adds about one inch in height to the fuel filter head assembly.

Fuel Filter List with	n 1 in -14 Threads
FF-104	FF-213
FF-105	FF-105C
FS-1242(B)	FS-1001
FS-1000	FS-1212
FF-105D	FS-1003

The Fleetguard® kit, Part Number 3832054-S, adapts to FS-1251 filter.

Recirculating Fuel Warmer - Part Number 3305782, can be used to warm inlet fuel for flow up to 9.5 l/pm [2.5 gpm].
 The unit circulates engine coolant around the inlet fuel to warm the fuel. The unit is most effective when immersion or tank heaters are used to warm the coolant. An optional thermostat, Part Number 3305783, can be used to bypass fuel when 27°C [80°F] is reached. Use Table 5 to determine the performance capability of this fuel warmer for

different operating conditions.

Table 5: Recirculating Fuel Warmer, Part Number 3305782 - Performance Data

	Temperature	Rise Chart	3.5325	
Inlet Fuel Temperature	Outlet Fuel Temperature (°F) Fuel Flow Rate			
(°F)	2-1/2 GPM	1-1/2 GPM	1/2 GPM	
-30	32	38	52	
-10	39	45	55	
10	47	53	59	
30	60	62	67	
50	71	74	77	
70	85	87	88	

- 3. Thermo Blend The Fleetguard® Thermo Blend fuel warmer recirculates warm deaerated drain fuel from the engine to the filter and injection system, rather than allowing it to return to the tank. A 10 to 15 minute engine-running warm up period is usually necessary to provide successful operation. A built-in thermostat automatically bypasses fuel at 43°C [110°F]. Part Number 3310200 must be used for all Midrange and Heavy Duty diesel engines. Part Number 3308750 must be used for all heavy duty off-highway equipment (such as 12 and 16 cylinder engines).
- 4. Thermo Blend FM, Part Number 3310630 The Fleetguard® Thermo Blend FM fuel warmer combines the return fuel heating principle with a special filter head. When used with Cummins Part Number 3315843 (Fleetguard® Part Number FS-1212) fuel-water separator, it provides fuel dewaxing, water removal, and filtration. A built-in thermostat automatically bypasses fuel at 21°C [70°F]. When using fuel warmers, do not overheat the fuel. The maximum fuel temperature at the inlet to the fuel pump is 70°C [158°F]. Alterations of heating devices must be reversible, or have some means to turn them off during warm weather operation. The fuel tank is heated by the injector return (drain) fuel from the engine. On typical installations, the cooling effect of the tank maintains fuel temperatures at an acceptable level.

On some installations, such as acoustically enclosed units, little cooling of the tank occurs because of the design. On these installations, a fuel oil cooler can be used to limit the temperature of the fuel at the fuel pump inlet to 70°C [158°F] or less.

Depending on the particular engine model involved, the engine horsepower will begin to decrease slightly above fuel inlet temperatures of 46°C [115°F]. The percent of power loss is **not** as great on engines with the Cummins PT® fuel system (less than 1 percent per 5°C [9°F]), due to the inherent viscosity compensating characteristics (see Power Loss section in this bulletin). Operation above 70°C [158°F] is **not** recommended due to the loss of the lubricating quality of the fuel with resultant wear to the fuel system components which depend on fuel for lubrication. A fuel warmer will **not** help if the fuel is below the pour point and can **not** be pumped to the warmer; therefore, in extremely cold conditions, fuel can be treated with light distillate fuel or treated with a pour point depressant to reduce the pour point, or it can be necessary to heat the fuel to allow it to flow.

When using fuel warmers that use engine coolant as a source of heat, some form of coolant heating during shutoff will allow the heater to become effective much more quickly after start-up. These fuel warmers must also be checked for leaks. Since the fuel warmer is on the suction side of the fuel pump and the cooling system is pressurized, any small leak will allow coolant to enter the fuel system.

## Other Considerations

Wax in the fuel will deposit in any restriction or sharp bend in the fuel plumbing system. If fuel starvation occurs during cold-weather operation and plugged fuel filters are **not** found, look for plugging of tank pick-up screens, sharp bends in the fuel lines, fittings, and so forth.

## Water Contamination

Free water (non-dissolved) in the fuel can freeze at low temperatures and the resulting ice crystals can plug fuel filters causing fuel starvation. Care must be taken to keep fuel storage tanks dry. Tanks can be "stuck" often with water detecting paste (usually obtainable from fuel suppliers) to be sure they are dry. If water is detected, it must be pumped out.

Keeping bulk fuel storage tanks dry has already been mentioned; however, if this is a persistent issue, a dryer (fuel-water separator) can be installed on the bulk fuel dispensing system.

Condensation in the vehicle fuel tank(s) occurs when the air in the fuel tank(s) cools down during a shutdown period. This moisture can be reduced by filling the vehicle fuel tank before engine shutdown to reduce the air space above the fuel.

Dissolved water comes out of solution as fuel cools. As fuel cools from 4 to -29°C, [40 to -20°F] the solubility of water in the fuel reduces 70 percent. Therefore, fuel pumped from a relatively warm underground tank into a vehicle which

sits overnight in sub-zero temperatures can cause some free water to separate. However, this source of free water is almost negligible, because even at high temperatures fuel will dissolve very little water (0.1 mass-percent at 71°C) (160°F)).

Additives can be used to prevent fuel line freeze up. These additives work by lowering the freeze point of water so that it will not freeze and cause lines and filters to plug. Although other additives may provide some benefits, Fleetguard's Fleet-tech™ Winter Conditioner is the only additive recommended by Cummins for this application.

NOTE: More cold weather engine operation recommendations are in Service Bulletin Number 3379009 and in the engine operation and maintenance manual.

## Microbial Contamination of Fuel

## A WARNING A

Although most of the microbes that will live in fuel tanks are common organisms to which humans are constantly exposed, contact with microbes or fungi from a fuel tank must be avoided. When a fuel system is contaminated and cleaning is necessary, workers must be protected. Remember that the fungi produce reproductive spores and when dry these can easily become airborne, so breathing protection must be provided or the microorganisms must be kept wet. Dispose of the water and sludge removed from fuel tanks properly. Never place these materials in sanitary sewer system since they can kill bacteria used in sewage treatment. Never place them in storm sewers or surface water streams since they can kill fish and other aquatic animals.

## WARNING A

The most common problem associated with exposure to these microbes is dermatitis which in some people can be quite serious. Any exposed skin must be thoroughly washed with warm, soapy water.

## A WARNING

Avoid eating, drinking and smoking while working with these microbes. Any ingestion of the microbes or exposure to broken skin must be considered serious. It is recommended that if this happens the worker be taken to a doctor, along with a sample of the microbes.

## A WARNING A

Biocides are generally only mildly toxic to humans and animals but must still be handled carefully. In cases of ingestion or contact with the eye, follow manufacturer's recommendations. Seek medical attention.

This section covers the recognition of and solutions to microbial contamination of diesel fuel.

To protect against fuel shortages, many users have been storing fuel and, as a result, the frequency of microbial contamination has increased. Microbial contamination of fuel, though not a new concern, is more common in metalworking industries which use water-soluble oils as cutting fluids or in long-term storage of hydrocarbon fuels than it is in diesel fleet operations. All hydrocarbon fuels are essentially sterilized by the high temperatures encountered in the refining process; however, they can become contaminated soon after leaving the refinery by microorganisms. These microorganisms, primarily bacteria and fungi, exist rather harmlessly in moisture-free fuel, passing through fuel systems without having any negative effects.

However, in the presence of water, these microorganisms begin to grow and reproduce. The rate of growth depends on how well the environment suits the particular microorganism's needs.

The growth of a large colony of microorganisms in a fuel system can cause several issues. The first and usually most obvious is fuel filter plugging with a greenish-black or brown slime, frequently accompanied by a foul odor. This slimy, string-like colony can also plug sharp bends in fuel lines, fuel meters and other restrictions. The second issue these microorganisms can cause is corrosion due to the acid by-products some of them produce. It is also possible, if the microorganisms pass through the fuel filter, that they will form deposits and cause damage in the fuel pump and injectors.

Some indicators of microbial contamination are:

- Slime deposits on tank walls, piping, or other surfaces which are exposed to fuel. These deposits are usually greenish-black or brown and are slick to the touch.
- Black or brown "stringy" material suspended in tank water bottoms.
- 3. Swelling or blistering of any rubber surface (washers, hoses, connectors, and so forth) that comes in contact with
- Sludge or slime deposits on filter surfaces.
- 5. Foul odor resembling that of rotten eggs (hydrogen sulfide).

A more conclusive approach is to routinely check the fuel by means of one of the several available test kits which are listed below. These can detect microorganisms long before there is any visible evidence of contamination.

The following list shows test kits of which we are aware. Listing of a kit can **not** be construed as a recommendation or approval; and, the fact that a kit is **not** listed **only** means we are unaware of it. Cummins has **not** tested any of these kits, but has **only** reviewed the manufacturer's literature. Users **must** evaluate the kits available to them and select one based on their own judgment.

- 1. Total Count Sampler, Catalog Number MTOO 000 25 for package of 25, from Millipore Corporation, Bedford, MA 01730, 1–800–645-5476. The Total Count Sampler contains a nutrient media specifically designed to encourage bacterial growth; however, many fungi will grow on it. Millipore recommends incubation at 35°C [95°F] for 24 hours; however, they can be incubated at room temperature for 36 to 48 hours. If the results on the Total Count Sampler are low and is still suspected, re-sample using Millipore's Yeast and Mold Sampler (Catalog Number MYOO 000 25 for package of 25). This sampler contains a nutrient media which suppresses the growth of most bacteria, but is rich in nutrients for fungi. For best results, use both samplers each time water bottoms are tested. These Millipore samplers are probably the most sensitive of those listed, and in fact, can lead one to overtreat a fuel system. Millipore samplers are also available from Millipore in Australia, Belgium, Brazil, Canada, Denmark, England, Finland, France, Italy, Japan, Mexico, Norway, Spain, Sweden, Switzerland, and West Germany. Inquiries from other countries can be directed to Millipore Intertech, Inc., P.O. Box 255, Bedford, MA 01730 U.S.A.
- Microbe Monitor Test Kit (From Air BP) British Petroleum Cleveland-Hopkins International Airport Cleveland, OH 44135 1–800–533-2340. One sample per kit. Incubates at room temperature.

When it has been established that microbial contamination is present and action must be taken, there are several approaches. The most obvious solution is prevention. Most of the bacteria and fungi involved are soil organisms which can become airborne or waterborne. Prevention of the entrance of microorganisms is **not** possible because these organisms can enter the fuel through many different routes.

Growth of these microorganisms can be prevented. Since all metabolic processes of an organism are conducted in water, denying the microorganism access to water will prevent growth, thus preventing the development of large, troublesome colonies. Therefore, the first and most important step in prevention is to keep fuel systems dry. Keeping a fuel system entirely dry is impossible. In cases where microbial contamination is a recurring issue, a microbicide can be used to chemically treat the fuel or the water.

There are three general classes of blocides: water-soluble, fuel-soluble, and universally soluble. Fuel-soluble biocides are best suited for treating fuels which are to pass through several storage steps in the distribution process. A fuel-soluble biocide injected into the fuel early in the distribution system is carried with the fuel through the entire downstream system, effectively sterilizing the fuel until usage. Fuel-soluble biocides are easier to add to the fuel system since the exact amount needed to treat a volume of fuel is easily determined and they have a low toxicity to human and other life forms. The obvious disadvantage to fuel-soluble biocides is cost; each batch of new fuel added to the system must be treated since the biocide is consumed as the fuel is consumed.

Water-soluble biocides are more economical for use in treating one step in a fuel distribution system, such as the end-user's storage tank. The water-soluble biocides, since they are insoluble in fuel, stay where they are placed until the water bottoms are pumped from the tank; therefore, the total amount of biocide purchased is less. There are a number of disadvantages to water soluble biocides. Since no biocide is carried downstream by the fuel, each successive tank in the system must be individually treated. There is some difficulty in determining how much biocide to place in a tank since that depends on how much water is in the tank. The biocide can not be thoroughly mixed with the water in the bottom of a tank. Water-soluble biocides are much more easily taken in by humans and other life forms: and therefore, must be disposed of properly when water bottoms are pumped from a tank. Water bottoms containing a water-soluble biocide must not be placed in a sanitary sewer system because the biocide can destroy the bacteria used by sewage treatment plants. These water bottoms must be treated as an acidic, industrial oily waste.

Universally soluble biocides are soluble in both water and diesel fuel. They allow you to treat the entire downstream system. However, each subsequent load of fuel does **not** need to be treated. The biocide will remain in any water that has collected at the bottom of the storage tank and continue to inhibit microbial growth. With certain types of biocides, the interval between treatments can be as long as six months. Like water-soluble biocides, universally soluble biocides are more easily taken up by humans and other forms of life. They also tend to be more expensive than the other types of biocides.

Treating a fuel tank that is infested with a large population of microorganisms will kill the microorganisms, but it will not eliminate the filter plugging they can be causing. The water and sludge containing the microorganisms must be removed from the fuel systems. First, clean the fuel system thoroughly. Next, a fuel-soluble or universally-soluble biocide must be added to the next few batches of fuel to kill any remaining microorganisms. Finally, the addition of a water-soluble or universally-soluble biocide can be continued for at least several months to be sure the microorganisms are all dead. If microbial contamination is a recurring issue, it is recommended that use of the water-soluble or universally-soluble biocide be continued permanently since this would be the most cost effective solution to the problem. This can be done by determining the amount of water that accumulates in tank bottoms between pump outs and adding about double or triple the amount of water-soluble biocide recommended to treat that volume of water. For example: you normally pump out approximately 379 liters [100 gallons] of water bottoms. In this case, after pumping

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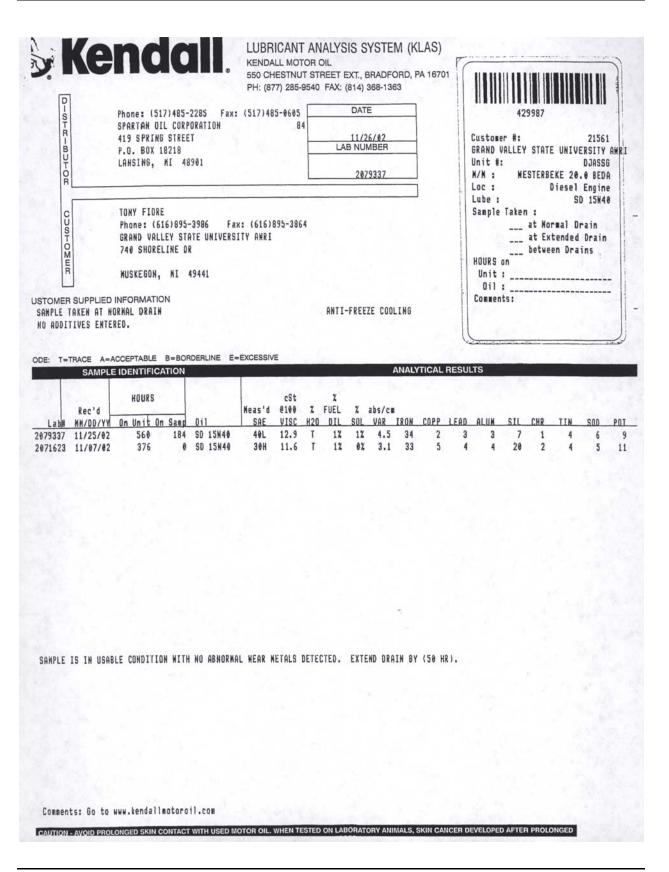
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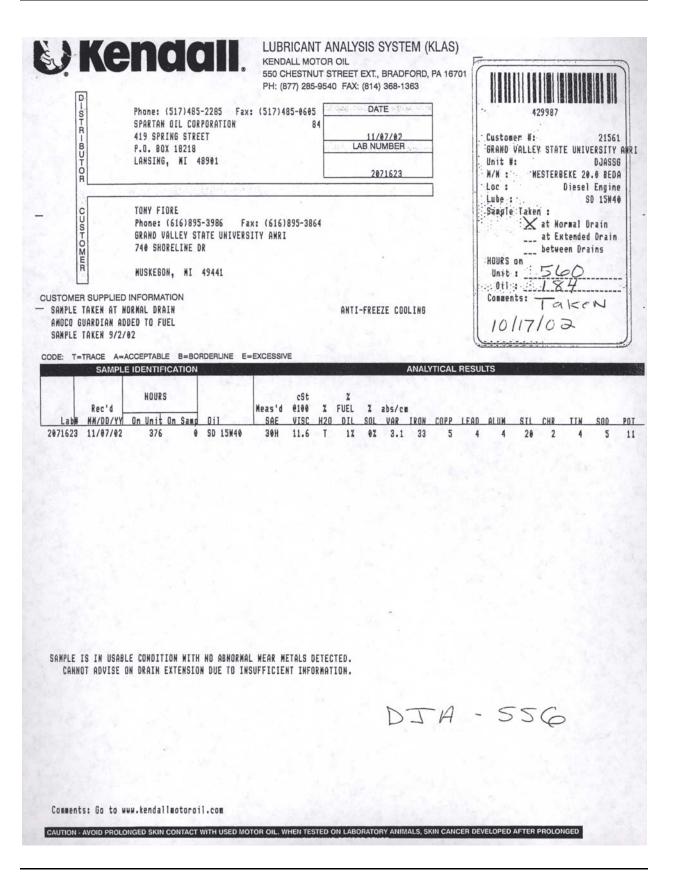
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**Westerbeke Corporation** 

**Engine Data** 







16 DECEMBER 2002

GRAND VALLEY STATE UNIVERSITY LAKE MICHIGAN CENTER 740 WEST SHORELINE DRIVE MUSKEGON, MI 49441

ATTN: ROBERT F. UDELL

SUBJECT: BIODIESEL

DEAR MR. UDELL,

IN RESPONSE TO YOUR LETTER OF 3 DECEMBER 2002 REGARDING THE USE OF 100% BIODIESEL IN YOUR WESTERBEKE DIESEL GENERATOR.

THE WESTERBEKE CORPORATION DOES NOT APPROVE, NOR DOES IT DISAPPROVE, OF THE USE OF BIODIESEL AS A FUEL SUBSTITUE IN ITS DIESEL ENGINES.

HOWEVER, IF A FAILURE OCCURS WHICH IS A RESULT OF THE USE OF BIODIESEL, WARRANTY WILL BE DENIED.

RESPONSIBILITY FOR WARRANTY WILL THEN FALL ON THE MANUFACTURER OF THE BIODIESEL FUEL SUBSTITUTE.

WESTERBEKE CORPORATION RESERVES THE RIGHT FOR FINAL DETERMINATION AS TO CAUSE OF FUEL SYSTEM OR ENGINE FAILURE.

WESTERBEKE CORPORATION CONTINUES TO RECOMMEND THE USE OF #2 DIESEL WITH A CETANE RATING OF #45 OR HIGHER AS THE FUEL OF CHOICE IN OUR MARINE DIESEL ENGINES.

RESPECTFULLY,

JOSEPH A. JOYCE SERVICE MANAGER

CC – BOB BISANTI – WESTERBEKE CORPORATION GREG HAIDEMENOS – WESTERBEKE CORPORATION TOM SUTHERLAND – WESTERBEKE CORPORATION

WESTERBEKE CORPORATION
MYLES STANDISH INDUSTRIAL PARK, 150 JOHN HANCOCK ROAD, TAUNTON, MA 02780-7319 • TEL. 508-823-7677 • FAX 508-884-9688 • WEBSITE: WWW.WESTERBEKE.COM

SEP-12-2002 16:16

WESTERBEKE CORP.

508 977 4310 P.01

From: BOB UDELL

# **FUEL SYSTEM**

9-12-02

## FUEL TANKS—GENERAL

It is very important that the design, construction and installation of all fuel system components meet the highest possible standards. Use only products specified for marine applications.

Fuel tanks for diesel engines and generators may be made of fiberglass, aluminum or stainless. Fuel tanks for gasoline engines and generators may be made of only fiberglass or aluminum; stainless is not appropriate for gasoline because improper welding can remove carbon leaving only steel, which will rust and then leak.

If the tank is made of fiberglass, be certain that the interior is gel-coated to prevent fibers from contaminating the fuel system. Copper or galvanized fuel tanks should not be used. The nominal thickness of a fuel tank depends on the material used. Any fitting or opening must be at the top of the tank. A drain plug at the bottom of the tank is not acceptable.

Avoid the use of fittings made of copper-based alloys such as brass as they will deteriorate the aluminum fittings. Fastenings for an aluminum tank should be 300 series stainless steel.

It is not necessary to mount the tank above the engine level, as the fuel lift pump provided will raise the fuel from the tank. The amount of lift should be kept to a minimum (6 ft (1.8 m) being maximum). If a tank is already installed above engine level, it can be utilized in this position.

Cleanliness and care are especially important when the fuel tank is installed because any dirt left in the tank will cause fouling when the engine is started for the first time.

CAUTION: Make sure the fuel tank filler is properly sealed to prevent water re-entry should it become awash. The fuel tank's vent should be routed so as to prevent water entry as well.

The fuel tank's fuel pickup tube should be clear and unobstructed, without screens or gauze strainers. Make sure that all fittings are sufficiently tightened to prevent leaking.

Fuel tanks that are located below the engine's fuel system level must have their fuel return connection at the tank extending down into the tank in the same manner as the pickup tube; otherwise, air will replace fuel siphoning out of the engine's fuel system through the return.

The fuel tank's vent should be located so that its discharge route cannot allow water to enter through to the fuel tank(s). Moisture must not be allowed to accumulate in the vent's line.

Mount the fuel rank and secure it into position. The NFPA recommends that the bottom tanks be installed on slatted wooden platforms to help prevent moisture condensation. Cylindrical tanks should be set in chocks or cradies and securely fastened. Insulate all wood or metal surfaces from the tank surface with a non-abrasive and non-absorbent material.

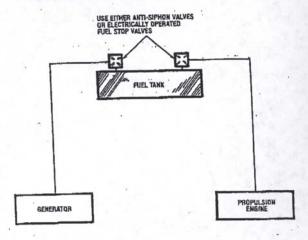
## FUEL TANKS—GASOLINE

Tanks must be labeled with the manufacturer's name, tank material and capacity. They also must be marked that they have been pressure tested to the requirements of Title 33 CFR, sub part J. If either the fuel-fill fitting or the tank is metallic, it will need to be grounded. A 10-gauge or larger stranded copper wire must be fastened from the metal components to the boat's ground.

Design the fuel tank vent line so that gasoline cannot spill onto the boat. A loop in the vent line from the top of the tank to the underside of the deck and then to the through-hull fitting will prevent this. The line should drain back to the tank with no traps. The vent line should be no less than 9/16 in. (14.3 mm) I.D. The through-hull vent fittings must be equipped with a flame arrestor.

## Fuel Tanks Located Above the Engine/Generator

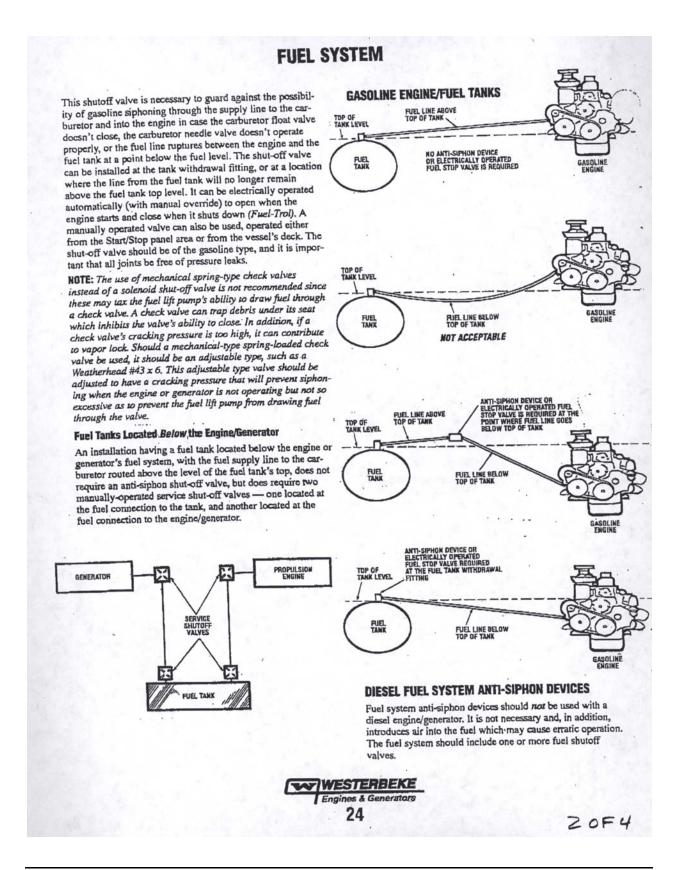
A carburetor float valve cannot be trusted to hold back fuel in an installation having a fuel tank located at or above the engine/generator's fuel system. This type of system, with some or all of the fuel supply line to the carburetor routed below the level of the fuel tank's top, requires a shut-off valve to shut off the fuel supply to the engine or generator when the engine isn't running.



FUEL TANKS LOCATED ABOVE THE ENGINE/GENERATOR



PAGE 10F4



# **FUEL SYSTEM**

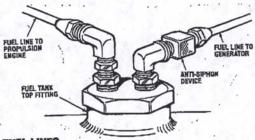
## **DUAL PURPOSE FUEL TANK**

If you're running both a generator and a propulsion engine and they use the same fuel, you can use the same fuel tank. However, before that decision is made, the following factors must be considered:

- There must be adequate fuel capacity for both engines — refer to the specifications section of your owner's manual for fuel consumption figures.
- In diesel installations the fuel returning to the tank is warm. To obtain maximum engine efficiency, fuel delivered to the injectors must be cooled. The fuel tank volume must be adequate to cool the returned fuel.

If a fuel tank is shared, a fuel line tee should not be used. A tee can cause erratic genset operation due to fuel starvation. The genset's fuel pump does not have the capacity to overcome the suction of the propulsion engine's fuel pump.

This is true also of the return lines. Pressure from one engine could be higher than the other and force return fuel back into the lower-pressure engine injector. The return line should enter the tank as far as possible from the supply lines.



## **FUEL LINES**

The proper installation of fuel lines is very important. All fuel line materials must be approved for marine installations and meet the requirements of both the USCG and the ABYC.

The fuel system should be installed in such a manner as to allow the engine-mounted fuel lift pump to maintain a positive inlet pressure to the injection pump under all operating conditions. As the fuel lift pump has a capacity in excess of that required by the injection pump, the overflow is piped to the fuel tank and should be connected at the top of the tank.

Great care should be taken to ensure that the fuel system is correctly installed so that airlocks are eliminated and precautions taken against dirt and water entering the fuel.

NOTE: The fuel supply line to the engine/generator should be from its own pick-up in the fuel tank and NOT teed off the supply line to another engine/generator.

Keep the fuel lines as far as possible from the exhaust pipe and hot engine areas; this is to keep the fuel at a minimum temperature to reduce the chance of vapor lock in gasoline installations. Run fuel lines at the top level of the fuel tank to a point as close to the engine or generator as possible to reduce the danger of fuel siphoning out of the tank if the line should break.

Fuel piping should always be routed and securely anchored to prevent leaks from vibration and chafing. Fuel piping is usually secured by copper straps every 12–14 in (30–36 cm). Use as few connections as possible, and install the lines so they are accessible and protected. Avoid locked-in torsional stresses.

## **Rigid Fuel Lines**

For installations with rigid fuel lines, Westerbeke recommends using copper tubing together with suitable flared fittings, both for the supply line and the return line. Use seamless annealed double flared fuel lines that are approved for marine installations. Run the tubing in the longest pieces obtainable to avoid the use of unnecessary fittings and connectors. The minimum size of the fuel supply line and fuel return line is 1/4 inch, inside diameter.

When a copper fuel line is used, electrically bond the fuel line to the vessel's common bonding conductor with a suitable strap or 10 gauge wire.

## Flexible Fuel Lines

If a rigid metallic fuel line is run into the engine/generator compartment, a length of flexible hose must be installed to absorb vibration from the engine/generator. Install a non-organic flexible hose without metal reinforcement between the rigid fuel line and the engine/generator to absorb the vibration. This line must be long enough to prevent binding or stretching because of engine/generator movement.

A flexible fuel line may also be installed between the fuel tank and the engine/generator for both the supply line and the return line. For the supply line, flexible hose may be installed from the fuel tank outlet to the fuel filter/water separator, and from the fuel filter/water separator to the engine-mounted fuel pump inlet.

Use suitable end fittings, and install all the hose in the longest runs possible to avoid the use of unnecessary fittings and connectors. There must not be an electrical connection between the hose end fittings: a bad ground in the cranking circuit will cause a wire-reinforced hose to become charged and ignite the fuel during cranking.

WARNING: Ignition of fuel can cause fire and severe personal injury or death. Be sure any flexible fuel line used between the fuel tank and the engine/generator meets ABYC and USCG requirements.



30F4

# **FUEL SYSTEM**

## SHUT-OFF VALVES

Make sure your fuel system has positive shut-off valves; know their locations and how they operate.

NOTE: See the U.S. Coast Guard publication "Fuel System Compliance Guideline" for basic fuel system layouts and shut-off valve locations.

## **FUEL FILTERS**

A primary fuel filter/water separator should be installed in the fuel supply line between the fuel tank and the engine/ generator to help remove contaminants in the fuel before the fuel reaches the engine mounted fuel lift pump. It should be mounted in an accessible location for ease in monitoring for water and contaminants, and for servicing. Such contaminants can cause the failure of components, and such failures are not warrantable. A recommended type of fuel filter/water separator is available from the list of accessories. A secondary fuel filter is mounted on the engine/generator, and it has a replacement filter element.

After installation, test the fuel system for tightness per USCG specification 33CFR183.542.

## FUEL

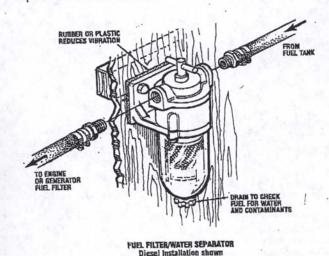
To insure satisfactory operation, an engine or generator must have a dependable supply of clean fuel.

Diesel Fuel - use No. 2 oil with a cetane rating of 45 or higher.

Gasoline - use unleaded 89 octane or higher.

WARNING: Gasoline leakage in or around the engine/generator compartment is a potential for fire and/or explosions. Repair leaks promptly and ensure that the compartment is properly ventilated.

Make sure there is a fire-extinguisher installed near the engine/generator and that it is properly maintained. Be familiar with its use. An extinguisher with the NFPA rating of ABC is appropriate for all applications.







ENGINE REQUIREMENTS — LUBRICATING OIL, FUEL AND FILTERS

## 5 DIESEL FUEL

## 5.1 QUALITY AND SELECTION

The quality of fuel used is a very important factor in obtaining satisfactory engine performance, long engine life and acceptable exhaust emission levels. For optimum engine operation and maximum service life, diesel fuels meeting the property requirements in Table 5-1, or the properties of EMA FQP-1a or 1b are recommended for use.

#### NOTE:

Fuels with sulfur content above 0.05 mass percent (500 ppm) are not recommended for DDC EGR engines. If engines are operated with fuels not meeting the 500 ppm sulfur content limit, the drain intervals must be shortened. Drain intervals may be determined by oil analysis or by using the drain intervals in Table 4-3.

5-1

## DIESEL FUEL

Property	Test Me	ethod	On-Highway		Off-Highway	
Property	ASTM	ISO	No. 1 No. 2		Off-Highway	
API Gravity, at 60° F Minimum Maximum	D 287	-	40 44	34 38	33 43	
Specific Gravity, g/ml @ 60° F Minimum Maximum	D 1298	3675	0.806 0.825	0.835 0.855	0.810 0.860	
Flash Point, °C Minimum	D 93	2719	38	52	Note 1	
Viscosity, Kinematic cSt @ 40° Minimum Maximum	D 445	3104	1.3 2.4	1.9 4.1	1.3 4.5	
Sulfur, wt.% (ppm) Maximum	D 2622	EN 24260	0.05 (500)	0.05 (500)	0.4 (4000)	
Cloud Point	D 2500	_		Note 2		
Filter Plugging Point	D 4359	309	-	Note 3	_	
Cetane No., Minimum	D 613	5165	45	45	45	
Cetane Index, Minimum	D 4737	4264	40	40	40	
Distillation % Vol. Recovery, °F (°C)  —IBP, Typical			350 (177)	375 (191)	320 (160) - 392 (200)	
10 %, Typical			385 (196)	430 (221)	392 (200)	
50%, Typical	D 86	3405	425 (218) 500 (260)	510 (256) 625 (329)	437 (225) - 527 (275) 626 (330)	
95%, Maximum Recovered Volume,			550 (288)	671 (355)	680 (360)	
% Minimum			98	98	98	
Water, % Maximum (Note 4)	D 2709		0.02	0.02	0.02	
Sediment > 1µm, mg/L Maximum	D 2276 or D 5452		10	10	10	
Total Contamination, mg/kg Maximum		DIN 51419	24	24	24	
Ash, % mass Maximum	D 482	6245	0.01	0.01	0.01	
Carbon Residue, on 10%, % mass	D 524	10370	0.15	0.35	0.3	
Copper Corrosion, Maximum	D 130	2160	No. 3a	No. 3a	No. 3a	
Accelerated Storage Stability mg/L, Maximum	D 2274		15	15	15	
DuPont Pad Test, Reflectance at 150° C, Minimum (High	D 6468		70	70	70	
Temperature Stability) Heat Content, Net, BTU/gal	D 4868		125,000 127,300	128,500 - 130,900	126,600 - 131,500	
Lubricity Load, gms, Minimum Wear Scar, um, Maximum	D 6078 D 6069		3100 460	3100 460	3100 460	

Table 5-1 Diesel Fuel Specifications

5-2

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## ENGINE REQUIREMENTS — LUBRICATING OIL, FUEL AND FILTERS

## Notes to Table 5-1

- 1. The flash point temperature is a safety-related property which must be established according to applicable local requirements.
- 2. The cloud point should be 10° F (6° C) below the lowest ambient temperature to prevent clogging of fuel filters by wax crystals.
- 3. The filter plugging point temperature should be equal to or below the lowest expected fuel temperature.
- 4. No free water visible.

## NOTE:

When prolonged idling periods or cold weather conditions below 32 °F(0 °C) are encountered, the use of 1-D fuel is recommended. Note, however, that transit coach engines are emission certified on either No.1 or No.2 fuel. To maintain emission compliance, only the correct certified fuel should be used.

## 5.1.1 FUEL LUBRICITY

It is recommended that all fuels used in DDC engines meet the minimum lubricity requirements listed in Table 5-1, "Diesel Fuel Specifications." Fuels not meeting the lubricity requirements may be additized to meet them.

## 5.1.2 PREMIUM DIESEL FUEL

Premium diesel fuels are not covered by any existing industry specification. It is recommended that the customer obtain additional information from the fuel marketer and compare properties to those listed in Table 5-1 before using.

## 5.1.3 HEAVY FUELS NOT RECOMMENDED

Heavy fuels intended for use in slow speed diesel engines and as burner fuel are not recommended for use in any Detroit Diesel engine. Marine fuels specified by ASTM D2609 are examples of such fuels. These fuels are known to cause combustion deposits and will likely reduce engine durability.

## 5.1.4 BIODIESEL FUELS

Biodiesel fuels are alkyl esters of long chain fatty acids derived from renewable resources. Biodiesel fuels must meet ASTM Specification D 6751. Biodiesel meeting the D 6751 specifications can be blended up to 20% maximum by volume in diesel fuel. The resulting mixture must meet the fuel properties listed in Table 5-1. Failures attributed to the use of biodiesel will not be covered by Detroit Diesel product warranty.

The following quotation is extracted from World-Wide Fuel Charter - Draft for comments - June 2002, page 46 for reference and guidance:

5-3

DIESEL FUEL

"Based on the technical effects of FAME [Fatty Acid Methyl Esters], it is strongly advised that FAME content be restricted to less than 5%. As a pure fuel, or at higher levels in diesel fuel, the vehicles need to be adapted to the fuel, and particular care is needed to avoid problems."

### 5.1.5 OTHER FUELS

Fuels listed in Table 5-2 and Table 5-3 have provided economic and availability advantages for some applications, particularly where No. 1 type fuels are required. These do not meet requirements listed in Table 5-1. Although not recommended, they have demonstrated acceptable performance in controlled applications.

Property	Jet A/A-1 D 1655	JP-5	JP-81	CONUS DF-1	CONUS DF-2	OCONUS DF-2
API Gravity, @ 60° F	44.3	41.1	45.6	42.3	34.2	38.5
Flash Point, °C	38	62	45	50	74	70
Viscosity, Kin., cSt @ 40° C	-	1.5	1.2	1.6	2.8	3.0
Cloud Point °C	-40	-46	-47	-41	-12	-19
Sulfur, % mass	0.3 Max.	0.4 Max.	0.4 Max.	0.05 Max.	0.05 Max.	0.3 Max.
Cetane Number	-	42	45	44	47	49
Distillation % Vol. Rec., °C						
-IBP	_	180	157	174	190	176
-10% Typical	205	191	175	196	222	219
-50% Typical	Report	215	200	219	265	365
-90% Max.	Report	242	236	246	313	311
Final Boiling Point, Max. Temp.	300	_	-	_	-	-
Heat Content, Btu/gal., Net	123, 608	125, 270	123, 069	125, 960	131, 207	127, 820

<sup>1.</sup> JP + 100 is not recommended in equipment with water-coalescing filters.

Table 5-2 Selected Typical Fuel Properties

5-4

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#### ENGINE REQUIREMENTS — LUBRICATING OIL, FUEL AND FILTERS

Туре	NATO Spec.	Mil. Spec	Application
JP-4	F-40	Mil-T-5624	Jet Fuel, Contains 50% Gasoline: Not Recommended
JP-5	F-44	Mil-T-5624	Jet Fuel, Kerosene Based
JP-8	F-34	Mil-T-83133	Jet A-1 with De-Icer and Corrosion Inhibitor
Jet A	None	None	Industry Standard Jet Fuel
Jet A-1	F-35	None	Jet Fuel, ASTM D 1655
DL-1/DL-2	F-54	W-F 800 CONUS	Specified Military Use Inside Continental U.S.
DA-2	F-54	W-F 800 OCONUS	Specified Military Use Outside Continental U.S.

Table 5-3 Fuel Type Specifications and Applications

Lower density fuels, such as those listed in Table 5-2 and Table 5-3 and "winter blended" diesel fuels, have a lower volumetric heat content than the standard No. 2 fuel listed in Table 5-1, "Diesel Fuel Specifications." Operating with these fuels will result in reduced engine output and reduced fuel mileage, compared to standard No. 2 fuel. Reductions of 5% are not unusual and may be as high as 10%. A good rule of thumb is this: The engine power is proportional to the heating value of the fuel.

Lower density fuels also tend to have lower viscosity and poor lubrication characteristics. Fuel filtration should be changed to that recommended for "Severe Duty Service" to prevent potential injector seizure from dirt contamination of fuel.

# 5.2 DIESEL FUEL PROPERTIES

## 5.2.1 DISTILLATION

The boiling range indicates the temperature range over which the fuel turns to a vapor and is a very important property in consideration of diesel fuel quality. Lower boiling range fuels, such as No.1, have a higher volatility, while fuels such as No. 2 are of lower volatility and higher temperature boiling range. Higher volatility fuels are preferred in conditions of prolonged idling, such as city coach applications or in cold temperatures. The determination of boiling range is made using ASTM Test Method D 86 or D 2887 (Gas Chromatography Test Method).

Although many specifications contain only a partial listing of the distillation results (Distillation Temperature at 90% Recovered, for example), this is not enough to determine the quality and suitability of the fuel for use in diesel engines. Diesel fuels are blended products which may contain high boiling constituents that can affect combustion. Only fuels with a minimum 98% recovery by distillation should be used. The full boiling range as shown in previous tables should be used for proper selection.

5-5

DIESEL FUEL

#### 5.2.2 95% BOILING POINT

Fuel can be burned in an engine only after it has been completely vaporized. The temperature at which the fuel is completely vaporized is described as the "End Point Temperature" in ASTM D 86 Distillation Test Method. Since this temperature is difficult to measure with good repeatability, the fuel's 90% or 95% distillation point is often used. DDC specifies the 95% temperature because it is closer to the end point than the 90% used by ASTM in D 975.

#### 5.2.3 CETANE NUMBER

Cetane Number is a relative measure of the time delay between the beginning of fuel injection and the start of combustion. In a cold engine, a low cetane number will cause difficult starting and white exhaust smoke until the engine warms up. In engines with charge air cooling, a low cetane number fuel may also cause white exhaust smoke during light load operation.

A minimum cetane number of 45 is specified for best engine performance. However, the cetane number alone should not be considered when selecting a quality fuel. Other properties, such as 95% distillation temperature and carbon residue, should also be considered.

Calculated Cetane Index is sometimes reported instead of Cetane Number. Cetane Index is an empirical property determined mathematically from boiling range temperatures and specific gravity of the fuel, whereas Cetane Number is determined through an engine test. Additives may be used by the fuel marketer to improve the cetane number; however, they have no effect on cetane index. Both properties should be evaluated when selecting diesel fuel.

#### 5.2.4 FUEL STABILITY

Diesel fuel oxidizes in the presence of air, heat and water. The oxidation of fuel can result in the formation of undesirable gums and black sediment. Such undesirable products can cause filter plugging, combustion chamber deposit formation, and gumming or lacquering of injection system components, with resultant reduced engine performance and fuel economy. Two tests are specified for fuel stability, ASTM Test Method D 2274 which measures diesel fuel storage oxidative stability and the DuPont Pad Test which measures high temperature stability. The DuPont Pad test should be conducted at 302° F (150° C). The results of the DuPont Pad Test are based on a visual rating of the filter pad by the amount of light reflected from the filter pad. A 100% rating is a clean pad, while a 50% rating is very dirty. ASTM D 2274 is a weighed measure of the sediment filtered from the fuel after storage. Although the results of D 2274 may vary with actual field storage, it does measure characteristics that will affect fuel storage stability for periods of up to 12 months.

### 5.2.5 FUEL SULFUR CONTENT

Fuels with sulfur content above 0.05 mass percent (500 ppm) are not recommended for DDC EGR engines. If engines are operated with fuels not meeting the 500 ppm sulfur content limit, the drain intervals must be shortened. Drain intervals may be determined by oil analysis or by using the drain intervals in Table 4-3.

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#### 5.2.6 FUEL OPERATING TEMPERATURE AND VISCOSITY

Since diesel fuel provides cooling of the injection system, the temperature of the fuel may vary considerably due to engine operating temperature. As fuel temperature increases, fuel viscosity decreases, along with the lubrication capabilities of the fuel. Maintaining proper fuel temperatures and selecting fuels with the viscosity ranges listed in Table 5-1, "Diesel Fuel Specifications", will assure proper injection system functioning.

When operating with reduced fuel viscosity or elevated fuel temperatures, the injectors will operate at reduced internal clearances. As a result, dirt and smaller particulate material may cause injector durability concerns. Filters on Detroit Diesel two stroke-cycle engines should be changed to those specified for "Severe Duty Service." Installing a fuel cooler or operating with fuel tanks above half full may also help eliminate the concern.

## 5.3 FUEL ADDITIVES

Detroit Diesel engines are designed to operate satisfactorily on a wide range of diesel fuels. The regular use of supplemental fuel additives is not required or recommended. Some additives may be beneficial in addressing **temporary** fuel quality problems, but should not replace proper fuel selection and handling.

#### 5.3.1 WATER CONTAMINATION

Some fuel additives provide temporary benefit when fuel is contaminated with water. They are not intended to replace good fuel handling practices. Where water contamination is a concern, the fuel system should be equipped with a fuel/water separator that should be serviced regularly. In marine and other environments where microbe growth is a problem, a fungicide such as Biobor® JF (or equivalent) may be used. Microbial activity may be confirmed with commercially available test kits. Follow the manufacturer's instructions for treatment. Avoid the use of fungicides containing chlorine, bromine or fluorine compounds, since these may cause fuel system corrosion.

When small amounts of water are present, supplemental additives containing methyl carbitol or butyl cellusolve are effective. Follow the manufacturer's instructions for their use. The use of isopropyl alcohol is no longer recommended due to its negative effect on fuel lubricity.

#### 5.3.2 FUEL ADDITIVES THAT ARE NOT ALLOWED

The following fuel additives are NOT allowed:

Used Lubricating Oil – Detroit Diesel specifically prohibits the use of drained lubricating oil in diesel fuel. Used lubricating oil contains combustion acids and particulate materials, which erode injector components, resulting in loss of power and increased exhaust emissions. In addition, the use of drained lubricating oil will increase maintenance requirements due to filter plugging and combustion deposits. Refer to Section 3.14, "Waste Oil Disposal and Rerefined Oils," for recommendations on proper used oil disposal.

5-7

DIESEL FUEL



# A CAUTION:

To avoid injury from contact with the contaminants in used engine oil, wear protective gloves and apron.

Gasoline - The addition of gasoline to diesel fuel will create a serious fire hazard. The presence of gasoline in diesel fuel will reduce the fuel cetane number and increase combustion temperatures. Tanks that contain such mixtures should be drained and cleaned as soon as possible.

Detroit Diesel Corporation will not be responsible for any detrimental effects which it determines resulted from the use of used lubricating oil or gasoline in the diesel fuel.

#### EVALUATION OF SUPPLEMENTAL FUEL ADDITIVES 5.3.3

Many supplements available today are intended to be added to the fuel by the customer. These include a variety of independently marketed products which claim to be:

- □ Cetane Improvers
- ☐ Emission Control Additives
- Detergents
- ☐ Combustion Improvers
- Smoke Suppressants
- □ Cold Weather Flow Improvers

Should a customer decide that a supplemental additive is temporarily required, the following is intended to provide guidance to the customer in evaluating potential safety hazards and deleterious engine effects.

- 1. A Material Safety Data Sheet (MSDS) should be carefully reviewed for special handling instructions and hazardous material content. Additives containing hazardous materials should not be used due to personal safety risk
- 2. A detailed compositional analysis should be provided by the supplier. Ash forming metallic elements and corrosive elements must not be present. Additives containing calcium, barium, zinc, phosphorous, sodium, magnesium, iron, copper and manganese are known to cause combustion ash deposits that can foul fuel injectors and create deposits which may adversely affect cylinder life. Halogenated compounds containing chloride, fluoride and bromide are corrosive, as are some sulfur containing compounds. The use of additives with these components should be avoided.
- 3. Many commercial diesel fuels today contain performance additives, particularly those marketed as premium diesel fuel. Any supplemental additive being considered must be compatible with the fuel it is to be used in. A mixture containing twice the recommended concentration of additive should be evaluated for compatibility to represent an overdosage condition, using the tests listed in Table 5-1, "Diesel Fuel Specifications."

5-8

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The Feasibility of Fueling the Research Vessels W.G. Jackson and D.J Angus with B	iodiesel

**Detroit Diesel Corporation.** 

**Engine Data** 

Annis Water Resources Institute	MR-2003-111
The reasibility of rucining the Research vessels w.G. Jackson	rand D.3 Angus with Diodieser
The Feasibility of Fueling the Research Vessels W.G. Jackson	and D. I. Angus with Riadiasal

### ENGINE REQUIREMENTS — LUBRICATING OIL, FUEL AND FILTERS

Character- istics	ASTM or Other Methods	Conditions Measured		Two-Stroke Cycle Engine Series Four-Stroke Cycle Eng		ke Cycle Engi	ne Series
		10 - 10	53, 71, 92	149	40, 50, 60	55	MBE 900, MBE 4000
Viscosity	D 445 DIN 51562	Engine & Oil				The same	
Kv100 °C, cSt., Min.			12.5 SAE 40	16.0 SAE 50	12.5 SAE 15W-40	12.5 SAE 15W-40	12.5 SAE 15W-40
Kv100 °C, cSt., Max.			16.3 SAE 40	22.0 SAE 50	16.3 (25.01) SAE 15W-40	16.3 (25.01) SAE 15W-40	16.3 (25.01 SAE 15W-40
Soot, % Max.	TGA (E1131) or FTIR <sup>2</sup>	Engine Combustion	0.8	0.8	1.5 (3.0)1	1.5	3
Pentane Insolubles, Max.	D 893 DIN 51565	Engine Combustion	1.0	1.0	1.0 (N/A) <sup>1</sup>	2.0	1.0 (NA) <sup>1</sup>
Total Base Number, Min.	D 4739	01		1.0 or 1	/3 New Oil <sup>3</sup>		
Total Base Number, Min.	D 2896 ISO 3771	Oil		2.0 or 1	/3 New Oil <sup>3</sup>		
Glycol, Max.	D 2982 DIN 51375	Engine		Ne	gative		C-1
Water, Max.	D 1744	Engine	The state of	(	0.3%	3/4- A	
Fuel Dilution, Max.	D 3524	Engine			2.5%	ki i	
Flash Point COC °C, Min.	D 92 ISO 2592	Engine & Oil	THE S	Not s	Specified		
Iron, Max.	D 5185	Engine Wear	150 (250) <sup>5</sup>	35	150	200	150
Copper, Max.	D 5185	Engine Wear	25	25	30	20	30
Lead, Max.	D 5185	Engine Wear	10	10	30	40	20

<sup>1.</sup> With API CH-4 / CI-4 Oil

NOTE: These limits are intended as guidance when a single oil sample is tested and are based on the normal oil drain intervals listed in Table 4-1. Actual limits are dependent on engine, application, drain interval and oil type. Refer to DDC Publication 7SE398 for determining warning limits specific to your application.

Table 4-4 Single Sample Used Oil Analysis Warning Limits

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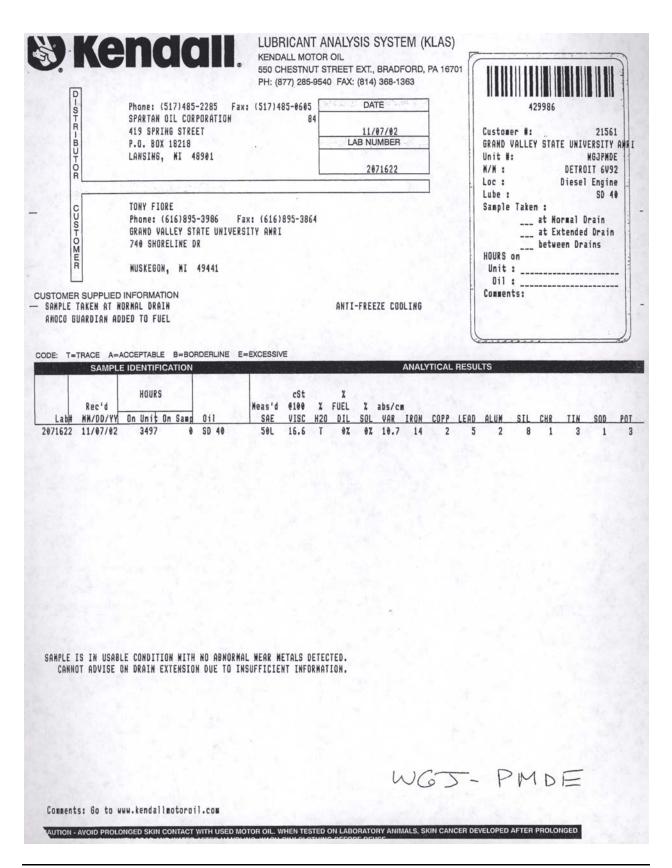
4-7

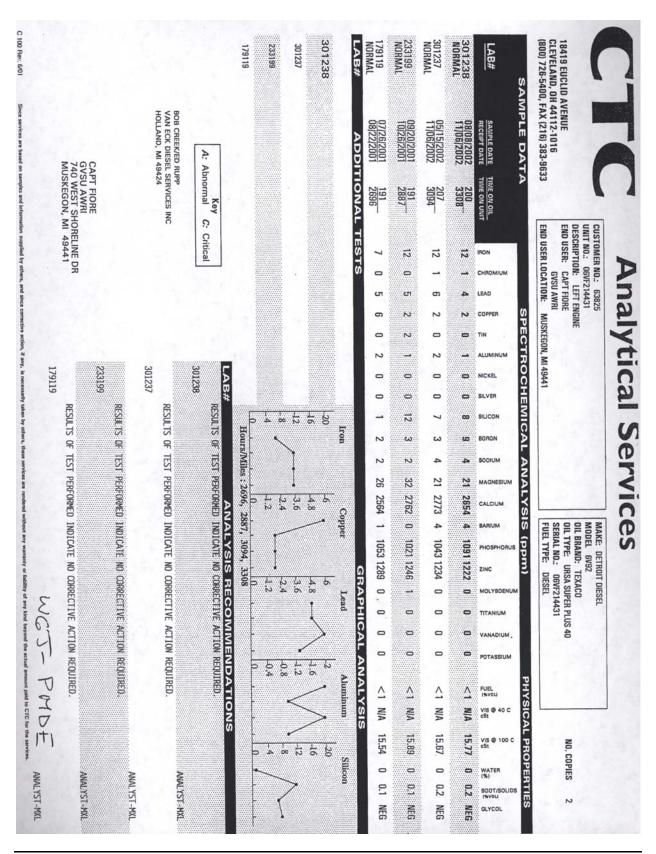
<sup>2.</sup> Infrared spectroscopy may also be used, provided it is calibrated to be equivalent to TGA.

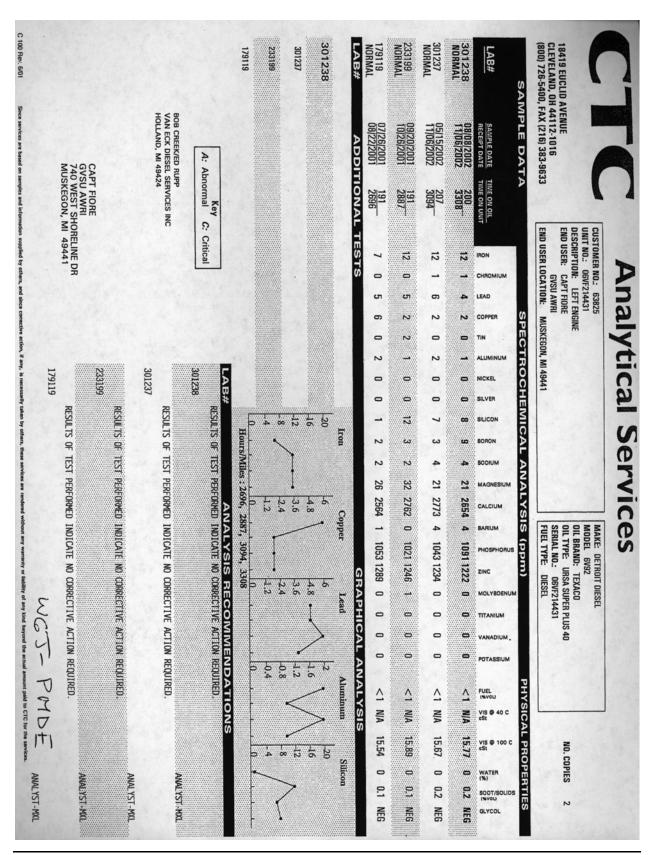
<sup>3.</sup> Whichever is higher

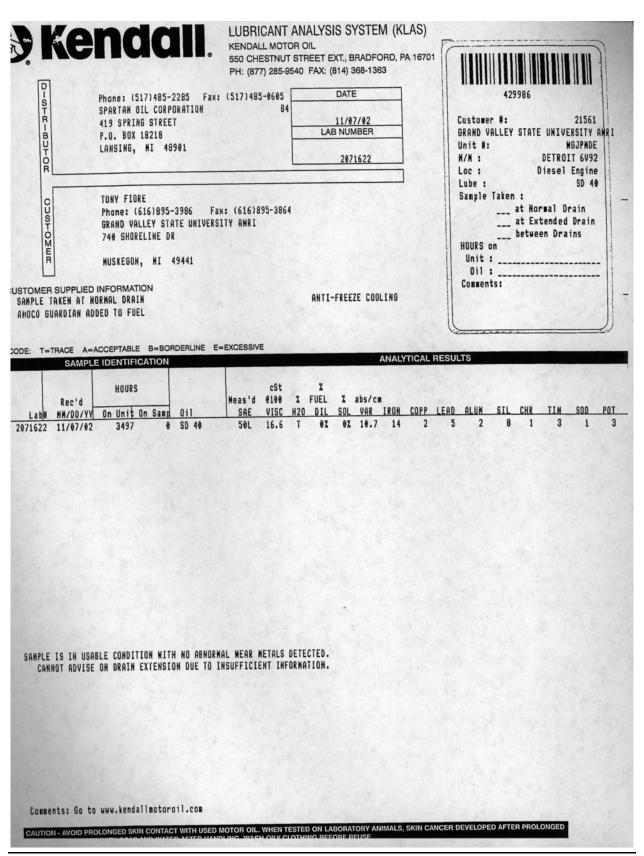
<sup>4.</sup> These are general limits. Wear metal limits must be determined for specific application and oil used.

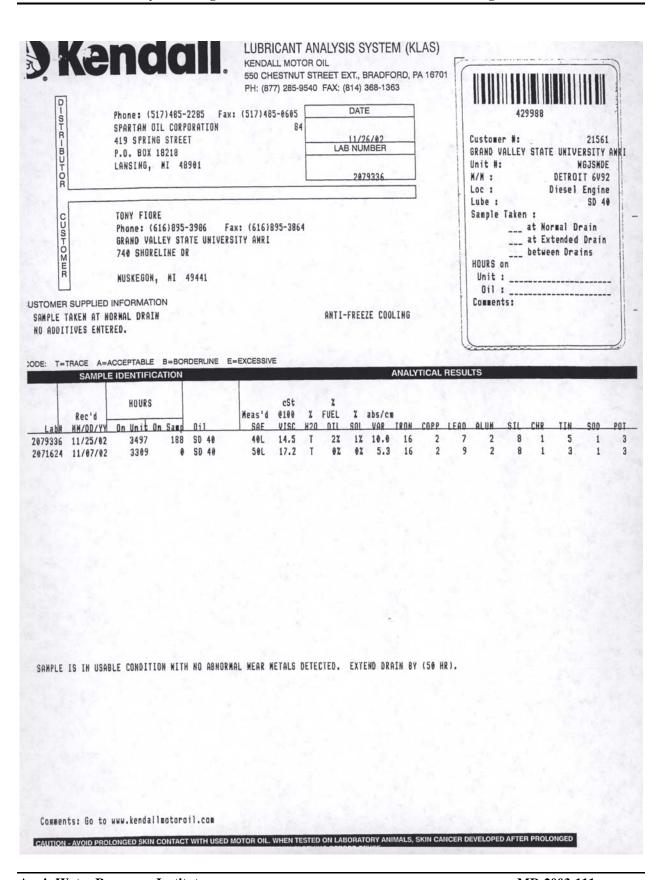
<sup>5.</sup> Marine engines only

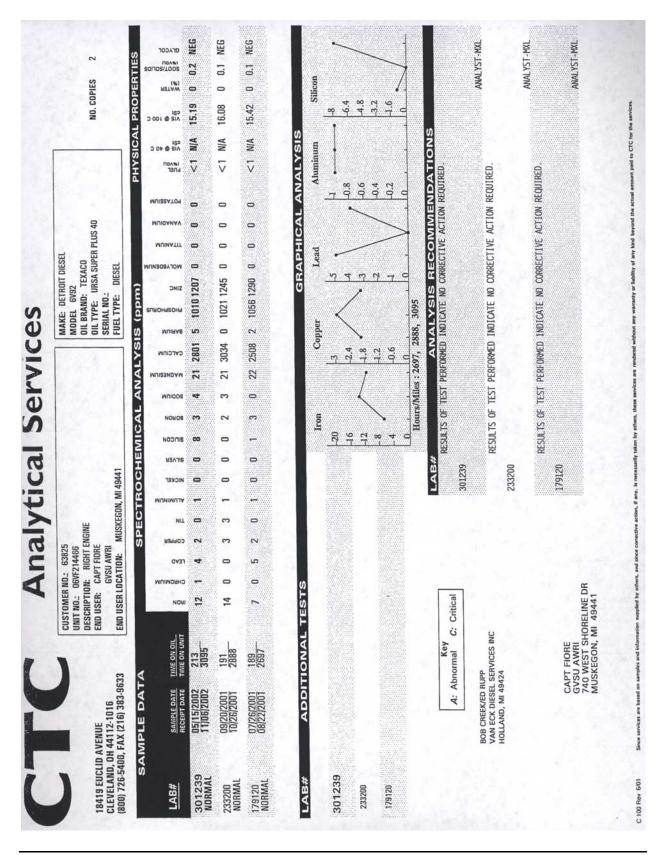


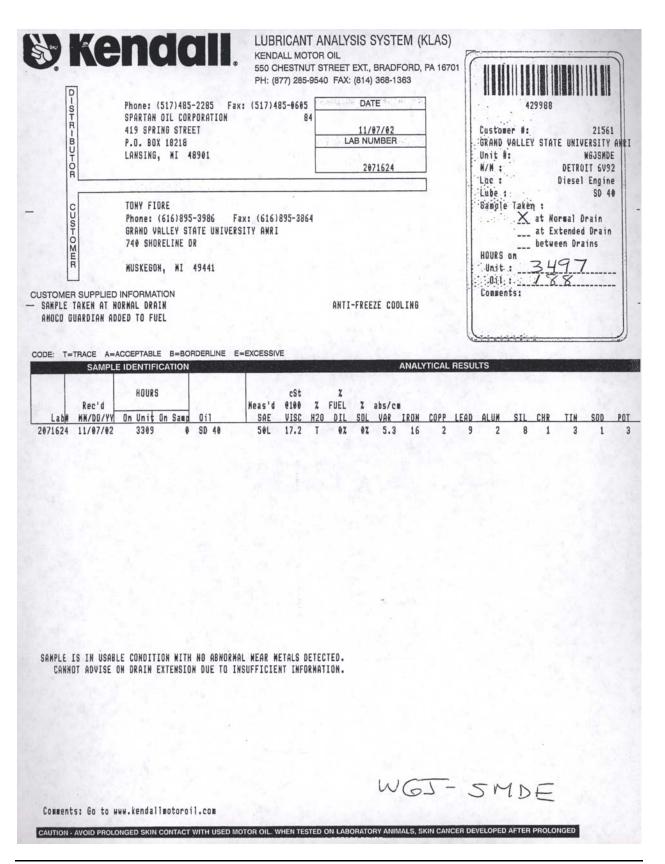


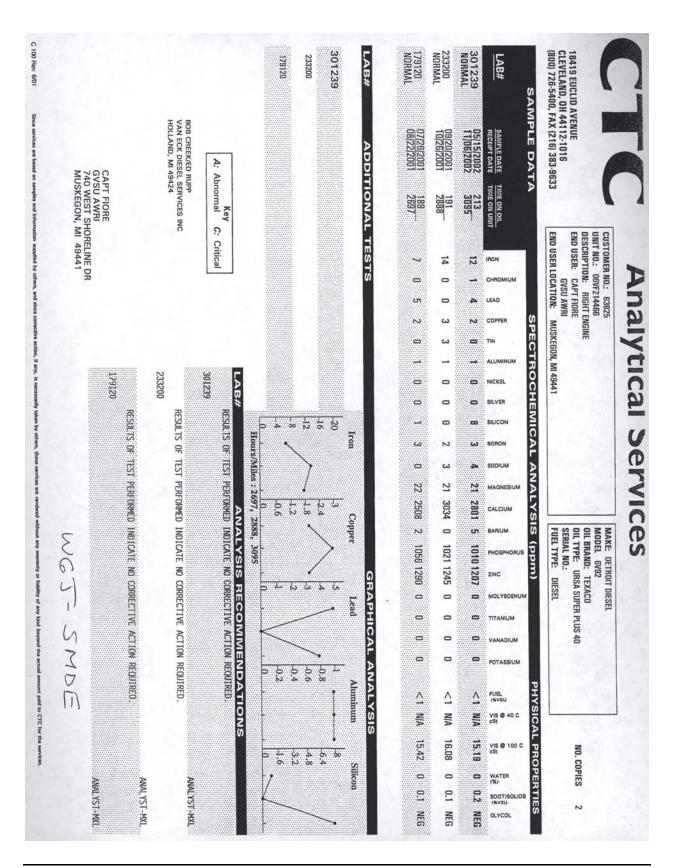


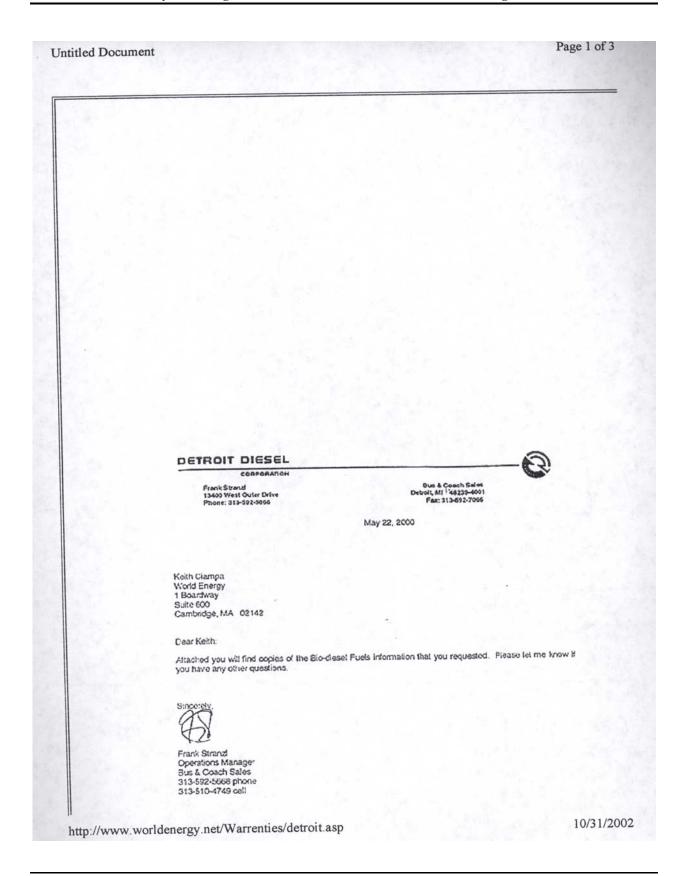












		P		
Property	ASTM Test Method	No. 1-D	110.2-D.A	
API Gravity, © 60°F* Specific Gravity, © 60°F*	D 287 D1298	39 - 44 0 803 - 0.625	0.635 - 0.655	
Flash Point, *C, min Viscosty, Knomutic cST @ 40°C	D 445	13.24	52 19-41 05(0.05) <sup>4</sup>	
Suiter with make Cloud Point *F CCP*	D 2622 D 2500	0.5 (0.06)* Note 1 -	Note 1	
Cetane No., Mn. Cetane No., Mn.	0 613 0 4737 0 86	45	45	
(hotelation % Vol. Recovery, *F (*G) IRP, Typica!*	17.00	350 (177)	375 (191) 430 (221)	
50% Typics 1 90% Max <sup>M</sup>		425 (218) 500 (260)	510 (266) 625 (32%)	
95% Max # Recovered Volume, % Min #		550 (263) 95	671 (355) 98	
Water, poin Mac# Sedment, poin Max 4	D 1744 D 22/6 er D 5452	10	200 10 0.01	
Ach, % Max Carbon Rosidue on 10%, with, Max	0 462 0 524 0 130	0.01 0.15 150.30	0.35 No.3b	
Cooper Controller, Max. Amoretained Storage Stability, Max.4 Control Red Set Refer Max.4	0 2274 TM-F21-615	15 mg/L	15mg/L	
Outport Past Test, Pating Max 4 Labridty, gm, Max* Table 6. Diesel Fuel 5	D4978*	2800	2600	
Survivious tale in Order West for type of a demand sale into the invitation stable in a global survey to appropriate or the contract to the countries of the contract to the order of the countries of the countri	Necessary several as record of several dispersion products when the book particle several dispersion products are record of the temperature and products are record of the control of the	relate section a make a relate section and the	pre- moned or (RU/II) and are blended reliums in deset fust. To a the properties tisted in the stole, "Table 6, support to require exhauts y increase engine exhauts They elso tend to havi- tions determinate engine."	
on process. The unit recommendation of the comment	on a wide variety on a wide variety of DDC engines	s. Use of these fuels m	oly petroleum-based distri ay require a reduction in a blends have not been for all fuel system durability of	5
all Detroit Dieset manufactured demonstrated trouble-tips operation of facts without the need for suppliem Biodieset Fuels Biodieset fuels may be produced for the produced fuels may be produced for	on a wide variety on a wide variety of DDC engines	I more rapidy than who is. Use of these fuels in in interval. These fuel in trated relative to diese	sy require a reduction 7 5	5 Y
all Detroit Dieset manufactured demonstrated trouble-tips operation of facts without the need for suppliem Biodieset Fuels Biodieset fuels may be produced for the produced fuels may be produced for	on a wide variety and DDC engines on methyl ester	I more rapidy than who is. Use of these fuels in in interval. These fuel in trated relative to diese	sy require a reduction 7 5	5
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all Detroit Dieset manufactured demonstrated trouble-tips operation of facts without the need for suppliem Biodieset Fuels Biodieset fuels may be produced for the produced fuels may be produced for	on a wide variety and DDC engines on methyl ester	I more rapidy than who is. Use of these fuels in in interval. These fuel in trated relative to diese	sy require a reduction 7 5	5
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all Detroit Dieset manufactured demonstrated trouble-tips operation of facts without the need for suppliem Biodieset Fuels Biodieset fuels may be produced for the produced fuels may be produced for	on a wide variety and DDC engines on methyl ester	I more rapidy than who is. Use of these fuels in in interval. These fuel in trated relative to diese	sy require a reduction 7 5	5
all Detroit Dieset manufactured demonstrated trouble-tips operation of facts without the need for suppliem Biodieset Fuels Biodieset fuels may be produced for the produced fuels may be produced for	on a wide variety and DDC engines on methyl ester	I more rapidy than who is. Use of these fuels in in interval. These fuel in trated relative to diese	sy require a reduction 7 5	5

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#### Other Fuels

In addition to the diesel fuels listed in Table 6, customers have used other fuels successfully, including fuels marketed as premium diesel fuels, kerosene-based jet fuels, and other fuels listed in Table 7. These fuels have provided economic and availability

advantages for some applications, particularly when 1-D type fuels are required, and may be used in a Detroit Diesel engines. These fuels should be accompanied by exhaust emission dat demonstrating emission equivalency to 1-D for thosengines requiring 1-D fuel. Fuel type specifications an applications are listed in Table 8.

Property	Jet A/A-1 D 1655	JP-5	JP-8	CONUS DF-1	CONUS DF-2	OCONUS DF
API Gravity, © 60°F Flash Point, °C Viscosity, Kin., eSt © 40°C Cloud Point °C Sutur, % mass Cetane Number	44.3 38 40 0.3 Max.	41.1 62 1.5 -46 0.4 Max. 42	45.6 45 1.2 -47 0.4 Max. 45	42.3 50 1.6 -41 0.05 Max.	34.2 74 2.8 -12 0.05 Max. 47	38.5 70 3.0 -19 0.3 Max. 49
Distration % Vol. Rec., *C IBP 10% Typical 50% Typical 90% Max. Frod Bollog Point, Max. Temp.	205 Report Report 300	180 191 215 242	157 175 200 236	174 195 219 245	190 222 255 313	176 219 365 311
Heat Content, Blu/gat., Net	123,608	125,270	123,069	125,960	131,207	127,820

Table 7. Selected Typical Fuel Properties

Type	NATO Spec.	Mil Spec.	Application
JP-4	F-40	MI-T-5624	Jet Fuel, Contains 50% Gasoline, Not Recommende:
JP.5	F-44	M4-T-5624	Jet Fuol, Kerosana Based
JP-8	F-34	Mi-T-83133	Jet A-1 with De-lost and Corrosion Inhibitor
Jet A	None	None	Industry Standard Jet Fuel
Jet A-1	F-35	None	Tot First ASTM D 1655
L-1/DL-2	F-54	W-F-800 CONUS	Specified Military Use Inside Continental U.S.
DF-2	F-54	W-F-800 OCONUS	Specified Military Use Outside Continental U.S.

Table 8. Fuel Type Specifications and Applications

Lower density fuels, such as those listed above and "winter blended" diesel fuels, have a lower volumetric heat content than the standard 2-D fuel listed in Table 6, "Diesel Fuel Specification Table." Operating with these fuels will result in reduced engine output and reduced fuel mileage compared to standard 2-D fuel. Reductions of 5% are not unusual and may be as high

as 10%. A good rule of thumb is this: The engi power is proportional to the heating value of the fuel

Lower density fue's also tend to have lower viscor and poor lubrication characteristics. Fuel filtratishould be changed to Powerguard Pius filters with are recommended for "severe duty service" to previoue to previoue to previoue to previoue to previoue.

http://www.worldenergy.net/Warrenties/detroit.asp

10/31/2002

# DETROIT DIESEL

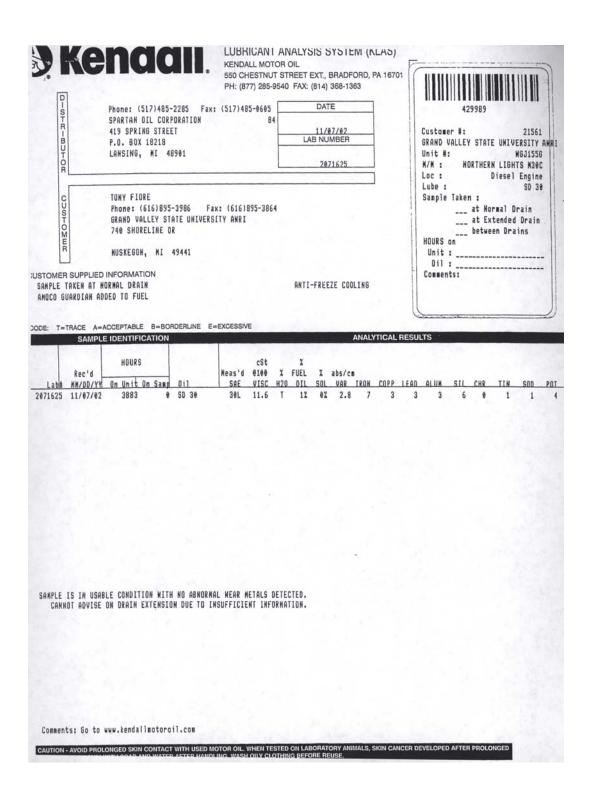


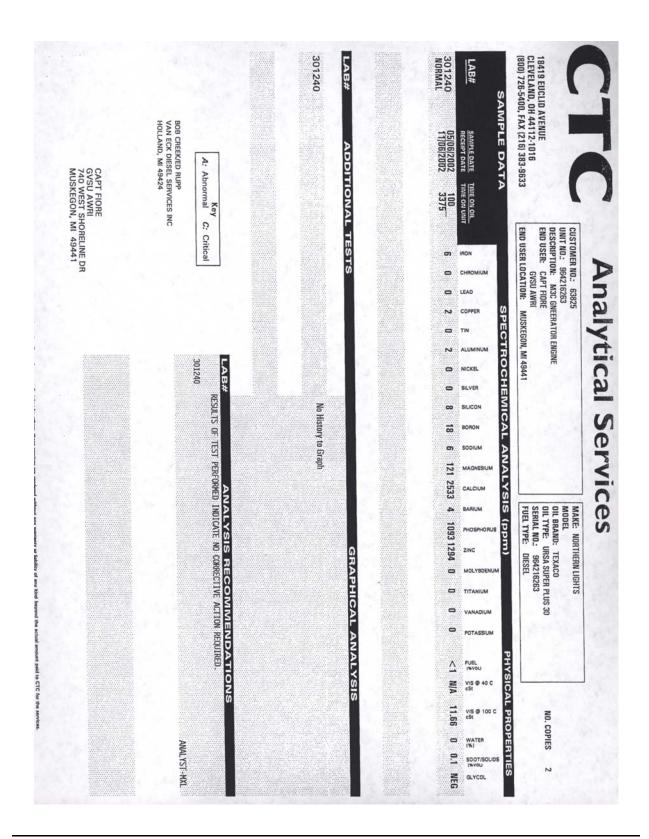
# Lubricating Oil, Fuel, and Filters

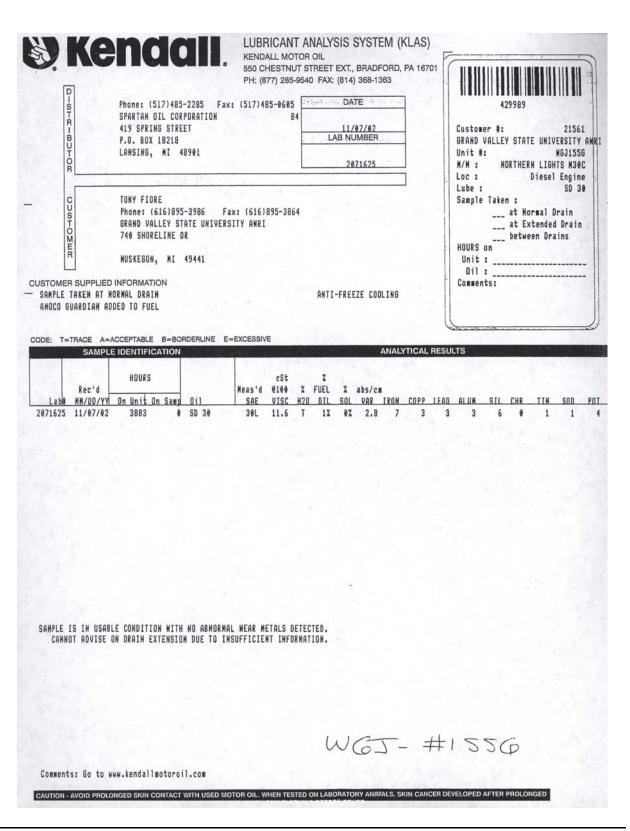


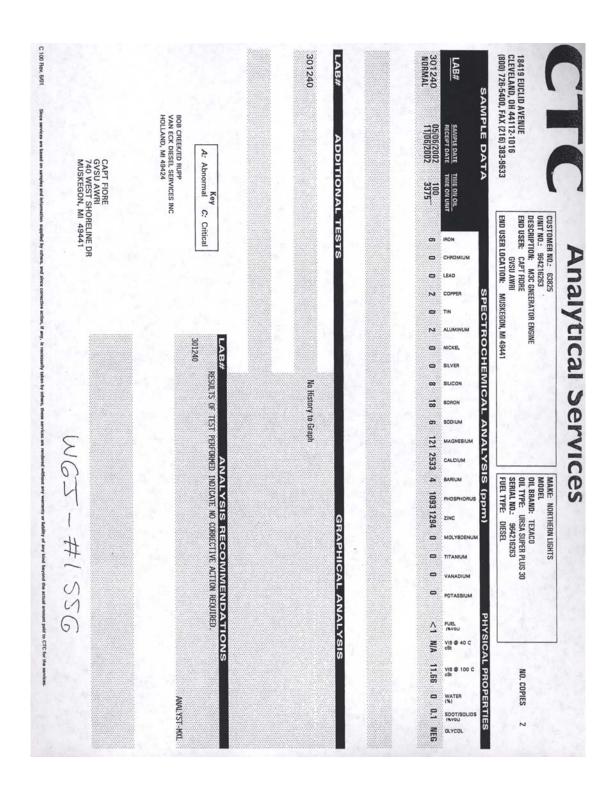
# **Engine Requirements**

Alaska Diesel Electric Engine Data









Product
Support
Bulletin



John Deere Power Systems

DATE: 12 October 2001

FUNCTIONAL GROUP CODE: 0400

APPLIES TO: John Deere PowerTech® and Non PowerTech® Diesel Engines

SUBJECT: BIODIESEL FUEL IN JOHN DEERE DIESEL ENGINES

DTAC SOLUTION: Legacy KX50441, Web 50441

The term "Biodiesel" describes the various fuels collectively known as Fatty Acid Methyl Ester (FAME). The most common source of biodiesel is soybean in the U.S. and Rape Seed in Europe. Biodiesel maybe referred to by a number of more specific terms, the most common being:

- Soybean Methyl Ester (SOME)
- Rape Methyl Ester (RME)
- Plant Methyl Ester (PME)

Biodiesel fuels may be used in John Deere diesel engines only if the fuel meets the provisional ASTM PS121 (U.S.) or DIN 51606 (German) specification listed in Table A.

NOTE: Raw pressed vegetable oils are NOT acceptable for use for fuel in any concentration. These oils do not burn completely, and will cause engine failure by leaving deposits on injectors and in the combustion chamber.

While a major environmental benefit of a biodiesel fuel is its ability to biodegrade, users must recognize that storage and handling is of prime importance as indicated below:

- Ensure the quality of the biodiesel fuel (fuel meets the specifications in Table A).
- Keep storage and vehicle tanks as full as possible to prevent moisture from collecting inside.
- Ensure all tank caps and covers are installed properly to prevent water from entering.
- Monitor water content of the fuel regularly (Bonds with water, creating acids).
- Limit the storage tanks from extreme temperatures (i.e. Direct sun or frost).
- · Limit the storage to under 1 year due to shelf life (degrades quickly, microbes, oxidation).
- Wash down spills with clean water immediately to prevent corrosion and damage to paint.
- Fuel filter may need to be replaced more often due to premature plugging.
- Check engine oil sump level daily prior to starting, a rising level may indicate lubricating oil
  dilution. This check is important for all engines and even more critical for engines equipped
  with rotary FIP.
- Instability resulting from blending biodiesel with mineral diesel fuel.



**ABCDEFG** 

## **APPENDIX VII**

# **CORRESPONDENCE**

**Detroit Diesel Corp.** 

**Cummins, Inc.** 

Dr. Alvin Womac

Dr. Leon Schumacher

**Northern Lights** 

Dr. Nigel Clark

Dr. Harvey Nikkel

Misc.

The Feasibility	y of Fueling tl	he Research `	Vessels W.G	. Jackson ar	d D.J Angus	with Biodies

# **CORRESPONDENCE**

**Detroit Diesel Corp** 

#### ENGINE REQUIREMENTS - LUBRICATING OIL, FUEL AND FILTERS

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All information subject to change without notice. (Rev. September 2002) 78E270 0209 Copyright © 2002 DETROIT DIESEL CORPORATION

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OIL DRAIN INTERVALS

# 4.5 USED LUBRICATING OIL ANALYSIS

Detroit Diesel's POWER Trac used oil analysis program is recommended for all engines. Oil analysis consists of laboratory tests to indicate conditions of the engine and/or the lubricant. The "Warning Limits" are listed in Table 4-4, "Single Sample Used Oil Analysis Warning Limits." Oil analysis cannot completely assess the lubricating oil and should not be used to extend oil drain intervals. Oil should be changed immediately if contamination exceeds warning limits listed in Table 4-4.

From: "Cantrell, Steve" < Steve. Cantrell@Detroitdiesel.com>

To: "udellb@gvsu.edu" <udellb@gvsu.edu>

Date: 2/21/03 3:03PM

Subject: OIL INFO

Mr. Udell,

The oil information can be found in DDC publication 7SE270.

I have included the following in this note:

Iron: <250 Copper: <25 Lead <10

I hope this helps.

If you have any comments please contact.

Thanks

Steve Cantrell
Marine Application Engineering

Detroit Diesel Corp. Phone: 313-592-7805 Fax: 313-592-7102

# Bob Udell - RE: Manufacture date of 6V92 engines

From: "Wickenheiser, Kenneth" < Ken. Wickenheiser@detroitdiesel.com>

To: "Bob Udell" <udellb@gvsu.edu>

Date: 9/25/2002 11:02 AM

Subject: RE: Manufacture date of 6V92 engines

Bob,

Both your engines were built in March of '96. That is the most accurate I can get.

Ken

----Original Message----

From: Bob Udell [mailto:udellb@gvsu.edu]
Sent: Tuesday, September 24, 2002 3:42 PM
To: ken.wickenheiser@detroitdiesel.com
Subject: Manufacture date of 6V92 engines

Ken:

Here's the information you requested I send.

2 - 6V92's

First:

Unit 6vF214466 S.O. 93688 Model 80627K20 325 HP at 1800 RPM Level 1 DDEC

Second:

UNit 6vF214431 5.O. 936687 Model 80627K21 325 HP at 1800 RPM Level 1 DDEC

Thanks for you help.

Bob Udell Research Assistant/Biofuel Analyst Annis Water Resources Institute Grand Valley State University. 740 W. Shoreline Dr. Muskegon, Mi 49441 (616) 895-3945

# **CORRESPONDENCE**

**Cummins, Inc.** 

From: <Powermaster@cummins.com>

To: <udellb@gvsu.edu>
Date: 9/26/02 4:50AM

Subject: Re: RQST00000099408 use of biofuels

Summary: use of biofuels

#### Solution:

Thank you for your email on the use of biofuels, soy diesel; we omitted ethanol additions to diesel which we do not allow.

As far as the specific engine for which you requested information:

Date of mfg: 28 January, 2002.

Other useful info: CONFIGURATION Number D402013MM22; CPL 2891

Cummins has not published any information about using or testing engines that run on soy based fuels. Cummins engines are designed to operate on No. 2 diesel fuel. We are not aware of any conversion components for Cummins engines to be run on soy fuels.

Cummins diesel engines will run on a great variety of fuels, but some fuels will give better performance, higher efficiency, improved reliability, or lower maintenance costs than others. Fuel must be selected based on overall operating costs, not just on the price per gallon. Cummins Diesel engines have been developed to take advantage of high-energy content and generally lower cost of No. 2-D fuels.

Cummins engines are designed to operate on commercially available Grade No.2 D fuel that meet the requirements of the American Society for Testing and Materials (ASTM) D975, Standard Specifications for Diesel Fuel Oils. Cummins recommends the use of a premium diesel fuel during winter operating conditions (20 degF or below).

Most all fuel suppliers in cold climates blend about 30 % No. 1 fuel in with the No. 2 diesel. Cummins does not recommend use of straight No. 1 fuel or kerosene, since it does not have enough lubrication qualities to avoid excessive wear on fuel system components. If ambient temperatures require the use of straight No. 1 fuel, then a lubrication additive should be added to the fuel.

Cummins diesel engines will operate on some 'Emergency' type fuels, however, fuels outside the recommended fuel oil properties are only meant to be used for short periods of time when no other fuels are available. Use of emergency fuels can have an adverse effect on engine performance and durability and Cummins assumes no warranty responsibility for repairs or increased costs of operation resulting from the use of fuels that do not conform to our recommendations.

Many 'Emergency' type fuels that do not conform to Cummins recommendations and do not have sufficient lubrication qualities, which may require additional maintenance and repairs to the engine fuel system components. Also some Emergency fuels are much more flammable than No. 2-D which may place the engine or operator at risk of fire or explosion.

Under no circumstances must gasoline, gasohol or alcohol be blended with diesel fuel. This practice creates an extreme fire hazard and under certain conditions an explosive hazard.

We have a 'Fuels for Cummins Engines' bulletin no. 3379001-05 to better familiarize yourself with our fuel specifications for your engine, that can be ordered from our literature supplier. You can reach Gannett Direct Marketing by calling 1-800-646-5609

or call 1-800-DIESELS and select the literature option or email to inquiry@gdms.com

02-28: Update - Cummins Position on Biodiesel

This communication serves as a general update on Cummins position on the use of biodiesel fuel. This

From: <Powermaster@cummins.com>

To: <udellb@gvsu.edu>
Date: 2/20/03 12:13PM
Subject: Re: RQST00000121397

Summary: Engine oil analysis and recommended wear limits

Solution:

Thanks for your Email message.

Cummins, Inc. has no published guidelines for wear metal contaminant levels. Oil analysis is a tool of the oil industry and may be used by Cummins in Laboratory tests but is not used by Cummins to determine oil change intervals. Oil change intervals are established at Cummins by actual engine testing in the Lab and in test equipment at customer locations. The published oil change intervals listed in Cummins manuals are established to provide excellent reliability and durability of the product.

Various Cummins engine families have different B50 'life to overhaul' expectations (300,000 miles for the mechanical B5.9; 400,000 for the ISB electronic B5.9), therefore the oil change intervals are different for some Cummins engine models. Cummins provides the oil change recommendations as well as the recommended oils to be used in Cummins engines and the end user must decide whether to follow these recommendations.

Cummins neither approves or disapproves of products made by other companies. Cummins does recommend that you use a quality multi-vis 15w40 oll that meets or exceeds API performance classification CF-4 SG or SF. The additive package in these oils is adequate for Cummins engines and additional oil additives are not necessary.

B and C series Cummins engines, with sliding cam tappets, require dual rated oils that include SG or SF qualities. This is described in Cummins Service Bulletin 3810340-02 (Oils for Cummins engines) dated May 1996, and in the B5.9 Operation and Maintenance (O&M) Manual, bulletin No. 3810205-12 (1/96). Cummins recommended oil change interval for the Cummins B5.9 engine is 3 months or 6000 miles, whichever comes first, regardless of the brand of oil used.

It's best not to collect a sample from the bottom of the oil pan. Contaminants tend to collect there in higher concentrations than in the rest of the oil, so you'll get an inaccurate sample. For oil analysis on our B and C field test engines, we use a company called Lubricon Inc.. They sell a small fitting that you can install into the top of the oil cooler, above the oil filter (next to the line going to the turbocharger). You can attach a hose to this fitting to collect oil into the sample bottle.

There are several other companies that do oil sampling; we would recommend that you go to your nearest Cummins distributor or Dodge dealer and ask them who they use for oil sample analysis. They will be familiar with local oil analysis labs, and they may also have sample kits ready for purchase.

If you need oil analysis, we are familiar with the following oil analysis provider:

Lubricon Inc. Lubricant Consultants, Inc. 350 E Churchman Avenue Beech Grove, IN 46107 Tel. 317-783-2968 Fax 782-9383

Recently we have learned of another location to send in oil samples for analysis. Many Cummins Distributors use the following location:

Polaris Laboratories 146 S. Park Av. Indianapolis, In. 46202 Tel. 317-808-3750

We thank you for your interest in Cummins products. Please let us know if you need assistance in locating the nearest Cummins-authorized Dealer or Distributor Service Provider. For assistance in locating a Service Provider, feel free to use Cummins North America Dealer Locator, which can be found on Cummins website:

http://www.cummins.com/service\_locator/index.cfm

Please let us know if you have other questions and if away from your computer or have a time-critical request that needs more urgent attention, feel free to call us toll-free (from North America) at 1-800-DIESELS (343-7357). Customers may also call Cummins switchboard 1-812-377-5000 (worldwide toll call) and ask for the "800-DIESELS Call Center" for assistance.

Email direct: powermaster@cummins.com

Regards,

Powermaster
Customer Assistance Center
Cummins, Inc.
Columbus, Indiana, USA

Details: Gentlemen:

I have been reviewing the Operation and Maintenance Manual looking for the wear limits recommendations on metals in the lubrication oil. We have been completing this analysis and am not sure what the limits should be. The Bulletin No.3666022-04 supplied with the engine does not seem to have this information.

Our Cummins 6BT5.9L M180 is installed in our Research Vessel D.J. Angus.

Robert (Bob) Udell Research Assistant/Biofuel Analyst Annis Water Resources Institute Grand Valley State University. 740 W. Shoreline Dr. Muskegon, Mi 49441 (616) 895-3945 Polaris Laboratories 146 S. Park Av. Indianapolis, In. 46202 Tel. 317-808-3750

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Our Cummins 6BT5.9L M180 is installed in our Research Vessel D.J. Angus.

Robert (Bob) Udell Research Assistant/Biofuel Analyst Annis Water Resources Institute Grand Valley State University. 740 W. Shoreline Dr. Muskegon, Mi 49441 (616) 895-3945 From:

<Powermaster@cummins.com>

To:

<udellb@gvsu.edu> 2/27/03 2:13PM

Date: Subject:

Re: RQST00000122715 lc b/isb biofuels & f/syst failures

Summary: Ic b/isb biofuels & f/syst failures

#### Solution:

Thanks for your email. Thre is a major difference: non Issue for you, and a non-issue for most ISB owners...... except for the early B's, which had rotary pumps, the later models had Bosch P7100 inline pumps, which are lubricated by engine oil; the issue for most VP-44's has been proven to be, in most cases, a result of insufficient fuel flow or contaminated fuel, while some of the VP-44 failures have been attributed to lift pump failures.

The fuel system was changed for the 2003 Ram trucks and the October 2002 emissions to the Bosch High-Pressure Common Rail, but the main reason for the changes are to meet new EPA standards. It should be noted that even low-cost VE pumps, given proper fuels/filters would last hundreds of thousands of miles, so the use of fuel as a pump lubricant is not a design issue, but rather an operation and maintenance issue.

You can't just believe or accept as true everything you read on the Internet and think it is going to happen to you. Yes, there have been failures of the lift pumps and VP44 injection pumps. The numbers are not near as great as what you are lead to believe.

The VP44 is completely fuel lubricated, as the VE pump is. It does not use oil lubrication like the P7100 does. The VP44 is expected to last at least a long as the P7100 in normal automotive applications. However, we obviously have much more "long-term" experience with the P7100 than we do with the VP44, so our knowledge base is still evolving. Soon after launch, the VP44 had its share of problems, just as the P7100 did when it was introduced, but we have worked closely with BOSCH to correct the issues with the pump, and we're confident that the VP44 will be a reliable fuel pump.

Fuels with low lubricity can cause increased wear or seizure of the VP44 fuel pump internal components. If you are not sure of the fuel you use add a lubricity additive is required. The use of biofuels is not approved by Cummins.

In March 2000, we contacted Bosch and they advised us that the so-called "B-10" life of the VP44 is 2000 hours at full fuel rating. In other words, if a pump were operated at 100 percent rated horsepower for 2000 hours, only 10 percent would fail; 90 percent would be okay. As the typical duty cycle of the ISB is considerably less than this, the expected life expectancy is considered more than adequate given proper fuels are used and proper restrictions are evident.

02-28-02: Update - Cummins Position on Biodiesel

# Background

With increased interest in emissions and reducing the use of "petroleum distillate-based fuels," some governments and regulating bodies are encouraging the use of bio fuels. Biodiesel fuels should be considered experimental at this time. Governmental incentives and/or environmental legislation to use bio fuels may have an impact on the sales and use of Cummins engines. This document attached below outlines Cummins criteria and parameters when using biodiesel fuel.

Warranty and Use of Biodiesel Fuel in Cummins Engines

Cummins neither approves or disapproves the use of biodiesel fuel. Cummins is not in a position to evaluate the many variations of biodiesel fuels or other additives and their long-term effects on performance, durability, or emissions compliance of Cummins products. The use of biodiesel fuel does

not affect Cummins Material and Workmanship warranty. Failures caused by the use of biodiesel fuels or other fuel additives are NOT defects of workmanship and/or material as supplied by Cummins Inc. and can NOT be compensated under the Cummins warranty.

You can find our statements on Biodiesel, Ethanol Diesel (or E-Diesel), and PuriNOx diesel on our website at http://www.cummins.com/na/pages/en/customerassistance/faq/index.cfm#5.

Thank you for choosing Cummins power or products. Please let us know if you need assistance in locating the nearest Cummins-authorized distributor or dealer. Please feel free to use our International Dealer Locator: (http://www.cummins.com/partserv/intro.html) found on the Customer Assistance page of the Cummins website (www.cummins.com).

Let us know if have other questions, or if away from your computer, feel free to call us (toll-free, from North America) at 1-800-DIESELS (343-7357), or 1-812-377-5000 (toll call, worldwide, ask for 800-DIESELS).

Regards,

Powermaster
Customer Assistance Center
Cummins, Inc.
Columbus, Indiana, USA
Email: powermaster@cummins.com

Details: Gentlemen:

I have some questions regarding the subject engines.

We have a 6BT5.9L M180 engine installed in one of our researh vessels. Does this engine have the rotary injector pump with aluminum construction that has been subject to some recent failures?

Also, a concern has been expressed over the lift pump contributing to some of these failure due to a reduction in output pressure that results in reduced lubricity (from reduced fuel) in the rotary pump.

I am aware that the ISB 5.9 installed in Freightliner buses has the rotary injector pump but are there any significant differences between the two engines i.e. ISB5.9L and 6BT5.9L M180?

Robert (Bob) Udell Research Assistant/Biofuel Analyst Annis Water Resources Institute Grand Valley State University. 740 W. Shoreline Dr. Muskegon, Mi 49441 (616) 895-3945

# The Feasibility of Fueling the Research Vessels W.G. Jackson and D.J Angus with Biodiesel

From:

<Powermaster@cummins.com>

To:

<udelib@gvsu.edu>

Date:

2/28/03 10:03AM

Subject:

Re: RQST00000122715 lc b/isb biofuels & f/syst failures

ok, the engine in the vessel; yes, that is a 6B, 12-valve design and would have the Bosch inline pump, lubricated by engine oil......Powermaster

L P7100 Pump oil lubricated ie. dopsn't home of pumps Zeelons los with 5 healurs of up. Hoump

From:

<wave.master@Cummins.com>
Bob Udell <udellb@gvsu.edu>

To: Date:

3/6/03 4:50PM

Subject:

Re: RQST00000122715 lc b/isb biofuels & f/syst failures

Bob.

Lucas pumps are fuel lubricated.

Best Regards, Wave Master

rjs

Bob Udell <udellb@gvsu.edu> on 03/06/2003 04:22:28 PM

To: wave.master@Cummins.com

CC:

Subject: Re: RQST00000122715 lc b/isb biofuels & f/syst failures

Wave MAster:

Is this a lubrication oil or a fuel lubricated pump?

Bob

>>> <wave.master@Cummins.com> 03/06/03 04:19PM >>>

Bob

According to our records your engine was built with a Lucas CAV DPA Rotary

fuel pump. The Cummins part number is 4020111. The supplier part number is

3369F as you have from the id plate.

I've not heard of the type of failure that you noted.

This pump is very different from the ISB fuel pump. About the only similarity is the fuel lines connect somewhat similar, therefore they look

a little bit alike.

Please let me know if you have any other concerns.

Best Regards,

Wave Master,

rjs

Bob Udell <udellb@gvsu.edu> on 03/06/2003 02:04:27 PM

To: wave.master@Cummins.com

CC:

Subject: Re: RQST00000122715 lc b/isb biofuels & f/syst failures

Wave.master:

I have been correspondioing with Powermaster and have sent him that info but to short cut the process here it is again:

6BT5.9L M180 Ser. No. 46181244 configuration D402013MM22 CPL 2891.

Power master told me that our engine has a Bosch inline injector (P7100

I think) pump but the fleet captain gave me the Delphi number from the pump data plate.

My question concerned the failures in the VP44 injector pump and the contributions to those failure by the lift pump. We would rather not have the injector pump that is falling on our vessels.

Bob Udell

>>> <wave.master@Cummins.com> 03/06/03 01:44PM >>>

Bob Udell,

Thank you for contacting Cummins Marine/Cummins MerCruiser Diesel Wave Master.

We will need your engine serial number to determine which pump was installed on your engine.

Probably what you have is a Lucas C.A.V. DPA pump. If you send your serial

number, I will be able to check with some of our engineers about your questions.

The ISB engine has many differences. The ISB fuel pump is electronic controlled, about the only similarity is looks. The ISB has a 24 valve cylinder head, different block, different injectors, different pistons,

and

other differences.

This is the statement usually sent to customers with inquiries regarding biofuels.

Cummins neither approves nor disapproves the use of biodiesel fuel. Cummins is not in a position to evaluate the many variations of biodiesel fuels or other additives and their long-term effects on performance, durability, or emissions compliance of Cummins Bob Udell <udellb@gvsu.edu> on 03/06/2003 02:04:27 PM

To: wave.master@Cummins.com

CC:

Subject: Re: RQST00000122715 lc b/isb biofuels & f/syst failures

#### Wave.master:

I have been correspondioing with Powermaster and have sent him that info but to short cut the process here it is again:

6BT5.9L M180 Ser. No. 46181244 configuration D402013MM22 CPL 2891.

Power master told me that our engine has a Bosch inline injector (P7100

I think) pump but the fleet captain gave me the Delphi number from the pump data plate.

My question concerned the failures in the VP44 injector pump and the contributions to those failure by the lift pump. We would rather not have the injector pump that is failing on our vessels.

# Bob Udell

>>> <wave.master@Cummins.com> 03/06/03 01:44PM >>>

# Bob Udell,

Thank you for contacting Cummins Marine/Cummins MerCruiser Diesel Wave Master.

We will need your engine serial number to determine which pump was installed on your engine.

Probably what you have is a Lucas C.A.V. DPA pump. If you send your serial

number, I will be able to check with some of our engineers about your questions.

The ISB engine has many differences. The ISB fuel pump is electronic controlled, about the only similarity is looks. The ISB has a 24 valve cylinder head, different block, different injectors, different pistons,

and

other differences.

This is the statement usually sent to customers with inquiries regarding biofuels.

Cummins neither approves nor disapproves the use of biodiesel fuel. Cummins is not in a position to evaluate the many variations of biodiesel fuels or other additives and their long-term effects on performance, durability, or emissions compliance of Cummins products.

The use of biodiesel fuel does not affect Cummins Material and Workmanship warranty. Failures caused by the use of biodiesel fuels

or

other fuel additives are NOT defects of workmanship and/or material as

supplied by Cummins Inc. and can NOT be compensated under the Cummins

warranty.

If you need assistance in locating a Cummins Distributor or Dealer call

us

toll free at 1-800-DIESELS (343-7357) or use the following link, and choose

the appropriate region.

http://www.cummins.com/index.cfm?changecountry=true

Or dial [011] 812-377-8136 (International)

Visit our Web site at [http://www.cummins.com/], or [ http://www.cmdmarine.com/]

Best Regards,

Wave Master

rjs

udellb@gvsu.edu on 03/06/2003 11:38:22 AM

Please respond to udellb@gvsu.edu

To: wavemaster@cummins.com

cc: udellb@gvsu.edu

Subject: Re: RQST00000122715 lc b/isb biofuels & f/syst failures

Bob ....we're realizing now that we should have forwarded your email to

the

Marine Group initially, but got sidetracked on the discussion of biofuels.

Cummins Marine - the customer has questions regarding the fuel system

his B5.9 Marine engine, and also about the compatibility (or lack thereof)

with biofuels; we should have passed this to you sooner ... my mistake.

Bill in Powermaster (we've included the previous and also an earlier

email)
BEGIN ORIGINAL
MESSAGE
Powermaster:
Thank you again for your trouble and quick response. Followiing the E-mail below I had our Fleet Captain check our pump against the information that you transmitted. He informs me that our Cummins has a
Delphi Fuel pump model 3369F341W Type 1331Ser. No. 19609KUG.
Is this fuel pump a Bosch pump private branded by Delphi and how do it relate to the information previously sent?
Bob Udell

>>> <Powermaster@cummins.com> 02/28/03 10:02AM >>> ok, the engine in the vessel; yes, that is a 6B, 12-valve design and would have the Bosch inline pump, lubricated by engine oil.......Powermaster

MESSAGE------END ORIGINAL

#### Gentlemen:

I have some questions regarding the subject engines.

We have a 6BT5.9L M180 engine installed in one of our researh vessels. Does this engine have the rotary injector pump with aluminum construction that has been subject to some recent failures?

Also, a concern has been expressed over the lift pump contributing to some of these failure due to a reduction in output pressure that results

in reduced lubricity (from reduced fuel) in the rotary pump.

I am aware that the ISB 5.9 installed in Freightliner buses has the rotary injector pump but are there any significant differences between

the two engines i.e. ISB5.9L and 6BT5.9L M180?

Robert (Bob) Udell Research Assistant/Biofuel Analyst Annis Water Resources Institute Grand Valley State University. 740 W. Shoreline Dr. Muskegon, Mi 49441 (616) 895-3945

The Feasibility of Fueling the Research Vessels W.G. Jackson and D.J Angus with Biodiese									
	•								

# **CORRESPONDENCE**

**Dr. Alvin Womac** 

#### The Feasibility of Fueling the Research Vessels W.G. Jackson and D.J Angus with Biodiesel

From: "Alvin R. Womac" <awomac@utk.edu>
To: "Bob Udell" <udellb@gvsu.edu>

Date: 9/17/02 2:10PM

Subject: RE: Appliation of biodiesel in the marine environment

Oh, yep the exhaust el had the coolant sea water discharged through a coaxial pipe arrangement - I simply plumbed the internal exhaust separately so that I could use it to dose the water for the fish.

The underlying assumption was that the exhaust would be water discharged - hence the effect on fish was examined.

Don't know about gaseous exhaust uptake differences between fresh and salt water.

----Original Message-----

From: Bob Udell [mailto:udellb@gvsu.edu] Sent: Tuesday, September 17, 2002 11:13 AM

To: awomac@utk.edu

Subject: RE: Appliation of biodiesel in the marine environment

Alvin:

Thanks again.

The root of my question was exhaust contamination of the raw water flow which I assume will be different for fresh or sea water.

Bob

>>> "Alvin R. Womac" <awomac@utk.edu> 09/17/02 09:51AM >>>

Bob,

Actually the swimming pool only provided capacitance of fresh water for the engine cooling circuit that cooled a heat exchanger serving as a radiator (i.e. pull in "seawater" that cools the engine glycol circuit through a heat exchanger). Fresh water was not in direct contact with the engine block as I recall.

There should be little if any effect on engine cooling whether it be fresh or sea water for the engine that I tested. The sea water pump pulled such an enormous volumetric flow rate that sea water temperature also had no appreciable effect on engine temperature. The sea water circuit was overly designed.

Fish mortality tests were in fresh water (Dechlorinated city water).

Al

From: "Alvin R. Womac" <awomac@utk.edu>

To: "Bob Udell" <udellb@gvsu.edu>

Date: 9/17/02 9:59AM

Subject: RE: Appliation of biodiesel in the marine environment

Bob,

Actually the swimming pool only provided capacitance of fresh water for the engine cooling circuit that cooled a heat exchanger serving as a radiator (i.e. pull in "seawater" that cools the engine glycol circuit through a heat exchanger). Fresh water was not in direct contact with the engine block as I recall.

There should be little if any effect on engine cooling whether it be fresh or sea water for the engine that I tested. The sea water pump pulled such an enormous volumetric flow rate that sea water temperature also had no appreciable effect on engine temperature. The sea water circuit was overly designed.

Fish mortality tests were in fresh water (Dechlorinated city water).

Al

----Original Message-----

From: Bob Udell [mailto:udellb@gvsu.edu] Sent: Tuesday, September 17, 2002 8:40 AM

To: awomac@utk.edu

Subject: RE: Appliation of biodiesel in the marine environment

# Alvin:

Thank you for your quick and informative response. I have not read the papers in their entiriety as yet but a quick question comes to mind. Your testing was done with fresh water, from an above ground swimming pool for some of the testing. I assume that this water was not clorinated or replicate seawater.

Bob

>>> "Alvin R. Womac" <awomac@utk.edu> 09/16/02 04:43PM >>>

Bob,

I've attached a summary article (96YLDSL..) published in "Liquid Fuels and Industrial Products from Renewable Resources," Proceedings of the Third Liquid Fuel Conference, published by ASAE, St. Joseph, MI, 1996 presented in Nashville & also presented at Yellowstone National Park in a Biodiesel meeting.

Also attached is a report (96Biod...) to the National Biodiesel Board - same information, but more interpretive information.

Don't let the engine set for a year or two with 100% biodiesel - else you may encounter some gum problems. I replaced one fuel lift pump (~\$50 as I recall) on the Volvo marine engine - possibly because it's elastomer in contact with the fuel was not compatible.

I assume that you are in contact with NBB (National Biodiesel Board).

Have the engine manufacturer on board (the project) so that they can advise.

Regards, Al

Alvin R. Womac, Ph.D., P.E. Biosystems Engineering & Environmental Science Dept. The University of Tennessee

P.S. ..... Grand Valley - seems as I recall that they have a good Power Hydraulics section - as mentioned in the Fluid Power magazine.

----Original Message-----

From: Bob Udell [mailto:udellb@gvsu.edu] Sent: Monday, September 16, 2002 2:20 PM

To: awomac@utk.edu

Subject: Appliation of biodiesel in the marine environment

Sir:

Annis Water Resources Institute of Grand Valley State University operates two diesel powered research vessels on the Great Lakes out of Muskegon, Michigan. We are considering operating our vessels on biodiesel as a feasibility demonstration and to gain the environmental advantages of the fuel.

I came across your name in my web research and would like to enlist your assistance if possible.

There is ample hard data on the use of biodiesel in automotive application but data generated from the use in marine applications is much harder to come by. I am in need of documented research and application data of biodiesel fuel use in marine engines. If you or any of your colleagues have worked in this area I would like know of available papers. The type of data required is exhaust emissions, fuel usage, and maintenance issues encountered. These data should be compared to petrodiesel in the same application.

**Bob Udell** 

Biofuel Analyst Annis Water Resources Institute Grand Valley State University. 740 W. Shoreline Dr. Muskegon, Mi 49441 (616) 895-3945 From: "Alvin R. Womac" <awomac@utk.edu>

To: "Bob Udell" <udellb@gvsu.edu>

Date: 9/19/02 4:58PM

Subject: RE: Further to our dialogue

Bob.

I believe that you got the diagram of the "experimental design" for the fish test - the footnote says that "0" was the control with clean water.

The fish results in table 8 show that we lost 4 control fish (4%), uniformly, in each fuel category. I'm thinking that you got this table also. (I'm looking at the published hard copy in the proceedings book. I highly recommend your procurement of that series of biofuel proceedings from ASAE.) My numbers indicate that once the fuel is combusted - that the advantages of the biofuel are slightly better for the environment for the most part. However, as I recall Peterson (Idaho) showed a tremendous difference with biofuel being less toxic than sugar in the raw fuel state. I believe he was looking at effects on Daphnia (??). Would need to look the article up to know for sure.

De-chlorination question - yep, there should not have been any differences associated with that - as you can imagine what is reported is only a small portion of the fish work. I worked with larger tanks and learned how to raise the fish under artificial conditions.

Best regards, Al

----Original Message----

From: Bob Udell [mailto:udellb@gvsu.edu] Sent: Thursday, September 19, 2002 12:59 PM

To: awomac@utk.edu

Subject: Further to our dialogue

AI;

A couple of question - this should be the last.

Did you have a control group of bluegills in fresh water over the five day exposure to exhaust dosed water?

Was the de-clorination process consistent - I assume it was.

I also see from some of the material I got from WVU website that you have done some testing of a Detroit 6V92 in the EERL -was there any operation with biodiesel by any chance? This is the exact engine our larger research vessel uses and any data you have available may be helpful. Would you be interested in any data we might get (it would be late next season most likely).

Our smaller vessel has a Cummins 6BT5.9 and a Westerbeke 20 on the Genset.

Bob

#### The Feasibility of Fueling the Research Vessels W.G. Jackson and D.J Angus with Biodiesel

From: "Alvin R. Womac" <awomac@utk.edu>
To: "Bob Udell" <udellb@gvsu.edu>

To: "Bob Udell" <udellb()
Date: 9/26/02 10:00AM

Subject: RE: Biodiesel marine applications and possible environmental impact projects

Bob,

I bought and used a mobile emissions analyzer that gave concentrations.

My research was criticized for not using an emissions test protocol that also included mass flow to get total emissions - and not just relative differences in concentration (i.e. take into account air and gas throughput of engine).

I guess it all depends on the intended use of the data.

Regarding grant money - I've not done a search or shook any trees lately for money in this area. I would start by contacting the National Biodiesel Board for leads, then look for state, Federal, or Foundation money. I don't know of any clear, direct leads at this point.

Best wishes,

Al

----Original Message-----

From: Bob Udell [mailto:udellb@gvsu.edu] Sent: Thursday, September 26, 2002 9:12 AM

To: awomac@utk.edu

Subject: Biodiesel marine applications and possible environmental impact projects

Al:

Some new possibilities have presented themselves for us in our biodiesel project.

We have located a manufacturer of mobil emissions test equipment who may loan us test equipment and training to use on our two boats. This would most likely happen in the spring of 2003. Comparisons of marine petrodiesel and biodiesel in eral world situations would be possible.

In discussing the possibilities, we also considered our mesocosm facility

and what might be accomplished in relation to biodiesel use in the marine environment.

Al Steinman, Director of the Annis Water Resource Institute, was also wondering where there might be grant money.

As a retired ex-aerospace engineer and manager much of this is still Greek to me.

Do you any thoughts on any of these ?

Regards:

Bob

# **CORRESPONDENCE**

Dr. Leon Schumacher

From: Leon Schumacher <schumacherl@missouri.edu>

To: Bob Udell <udellb@gvsu.edu>

Date: 12/25/02 11:54AM
Subject: Re: Dodge truck testing

Bob

We have both used the Cummins Engine Co. Recommendations for Lube oil. 15W40

I have used Cummins Blue...

We have had independent labs analyze this oil at every oil change.

I have some papers posted in the internet that you can review...

www.missouri.edu/~pavt0689

Click on the link to U of Missouri

Merry Christmas

Leon

\_\_

Leon Schumacher
Associate Professor
235 Agricultural Engineering Building
University of Missouri
Columbia, MO 65211
Phone: 573-882-2126

Fax: 573-884-5650 schumacherl@missouri.edu From: Leon Schumacher < schumacherl@missouri.edu>

To: Bob Udell <udellb@gvsu.edu>

Date: 9/23/02 8:00PM

Subject: Re: Biodiesel in Cummins Engines

Bob

This is the same model Cummins engine. What year was yours made? This would be helpful to know... as if mfg. after 1993, the engine would most likely be in a better position to use biodiesel at 100%.

Are you planning to use the biodiesel at 100% or 20%?

Leon

From: Leon Schumacher <schumacherl@missouri.edu>

To: Bob Udell <udellb@gvsu.edu>

Date: 1/6/03 2:48PM

Subject: Re: Dodge truck testing

Bob

I really do not feel we can pin this down to the sulfur... rather, the environment that the engine runs in... mine runs down the road... all the grime on the road is a problem when you only use a single element to filter the air... you actually get better results from a farm tractor in the field... dual element filtering...

my thoughts,...

Leon

Leon Schumacher
Associate Professor
235 Agricultural Engineering Building
University of Missouri
Columbia, MO 65211
Phone: 573-882-2126
Fax: 573-884-5650

schumacherl@missouri.edu

# The Feasibility of Fueling the Research Vessels W.G. Jackson and D.J Angus with Biodiesel

From: Bob Udell

To: "schumacherl@missouri.edu".GWIASMTP.SMTPDOM

Date: 1/6/03 2:45PM

Subject: Re: Dodge truck testing

Leon:

Thanks for the reply. My real concern is that your test data and our experience show an order of magnitude difference in the wear metals in the oil - yours being the higher. I would guess that the difference might be that the marine diesel has significantly more sulfur. What would you think?

Bob

```
Leon Schumacher <schumacherl@missouri.edu>
From:
To:
                 Bob Udell <udellb@gvsu.edu>
                 2/25/03 6:21PM
Date:
Subject:
                 Re: Engine wear data from St. Louis bus test
Bob
I was a bit startled when I compared the results of these oil analysis.
It is difficult to put a finger on things like this... and even as of
this date, I have not a good answer.
I have yet to see this repeat itself...
Leon
Bob Udell wrote:
> Leon:
> You must have been away - I thought that I may have worn out my welcome
> - it's good to commulunicate with you again.
> I have two papers on the St Louis study No. 956736 "Maintenence,
> Repair, Exhasut Emissions, Associated with Biodiesel Fuelling of Urban
> Buses" and "Lessons Learned While Fueling with Biodiesel". Is there
> another one?
> Since my last E-mail I discovered the the buses oil analysis exceeded
> the DDC recommeded limits for copper and lead and werre close to the
> iron limit of 150ppm - did you realize this? So I think that there was
> something going on besides the switch to B20 what do you think.
> Bob
>>>Leon Schumacher <schumacherl@missouri.edu> 02/25/03 10:18AM >>>
> Bob
> I understand your thoughts on this one. This was a MAJOR overhaul.
> Meaning, bearings, liners, rings, etc.
> This could be an issue. However, the diesel engines were in the same
> situation.
> When I analyzed this statistically, I was unable to determine
> I have a paper that addresses this directly... have you seen the one
> that compiles all of MU's oil analysis data with the University of
> Idaho's?
 > Leon
```

From: Leon Schumacher <schumacherl@missouri.edu>

To: Bob Udell <udellb@gvsu.edu>

Date: 2/25/03 10:19AM

Subject: Re: Engine wear data from St. Louis bus test

Bob

I understand your thoughts on this one. This was a MAJOR overhaul. Meaning, bearings, liners, rings, etc.

This could be an issue. However, the diesel engines were in the same situation.

When I analyzed this statistically, I was unable to determine differences.

I have a paper that addresses this directly... have you seen the one that compiles all of MU's oil analysis data with the University of Idaho's?

Leon

Bob Udell wrote:

- > Dr. Schumacher.
- -
- > I have reviewed your engine wear data from the St. Louis bus test and
- > caompared it with our experience from two years of operating the same
- > engine on our research vessel the W.G.Jakson which as raised a question
- > regarding the overhaul of the bus engines that occurred just before the
- > testing. What was the extent of the overhaul and was it sufficient that
- > the wear metals could have been excessive for your test because of a
- > breakin period on ht engines?
- >
- > See my attached data.
- >
- > Robert F. (Bob) Udell
- > Research Assistant/Biofuel Analyst
- > Annis Water Resources Institute
- > Grand Valley State University.
- > 740 W. Shoreline Dr.
- > Muskegon, Mi 49441
- > (616) 895-3945

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Leon Schumacher
Associate Professor
235 Agricultural Engineering Building
University of Missouri
Columbia, MO 65211

Phone: 573-882-2126 Fax: 573-884-5650 schumacherl@missouri.edu

Zinc 1150	Zinc	1222.0	1234.0	1246.0	008.2			1207 0	1245.0	1290.0	748.4	
Barrium Phosphorous 3 1047	Barrium Phosphorous	1091.0	1043.0	1021.0	844.6	2		10100	1021.0	1056.0	617.4	
Barrium 3	Barrium	4.0	4.0	0.0	2 4	3		20	000	2.0	4.	
Slend Calcium 995	Calcium	2654.0	2773.0	2762.0	2450.5	2120.0		0 1000	30340	2508.0	1668.6	
Detroit Diesel 6V92 Engine Average Data from University of Missouri for B20 Blend Aluminum Silicon Chromlum Tin Sodium Potasium Boron Magnesium Calcit 1 17.4 4.8 5.9 25.7	Magnesium	210	21.0	32.0	20.0			25	21.0	22.0	12.8	
of Misso Boron 19.8	ingine Boron	00	3.0	3.0	2.0	5.4 e Engine			0.0	3.0	1.6	
iversity o	ain Drive E	0.0	000	0.0	0.0	U.b.	3.0	3.0	0.0	0.0	12	
rta from University Sodium Potasium 25.7	W. G. Jackson Detroit Diesel 6V92 - Port Side Main Drive Engine Chromlum Tin Sodium Potasium Boro	2.5	4.0	20	2.0	2.6 arboard Side	1.0	0.5	0.4	0.0	1.8	
rage Da Tin 5.9	W. Cel 6V92 -	3.0	0.0	50	0.0	1.0 3V92 - St	3.0	2.0	0.0	0.0	22	
Silicon Chromium	Detroit Dies Chromium	0.5	2 0	00	0.0	0.6 1.0 2.6 0.6 3.4 Defroit Diesel 6V92 - Starboard Side Main Drive Engine	1.0	1.0	1.0	0.0	9.0	
Silicon 17.4	Silicon	0.0	2.0	12.0	1.0	7.2	8.0	8.0	8.0	0.0	5.0	
etroit Diese Aluminum 1	Aluminum	20	200	1.0	2.0	9.	2.0	2.0	1.0	0.0	4.1	
Dead 14.5	Lead	2.0	0.4	2.0	5.0	2.0	9.0	0.7	4.0	0.0	2.0	
Copper 32.9	Copper	2.0	2.0	20	0.9	2.8	20	2.0	2.0	3.0	22	
lron 147	<u>no</u>	14.0	12.0	120	7.0	11.4	160	16.0	12.0	14.0	13.0	
Viscosity 16.7	Viscosity	16.6	15.8	15.9	15.5	Averages	17.2	14.5	15.2	16.1	Averages	

# **CORRESPONDENCE**

**Northern Lights** 

From: Bob Udell

To: "pleask@northern-lights.com".GWIASMTP.SMTPDOM

Date: 9/16/02 3:16PM Subject: Re: Fw: Bio Diesel

Paul:

Per our telecon this date 9/16/02: I understand that Northern Lights position on use of B100 biodiesel in their gen sets is that biodiesel fuels meeting the ASTM provisional specification PS121 (which has been superceded by ASTM D6751) or DIN 51606 are acceptable fuels. All current workship and materials warranties that are in effect will remian in effect if biodiesel fuel meeting the above specifications is utilized in Northern Light generator sets. The most restrictive case is that of the Injector pump on the John Deere engines which is why Northern Lights distributes the John Deere literature as their poition on use of biodiesel for the various engines supplied on Northern Lights generator sets.

Please confirm that I have correctly understood your position.

Bob

>>> "Paul Leask" <pleask@northern-lights.com> 09/16/02 02:35PM >>> Hi Bob

Here is what I have regarding specs regarding Bio Fuel Hope this helps

Paul leask

----- Original Message -----From: "Dick Gee" < dickg@northern-lights.com>

To: "Paul Leask" pleask@northern-lights.com
Sent: Thursday, September 12, 2002 2:17 PM

Subject: FW: Bio Diesel

# **Bob Udell - RE: Bio Diesel use in Northern lights Gensets**

From: "Dick Gee" <dickg@northern-lights.com>

To: "Bob Udell" <udellb@gvsu.edu>

Date: 9/17/2002 11:43 AM

Subject: RE: Bio Diesel use in Northern lights Gensets
CC: "Paul Leask" <ple>pleask@northern-lights.com>

#### Dear Mr. Udell,

The IMO regulations include engines of 175 BHP and above.

The US EPA regulations include all engines less then 50 BHP.

CARB covers the engines more then 50 and less then 175 BHP.

I mention all the above because I do not know what size engine you are working with nor where you are in the world.

We also cannot be sure what the emission impact will be.

Best Regards, Dick Gee

----Original Message----

From: Bob Udell [mailto:udellb@gvsu.edu]
Sent: Tuesday, September 17, 2002 5:08 AM

To: Dick Gee Cc: Paul Leask

Subject: Re: Bio Diesel use in Northern lights Gensets

# Dear Mr Gee:

Thank you for your clear and definitive response. I assume that the out of compliance emission standard that will occur is the increased NOx emissions and that the standard is that of the IOM. Is this the case ?

#### Bob Udell

>>> "Dick Gee" <dickg@northern-lights.com> 09/16/02 06:02PM >>>

Dear Mr. Udell,

The use of bio diesel fuel (ASTM D6751-02) as a "blend component" (not to exceed 5 %) with diesel fuel per ASTM D 975 is approved for use in Northern Lights diesel generator sets. The standard warranty policies & conditions will continue to apply.

The use of such "blended" fuel may render the engine to be out of emission compliance. Such out of compliance issues will NOT be the responsibility Alaska Diesel Electric and will not be covered by any warranty.

Best Regards, Dick Gee Vice President & Technical Director Alaska Diesel Electric

#### Hi Bob

Regarding your question about recommendations as to the limits of Iron, Copper,lead and so on

We do not publish any limits for these numbers for the following reasons

These numbers are affected by the test interval period. Example if you run a unit for one hundred hours and test the oil then you run the same unit for two hundred hours you will get two very different results. Oil sample test should be done at the same interval example 100 hours after oil change, after doing this a few times you should have established a base line. From this base line you will be looking for a substantial change in the results this will indicate a possible problem

Paul leask

--- Original Message ----

From: info To: Paul Leask

Sent: Tuesday, February 25, 2003 9:44 AM

Subject: FW: Engine wear metals recommendations

----Original Message----

From: Bob Udell [mailto:udellb@gvsu.edu] Sent: Monday, February 24, 2003 10:18 AM

To: info

Subject: Engine wear metals recommendations

Does Northern Lights have recommnedations as to the limits of Iron, Copper, Lead Silicon, and Chromium that are acceptable in engine oil analyses?

From:

Anthony Fiore

To:

Udell, Bob

Date:

2/10/03 3:40PM

Subject:

Re: data & Stuff

BOB,

WGJ-750 GLS

MDE'S- LUBE OIL AND FUEL FILTERS EVERY 200 HRS

SSG'S- LUBE OIL AND FILTER EVERY 100 HRS, FUEL FILTERS EVERY 200 HRS

DJA-GL'S? 300 IN Two 100 CALLON Points

I HAVE TO STOP BY THE DJA TO GET THE TANK CAPACITY I JUST CAN'T REMEMBER THE #.

MDE- OIL AND FUEL FILTERS EVERY 200 HRS

SSG - OIL AND FUEL FILTERS EVERY 100 HRS

TONY

>>> Bob Udell 02/10/03 02:59PM >>>

Tony:

I need the following:

Fuel tank capacities for the two boats.

Oil change interval for the two boats.

I will need copies of the engine and genset literature that came with the manual for both the boats -not the parts lists, repair & maintenance stuff just the general descriptions of the engines/gensets no of cylinders, aspiration, HP, watts, etc.....

Bob

# **APPENDIX VIII**

# **BIODIESEL Handling and Use Guidelines**

NREL/TP-580-30004

NREL/TP-580-30004

# **Biodiesel Handling and Use Guidelines**

K. Shaine Tyson



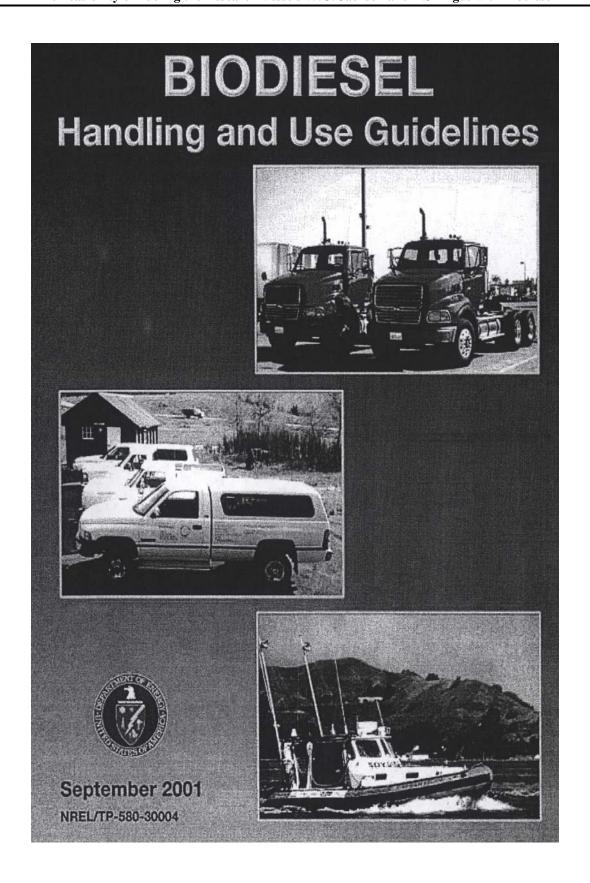
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#### **BIODIESEL HANDLING AND USE GUIDELINES**

#### 1 Introduction

This document is a field guide for end-users (firms and individuals that are using biodiesel or blends of biodiesel and diesel fuel), distributors, (firms and individuals who are purchasing biodiesel for blending, storage, or distribution to others), and those involved in related activities. These guidelines cover fuel use and handing issues that could be anticipated or encountered in the field. Put this document where employees can access it and be sure to use it as a reference when questions are raised by your customers or your employees.

#### 2 Biodiesel Fuel

Biodiesel is a fuel manufactured from vegetable oils, recycled cooking grease, or animal fats. The fuel typically contains up to 14 different types of fatty acids (Table 1) that are chemically transformed into fatty acid methyl esters (FAME). Different fractions of each type of FAME present in various feedstocks (Table 2) influence some of the properties of the fuel (Table 3). High levels of saturates (C14:0, C16:0, C18:0) raise cloud point, raise Cetane number, reduce NOx, and improve stability. More polyunsaturates (C18:2, C18:3) will reduce cloud point and Cetane, reduce stability (unless stability additives are used), and raise NOx.

Biodiesel always refers to the pure fuel. Biodiesel blends or BXX refers to a fuel that is composed of XX% biodiesel and 1-XX% diesel fuel. For example, B100 is pure biodiesel and B20 is a blend of 20% biodiesel and 80% diesel fuel. The diesel fuel can be No. 1, No. 2, or JP8. Some biodiesel blends may not meet ASTM D975 standards depending on how much biodiesel is present. Biodiesel blends stay mixed in the presence of water.

Biodiesel and biodiesel blends should only be used in compression-ignition (CI) engines that were designed to be operated on diesel fuel as described by ASTM D 975 or related military specifications. Do not put biodiesel fuels or blends into gasoline engines. Biodiesel and biodiesel blends can be used in CI engines in diesel-powered cars, trucks, tractors, boats, shipping equipment, irrigation systems, mining equipment, electrical generators, and in most applications where diesel is typically used. More detail is provided in the following sections.

Biodiesel has a specific gravity of 0.88 compared to 0.85 for diesel fuel. Because it is slightly heavier than diesel fuel, splash blending biodiesel on **top** of diesel fuel is the common mixing procedure. Rack blending is being considered in some states where B2 blends are being considered. B2 is a high-lubricity diesel fuel made with 2% biodiesel.

Biodiesel contains no nitrogen or aromatics and typically contains less than 15 ppm sulfur. Biodiesel contains 11% oxygen by weight, which accounts for its slightly lower heating value (energy content) and its characteristically low carbon monoxide, particulate, soot, and hydrocarbon emissions. The energy content of biodiesel is roughly 10% less than diesel No. 2 and comparable to diesel No.1. Fuel efficiency is the same as diesel fuel. Fuel economy, power, and torque are proportional to the heating value of biodiesel or the biodiesel blend. For example,

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B20 tends to reduce power, torque, and fuel economy by slightly less than 2%.

Table 1. Structural Formula for Fatty Acids used in Biodiesel

Fatty Acid Name	No. Of Carbons & Double Bonds	Chemical Structure (= denotes double bond placement)
Caprylic	C8	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>6</sub> COOH
Capric	C10	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>8</sub> COOH
Lauric	C12	CH₃(CH₂)₁0COOH
Myristic	C14	CH₃(CH₂)₁₂COOH
Palmitic	C16:0	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>14</sub> COOH
Palmitoleic	C16:1	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>5</sub> CH=CH(CH <sub>2</sub> ) <sub>7</sub> COOH
Stearic	C18:0	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>16</sub> COOH
Oleic	C18:1	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CH=CH(CH <sub>2</sub> ) <sub>7</sub> COOH
Linoleic	C18:2	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>4</sub> CH=CHCH <sub>2</sub> CH=CH(CH <sub>2</sub> ) <sub>7</sub> COOH
Linolenic	C18:3	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>2</sub> CH=CHCH <sub>2</sub> CH=CHCH <sub>2</sub> CH=CH(CH <sub>2</sub> ) <sub>7</sub> COOH
Arachidic	C20:0	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>18</sub> COOH
Eicosenoic	C20:1	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CH=CH(CH <sub>2</sub> ) <sub>9</sub> COOH
Behenic	C22:0	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>20</sub> COOH
Eurcic	C22:1	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CH=CH(CH <sub>2</sub> ) <sub>11</sub> COOH

Table 2. Weight Percent of Fatty Acids in Fat and Oil Feedstocks

Fatty Acid Fat or Oil	C8:0	C10:0	C12:0	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0 C22:0	C20:1 C22:1	Other
Tallow	1	ŧ	0.2	2-3	25-30	2-3	21-26	39-42	2	1	0.4-1	0.3	0.5
Lard	ŀ	1	1	1	25-30	2-5	12-16	41-51	4-22	ŀ	1	2-3	0.2
Coconut	6-5	4-10	44-51	13-18	7-10	1	1-4	8-5	1-3	1	1	- [	1
Palm Kernal	2-4	3-7	45-52	14-19	6-9	0-1	1-3	10-18	1-2	1	1-2	1	1
Palm	1		1	1-6	32-47	1	1-6	40-52	2-11	1	1	1	1
Safflower	-	1	-	1	5.2	1	2.2	76.3	16.2	1	1	1	1
Peanut	-	1	1	0.5	6-11	1-2	3-6	39-66	17-38	1	5-10	1	1
Cottonseed	1	-	1	0-3	17-23	1	1-3	23-41	34-55	1	1	2-3	1
Сош	ł	1	1	0-2	8-10	1-2	1-4	30-50	34-56	1	1	0-2	1
Sunflower	1	1	1	1	0.9	- 1	4.2	18.7	69.3	0.3	1.4	1	1
Soybean		1	1	0.3	7-11	0-1	3-6	22-34	9-09-09	2-10	5-10	1	1
Rapeseed	1	1	1	1	2-5	0.2	1-2	10-15	10-20	5-10	6.	9-09	1
Linseed	-	1	1	0.2	5-9	1	0-1	9-29	8-29	45-67	1	1	1
Mustard	i i	1	1	1	3.0	1	1.5	15-60	12	5-10	1	10-60	1

Table 3. Selected Fuel Properties for Diesel and Biodiesel Fuels

Fuel Property	Diesel	<b>Biodiesel</b>
Fuel Standard	ASTM D975	ASTM PS 121
Fuel composition	C10-C21 HC	C12-C22 FAME
Lower Heating Value, Btu/gal	131,295	117,093
Kin. Viscosity, @ 40 °C	1.3-4.1	1.9-6.0
Specific Gravity kg/l @ 60 °F	0.85	0.88
Density, lb/gal @ 15°C	7.079	7.328
Water, ppm by wt	161	.05% max
Carbon, wt %	87	77
Hydrogen, wt %	13	12
Oxygen, by dif. wt %	0	11
Sulfur, wt %	.05 max	0.0 - 0.0024
Boiling Point, °C	188-343	182-338
Flash Point, °C	60-80	100-170
Cloud Point, °C	-15 to 5	-3 to 12
Pour Point, °C	-35 to -15	-15 to 10
Cetane Number	40-55	48-65
Stoichiometric Air/Fuel Ratio	15	13.8
wt./wt.		
BOCLE Scuff, grams	3,600	>7,000
HFRR, microns	685	314

# 3 Biodiesel Fuel Quality

ASTM PS 121 (Table 4) provides the standards to ensure good fuel quality. PS 121 is a provisional standard; a final standard should be available by winter, 2001. The standard is independent of any manufacturing process or feedstock. ASTM PS 121 is designed to ensure that biodiesel has the fuel properties for safe operation in a compression ignition engine and ensures that poor processing has not contaminated the fuel with products that will create engine damage.

Key fuel-quality issues are described below:

- Biodiesel flash point is typically high (greater than 150°C). FAMEs are not volatile. The limit for D93 is set at 100°C to ensure that the manufacturer has removed excess methanol used in the manufacturing process. Residual methanol in the fuel is a safety issue because very small amounts reduce the flash point. Methanol can also affect fuel pumps, seals, elastomers, and can result in poor combustion properties.
- The Sulfated ash test ensures the removal of all the manufacturing catalysts. High levels of manufacturing catalysts in the fuel can result in injector deposits or filter plugging.
- Acid numbers will become elevated if the fuel ages, or if it was not properly manufactured. Acid numbers higher than 0.10 have been shown to be associated with fuel system deposits, and reduce the life of fuel pumps and filters.

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processed fuel residues, water, or other contaminants and the fuel shipment should be returned to the manufacturer.

Currently, you can test for biodiesel fuel quality before it is blended, but not after it is blended with diesel fuel. There is an experimental technique for testing B20 or other blends, but it does not detect free glycerin and thus cannot perform a complete ASTM PS 121 test. Once biodiesel is blended, it is very difficult to determine if it was a good quality fuel to begin with. Therefore, the person or organization that actually blends the biodiesel into the diesel fuel is responsible for ensuring that the biodiesel meets ASTM standards.

Biodiesel production is currently a batch process in the U.S. and fuel quality varies from batch to batch. Check the product specification sheet for batch number, production date, testing date, and other information. For marketers that are blending large biodiesel volumes, be proactive and test one gallon of fuel from each delivery, or at least save a gallon for future testing in case some customer concerns arise. Williams Laboratory Services in Kansas City is the only commercial laboratory with extensive field experience in testing biodiesel fuel quality. Marketers and blenders should be especially careful with new biodiesel producers or marketers, since their track record on fuel quality has yet to be established. The biodiesel industry is largely self-policing but not effectively so.

The biodiesel industry has developed a fuel certification program to ensure fuel quality throughout the production and distribution chain. At this time, the program has not been fully implemented and is voluntary. Firms that receive accreditation will have the highest assurance of fuel quality possible.

# 4 The "Right" Blend

Biodiesel can be used pure or mixed in any proportion with diesel #2 or diesel #1 (kerosene). The military has its own biodiesel specifications and guidelines, including blends with JP8. Military users need to use the guidelines adopted by their organization. These guidelines are for general use. Most customers use a 20% blend of biodiesel with 80% diesel fuel called B20 for a variety of reasons:

- B20 minimizes the impact of the biodiesel cost on the customer.
- Federal EPAct guidelines require a minimum 20% blend, although higher blends are acceptable.
- A 20% blend keeps NOx increases small (1-4%) and within the legal emission limits for engines.
- A 20% blend still gives good emission benefits by reducing soot, particulates, hydrocarbons, carbon monoxide, and carbon dioxide by more than 10% each.
- B20 does not create major problems with filter plugging and deposit formation that can result from the interaction between biodiesel and the accumulated sediments and sludge that form in diesel storage tanks. See the section on solvency for more details.
- B20 controls the increase in cloud and pour point by a manageable level that cold flow additives can control. See the section on cold weather issues for more details.
- Few material compatibility problems arise with B20. Higher blend levels will cause more

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problems with rubber seals, gaskets, and hoses unless these have been replaced with biodiesel resistant materials. (See material compatibility.)

B20 is basically a trade off between cost, emissions, cold weather, material compatibility, and solvency issues. It is a good starting point for new users because B20 users rarely encounter problems. Users should be careful when moving from B20 to higher blends since the risk of encountering problems increase. These problems can be managed but you need to anticipate them and develop strategies for managing them. Higher blends have been used over extended periods of time and some commercial fleets are using B100.

Blends of 35%, 50%, and higher can provide significant emission reduction benefits for carbon monoxide, particulates, soot, and hydrocarbons (Table 5). Higher blend levels of biodiesel significantly reduce polycyclic aromatic hydrocarbons and other toxic or carcinogenic compounds found in diesel exhaust. Higher blend levels also provide significant reductions in greenhouse gas emissions and increase the renewable content of the fuel.

Table 5. Tailpipe Emission Changes with Biodiesel Fuels

Emission	B100*	B20**
Carbon Monoxide	-43.2%	-12.6%
Hydrocarbons	-56.3%	-11.0%
Particulates	-55.4%	-18.0%
Nitrogen oxides	+5.8%	+1.2%
Air toxics	-60% to -90%	-12% to -20%
Mutagenicity	-80% to -90%	-20%
Carbon dioxide***	-78.3%	-15.7%

<sup>\*</sup>Average of data from 14 EPA FTP Heavy Duty Test Cycle tests, variety of stock engines
\*\*Average of data from 14 EPA FTP Heavy Duty Cycle tests, variety of stock engines
\*\*\*Life cycle emissions

One downside of higher blend levels is an increase in nitrogen oxides emissions (NOx). Biodiesels with high levels of polyunsaturates produce more NOx than biodiesels with high levels of saturates. The flip side to this issue is that fuels with high levels of polyunsaturates have good cold weather properties, and fuels with high levels of saturates have poor cold weather properties. Summer blends and winter blends may be one strategy for the customer, but this is not a standard practice for the biodiesel industry at this time. Research has identified one additive that provides a limited amount of control on NOx emissions. One percent DTBP (ditertiary butyl peroxide) by volume in B20 can make B20 NOx neutral with diesel fuel. The effect of five percent DTBP in B100 has different effects on different biodiesels. This problem may be resolved in the near future as other additives or solutions are identified.

Higher blends of biodiesel are popular with users in pristine or vulnerable environments, because they are biodegradable and reduce the toxicity of diesel fuel. B100 is used in commercial fleets, marine vessels, and in mining equipment. Extra precautions may be required to resolve solvency

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concerns or to protect the customer from cold weather. Modifications may be required to replace materials with compatibility concerns. If customers want to use B100 or higher blends, the sections on solvency, cold weather, and material compatibility are mandatory reading.

# 5 Splash Blending

Biodiesel is slightly heavier than petroleum diesel. Biodiesel has a specific gravity of 0.88 compared to petroleum diesel at 0.85. Biodiesel should be splash blended on **top** of petroleum diesel, otherwise, the fuels may not mix properly. If you've made a mistake and added the biodiesel to the bottom of the tank and it did not mix with the petroleum diesel, you have several options:

- Find a way to agitate the fuels together,
- Pump the fuels out into a tank truck and then pump them back down together,
- You can ignore the problem if you are not worried about solvency, material compatibility, or cold weather, since biodiesel can be burned as a 100% pure fuel.

Biodiesel blends will not separate in the presence of water, however, for good housekeeping and tank/fuel maintenance, water in the storage systems should be monitored and minimized.

Biodiesel can be stored in standard diesel storage tanks. Copper, brass, zinc, lead, and tin parts should be replaced with aluminum or steel since these metals oxidize both diesel and biodiesel fuels. Please read the sections on cold weather storage issues and solvency before proceeding with B100 storage!

# 6 Cold Weather Blending and Storage

Like any diesel fuel, biodiesel can gel at low temperatures. Some types of biodiesel freeze at higher temperatures than others, depending on the level of saturated components in the fuel.

- Pure biodiesel should be stored at temperatures at least 15 degrees higher than the pour point of the fuel (30°F to 56°F). A storage temperature of 45°F to 50°F is fine for most B100.
- Blends of biodiesel and diesel should be stored at temperatures of at least 15 degrees above the pour point of the blended fuel.
- Pure biodiesel can be stored underground in most cold climates, but above ground fuel systems should be protected with insulation, agitation, heating systems, or other measures if freezing weather is common. This precaution includes tanks, pumping equipment, and the vehicles themselves.
- Blended fuels can be stored below ground in most climates. Above ground storage should consider special precautions if temperatures routinely fall below the pour point of the blended fuel.
- Biodiesel can be splash blended with no problems if the diesel fuel temperature is 50°F or higher. If biodiesel is blended with cold diesel fuel (fuel temperature is less than 45°F to 50°F), the saturated compounds in the biodiesel can crystallize and plug fuel filters and fuel lines. If crystals have already formed the solutions include:
  - See if they disappear as the fuel warms with ambient weather conditions

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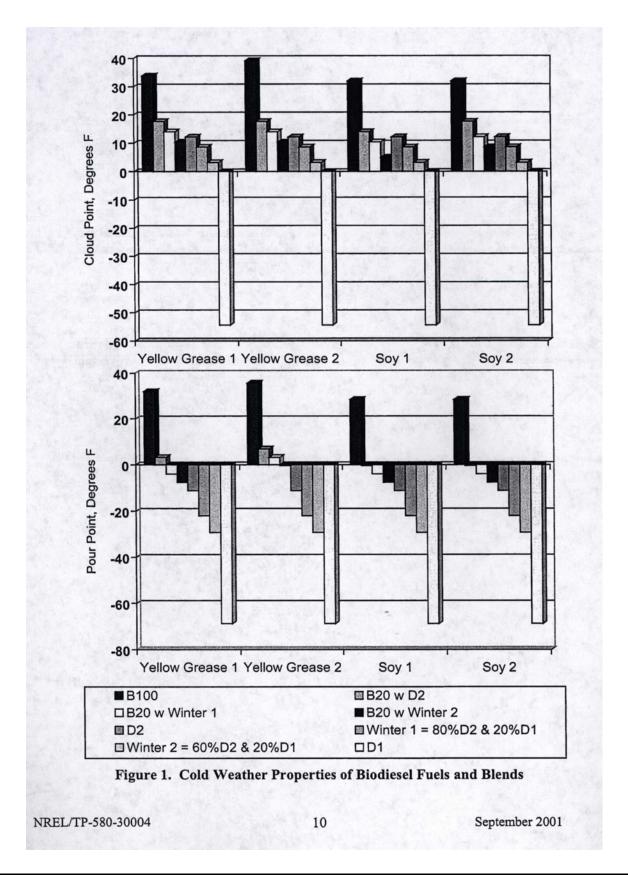
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- Heat the fuel to above 100°F or until the crystals dissolve
- Filter the solid fuel crystals out. They can be reused when they melt.
- To prevent forming crystals, blend biodiesel with kerosene in a 50:50 mix first (make sure the temperature of the kerosene is above 45°F), then blend the biodiesel-kerosene mix into the cold diesel fuel. Do not forget to adjust your blending formula so that you end up with a 20% blend of biodiesel in the final fuel.
- Pure biodiesel is difficult to ship in cold weather. In the winter, most biodiesel is shipped one of three ways:
  - hot in tank cars for immediate delivery,
  - frozen in tank cars equipped with steam coils (the tank cars are melted at the final destination with steam),
  - in 20% blends with available winter diesel, or
  - in a 50% blend with diesel No. 1 (kerosene). A 50:50 blend of soy biodiesel and kerosene has a pour point of 0°F in most cases.
- Adjusting the blend of kerosene in the diesel fuel can modify the cloud and pour point temperatures of B20. Figure 1 shows the cloud and pour point for several different types of B100 and the impact on cloud and pour when B20 is produced from different diesel fuels. B20 with D2 is a blend of 20% biodiesel with 80% straight diesel No. 2. The other two B20 blends shown are blends of 20% biodiesel with 80% winterized diesel fuel. In one case the winterized diesel consists of 80% No. 2 and 20% No. 1 and in the other case the winterized diesel consists of 60% No. 2 and 40% No. 1. The cloud and pour points of the No. 2, No. 1, and the two winterized diesel fuels are also shown for comparison. The point of the chart is to show that you can produce a B20 fuel that has the desired cloud and pour points by adjusting the amount of No. 1 diesel in the diesel fraction of the mix.
- No. 1 diesel (kerosene) and pour point depressants have been used with good results in B20. Pour point depressants work on the diesel part of a biodiesel blend and can reduce the gel and cloud properties of blended fuels. No additives have been shown to be effective on B100.

B20 may be stored in above ground tanks, depending on the cloud and pour points of the blended fuel and the local ambient weather conditions. For example, a B20 blend made with No. 2 diesel will raise cloud point by 2 °F to 7°F. B20 made with No. 1 diesel will have a cloud point of -15°F to 0°F depending on the properties of the biodiesel fuel. There are no lubricity issues with kerosene and biodiesel blends. Since biodiesel is a lubricant, 1%-2% would be enough to lubricate kerosene.

User experience with cold weather varies. B20 blends are used in some very cold climates such as northern Minnesota and Wyoming where temperatures routinely fall below –40°F in the winter. B20 was used in an airport shuttle fleet for four years in Boston with no problems. Some users have reported using B100 in extremely cold climates such as in Yellowstone National Park. The vehicles were equipped with winterization packages and no other precautions were noted. Since widespread experience with B100 and higher blends in cold climates is lacking in the United States, users should be alert to potential problems and take reasonable steps to prevent them if possible. We can only conclude that laboratory tests appear to be more conservative than field experience.

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# 7 Stability

Oxidative stability is a major industry issue for diesel and biodiesel fuels. Some biodiesels are more stable than others and some unstable biodiesel contain stability additives that perform very well (Table 6). The tendency of a fuel to be unstable can be predicted by the Iodine number (ASTM D 1510) but the test method may not pick up the presence of stability additives. Iodine number actually measures the presence of C=C bonds that are prone to oxidation. The general rule of thumb is that instability increases by a factor of 1 for every C=C bond on the fatty acid chain; thus, 18:3 are three times more reactive than C18:0. Stability can be predicted from knowledge of the feedstock only if you know the proportion of C18:2 and C18:3 fatty acids present in the fuel and know whether or not the fuel has been treated for stability. High fractions of those two types of fatty acids can adversely affect fuel stability if additives are not used. The accelerated stability test—ASTM D 2274—can provide an idea of whether the fuel stability is poor, average, or good.

Table 6 Modified ASTM D 2274\*

Biodiesel Fuel	Additives	Total Insoluables, Mg/L**
Soy 1	No additive	13.60
Soy 2	No additive	14.32
Soy 1	Tenox 21	0.09
Soy 3	Tocopherol	1.87
Yellow grease 1	No additive	0.89
Yellow grease 2	No additive	12.37

<sup>\*</sup>Data from Southwest Research Institute under contract to the National Renewable Energy Lab.

\*\*High levels of insoluables indicate unstable fuels.

Poor stability can lead to increasingly high acid numbers, increasing viscosity, and the formation of gums and sediments that can clog filters. Comparing the fuel's acid number and viscosity over time can provide some idea about whether or not the fuel is oxidizing, but you need to take a sample at the beginning when the fuel is fresh and then sample on a regular basis after that.

Long-term storage in the presence of diesel fuel, diesel additives, water, sediments, heat, and air has not been adequately documented in the field. Biodiesel and blends of biodiesel and diesel fuel should not be stored for longer than 6 months in either storage tanks or vehicles until better field data is available. If it becomes necessary to store biodiesel longer than 6 months, or the storage conditions are poor, use antioxidants. The common antioxidants that work with biodiesel are TBHQ (t-butyl hydroquinone), Tenox 21, and tocopherol (Vitamin E). Most of these are sold by food additive firms. Powdered antioxidants are difficult to mix into biodiesel. A trick used is to heat a small amount of biodiesel (1 gal or so) up to 100°F or until all the powdered antioxidant is dissolved. Then mixed the treated biodiesel into the bulk biodiesel fuel.

Biocides are recommended wherever biological growth in the fuel has been a problem. If biological contamination is a problem, housekeeping needs to be improved and water contamination needs to be reduced, since the algae grows in the water and not in the fuel itself.

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# 8 Solvency

Biodiesel is a mild solvent. On prolonged contact with painted surfaces, it may deface some paints. Always wipe up spills and dispose of rags in a safe manner. Biodiesel soaked rags can self-combust if not handled properly.

The most commonly encountered problem with solvency is biodiesel's tendency to "clean out" storage tanks, including the vehicle fuel tanks and systems. No. 2 diesel tends to form sediments that stick to and accumulate in storage systems, forming layers of sludge or slime in the fuel systems. The older the system, and the poorer the maintenance, the thicker the accumulated sediments become. Biodiesel will dissolve these sediments and carry the dissolved solids into the fuel systems of vehicles. Fuel filters will catch most of it, but in severe cases, the dissolved sediments have caused fuel injector failure.

Few problems have been encountered with B20 in typical diesel storage situations. The effect is very similar to switching from diesel No. 2 diesel to No. 1. The solvency effect of the biodiesel in B20 is sufficiently diluted so that most problems encountered are minor. These problems include an occasional plugged fuel filter. Drivers should be aware that sediments in the vehicle system may plug fuel filters during the first few weeks using B20 and that they should keep some extra filters in the glove box. Do not remove the fuel filter if it becomes plugged without replacing it.

When using B20, the problem typically goes away after the first few tanks of fuel. If the problem does not disappear, send the fuel filters to Williams Laboratory for analysis, since you may have a problem with biodiesel fuel quality or biological growth in the fuel.

The solvency problems occur most often when customers try to put higher blends or even pure biodiesel into aged and dirty systems that previously held No. 2 diesel fuel. If you do not clean out the diesel fuel storage tanks before using biodiesel blends of 30% or higher, there is a strong risk that excessive fuel filter plugging and fuel injector failure may occur. We recommend cleaning fuel storage tanks (remove water and accumulated sediments) before using higher blend levels or B100.

Consumers that did not encounter any problems with B20 assume they can switch to higher blends without any concern because they think the B20 already cleaned their tanks. B20 doesn't really clean the tanks, it's too diluted. Once again, tanks should be cleaned before switching to higher blend or B100 fuels.

If you have been using biodiesel for a while (3 months or more) and a sudden problem with plugged fuel filters arises, it is probably the result of a bad batch of biodiesel or a bad batch of diesel fuel. Notify the supplier immediately and retain a fuel sample and the filters for testing.

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# 9 Material Compatibility

Brass, bronze, copper, lead, tin, and zinc will oxidize diesel and biodiesel fuels and create sediments. Lead solders and zinc linings should be avoided, as should copper pipes, brass regulators, and copper fittings. The fuel or the fittings will tend to change color and sediments may form, resulting in plugged fuel filters. Affected equipment should be replaced with stainless steel or aluminum. Acceptable storage tank materials include aluminum, steel, fluorinated polyethylene, fluorinated polypropylene, and Teflon. Table 7 has some information on specific materials.

Table 7. Material Compatibility with Biodiesel Fuels

Material	BXX	Effect compared to diesel fuel
Teflon	B100	Little change
Nylon 6/6	B100	Little change
Nitrile	B100	Hardness reduced 20%
	B100	Swell increased 18%
Viton A401-C	B100	Little change
Viton GFLT	B100	Little change
Fluorosilicon	B100	Little change in hardness
	B100	Swell increased 7%
Polyurethane	B100	Little change in hardness
	B100	Swell increased 6%
Polypropylene	B100	Hardness reduced 10%
	B100	Swell increased 8-15%
Polyvinyl	B100	Much Worse
	B50	Worse
	B40	Worse
	B30	Worse
	B20	Comparable
	B10	Comparable
Tygon	B100	Worse

The effect of B20 on vulnerable materials is diluted compared to higher blends. Some slow oxidation can occur, although it may take longer to materialize. Biodiesel also can affect some seals, gaskets, and adhesives, particularly those made before 1993 and those made from natural or nitrile rubber. It is primarily for these reasons that vehicle and storage equipment are modified. Most engines made after 1994 have been constructed with gaskets and seals that are generally biodiesel resistant. Earlier engine models or rebuilds may use older gasket and seal materials and present a risk of swelling, leaking, or failure. Fuel pumps may contain rubber valves that may fail. The typical approach is to create a maintenance schedule that checks for potential failures. Users can also contact engine manufacturers for more information.

#### 10 Warrantees

The landscape is littered with different engine warrantees depending on the engine manufacturer. No consistency exists at this time. Caterpillar offers a B100 warrantee on most of their newer engines that is feedstock neutral if fuels meet either ASTM PS 121 or the CAT standards. Caterpillar has tested various types of biodiesel and examined the underlying chemistry of the fuels. John Deere offers B100 warrantees on some equipment. Other firms (Cummins, DDC, etc.) offer B20 warrantees that may or may not be feedstock specific. Feedstock specificity is based on a lack of information or a misunderstanding of biodiesel chemistry. In some cases, feedstock limitations are proxies for fuel properties that are not included in the ASTM PS 121 for biodiesel. Feedstock specifications may be an attempt to limit variations in fuel properties and thus, limit risks associated with using a new fuel. Biodiesel fuel properties vary just as much as diesel fuel properties, so some of this concern may be unnecessary. This issue will become less important as engine manufacturers improve their understanding of biodiesel chemistry and more data becomes available. Until then, the smart thing to do is to contact the engine manufacturer for information.

To further complicate matters, no engine warrantee covers fuels. Engines are warranted for materials and workmanship only, regardless of the fuels used, although they are designed to operate on diesel fuel that meets ASTM D 975. Most B20 and higher blends do not meet D 975.

Limits on engine warrantees are meant to discourage consumers from engaging in risky behaviors that may lead to engine damage. Thus, to some extent, the limitations on warrantees are moot. Nonetheless, in order to prevent misunderstandings, the warrantee limitations should always be considered before biodiesel fuels are implemented.

Damage caused by poorly processed biodiesel or biodiesel that does not meet ASTM standards will not be covered by the engine warrantee, but may be covered under general liability insurance carried by the biodiesel producer or broker. New users should make sure that their biodiesel suppliers provide general liability coverage.

# 11 Safety and Environmental Regulation

Composition Information: Biodiesel contains no hazardous materials. Biodiesel contains a variety of fatty acid methyl esters with carbon chain lengths varying between 12 and 22, where 18 carbon chains are the most common. Small quantities (less than 1%) of other materials may be present and should not exceed fuel quality standards.

**Handling and Storage:** Store in clean, dry, approved diesel equipment between 50° F and 120°F. Keep away from oxidizing agents, excessive heat, and ignition sources. Store and use in well-ventilated areas. Do not store or use near heat, spark, or flame. Store out of the sun. Do not puncture, drag, or slide drums or totes. Drum and totes are not pressure vessels; never use pressure to empty.

Inhalation: Negligible danger unless heated to produce vapors. Vapors or finely misted

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materials may irritate the mucous membranes and cause irritation, dizziness, and nausea. If this occurs remove to fresh air. If vapors or mists are generated, wear a NIOSH approved organic vapor/mist respirator.

Eye Contact: May cause irritation. Irrigate eye with water for at least 15 to 20 minutes. Seek medical attention if symptoms persist. Safety glasses, goggles, or face shield are recommended to protect eyes from mists or splashing.

Acute Oral Toxicity/Rates: Biodiesel is nontoxic and there are no hazards anticipated from ingestion incidental to industrial exposure. If ingested, give one or two glasses of water to drink. If gastro-intestinal symptoms develop, consult medical personnel. (Never give anything by mouth to an unconscious person.) Effects are similar to those associated with laxatives. The acute oral LD50 (lethal dose) is greater than 17.4 g/Kg body weight. By comparison, table salt (NaCL) is nearly 10 times more toxic.

Skin Irritation – Humans: A 24-hr. human patch test indicated that undiluted biodiesel produced very mild irritation. The irritation was less than the result produced by a 4 percent soap and water solution. Wash with soap and water. Avoid contact with hot fuel as it may cause burns. PVC coated gloves are recommended to prevent skin contact. May soften skin.

Aquatic Toxicity: A 96-hr. lethal concentration of biodiesel for bluegills was greater than 1000 mg/L. Lethal concentrations at these levels are generally deemed "insignificant" according to NIOSH (National Institute for Occupational Safety and Health) guidelines in its *Registry of the Toxic Effects of Chemical Substances*.

**Biodegradability:** Biodiesel degrades about four times faster than petroleum diesel. Within 28 days, pure biodiesel degrades 85% to 88% in water. Dextrose (a test sugar used as the positive control when testing biodegradability) degraded at the same rate. Blending biodiesel with diesel fuel accelerates its biodegradability. For example, blends of 20% biodiesel and 80% diesel fuel degrade twice as fast as #2 diesel alone.

Flash Point: The flash point of a fuel is defined as the temperature at which it will ignite when exposed to a spark or flame. Biodiesel's flash point is over 150°F, well above petroleum based diesel fuel's flash point of around 125° Fahrenheit. Testing has shown the flash point of biodiesel blends increases as the percentage of biodiesel increases. Therefore, biodiesel and blends of biodiesel with petroleum diesel are safer to store, handle, and use than conventional diesel fuel.

Fire Fighting Measures: Firefighters should use self-contained breathing apparatus to avoid exposure to smoke and vapor. Combustion produces carbon monoxide and carbon dioxide along with thick smoke. Fires may be extinguished with dry chemical, foam, halon, CO2, or water spray (fog). Use water spray to cool drums exposed to heat or flames. (Caution-Water stream may splash the burning liquid and spread fire.) Oil soaked rags can cause spontaneous combustion if not handled properly. Before disposal, wash rags with soap and water and dry in well ventilated area.

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Accidental Release/Spills: Remove sources of ignition, contain spill to smallest area possible. Stop leak if possible. Pick up small spills with absorbent materials such as paper towels, "Oil Dry," sand, or dirt. Recover large spills for salvage or disposal. Wash hard surfaces with safety solvent or detergent to remove remaining oil film. Greasy nature will result in a slippery surface.

#### Regulatory:

UN HAZARD CLASS: N/A

NMFC (National Motor Freight Classification): PROPER SHIPPING NAME: Fatty acid ester IDENTIFICATION NUMBER: 144920 SHIPPING CLASSIFICATION: 65

**OSHA:** This product is not hazardous under the criteria of the Federal OSHA Hazard Communication Standard 29 CFR 1910.1200. However, thermal processing and decomposition fumes from this product may be hazardous as noted in fire fighting section.

TSCA: This product is listed on TSCA.

CERCLA: (Comprehensive Response Compensation and Liability Act). NOT reportable.

SARA TITLE III: (Superfund Amendments and Reauthorization Act), Section 312 Extremely Hazardous Substances, None. Section 311/312 Hazard Categories, Non-hazardous under Section 311/312. Section 313 Toxic Chemicals, None.

RCRA: If discarded in its purchased form, this product would not be a hazardous waste either by listing or by characteristic. However, under RCRA, it is the responsibility of the product user to determine at the time of disposal whether a material containing the product or derived from the product should be classified as a hazardous waste (40 CFR 261.20-24).

CALIFORNIA PROPOSITION 65: The following statement is made in order to comply with the California Safe Drinking Water and Toxic Enforcement Act of 1986. This product contains no chemicals known to the state of California to cause cancer.

#### 12 Taxes

At this time, biodiesel is not exempt from federal excise taxes and it is not exempt from most state or local taxes. That means that biodiesel and biodiesel blends are taxed at the same rate as diesel fuel and the taxes are handled in the same manner. Some states have passed legislation that either reduces fuel excise taxes or provides other incentives. For local exceptions to this statement, please contact the local tax authorities.

#### 13 Incentives

At the present, there are no national financial incentives such as excise tax credits or government subsidies for purchasing biodiesel. Some states or local communities may offer incentives for

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specific blends or for special groups of users. Please check with the local energy office or other transportation agencies for up to date information for your state and city.

The City of Cincinnati qualified for a grant from the Dept. of Transportation Congestion Mitigation and Air Quality Program in 2000 that paid the difference between the cost of biodiesel and the cost of diesel fuel. These grants are available to other communities through the Clean Cities Program. For more information contact the Clean Cities Hotline at 1-800-CCITIES (1-800-224-8437).

The Energy Policy Act of 1992 (EPAct) provides an indirect incentive program to federal and state fleets which may be applied to municipal fleets and large commercial fleets in the near future. The EPAct regulation requires federal and state fleets to purchase alternative fueled vehicles. The regulation sets the requirements for a percentage of each year's purchases, so that some fraction of that year's vehicle purchases must be able to run on alternative fuels. Unfortunately, the government is not willing to claim that all diesel vehicles are alternative fueled vehicles just because biodiesel can be used in all existing diesel vehicles. Therefore, a special exemption was created for biodiesel. The government will give the fleet an "alternative vehicle credit" (a paper credit, not a financial credit) to a qualified customer (federal or state governments and some utilities) that purchases 450 gallons of pure biodiesel and uses it in a blend of at least 20% (B20) in a heavy-duty vehicle with a gross weight of 8,500 pounds or more. There is no requirement to use B20 year round. For multiple credits, multiple purchases of 450 gallons of B100 are all that is required, and they can be burned in one or more vehicles as long as the mixture used exceeds 20%. Most federal and state fleets have started to shift a large part of their heavy-duty fleets to biodiesel on a regular basis. Some fleets in northern climates limit purchases in winter months, but resume again in the spring and use B20 throughout the spring, summer, and fall months. For more information on EPACT, contact the Lee Slezak, U.S. Department of Energy, (202) 586-2335.

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By: Robert F. Udell

Date: September 30, 2003

# The Marine Market for Biodiesel Fuel in the West Michigan Tri-Plex. TABLE of CONTENTS Paragraph Page No. SCOPE: 1 2) TRI-PLEX DIESEL FUEL MARKET DESCRIPTION: 2 MARKET ASSESSMENT METHODOLOGY: 3) **ASSUMPTIONS and EXTRAPOLATIONS:** 9 4) **RESULTS and DISCUSSION:** 11 5) WEST MICHIGAN TRI-PLEX - POTENTIAL BIODIESEL FUEL MARKET 23 **ACKNOWLEDGEMENTS:** 23 **TABLES** Table 1 - Tri-Plex Drowned River Mouth Lake Descriptions 3 Table 2 - Tri-Plex Recreational Boat Density 12 Table 3 - Summary of Marina Survey Responses by Region 14 Table 4 - Recreational Boats and Diesel Engines by Region 16 Table 5 - Total Petrodiesel Fuel Consumed by Region 18 Table 6 - Type of Fuel Used - User Responses 19 Table 7 - Type of Fuel Used - Boat Inspections 20 22 Table 8 - Potential Biodiesel Sales - Recreational Market

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#### 1) SCOPE:

This market study was undertaken to complement the study initiated by a grant from Dr. William G. (Bill) Jackson to determine the feasibility of operating the Annis Water Resources Institute (AWRI) research vessels on biodiesel. Both the R/V W.G. Jackson (Jackson) and R/V D.J. Angus (Angus) currently contribute to the degradation of air and water quality by use of petroleum based diesel fuel (petrodiesel) which is in conflict with the charter and spirit of AWRI.

The recommendation of the "The Feasibility of Fueling the Research Vessels W.G. Jackson and D.J Angus with Biodiesel" is to initially use a petrodiesel and biodiesel blend (B20) in the AWRI vessels to gain some environmental benefits and experience to determine if fueling both boats with biodiesel is feasible. B20 is a blend of 20% biodiesel and 80% petrodiesel. Unblended biodiesel is called biodiesel, B100, or "neat" biodiesel. The use of biodiesel in the Angus is feasible with little concern and should not increase fuel consumption more than 5%. However, the use of biodiesel in the Jackson has the potential to increase fuel consumption by 30% and economic considerations may preclude its use.

The Jackson operates out of the Lake Michigan center on Muskegon Lake, Muskegon, Michigan while the Angus operates out of Grand Haven, Michigan. Operating the vessels on biodiesel is easily accomplished in a one time event scenario but may be difficult to sustain due to cost or availability of biodiesel in the Muskegon and Grand Haven areas in the long term. It is anticipated that this market study will give an indication of the demand for biodiesel in West Michigan thus providing confidence in the long term availability of biodiesel to our vessels.

#### 2) TRI-PLEX DIESEL FUEL MARKET DESCRIPTION:

- a) Users: The diesel fuel user group (users) is a mixture of recreational boaters, Coast Guard, commercial watercraft, and miscellaneous other boats. The recreational boating segment, by far, is the largest single group (in number) to consider. Commercial and miscellaneous other boats consisting of tugs, dredges, towboats, tourist cruise boats, research vessels, rescue, and buoy tenders also form a significant market segment (in numbers). One Commercial Operator dominates the entire diesel fuel market in that it consumes nearly four times the combined total of all other users. With this one exception, the recreational diesel fuel market is the largest consumer of diesel fuel with all other users forming a secondary market.
- b) Distributors: The distribution of marine diesel fuel within the Tri-Plex is by tank truck to individual marinas or directly to larger vessels at dockside.
- c) Retail: Diesel fuel is sold to recreational boaters primarily by marinas within the Tri-Plex. The fuel sold is generally automotive fuel dyed red to differentiate it from

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automotive fuels. However, high sulfur, off road fuel could (legally) be sold. Some recreational users purchase their fuel at automotive retailers and transport to their boats in small containers to avoid the premium normally paid by marine fuel users.

Legislation requiring double walls on fuel storage tanks and containment measures resulted in a significant reduction in the number of fuel retailers in recent years reducing the number of marinas offering fuel. Most areas discussed in this study have only two retailers. The number of retailers in the regions and responses from marinas has limited the presentation of fuel sold/used data in this report to three market segments rather than the five initially planned.

#### 3) MARKET ASSESSMENT METHODOLOGY:

#### a) Constraints:

i) Geographical Constraint: The geographical area was selected to encompass the area in which AWRI operates and can most effectively influence. The area also coincides with the area of interest to the West Michigan Strategic Alliance for economic growth and the focus of their regional planning – the West Michigan Tri-Plex (Tri-Plex). The Tri-Plex is a triangular area formed by Whitehall on the North, Saugatuck/Douglas on the South and Grand Rapids on the East. This area was considered both small enough to allow a time and resource constrained market study and large enough to allow extrapolation of data to the total population of diesel fuel users in the area.

The East coast of Lake Michigan has unique features caused by the glaciers that once covered the area, erosion, and changing lake levels during the past few thousand years. These conditions resulted in five drowned river mouth lakes in the Tri-Plex. The study also looked at these areas as five individual and distinct regions to determine if there were characteristics and trends unique to any of the smaller areas.

(1) Geographic Segmentation: There are marinas, commercial operators and recreational boats both in marinas and at private docks within each region. These five segments have been identified by the geographical descriptions and numbers defined in Table 1.

Region 1, Whitehall, includes all areas bordering on White Lake but does not include any area of the White River upstream of Dowling Street.

Region 2, Muskegon, includes all areas boarding on Muskegon Lake but no areas North-East of the Whitehall Rd bridge over the Muskegon River or the Bear Lake channel North of the Ruddiman St. Bridge.

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- c) Data acquisition: The primary data gathering approach was by questionnaires distributed either by US mail or by personal visit. (See Appendix N) Supplemental data were gathered by personal or telephone interviews. The following questionnaires were created to gather data:
  - 1. DIESEL FUEL SURVEY DISTRIBUTORS (Distributor Survey)
  - 2. DIESEL FUEL SURVEY MARINAS (Marina Survey)
  - 3. DIESEL FUEL SURVEY BOATERS (User Survey)
  - DIESEL FUEL SURVEY COMMERCIAL OPERATORS (Commercial Operator Survey

#### i) Survey Questionnaires:

(1) Distributors: The Distributor Survey questionnaire (See Appendix F) focuses on the volume of diesel fuel distributed into the five regions. In addition, information was requested regarding the volume of spilled diesel fuel, if any, general knowledge of biodiesel, and pending legislation that could affect sales of petrodiesel.

The individual distributors on the list were sent questionnaires with cover letters stating the purpose of the survey and requesting a response within 30 days. A self addressed, postage paid, envelope was supplied with each questionnaire. Each respondent was told that they would receive the resulting marketing data as an incentive to respond to the questionnaire. Each questionnaire was coded to identify the responding distributor.

Seventeen Distributor Survey questionnaires were mailed with only 2 (12%) being returned. Neither of the responding distributors sold marine diesel fuel in the Tri-Plex area. The question asking for multiple year fuel shipments probably discouraged responses as the data most likely would require some research. There may also be an issue with the nomenclature "marine diesel" as the recreational diesel sold at marinas is called often dyed diesel and is over-the-road diesel fuel dyed red as opposed to true marine diesel which has high sulfur content. The fuel is dyed to indicate compliance with tax laws.

Questions were included on the questionnaire to confirm or change the assumed distribution system. Distributor responses to the questionnaire were insufficient to confirm or change the assumed distribution process.

(2) Marinas: The Marina Survey questionnaire (See Appendix H) researches fuel sold for multiple seasons, average price for the latest season, number of spills, estimated volume spilled, and knowledge of biodiesel. The

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underlying goal of the questionnaire was to obtain permission to survey recreational boaters within the marinas - the largest pool of users.

The individual marinas on the list are the primary retailers of recreational diesel fuel within the five regions. Each of the identified marinas (54) was sent a questionnaire with a cover letter stating the purpose of the survey and requesting a response within 30 days. Each questionnaire also requested permission to distribute the User Survey questionnaires to each boat in the marina in late May and place a collection box in the marina office which would be picked up in early July. A self addressed, postage paid, envelope was supplied with each questionnaire for the marina to return their response. Each marina was told that they would receive the marketing data if they responded to the questionnaire as an incentive. Each questionnaire was coded to identify the responding marina. 37% of the marinas surveyed returned a completed questionnaire.

The marinas were asked if they would host a seminar to acquaint boaters in their marina with the benefits of biodiesel -20% percent of the surveyed marinas volunteered to host a seminar. Also, marinas were asked whether they were aware of biodiesel as a fuel and pending legislation that could affect their diesel fuel sales and capital equipment, i.e. storage tanks and fuel pumps.

Questions were included to identify distributors not on the initial target list. Two were identified from the Marina Survey responses and two potential distributors were added as a result of tours of Region 3, Grand Haven/Spring Lake, when completing the marina target list. None of the four additional distributors responded to the distributor questionnaire.

#### ii) Users:

(a) Recreational Boaters: The User Survey questionnaire (See Appendix I) was intended to gather the majority of the data to be used for this market study.

This questionnaire gathered data on the sensitivity of potential users to price variations and premium (cost above petrodiesel pricing) that might be encountered in the purchase of biodiesel. Also, boaters were asked if they had an interest in attending biodiesel, educational seminars.

The recreational boaters were either surveyed by questionnaire or, in those cases where the marinas would not allow the survey, counted by a personal visit to the marina with the expectation that data could be created by extrapolation from the questionnaire responses. The User Survey questionnaires were hand delivered to each boat and a collection box

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placed in the marina office for collection of responses. A cover letter was included stating the purpose of the survey and requesting a response be placed in the collection box within 30 days. A memento (keychain) from AWRI/Grand Valley State University was included as an incentive to respond to the questionnaire. The questionnaire, cover letter, and memento were sealed in a plastic bag and placed in the cockpit of the boats in each marina surveyed. The plastic bag was used so the survey would survive any adverse weather that might occur before the boat owner returned to the boat. Each questionnaire was coded to identify the marina from which the response was received. 2,450 survey packages were prepared for distribution to recreational boaters. However, only 1385 were distributed as there were misleading data from the marina survey as to the number of boats in marinas. User's surveys were distributed in late May, 2003.

The volume of incidental fuel spills was a target of the User Survey as often small incidental spills occur when fueling are not considered significant but incidental spills from a large number of boats could be.

The questionnaire included an opportunity for respondents to make comments on the survey. The comments received are documented in Appendix M.

In mid June, a follow-up letter was sent to each marina in which the user survey was distributed to inform the marina that the survey had been distributed, request that the marina operator not discard the collection box or move it to a location that would be difficult to locate, and to restate the dates the collection boxes would be picked up.

79 of the 1385 (5.7%) questionnaires distributed were returned. The respondents were primarily diesel fuel users and indicated a response that was not a true representation of the distribution of fuel used by the recreational boating community.

78% of the respondents indicated that they would attend a biodiesel seminar if made available in their home marina and 53% indicated that they would be willing to travel 4 miles to attend a biodiesel seminar. Neither percentage proved to be an accurate indication of interest in a biodiesel seminar, as total attendance at the three seminars was 10 people whereas responses to questionnaires indicated a possible attendance of 44. Two marinas, Anchorage Marina in Holland and Ellenwood Landing in Montague, made commendable efforts to advertise the seminars by locating the announcements in multiple locations, articles in their newsletters, announcing the start of the seminar on their public address systems, and provided excellent facilities. In the third marina, the

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announcement AWRI mailed to the marina could not be found on any bulletin board, the marina office was not aware that there was any seminar planned and no facilities were made available – predictably, there were no attendees from the 21 boaters who indicated an interest in attending the seminar.

(b) Commercial Operators: The Commercial Operator survey questionnaire (See Appendix G) was designed to gather supplementary diesel fuel data to be used for this study. It was believed that the commercial market was a secondary market but a small number of boats operating a large number of hours per season may be significant. The questionnaire was supplemented by telephone or personal interviews. Few responses to the questionnaire were received and data presented in this report is primarily from personal contacts or telephone interviews. Two commercial operators were unwilling to share information and so the fuel used by commercial operators is understated. One commercial operator in Region 2 dominates the market using nearly four times the fuel of all other consumers combined.

Six of the 19 questionnaires distributed to Commercial Operators were returned (31.5%). All other fuel used data gathered from commercial operators was by telephone interview.

#### d) Survey Target Selection:

- i) Distributors: The Distributor Survey (See Appendix J) candidates were selected from area telephone directories and internet websites. The candidates were selected based on the description of products sold and location. Two supplemental distribution points of sale were added as a result of a tour of Region Three by car while verifying the marina candidate list. Two additional distributors were added to the candidate list from the marina survey responses.
- ii) Commercial Operators: The Commercial Operators (See Appendix L) candidates were selected from area telephone directories, internet websites, and knowledgeable locals. The candidates were selected based on the description of services rendered and their location.
- iii) Marinas: The Marina Survey (See Appendix K) candidates were selected from area telephone directories, internet websites, personal experience, and knowledgeable locals. The term marina as used in this report includes yacht clubs and condominiums with attached marinas. Each geographical area was then visited to ensure all candidates were identified and to add or correct the candidate list where necessary. In general, this resulted in adding or changing between 20 and 40 % of candidates on the regional lists and was deemed a worthwhile use of

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the time to accomplish the drive-by. Region 5 nearly doubled in number of candidate marinas.

Distribution of the market data and extrapolation to the future market was dependent on sufficient responses to preserve anonymity of any single respondent. This was assumed to be three to four marinas depending on the total number of users, fuel sold, or unique conditions that could reveal an individual respondent's identity. There are not sufficient fuel retailers or historical data to allow a regional discussion and trend analysis of fuel used/sold.

#### iv) Users:

(1) Recreational Boaters: The User Survey questionnaires were distributed to boater in marinas allowing the User Survey (Question 17 on Marina Survey questionnaire). Recreational boats excluded from the data, in general, do not use diesel fuel but add to the total population in the Tri-Plex and contribute to the degradation of the environment within the Tri-Plex.

The Grand River, upstream of Grand Haven supports a significant number of recreational watercraft at private docks and in marinas. Three river marinas were counted and two surveyed. The character of the user group on the Grand River is different from that found in the drowned river mouth lakes and may be deserving of more attention than allowed by this market study.

The total number of recreational boats in Regions 3 and 5 in this report is understated the areas along the rivers are inaccessible.

(2) Commercial Operators: Commercial and other work boats (See Appendix L) identified by responses to the Marina and User Survey questionnaires were surveyed by a questionnaire added at a late date and a follow-up telephone contact. Commercial vessels observed during the manual count were excluded from the data but may add to the total population in the Tri-Plex. Commercial vessels are difficult to determine ownership and so vessels observed within the Tri-Plex were not counted. Only commercial vessels reported by questionnaire responses or telephone interviews are included in this report.

There are a number of charter boats (fishing) that operate out of Grand Haven, and Saugatuck and few out of the other regions. These vessels were included in the (recreational) user group. None was found to use diesel fuel.

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# 4) ASSUMPTIONS and EXTRAPOLATIONS:

#### a) Assumptions:

i) Responses: This market study was dependent on sufficient responses to the various questionnaires to make reasonable extrapolations to the total population of users. The Marina Survey questionnaire responses and personal contacts with commercial operators provided sufficient data regarding fuel used in the Tri-Plex. User Survey questionnaire responses provided sufficient data on fuel and price sensitivity to make reasonable forecasts for biodiesel sales to recreational boaters.

Commercial Operators questionnaires provided insufficient historical data to extrapolate to future growth. Consequently, only the fuel used in 2002 is used in this report and no estimated growth is attempted.

User Survey questionnaire responses were insufficient to correlate fuel sold by marinas to fuel used by recreational boaters. Consequently, responses were used only to estimate potential biodiesel sales based on percentages of respondents willing to buy under the scenarios considered.

- ii) Distribution of data: The underlying assumption in this study is that there would be an even distribution in the data received from the users. This proved not to be the case as the user responses were predominately from users of diesel fuel. The User Survey questionnaire itself may have been the cause for the diesel fuel bias. The questionnaire was headed "Diesel Fuel Survey Boaters" and allowed respondents that did not use diesel fuel to skip a number of questions. These two items may have given the impression that a response from non-diesel fuel consumers was not important.
- iii) Fuel usage: The fuel sold within each region is assumed to be consumed in the region. This assumption introduces an error but quantification is difficult. Recreational boats and commercial operator boats leaving a region (buying fuel elsewhere) may be offset by boats entering from other regions. No correction was attempted for this error.
- iv) Distributors: The Distributor Survey questionnaire was assumed to be an attempt to gather data from sources likely to be unwilling to respond with meaningful data. The intention was to rely on user and marina fuel used and sold data rather than data from a small group of distributors. Any fuel sold data received from the distributor segment was to be used for comparison to fuel used information from the user group. Insufficient data was received to confirm the fuel sold data from marinas.
- v) Marinas: The Marina Survey questionnaire was intended to gain some data but it was anticipated that the number of marinas and responses might insufficient to

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- (1) Price sensitivity: Percentages of respondents that indicated that they would buy biodiesel and premiums they are willing to pay were assumed to apply to the entire population of (recreational diesel fuel) users. A margin of error is calculated for these extrapolations.
- (2) Biodiesel Market Available: The available biodiesel market was estimated using the percentage of recreational boaters that indicated that they would buy biodiesel under the price options considered. No estimate of the available market for biodiesel sales to commercial operators is included.
- (3) Fuel Consumed: Fuel consumed in each region is fuel sold by marinas and fuel used by commercial operators, no extrapolation from recreational boaters' responses was made.

One marina in Region 2 did not have sufficient records to provide annual fuel sold data. Fuel sold data for this marina was annualized from three months sales in 2003. With this single exception, the data gathered is simply reported. Commercial fuel used is also reported directly from questionnaire responses or personal interviews. Estimated biodiesel fuel sales are for recreational fuel only

(4) Diesel Engines: The number of diesel engines in each region is estimated from the total estimated number boats, Marina Survey responses, and the percentages of sail and power boats using diesel fuel from the inspection of boats at two marinas (See Table 7).

# 5) RESULTS and DISCUSSION:

Table 2 is the recreational boat density by region. Region 3 provides the calculation for Spring Lake only and excludes the lower Grand River - downstream of 104<sup>th</sup> Ave.

TABLE 2

	Tr	i-Plex Re	creational Bo	at Densi	ty	
		]	Lake	Total	Boats per	Boats per mile of
Region	Description	Area <sup>1</sup>	Perimeter <sup>2</sup>	Boats	acre	shoreline
1	Whitehall	2535	16.922	1057	0.42	62.5
2	Muskegon	4232	29.622	1544	0.36	52.1
Part of	Grand Haven <sup>3</sup>	1028	22.637	756	0.74	33.4
4	Holland	1801	16.699	1330 0.74		79.6
5	Saugatuck	321	5.557	780	2.50	140.4

1 - Area in acres, 2 - Perimeter in miles, 3 - Spring Lake only

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Regional and Tri-Plex summary data and available biodiesel market estimates are summarized in Tables 3, 4, 5, and 8. Some detail data has been combined with other regions to preserve anonymity of respondents.

- a) Distributors: This portion of the distribution network was anticipated to be the most sensitive to outside inquiries and to disclosure of volumes of fuel shipped into the region. Price history was not a survey question because of this sensitivity and a better source for this information was the user's questionnaire which had questions to explore price and user sensitivity to price variation. The number of distributors was small, just seventeen, and the small number of respondents (2 neither of which serviced the marine users) would not allow extrapolation of data or conclusions to be made.
  - i) Biodiesel Awareness: Only one respondent answered the questions on the survey form indicating some familiarity with biodiesel as a fuel. The second was non-responsive merely indicating that they didn't sell diesel in to the marine market in the Tri-Plex.
  - ii) Pending Legislation: Only one of the two distributors who responded was aware of legislation that could affect his sales of diesel fuel.
- b) Marina Survey Questionnaire Responses: Table 3 summarizes the responses received from marinas. The Table contains only data provided by marinas no extrapolations have been included. The fuel sold data is assumed to be fuel sold to recreational boats. The numbers of boats are only those reported in responding marinas. Note that regions with similar characteristics, 1 and 2, and 3 and 5, have been combined to preserve anonymity of responses. Regions 3 stands alone as there were sufficient responses to preserve anonymity.

A surprising number of marinas responded favorably to allowing the boaters to be surveyed and to hosting a seminar. From the 54 surveys distributed, 20 were returned (37% return rate), 17 (31%) allowed the user survey to be distributed in their marina (distributed in 14), and 11 (20%) volunteered to host biodiesel seminars.

The number of marinas responding to the December survey from Regions 4 and 5 was insufficient to insure anonymity and to allow general conclusion to be made regarding the region. These regions were resurveyed in April of 2003. It was hoped that a second mailing of surveys to marinas might produce sufficient added responses to allow the regions to be treated individually. This proved to be the case for Region 5 as three additional questionnaires were returned. However, Region 4 had no additional responses. Data from both the December and April surveys are included in the tables.

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Four marinas reported spills of diesel fuel totaling approximately 27 gallons per year 20 gallons of which is reported in Lake Macatawa. As one of the goals of this study was to assess the significance of the volume of incidental diesel fuel spills and the potential impact on the environment, the lack of any appreciable spilled volume can be either encouraging or disappointing. Encouraging if it accurately reflects the total spilled volume or disappointing if underreported due to fears of consequences of admitting petroleum spills. No determination of accuracy of the spilled volume is possible from the available data and further research should be considered to assess the true situation.

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Region         Summary of Marinas Boats         Summary of Marinas Boats         Summary of Marinas Boats         Summary of Marinas Boats         Summary of Marinas Marinas Marinas         Summary of Marinas Marinas         Summary of Marinas Marinas         Non-Sail         Fuel Sold <sup>1</sup> Fuel Sollol <sup>2</sup> Callons         Seminar         Surveyed           1         4         390         142         14         7         1         3           2         14         5         387         11         101,982         20         2         2           3         15         5         783         83         37         52,862         0         4         4 <sup>2</sup> 5         7         4         492         116         73         11         11         11           Tri-Plex         54         20         2,568         729         126         126         126         127,965         17         11         17	Marinas   Responding   Reported in   Reported in   Piesel Eng   -Gallons   -Gallons   Responding   Reported in   Reported   Reported in   Reported   Re					TABLE 3	E 3				
Marinas Surveyed         Responding Marinas         Reported in Reported in Sulfoats         Reported in Sulfoats         Non-Sail Diesel Eng Diesel E	Marinas         Responding         Boats Agrinas         Sailboats Surveyed         Non-Sail Agrinas         Fuel Soild Parinas         Fuel Soild Parinas         Fuel Soild Parinas         Fuel Soild Parinas         Host England         Host England         Host Agrinas         Host Seminar           12         4         390         142         14         58,121         7         1           6         2         516         22.3         71         101,982         20         2           15         5         783         83         37         52,862         0         4           1 5         5         783         83         37         52,862         0         4           2 5         78         44         492         116         73         52,862         0         4           2 5         78         44         720         116         73         52,862         0         4           2 5         78         116         73         129         120         212,965         27         11           2 5         84         20         2,568         729         196         212,965         27         11           2 8         20				Summary of	Marina Surv	ey Response	s by Region			9
12         4         390         142         14         58,121         7         1           14         5         387         165         1         0         2           6         2         516         223         71         101,982         20         2           15         5         783         83         37         52,862         0         2           7         4         492         116         73         6         4         4           54         20         2,568         729         196         212,965         27         11	12	Region	Marinas	Responding Marinas	Boats Reported in Marinas	Sailboats Reported in Marinas	Non-Sail Diesel Eng	Fuel Sold¹ - Gallons	Fuel Spilled - Gallons	Host	Allow Survey
14         5         387         165         1         District         0         2           6         2         516         223         71         101,982         20         2           15         5         783         83         37         52,862         0         2           7         4         492         116         73         6         4         4           54         20         2,568         729         196         212,965         27         11	14   5   387   165   1   101,982   20   2     15   5   783   83   37   52,862   0   2     16   2   216   223   71   101,982   20   2     17   4   492   116   73   52,862   0   4     7   4   492   116   73   122,965   27   11     54   20   2,568   729   196   212,965   27   11      The sold by marinas combined for similar Regions as noted to maintain confidentiality of relailers   Photal I marinas were surveyed – two were surveyed in Region 1 and two were surveyed in Region 5.   And all marinas Surveyed – Number of marinas in the region and number of Marinas Surveyed. Responding Marinas – Number of questionmaires returned from the marinas by responding marinas. Sailboats Reported in Marinas – Total number of of sailboats reported by responding marinas. Sailboats Reported in Marinas – Total number of sailboats reported in marinas by responding marinas. Fivel Sold – Volume of fiuel reported spilled in 2002 by responding marinas in gallons. Fivel Sold – Volume of fuel reported spilled in 2002 by responding marinas in gallons. Host Seminar – Number of responding marinas allowing the User Survey to be distributed.  Allow Survey – Number of responding marinas allowing the User Survey to be distributed.	1	12	4	390	142	14	58 121	7	1	32
6         2         516         223         71         101,982         20         2           15         5         783         83         37         52,862         0         2           7         4         492         116         73         0         4         4           54         20         2,568         729         196         212,965         27         11	6	7	14	5	387	165	1	17160	0	2	3
15         5         783         83         37         52,862         0         2           7         4         492         116         73         0         4           54         20         2,568         729         196         212,965         27         11	15   5   783   83   37   52,862   0   2     7	4	9	2	516	223	11	101,982	20	2	2
7         4         492         116         73         32,002         0         4           54         20         2,568         729         196         212,965         27         11	7 4 4 492 1116 73 52,002 0 4 4  Fuel sold by marinas combined for similar Regions as noted to maintain confidentiality of retailers  Narinas Surveyed – Iwo were surveyed in Region 1 and two were surveyed in Region 5.  Marinas Surveyed – Number of marinas in the region and number of Marina Surveys distributed. Responding Marinas – Total number of boats reported in marinas by responding marinas. Sailboats Reported in Marinas – Total number of sailboats reported in marinas by responding marinas. Sailboats Reported in Marinas – Total number of sailboats reported in marinas by responding marinas. Sailboats Reported in Marinas – Total number of sailboats reported by responding marinas. Sailboats Reported in Marinas – Total number of sailboats reported by responding marinas. Sailboats Reported of the reported sold in 2002 by responding marinas in gallons. Fuel Solld – Volume of fuel reported spilled in 2002 by responding in gallons. Host Seminar – Number of responding marinas willing to host a biodiesel seminar. Allow Survey – Number of responding marinas allowing the User Survey to be distributed.	3	15	5	783	83	37	630 63	0	2	5
54 20 2,568 729 196 212,965 27 11	- Fuel sold by marinas combined for similar Regions as noted to maintain confidentiality of retailers  - Fuel sold by marinas combined for similar Regions as noted to maintain confidentiality of retailers  - Not all marinas were surveyed – two were surveyed in Region 1 and two were surveyed in Region 5.  - Marinas Surveyed – Number of marinas in the region and number of Marina Surveys distributed.  Responding Marinas – Number of questionnaires returned from the marinas by responding marinas.  Boats Reported in Marinas – Total number of boats reported in marinas by responding marinas.  Sailboats Reported in Marinas – Total number of sailboats reported in marinas by responding marinas.  Non-Sail Diesel Eng. – Number of power boats with diesel engines reported by responding marinas.  Fuel Sold – Volume of fuel reported sold in 2002 by responding marinas in gallons.  Fuel Spilled – Volume of fuel reported spilled in 2002 by respondents in gallons.  Host Seminar – Number of responding marinas willing to host a biodiesel seminar.  Allow Survey – Number of responding marinas allowing the User Survey to be distributed.	20	7	4	492	116	73	709,70	0	4	45
	l sol	Tri-Plex	54	20	2,568	729	196	212,965	27	11	17

c) Total Recreational Boats: The database of recreational boaters was supplemented by counting boats in marinas that did not respond to the Marina Survey questionnaire and boats not in marinas, i.e. private docks or moorings.

Table 4 includes the counted boats by region to estimate the total number of boats in each region and the Tri-Plex. The total number of diesel engines is estimated from data provided and an independent inspection of boats in two marinas. (See Section 5e)

Some regional differences become apparent from examination of the data. Recreational boaters in the Grand Haven and Saugatuck/Douglas, Regions 3 and 5, have significantly fewer sailboats - attributed to the lack of protected waters for day sailing similar to the drowned river mouth lakes of White Lake, Muskegon Lake, and Lake Macatawa. The percentage of sailboats for Regions 3 and 5 is 8.8% compared to 42.7% for Regions 1, 2 and 4, both significantly different than the 28% average for the Tri-Plex

Marinas generally did not answer Question 1 on the Marina Survey accurately. To the question "How many boats were in slips/moored in your marina in 2002?" Responses received ranged from the total number of slips in the marina to how many boats were serviced in 2002. This inaccuracy caused the preparation of nearly double the surveys required. Also, contributing to excess survey packages was the late spring weather and low water level causing many boaters to delay launching their boats. (180 boats not yet launched were counted in two marinas that have 540 slips (33% of capacity). These boats are not included in the totals for the region but indicate the potential undercount of the totals represented in the report.) A total of 1385 user survey packages were distributed (of the 2450 prepared) to recreational boats in marinas in the Tri-Plex.

Three small marinas (with 4, 7, and 9 slips) that granted permission to survey their customers and indicated that they had no slips leased to sailboats were not surveyed. This was done to reduce the time and materials required to complete the user survey. The small marinas not surveyed were manually counted during a visit as were larger marinas that did not respond.

The 17 collection boxes suffered various fates. One was nearly destroyed by a young Labrador, one was lost (likely thrown out with an undetermined number of responses) and replaced later, one was not picked up as the private marina was inaccessible and the contact person could not be reached to arrange the pick-up of the collection box. One marina threw out their collection box as it was empty (when it was thrown out is an unanswered question), and at least one was located (hidden?) where it was difficult for the boaters to find. All these issues adversely affected the number of responses.

79 (of the 1385 surveys distributed) of the recreational boat surveys distributed in the marinas in the Tri-Plex were returned (5.7 %). Region 1 had a 13.5 % rate of response while Region 2 had just 2.5 % returned.

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			The Mar	The Marine Market for Biodiesel Fuel in the West Michigan Tri-Plex	or Biodie	sel Fuel in the	he West	Michigan Tr	i-Plex		
						TABLE 4					
			Reci	Recreational Boats and Diesel Engines by Region	oats an	d Diesel Er	igines b	y Region			
19	Boats F	Boats Reported in Marinas	Boats (	Boats Counted in Marinas	Misc.	Misc. Counted Boats	Total	Estin	Estimated Boats using Diesel Fuel	sing Diese	l Fuel
CCION	Power Boats	Sailboats	Power Boats	Sailboats	Power Boats	Sailboats	Boats	Reported	Estimated	Total	Margin of error(+/-)
1	248	142	142	104	320	101	1,057	14	188	202	74
7	224	163	577	432	74	80	1,550	1	438	439	162
3	700	83	913	56	422	14	2,188	37	159	196	72
4	293	223	184	370	195	65	1,330	7.1	415	486	179
2	405	87	79	5	188	16	780	73	78	151	55
ri-Plex	1,870	869	1,895	196	1,199	276	9069	196	1,321	1,474	581

Boats Reported in Marinas - Number of sail and power boats reported in respondents to the Marina Survey questionnaire. Boats Counted in Marinas - Number of hand counted sail and power boats in marinas. KEY:

Misc. Counted Boats - Number of hand counted sail and power boats at private docks or moorings.

Total Boats - Sum of reported, counted and misc. sail and power boats

Boats with Diesel Engines – Vessels with diesel engines reported.

Estimated Boats using Diesel Fuel - Estimated number of recreational boats using diesel fuel by Region.

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d) Commercial Operators: Table 5 summarizes fuel sold data. The data was obtained primarily from personal contacts and not from questionnaire responses.

Table 5 also includes the total fuel sold by region and for the Tri-Plex. The total fuel sold estimate is the sum of the reported commercial operator fuel used in 2002 summed with the marina fuel sold data. This estimate is understated as there are two commercial operator and one marina that would not provide fuel data. There were fuel sold data received from distributors that would support or contradict the reported data.

The assumption that commercial operators formed a secondary market proved marginally correct. One large commercial operator consumes nearly four times the total of all other commercial operators and recreational boats combined. With this lone exception, recreational boats are the primary users of diesel fuel.

#### e) Recreational Users:

Analysis of the User Survey responses would lead to the conclusion that 86% of the recreational sailboats and that 32% of the power boats have diesel engines. Table 6 summarizes the recreational boaters responses as to type of vessel and fuel used.

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196 700	58,121	Total 1,116,848	Total Reported Spilled Volume Gallons - 2002 7
	101,982	102,682	0
151 1500	52,862	65,109	20
4 1,0	212,965	1,284,639	32

TABLE 6

	Boats that u	se diesel fuel	Boats that	use gasoline	Total
	Sail	Power	Sail	Power	Total
Number	25	16	4	34	79
Percent <sup>1</sup>	32.00%	20.00%	5.00%	43.00%	100%
Sails Boats	25	NA	4	NA	29
Percent <sup>2</sup>	86.00%	NA	14.00%	NA	100%
Power Boats	NA	16	NA	34	50
Percent <sup>2</sup>	NA	32.00%	NA	68.00%	100%
Percent <sup>3</sup>	37.	00%	63.	00%	100%

<sup>1 -</sup> Percentage of total boats, 2- Percentage of total sailboats or total power boats, 3 - Percentage of total boats

Because of the low number of responses and the suspected bias toward diesel fuel in the responses, supplementary data was gathered with visits to a large marina in Region 2 and a marina in Region 1 to determine fuel used by inspecting the fuel filler cap, boat transoms (diesel engine exhaust will discolor boat transoms), or engine control panels on all boats. This exercise resulted in the distribution of diesel fuel and gasoline use between sail and power boats listed in Table 7.

TABLE 7

	Type of 1	Fuel Used – l	Boat Inspec	ctions	
	Boats that u	se diesel fuel	Boats that	use gasoline	Total
	Sail	Power	Sail	Power	Total
Number	95	12	60	206	373
Percent <sup>1</sup>	25.47%	3.22%	16.09%	55.23%	100%
Sails Boats	95	NA	60	NA	155
Percent <sup>2</sup>	61.29%	NA	38.71%	NA	100%
Power Boats	NA	12	NA	206	218
Percent <sup>2</sup>	NA	5.50%	NA	94.50%	100%
Percent <sup>3</sup>	28.	69%	71	.31%	100%

<sup>1 -</sup> Percentage of total boats, 2- Percentage of total sailboats or total power boats, 3 - Percent of total boats.

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There lack of agreement between Tables 6 and 7 support the supposition that the data from the user responses was skewed toward diesel fuel users and not a true cross section of users (37% from Table 6 and 28.7% in Table 7). There is potential agreement between the percentage of power boats with diesel engines from the marina survey data (5.3% - See Appendix D) and the data from the marina boat inspection data (5.5%).

For purposes of estimating the number of recreational boats using diesel fuel, the percentages of Table 7 are used in this report.

Elimination of the confusion created by the diesel fuel bias in the user responses would require a resurvey and responses that were more reflective of the total population of users. Follow-up interviews with users may also be necessary.

f) Potential Recreational Biodiesel Market: Table 8 estimates the available recreational market for biodiesel. The available market is estimated using the percentage of respondents that would buy biodiesel under the scenarios considered in this study.

#### These scenarios are:

- 1. Biodiesel is available for purchase by the boater at the price and location where the boater currently buys his petrodiesel fuel at parity with petrodiesel.
- Biodiesel is available for purchase by the boater at a price 10% higher than petrodiesel at the location where the boater currently buys his petrodiesel fuel.
- Biodiesel is available for purchase by the boater at a price 30% higher than petrodiesel at the location where the boater currently buys his petrodiesel fuel.

The questionnaire asked if the boaters would buy biodiesel priced at \$0.16 or \$0.48 higher than petrodiesel which equates to a 10% or 30% premium when the questionnaire was formulated.

The historical data gathered from marinas and distributors did not provide adequate information to forecast potential biodiesel sales for 2003 thru 2005 as was planned. An alternate approach to predicting future sales is to use fuel or engines sales trends. This approach ignores any regional growth differences but is the only possible approach at this time. The national trend in diesel engine sales in recreational boats reported by the National Marina Manufacturers Association (NMMA) is an increase of 3.5% per year. The national diesel fuel sales are increasing at a rate of approximately 1.4% per year. Using the engine sales trend may be a more accurate predictor of future fuel sales as this is a trend established over a five year period whereas the fuel sales trend is over a ten year trend does not reflect an upturn in the preference for diesel engines that has occurred in the recent past.

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Recorded   Reported   Ruel Sold,   Price   Premium   Estimated volume of   Biodiesel at 10% over   Diodiesel at Parity wt.   Diodiesel at 10% over   Diodies										
Reported Fuel Sold, 2002         Fuel Sold, 2002         Average Biodiesel Petrodiesel at Parity wt. Petrodiesel at 10% over Permium Podologesel at Parity wt. Petrodiesel 2002         Estimated volume of Petrodiesel at 10% over Petrodiesel 2002           \$2002         Biodiesel Gallous 2002         Gallous error (+/-)			POTEN	LIAL BIODI	ESEL SAL	1	EATIONA	L MARKET	J	
gallons - 2002         Biodiesel 2002         Gallons error (+/-)         Margin of error (+/-)         Gallons error (+/-)         Margin of error (+/-)         Margin of error (+/-)           58,121         ND         \$0.263         19,305         1,963         14,479         2,805           101,982         \$1.660         \$0.263         36,403         3,701         36,403         7,053           101,982         \$1.660         \$0.448         101,982         3,152         42,940         4,505           \$2,862         \$1.690         \$0.263         31,000         10,369         23,250         8,320           \$2,862         \$1.510         \$0.518         16,397         1,667         13,664         2,647           x         \$1.531         \$0.346         205,086         20,852         130,735         25,331		Reported Fuel Sold,	Fuel	Average	Estimated biodiesel a Petro	volume of t Parity wt.	Estimated biodiesel at Petro	volume of 10% over diesel	Estimated biodiesel a Petro	Estimated volume of biodiesel at 30% over Petrodiesel
58,121         ND         \$0.239         19,305         1,963         14,479         2,805           101,982         \$1.660         \$0.263         36,403         3,701         36,403         7,053           101,982         \$1.660         \$0.448         101,982         3,152         42,940         4,505           \$2,862         \$1.690         \$0.263         31,000         10,369         23,250         8,320           \$1.510         \$0.518         16,397         1,667         13,664         2,647           \$1.535         \$1.631         \$0.346         205,086         20,852         130,735         25,331	REGION	gallons - 2002	2002	Fremum - Biodiesel	Gallons	Margin of error (+/-)	Gallons	Margin of error (+/-)	Gallons	Margin of error (+/-)
58,121         ND         \$0.263         36,403         3,701         36,403         7,053           101,982         \$1.660         \$0.448         101,982         3,152         42,940         4,505           \$2,862         \$1.690         \$0.263         31,000         10,369         23,250         8,320           \$1.510         \$0.518         16,397         1,667         13,664         2,647           \$1.531         \$0.346         205,086         20,852         130,735         25,331	1		\$1.690	\$0.239	19,305	1,963	14,479	2,805	4,826	780
101,982         \$1.660         \$0.448         101,982         3,152         42,940         4,505           \$2,862         \$1.690         \$0.263         31,000         10,369         23,250         8,320           \$1.510         \$0.518         16,397         1,667         13,664         2,647           \$1.531         \$0.346         205,086         20,852         130,735         25,331	2	58,121	N ON	\$0.263	36,403	3,701	36,403	7,053	0	0
\$2,862         \$1.690         \$0.263         \$1,000         \$10,369         \$23,250         \$320           \$1.510         \$0.518         \$16,397         \$1,667         \$13,664         \$2,647           \$12,965         \$1.631         \$0.346         \$205,086         \$20,852         \$130,735         \$25,331	4	101,982	\$1.660	\$0.448	101,982	3,152	42,940	4,505	26,837	4,337
52,862         \$1.510         \$0.518         16,397         1,667         13,664         2,647           212,965         \$1.631         \$0.346         205,086         20,852         130,735         25,331	3		\$1.690	\$0.263	31,000	10,369	23,250	8,320	0	0
212,965 \$1.631 \$0.346 205,086 20,852 130,735 25,331	5	52,862	\$1.510	\$0.518	16,397	1,667	13,664	2,647	5,466	883
	Tri-Plex	_	\$1.631	\$0.346	205,086	20,852	130,735	25,331	37,129	000°9

## 6) WEST MICHIGAN TRI-PLEX - POTENTIAL BIODIESEL FUEL MARKET:

#### a) Market Description:

The West Michigan Tri-Plex diesel fuel market is dominated by one commercial operator. Recreational boaters that use diesel fuel are approximately 29% of the total recreational boats in the Tri-Plex. The total number of diesel powered sail boats in the Tri-Plex is approximately 1,190. Adding to the total number of diesel powered vessels in the Tri-Plex, are an estimated 273 non-sail diesel powered recreational boats, and 42 operated by commercial operators approximately or an approximate total of 1,505 diesel powered watercraft — many power boats with multiple engines. Total marine diesel fuel consumed in the Tri-Plex was nearly 1,290,000 gallons in 2002.

The recreational boaters surveyed in the Tri-Plex indicate that they would buy biodiesel at an average price of \$0.38/gallon above petrodiesel. The acceptable average premium the recreational market is willing to pay for biodiesel varies from \$0.24 to \$0.52 per gallon within the five regions considered.

The recreational boaters' responses indicate that marinas could sell approximately 130,000 gallons of biodiesel at a price 10% higher than petrodiesel. Biodiesel would be priced significantly above this figure. However, B20 could be priced at an acceptable level and may be more acceptable to recreational boaters given some of the concerns expressed in the comments received. An annual growth rate of 3.5% per year in recreational boats with diesel engines implies a similar growth in recreational fuel sales.

At parity with petrodiesel, approximately 200,000 gallons of biodiesel fuel could be sold annually with an estimated growth rate of 3.5% per year.

B100 at a premium of 30% above petrodiesel is neither acceptable to boaters nor offered from distributors.

The commercial market offers the biggest single opportunity in that over one million gallons of diesel fuel is consumed in the Tri-Plex. However, the available commercial market for biodiesel or a blend is beyond the scope of this study.

#### 7) ACKNOWLEDGEMENTS:

a) Reviews: Special thanks to Steve Parker, Manager - Business Development, of Eaton Aerospace, marketing professional and former co-worker for his review and constructive comments on this study and report.

Annis Water Resources Institute Grand Valley State University 22 of 22

# APPENDIX A

## WEST MCHIGAN BIODIESEL MARKET STUDY SUMMARY

Responses	Counted and e	Canada and a	oats in marinas	Responses	Region 5 - Sau		Responses	Misc	oats in marinas	Responses	Region 4 - Ho		Responses	Misc	oats in marinas	Responses	Region 3 - Gra		Responses	Misc	oats in marinas	Responses	Region 2 - Muskegon		Responses	Misc	Boats in mari	Responses	Region 1 - Wh		₽			_	No. of Surveys Distributed	1385		RECREAT
Segment Totals	Counted and esumaied - MISC Doma	ctimated - Misc Boat	hats in marinas - from Marina survey	Responses - User Sub total page	Region 5 - Saugatuck/Douglas		Segment Totals	Misc Boats - private docks	oats in marinas - from Marina survey	Responses - User Sub total page	Region 4 - Holland/Lake Macataw		Segment Totals	Misc Boats - private docks	oats in mannas - from Marina survey	Responses - User Sub total page	Region 3 - Grand Haven/Spring L	- C	Segment Totals	Misc Boats - private docks	oats in marinas - from Marina survey	Responses - User Sub total page	skegon		Segment Totals	Misc Boats - private docks	Boats in marinas - Marina seg sum	Responses - User Sub total sheet	Region 1 - Whitehall/Montague		Marina/Region		Entered Data		Number of Respondants	79		RECREATIONAL USER SEGMENT SUMMARY
s 108 672	ŀ	16	y 92 484	6 6 5			658 672	65	593	14		F	133 1770	153	139	1	-	-	676 874		596	3		-	347 710	101	246	0		-	Sall boats	Question 1	Number		Number of boats considered in study	6866		Number of boats in Marinas
2 95	t	1	4 73	8		-	2 145	t	+	+		-	+	t	+	37	-	-	4 437	+	+				0 189	+	-	1	0	-	Question 2		Number	-	n Diesel Engines	966		Diesel Engine
1.12.55				78 6200	₩					100 LOW	00781 822		1			1	0081 0E		-			13 0	15 0				No. of the last	00 070	88   6700		Sall boats  Power boats	Question 4	Number		Gallons, Estimated - Recreational users	212965		2002 Fuel used
\$1.898	000			0 31.898	-100	-	31./31	135 13		od i	n sı 751			\$1.800		000	008 13 0		32,000			92,000	000		31.095	200		ᆎ	\$1 695		Question 5		Dollars		Avg 2002 Price Paid	\$1.829		2002 d Fuel Price
31./00	0.07			31.700	200		Olerit.	\$1 578			\$1.578			\$2,400			\$2,400		30,000	2000		90.000	000 ns		31.033	61 633			\$1.633		Question 6		Dollars		Avg 2001 Price Paid	\$1.828		2001 Fuel Price
4.7	24	24		4	2			7.	34		4.5			0	0		0		104	437	437		-						0		Question 7		Number		Work Boats identifed by Boaters	80		Diesel Work Boats
	1	-			0.1			6	6		8.0			3.14468	3.14468		0.1		0.0	00	0		0.0			5	5		0.3		Question	3	Number		Gallons Spilled in 2002	15		2002 Small Spills
	331	331	221		28			677	677		89			75	75		3		04.40	5746	5246		12			419	419		20		Question	9	Number		Times per season	6749		Clean
	24	4.7	74		2			23	23		3			25	25		1			0	0		0			63	63		3		Question 1	10	Number		Percent Yes Respon's	11.4%		Health Issues
	83	8	83		7			115	115		15			101	101		4			437	437		1			105	105		5		Question	11	Nmuber		Percent Yes Respon's	40.5%		Heard of Biodiesel
	71		71		6			145	145		19			101	101		4			437	437		1			168	168		00		Question	12	Number		Percent Yes Respon's	32.1%		Cost & Place
	59	50	59		S			115	115		15			75	5	3	3			437	437		1			126	126		6		Question	13	Number		Percent Yes Respon's	13.478	40 00	Pay Premium
	STC-06	80 519			\$0.518			\$0.448			\$0.448			\$0.263			\$0.263	200		\$0,263			\$0.263			\$0,239			\$0.239		Question	14	Dollars		Dollars above Diesel	40.00	246 03	Price Premium
	37	50	59		5			61	10		~	,		10	10	75		,		437	437		1			126	126		6		Question	15	Number		Yes Respon's	+	56.1%	16 Cent Premium
	4.7	24	24		2			38	30	70	J					0	•			0	0		0			42	42		2	,	Question	16	for Yes	- 1	Yes Respon's		22.0%	48 Cent Premium
	100	154	154		13			1/0	75.1	176	0	72		4.76	757	252	10	10		1749	1/47	1700	+	4		252	252		71	10	Question	17		-	Yes Respon's		78.5%	Attend a Seminar
	1	95	95		×			130	138	138	10	18			151	151		6		8/4	4/10	074		3		168	108	160	0	0	Question	18	for Yes	0 for No 1	Yes Respon's		53.2%	within 4

48 Cent Attend a within 4 Premium Seminar Miles	1 O for No 1 O for to Yes for	tlon t	Ques		1	5	2 12 8			0 2 1	2	0	7 4 7			2	0 8	0 0	+	10			+	14	2 77			2 13 8	2 13 8		
	- 4	r noli	gene		4	2	9			0	-	0	-			0	-	0	7 0	3			2	3	00	-	0	5	5	1	
Price Premium		r not	Quest		\$0.19	\$0.33	\$0.24	Ngal		\$0.00	\$0.53	\$0.00	\$0.26	S/gal		\$0.00	\$0.10	\$0.00	\$0.33	30.00	Sypal		\$0.55	\$0.35	\$0.45	S/gal	\$0.00	\$0.52	\$0.52	\$/gal	N
Buy bio at premium	0 for No 1 for Yes	ı uoı	Quest		4	2	9			0	1	0	1			0	1	0	2	0	,		1	00	15		0	2	2		
Same Cost & Place	0 for Petro 1 for Bio	st no	Quest		5	3	8			0	-	0	1			_	1	0	2	0	4	-	10	6	19		0	9	9		
Heard of Biodiesel	o for	tt no	Questi		7	3	5			0	-	0	1			-	-	-	-	0	4		9	6	15		c	2	1	1	
Health Issues		01 no	greeng	,	,	1	3				0	0	0			0	-	0	0	0			3	0	3		-	0	1		
Clean	Number	e no	Guest		01	2 10	20				13	0	12			-	9	0	0	0	3	-	32	57	68		-	200	07 80	24	-
2002 Small Spills	Number	8 no	dreeu		900	0.00	0.25			90	0.00	000	0.00			000	000	000	0.13	0.00	0.13		0.50	0.25	0.75		9	0.00	0.00	0.00	-
Diesel Work Boats	0 for No 1 for Yes	Z uc	Zuestlo			0	0				0	- 0	-				0	0	0	0	0		٠	0	5			0	7	7	1
2002 Fuel 2001 Fuel Price Price	Dollars	9 00	oliseuf			\$1.67	51.53	S/gal			\$0.00	30.00	60.00	S/gal			\$1.60	\$1.30	07.12	\$0.00	\$2.40	S/gal	21.5	07.12	85 13	S/gal		\$0.00	\$1.70	SL.70	or Day
2002 Fuel Price	Dollars	9 U	otseut	0		\$1.71	\$1.60	S/gal			\$0.00	\$2.00	90.00	S/gal			\$1.80	20.00	\$1.80	\$0.00	\$1.80	\$/gal	61.67	\$1.37	81.75	S/gal		\$0.00	\$1.90	\$1.90	Ar 1504
2002 Fuel used	Number	Question 4	ower			9200	200	00/0			0	0		0			300	0	1500	0	1800		2015	2400	10400	10400		0	6200	6200	
2002 Fr	Number	Ques	lis2 atso			48	40	88			0	15	0	13			0	30		0	30			138	2007	338		0	78	78	
Diesel Engine	0 for No 1	21	ropsen	Ö		9	3	6			0	-	0	-			-	-	0	0	4			01	6	19		0	8	80	
Number of boats	Number	Question 1	19WC	d d		3	-	4			0	0	0	0			-	0	0	7	3			4	2	9		0	5	5	
	Number	Ones	ilsi	q		3	2	2			-	2	0	3			0	-	0	0				9		14		0	9	9 8	
USER SEGMENT SUBTOTALS by Marina and Region	Entered Data		Marina/Region		hitehall			Segment Totals		uskegon				Segment Totals		Region 3 - Grand Haven					Commont Totale	Segment 10tais	olland			Segment Totals	neatuck			Segment Totals	
USER S BTOTAL			6	3	Region 1 - Whitehall	M-13	M-14	Responses	-	Region 2 - Muskegon	M-17	M-26	M-43	Responses	T	ion 3 - G	M-31	M-44	M-45	Y-1	7-X	Kesponses	Region 4 - Holland	M-7	M-12	Responses	Region 5 - Saugatuck	M-54	M-56	Responses	

	R SEGI	ATA	Number of Sallboats	Dicsel Engine	Typical Senson Fuel	2002 Fuel Price	2001 Fuel Price	Diesel Work Boats	2002 Small Spills	Clean Transom	Health Issues	Heard of Biodiesel	Same Cost & Place	Would pay more	Price Premium	16 Cent Premium	48 Cent Premlum	Attend a Seminar	Attend a Seminar - 4 miles	Added Comment	Percent of Sall with Diesel engines reported by users	Percent of Sallors Interested Servinar
•	T	70	11	41	33648	14	\$1.016	1.5%	1	167	11.4%	40.8%	44.1%	38.0%	1	29.1%	11.4%	79.6%	63.2%	40.5%	0.6	27
Tol-Plex Total	from Data	Number of Response	Number	Number of Yes Respon's	Gallons Total of all users	Ave 2002	Avg 2001 Fuel Price	Percent Yes Respon's	Gellons	Number of times per sesson	Percent Yes Respon's	Percent Yes Respon's	Percent Yes Respon's	Percent Yes Respon's	Avg Dollars above Dissel	Percent Yes Respon's	Percent Yes Respon's	Parcent Yes Respon's	Percent Yes Respon's	Percent Yes Respon's	Assumed votume per small spill (pints)	Number of Sallors Interested Seminer
	T	ID COOR	S for No 1 for Yes	0 for No 1	Humber	Dallars	Dellars	Difer No. 1 for Yes	Number	Hamber	6 for No 1	8 for No. 1 for Yes	8 for patro 1 for blo	8 for No. 1 for Yes	Dellars	Stor No 1	Efer He 1 for Yes	O for He 1	0 for No 1	8 for No 1 for Yes	Name of IQ Code	8 for No 1 for Yes
Estand Dec		Marina D	Question 1	Question 2	Duestion 4	Question 6	Question 6	Cuestion 7	Question #	Question 9	Question 18	Question 11	Question 12	Chestion 13	Guestion 14	Question 16	Question 16	Guesdon 17	Question 18	Question 19	Normal Fast Doct	Salbouts interested in Seminar
		Ya.	0	0	NA	NR NA 1.66	NR NA L5	NA 0	NA 2	NA 3	NA 0	NA 0	NA 1	NA 0	0.42 NA 0	NA 0	NA 0	0	0	0		0
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	1022			I feel used	10	NA	NA	0	0	3	0	1	1	1	1.5		1	1	1	1		1
M-7	Totals		6	10 No of	5538	\$1.57 \$/gal	\$1.52 \$/gal	5 Yes Rsp.	0.500 Gallena	32 No of	yes Res	Yes Rep	10 Yes Rap	7 Yes Rap	\$0.547 . \$/gal		3 c Pay 48	9 e Attend	7 Attend	4 Added		100.01
2000	ERRE	10.00 kg	54,5%	D Engine	40	\$9.410 2.25	\$9,100 NR	40.9%	0	Timer	27.3%		90.9% NR		\$5,470	45.5% NR	NR	81.8%	63.6%	36.4%		percer
			0	0	30 NA 25	NA NA	NA NA NA	0	NA 1	NA 18	NA 0	1	1	1	0.5 0.05 0.125	0	0	1 0	1	1 0		0
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M-I	2 Total		8	oat fisel use g r No of	13200	51.93		0 Yes Rsp	0.250 Gallon		Yes Ra	p. Yes Ra	p. Yes Ra	p. Yes Re	\$0.34 p. \$/ga		c Pay 48	e Atten	d Atten			97.4
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0 1 M-1	13 Tota	b	Numb	er No o			Dollar	Yes Ray	p. Galler		Yes R	p. Yes R	sp. Yes R	p. Yes R	sp. S/ga	Pay I	6 c Pay 4	Be Atter	nd Atter	d Added		100. pers
			1	1	20	NA.	NR NR	0	0	1	0	1	1	0	0.5	0	0	1	1	0		
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				ost fuel use		_	NA	NA	NA	NA	NA.	NA.	NA	NA	N/	N/A						
5 1 M-	14 Tate		2	bost fuel us	red 200 240 Callo	\$1.6	\$1.55	Yes Rs	0.25	) 1	f Ves F	ap. Yes R	an. Yes R	ap. Yes R					nd Atte			100
400	- DOWNERS	00000	<b>***</b>	D Eng	ines	\$1.60	0 \$1.55 NA	0.0%		Time	20.0	% 60,0	% 60.0	40.0	% S1.0	00 40.0	% 40.0 NE	% 100.0 E NE	0% 80.0	% 40.0%		pers
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			Sail Power	oost fuel use bost fuel u	ed 0																	
3 1 M		2000000	Num	ber No	of Galle	\$0.0 003 \$/ga	50.00 So.00	0 0 d Yes Rs 00 0.0%	p. Galle	ms No	of Yes I	0 tsp. Yes F % 0.0	tsp. Yes F	ap. Yes F	Rsp. 5/g	al Pay	ide Pay	48 e Atte	end Atte	nd Added		100
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2	1-25 Tot	200000	2	1		5 52.0	0 \$0.0 d \$/gs	Q 1 U Yes R	o.oc sp. Gaile	nns No	of Yes	Rap. Yes I	Rap. Yes l	lap. Yes !	80. Rap. 5/	al Pay	16 c Pay	48 c Att	end Atri	end Added		101
-		0000000		DEn	tines	\$2.0 0 1.1	00 \$0.00	00 50.09	0	Tim	es	50.0	30.0	7% 50.0	0% S0.	S25 50.	0% 0.0	7% 100	0% 30.0	30.09		per
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1 M	JI To	all parties	Num	D En	of Gat	70ft 3/g	2 3/g	na Tes R	OF UNI	146	104	maps I es	105 I 105	Tel	- av	200		- E-	Jane Half	in 4 Comme	- 8	per

	ID COOR	a for Na 1 for Yes	G for Ho 1 for Yes	Number	Dollers	Dollars	O for No 1 for Yes	Humber	Number	S for No 1 for Yes	0 for No 1 for Yes	0 for petra 1 for blo	Ofor No 1 for Yes	Dollars	O for No 1 for Yes	G for Ha 1 for Yes	0 for No 1 for Yes	0 for No 1 for Yes	0 for No 1 for Yes	Name of ID Code	0 for 1
Esterned On	Marina 1D	Question 1	Question 2	Question 4	Question 6	Question 6	Question 7	Question 8	Question 9	Question 10	Question 11	Question 12	Question 13	Question 14	Question 16	Question 16	Question 17	Question 18	Question 19	Normal Fuel Dock	Sailboats Interested in
Respondent	No.ENG																,,,,,,,,,,				0
	***************************************	Mary Printers and Publishers and Pub	fuel used at fuel used	0																-	$\vdash$
New York Control of the Control of t		0	0	0	\$0.00	\$0.00	0	0.000	0	0	0	0	0	\$0,000	0	0	0	0	0		0
M-13 Totals		Number	No of D Engines	Gallons	\$/gal \$0,000	\$/gal \$0.000	Yes Rsp.	Gatlons	No of Times	Yes Rsp.	Yes Rap.	Yes Rap.	Yes Rsp.	\$/gal \$0.000	Pay 16 e	Pay 48 e	Attend #D[V/0]	#DIV/0	#DIV/01		#O(V
The Control	DYLLS	0	0	NR	NA	NA	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR .	1	1	0		0
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60 C (20)	La Trivia	1	1	30	NA	1.5	0	0	1	1	1	1	1	0.2		0	i	1			
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		-	t fuel used out fuel used	0																	
	***************************************	1	1	30	00.02	\$1.50	0	0.000	3	1 V D	1 V P	Yes Rsp.	Yes Rap.	\$0.100 \$/gal	1 Pay 16 c	Pay 48 c	5 Attend	Attend	Added	-	100
M-44 Totals		Number	No of D Engines	Gallons	\$/gal \$0,000	\$/gal \$1,500	Yes Rsp. 0.0%	Gallons	No of Times	Yes Rsp. 20.0%	Yes Rsp. 20.0%	20.0%	20.0%	\$0.200	20.0%	0.0%	100.0%	60.0%	20.0%		pert
	NU S	0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA NA	NA NA	NA NA	0	0	0		
1875 W		Sailbox	of fuel used	NA 0	NA.	NA	NA	NA	NA	NΛ		NA	NA	I NA	NA NA	INA					
		Power b	ont fuel used	0	<b>*******</b>	<b>******</b>	****														
M-45 Total		Number	No of	Gallons	\$0,00 \$/gal	\$0.00 \$/gal	Yes Rsp.	Gallons	Noof	Yes Rsp.	Yes Rap.	Yes Rep.	Yes Rap.	\$0.000 \$/gal	Pay 16 e	Pay 48 c	Attend	Attend	Added		100
	********		D Engine	_	\$0.000	\$0.000	0.0%	- Calleria	Times	0.0%		0,0%	0.0%	\$0,000	0.0%	0.0%	50.0%	50.0%	0.0%		per
	2000000	Cailbo	at fuel used	0	200000000									5 900000000	0.8000000	********					-
is see		-	oat fuel used	0			*****														
		0	0	0	S0.00 Dollars	S0.00 Dollars	Yes Rsp.	0.000 Gallona	No of	Yes Rsp	Ves Rap	Yes Rap	Yes Rap.	S0,000 Dollars	_	Pay 48 c	Attend	Attend	Added		10
M-S4 Total	•	Numbe	D Engine	Gallons	#DIV/01	\$0.000	#DIV/01	Gallona	Times	#DIV/01	-	-	-	of the second second	Martin Commission	-	_	#DIV/0			per
		0	1	2500	1,75	1.65	NA.	0	15	0	1 NA	1 NA	I NA	0.125	I NA	NA NA	1	1	1	-	-
		0	0	NA 33	NA 2.65	NA NA	NA 0	NA 0	NA I	NA 1	NA 1	NA 1	I	NA 2.25	I	1	1	1	0		
v.)		1	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NΛ	NA	NA	1	0	0		F
		1	0	NA 23	NA NA	NA NA	NA 0	NA 0	NA 8	NA I	NA 1	NA I	NA 1	0.25	NA 1	NA 0	0	1	+-		
		1	İ	23	2	2.1	0	0	2	0		1	1	0.5	1		1	1	1		
		0	++	500	1.98	NA 1.15	1 0	0	0	0	1	10	0	0	0	0	++	0	0	1	-
		0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	0	1		
		0	1 0	2000 NA	1.89 NA	1.9 NA	NA NA	NA NA	NA.	NA NA	NA NA	NA.	NA NA	NA	NA	NA NA	++	++	0		-
		0	0	NA	NA	NA	NA	NA	NA	NA.	NA	NΛ	NA	NA	NA	NA	0	0	1		
X. 1. S.		0	1	800 NA	NA NA	NA NA	NA NA	0 NA	NA NA	0 NA	I NA	NA NA	NA NA	NA NA	NA NA	NA NA	++	0	0	-	-
	*******	474	oat fuel used	78		, NA															
W. C. C.		144	boet fuel use		81.00	81.70	1	0.063	28	2	7	6	5	\$0.518		1	-13	8	9	1	1
M-56 Tota	de	Numb	er No of	6278 Gallona	\$1.90 \$/gal	\$1.70 \$/gai	Yes Rap	. Gallons		Yes Ra	p. Yes Rs	Yes Rs	. Yes Ray	. S/gal	Pay 16	e Pay 48	e Atten	Atten	d Added		
			D Engin		\$11,390 NA	\$6,800 NA	13.3% NA	_	Times	13.3% NA	46.7% NA	40.0% NA	33.3% NA	\$3.62: NA	THE RESERVE OF	13.3% NA	86,7%	53.3%	60.0%		Pe
2	Y-1		1	900	NA NA	NA NA	0	NA 0	0	0	0	1	1	0.125	1	0	1	I	1		
3	Y-1	0	_	NA	NA	NA.	NA.	NA.	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA		NA NA	0	0	0		-
5	Y-1		_	600	1.8	NA 1.7	NA 0	NA 2	NA 0	NA 0	NA I	NA I	NA 1	0.2		0	1	1	0		
6	Y-1	0	0	NA	NA	·NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA.	0	0	0		-
			oat fuel used boat fuel use						4	-								****			
S ESSENTIAL SES		₩ 0	2	1500	\$1,80	\$1.70		0.125			1	1	2	50.32	5 1	0	1				1
Y-1 Tot	ala		er No of				Yes Rs	p. Gallon	I No of		16.7%										pt pt
E TO A																					
200		Sailt	oat fuel used																		-
	200		bost fuel use	0	\$0.00	\$0.00	0	0	0	0	0	0	0	\$0.00	0 0	0	0	0	. 0		
Y-2 Tot		// Num!	er No o	Gallon	s S/gal	S/gal	Yes Re	p. Gallon	s Noo	Yes R	sp. Yes Ri	p. Yes Ra	p. Yes Rs	p. Dolla	Pay 10	e Pay 49	c Atten	d After	d Added		P
			D Engli	nes			) WDIV/	or	Time	a   #DIV/	OL   WDIA!	a:   #DTA	or I #DIA/	01 30.00	0   #DIV	AL MOTAL	e.   #D14	AL WOLV	01 #DIV/0	<u> </u>	J.L.P
			t fluel used	471											000 000 000		005 0000000	004000000		000	78

# APPENDIX B

## **DISTRIBUTION SUMMARY BY REGION**

		WES	MICHIG	ANI MA	and var			EST MICHIGAN TRIST LEAD DESCRIPTION OF THE PROPERTY OF THE PRO			4
Region	Region name	sanivaM to vadmuM	ni staoa I Ison I Boats in Mecreational Boats - 2002/2003 (A)	Recreational Boats Condominium Marinas - 2002/2003	Recreational Boats in Yacht Club Marinas- 2002/2003	Other recreational Boats - 2003 (B)	Total No of Recreational Boats - 2002/2003 (C)	Recreational Sailboats 2002/2003	Recreational Power Boats - 2002/2003	Commercial Vessels	Percent of User Surve: Questionnaires Returned
	Whitehall	12	636	15	29	421	1,057	347	710	0	13.5%
7	Muskegon	14	1,396	15	169	154	1,550	675	875	32	2.5%
3	Grand Haven	15	1,752	72	173	436	2,188	153	2,035	ε	3.0%
4	Holland	9	1,070	0	74	260	1,330	859	672	2	11.2%
2	Saugatuck	7	576	13	46	204	780	108	672	2	4.8%
	Total Tri-plex	54	5,430	115	491	1,475	906'9	1,941	4,964	42	5.7%
3	These data include marinas at Condominiums and Yacht Clubs	ndominium	s and Yacht Ch	sqr				***			
(B)	These data are from counting total number of boats and sail boats at non-responding mannes and as private coors in some corresponding mannes and as private counting to the control of the	al number o the Tri-Plex	f boats and sam	ber of boats and sail boats at non-responding maines an -Plex that were counted or noted from survey responses.	n survey respon	ses. There are a	additional boats not	There are additional boats not included - see text Para. 2.b)	Para. 2.b)		

	WEST MICHIC	CHIGAN	TRI-PLE	X DIESEL	FUEL M	ARKET ST	TOT-YOU	TRI-PLEX DIESEL FUEL MARKET STUDY- TOTAL DIESEL FUEL MARKET	UEL MARI	ŒŢ	
Region	Region name	Diesel Engine Trend % per Year (NMMA), 1997 -2002 (D)	Sailboats u8sing Diesel Fuel- Estimated 2003 (E)	Power Boats using Diesel Fuel - Estimated 2003	Commercial Vessel - Land Fuel - 2003	Total Boats using Diesel Fuel - Estimated 2003 (F)	Diesel Fuel Sold, Gallons - 2002 (G)	Regional Sales Trend - 0002 - 1ear 1-8000 (H) 2002	Estimated Diesel Fuel Sales, Gallons - 2003 (J)	Estimated Diesel Fuel Sales, Gallons - 2004 (J)	Estimated Diesel Fuel Sales, Gallons - 2005 (J)
	Whitehall	3.5%	213	52	0	265	21,718	3.5%	22,478	23,265	24,079
2 N	Muskegon	3.5%	414	49	32	495	1,095,130	3.5%	1,096,404	1,097,723	1,099,088
3	Grand Haven	3.5%	94	147	3	244	41,747	3.5%	42,832	43,955	45,117
4	Holland	3.5%	403	104	2	209	102,682	3.5%	106,251	109,946	113,769
5 8	Saugatuck	3.5%	99	106	5	177	23,362	3.5%	24,127	24,919	25,739
	Total Tri-plex	3.5%	1,190	458	42	1,690	1,284,639	3.5%	1,292,093	1,299,807	1,307,792
(0)	This is the histroical trend in sales of diesel engines to new boats from NMMA Website. See para. 5f.) These estimates are based on the total of reported and counted boats multiplied by the percentage of sailboats using diesel fuel from Table 7.	iles of diesel er e total of repor	ngines to new be	oats from NMM d boats multipli	fA Website. So ed by the perce	ee para. 5f.) entage of sailboat	is using diesel fue	el from Table 7.			
	These estimates are based on the total of reported and counted boats multiplied by the percentage of power boats using diesel fuel from Table 7.	e total of repor	rted and counte	d boats multipli	ed by the perce	entage of power t	boats using diesel	fuel from Table 7.			
	These data are the reported fuel sales in each region from the marina survey and follow-up interviews This rate of enough is simply the reported historical sales trend in diesel engines reported by NMMA.	I sales in each	region from the orical sales tren	marina survey	and follow-up ines reported by	interviews with n y NMMA. See pa	each region from the marina survey and follow-up interviews with non-responding marinas dhistorical sales trend in diesel engines reported by NMMA. See para. 5f.)	arinas			
	Estimated fuel sales are 2002 fuel sold by marinas using the regional sales trend per year summed with the 2002 commercial operator. (No growth in commercial fuel sales assumed)	uel sold by ma	rinas using the ı	regional sales tr	end per year su	ımmed with the 2	2002 commercial	operator. (No growtl	in commercial fu	iel sales assume	(p

	WEST MICHIGAN TRI-PLE		IESEL FU	TEL MARI	CET STUI	OY- AVAIL	ABLE REC	K DIESEL FUEL MARKET STUDY- AVAILABLE RECREATIONAL MARKET FOR BIODIESEL	MARKET	FOR BIOD	IESEL
	100									3	1
Region	Region name	Percent of Boaters Willing to Buy at Parity (K)	Percent of Boaters Willing to Buy - 10% Cent Premium (L)	Percent of Boaters Willing to Buy - 30% Cent Premium (M)	Recreational Diesel Fuel Used, Gallons - 2002 (N)	Estimated Recreational Fuel Sales, Gallons - 2003 (P)	Estimated Biodiesel Recreational Market at Parity, Gallons - 2004 (R)	Estimated Biodiesel Recreational Market at average premium (\$0.34) Gallons - 2004 (S)	Estimated Biodiesel Recreational Market at 10% Premium, Gallons - 2004 (T)	Estimated Biodiesel 10% Premium, Gallons - 2005 (T)	Estimated Biodiesel Recreational Marketat at 10% Premium, Gallons - 2006 (T)
	1000	%8 88	%9 99	22.2%			19,961	14,479	14,970	15,494	16,037
_	Wnitenali	0/0*00	20000		10103	60 155					
2	Muskegon	100.0%	100.0%	%0.0	171'96	CCTion	37,677	12,134	37,677	38,996	40,361
4	Holland	100.0%	42.1%	26.3%	101,982	105,551	109,246	79,936	44,437	45,992	47,602
3	Grand Haven	100.0%	100.0%	%0.0			32,085	23,250	32,085	33,208	34,370
					52,862	54,712					
5	Saugatuck	75.0%	62.5%	22.2%			16,970	9,937	14,142	14,637	15,149
	Total Tri-plex	92.7%	56.1%	22.0%	212,965	220,419	215,939	139,736	143,312	148,328	153,519
3	These data are based on willingness to buy biodiesel at cost equal to the petrodiesel price at the boaters normal fuel dock	ress to buy bit	odiesel at cost e	equal to the petr	odiesel price at	the boaters non	mal fuel dock				
	These data are based on willingness to use biodiesel at 10% over petrodiesel at new fuel dock (not home marina)	ress to use bio	diesel at 10%	over petrodiesel	at new fuel do	ck (not home m	arina)				
	These data are based on willingness to use biodiesel at 30% over petrodiesel at new fuel dock (not home marina) adjusted for the total number of boaters.	ress to use bio	diesel at 30%	over petrodiesel	at new fuel do	ck (not home m	arina) adjusted for	the total number of bo	oaters.		
	These data are the reported fuel sold by marinas	sold by marin	as								
	These estimates are made by increasing the 2002 reported fuel sold by marinas by the historical growth (3.5%/year) in diesel engines	reasing the 20	302 reported fu	el sold by marin	as by the histor	rical growth (3.	5%/year) in diese.	engines			
	These estimates are the estimated 2003 fuel sales adjusted by the historical growth in diesel engines and the percentage willing to buy at 10% premium over petrodresel	d 2003 fuel sa	ales adjusted by	y the historical g	rowth in diesel	l engines and the	e percentage willin	ig to buy at 10% prem	ium over petrod	iesei	
	These data are the estimated 2003 fuel sales adjusted by the historical growth in diesel engines and the percentage of boaters (35.4%) willing to buy biodiesel at a price that	03 fuel sales a	djusted by the	historical growt	h in diesel engi	ines and the per	centage of boaters	(35.4%) willing to buy	, biodiesel at a pi	rice that	
	was justifable and comfortable to them (a \$0.345/gallon average premium for the Tri-Plex)	o them (a \$0.	345/gallon aver	rage premium fo	or the Tri-Plex)						
6	These data are the estimated 2003 fitel sales adjusted by the historical growth in diesel engines and the percentage of boaters willing to buy biodiesel at pariety	33 fuel sales a	diusted by the	historical growt	h in diesel engi	ines and the per	centage of boaters	willing to buy biodies	el at pariety		

	WEST MICHIGAN TRI-PLEA DIESEL FUEL MANNET STODI-EN EXCELLENCE	V TRI-PL	EA DIES	EL FUEL I	MAKKET						
Region	Region name	Diesel Engine Trend % per Year (NMMA), 1997 -2002 (D)	Health Related Complaints - 2002	Reported User Spills, Gallons - 2002 (U)	Distributor Reported Spills, Gallons - 2002	Marinas Reported Spills, Gallons - 2002	Reported Spills Impacting Water Quality, Gallons -	Estimated Spills Other Areas, Gallons	Estimated Spills Impacting Water Quality, Gallons - 2003 (W)	Estimated Spills Impacting Water Quality, Gallons - 2004 (W)	Estimated Spills Impacting Water Quality, Gallons - 2005 (W)
1 W	Whitehall	3.5%	33.3%	0.3	NA	7	7	NA	NA	NA	NA
2 N	Muskegon	3.5%	%0.0	0.0	NA	0	0	NA	NA	NA	NA
3 G	Grand Haven	3.5%	25.0%	0.1	NA	0	0	NA	NA	NA	NA
4 H	Holland	3.5%	15.0%	4.5	NA	20	25	NA	NA	NA	NA
5 8	Saugatuck	3.5%	18.2%	0.1	NA	0	0	NA	NA	NA	NA
	Total Tri-plex	3.5%	11.4%	4.9	NA	27	32	NA	NA	NA	NA
9 8	This estimate is based on non-reported, No estimate was possible from the limit		incidental spills with ted data received the very limited data r	incidental spills with an average spilled volume of .25 pints adjuted data received the received the marina and user surveys.	ed volume of .2	5 pints adjuste	incidental spills with an average spilled volume of .25 pints adjusted to the total population of boats. ed data received the received the marina and user surveys. Total spills are believed to be higher	ition of boats.			

						1000		EA DIESEL FUEL MANAGE STORY			5
Region	Region name	saniraM to radmuM	ni esand latoT 2002 - eanivaM	Percentage Sail in Marinas	ot gnilliW saniraM sranima& teoH	Percent of Marinas  Willing to Host  Seminar	Boaters Interested in Seminars	Number Willing to Travel to Local Seminar	Teninal Seminar Attendance	Actual Seminar Attendance - August 2003	Percentage of Boaters Interested Actually Attending
	Whitehall	12	636	38.7%	1	8.3%	12	8	20	4	20.0%
	Muskegon	14	1396	42.7%	2	14.3%	4	2	9	Not Held	NA
3	Grand Haven	15	1752	8.1%	2	13.3%	10	9	16	Not Held	NA
	Holland	9	1070	55.5%	2	33.3%	23	18	41	9	14.6%
2	Saugatuck	7	576	16.0%	4	57.1%	13	8	21	0	%0.0
	Total Trinlay	24	5430	30.9%	11	%9.6	62	42	104	10	%9.6

						EX DIESEL FUEL MAKAET STODI-EDOCATION					
Region	Region name	SaniraM to radmu/	ni stao Blato T 2002 - sanitaM	ni liag egancereq ReniraM	Marinas Willing to sranimas teoH	Percent of Marinas willing to Host Seminar	Boaters Interested in Seminars	Number Willing to Travel to Local Seminar	Potential Seminar	Actual Seminar Attendance - August 2003	Percentage of Boaters  Yercentage of Boaters  Yercentage of Boaters
	Whitehall	12	636	38.7%	1	8.3%	12	8	20	4	20.0%
7	Muskegon	14	1396	42.7%	2	14.3%	4	2	9	Not Held	NA
3	Grand Haven	15	1752	8.1%	2	13.3%	10	9	16	Not Held	NA
4	Holland	9	1070	55.5%	2	33.3%	23	18	41	9	14.6%
5	Saugatuck	7	576	16.0%	4	57.1%	13	8	21	0	%0.0
	Total Tri-nlay	24	5430	30.9%	11	%9.6	62	42	104	10	%9.6

# **APPENDIX C**

## **COMMERCIAL OPERATOR SUMMARY BY REGION**

Aware of Legislat'n	5.6%	Percent Yes	Y or N Spec No.		tion 8		NA NA								NR NR										sal mo				
Heard of Biodiesel	5.6%	Percent Yes	YorN		7 noit	Ques	Y								NR					-				-	Total Yes				
Average Spill	0	Gallons	Number		9 uoi	Quest	0								NR				7										
Spills in last two years	%0.0	Percent Yes	Nach		è noi	Quest	z								N.									0	Total Yes				
CARB or Low Sulfur	2.6%	Percent Yes	,	TOFN	£ aoi	Quest	Y								NA.	VIII.	000		- B. Chr.					-	Total Yes				
Meet a Standard	%0.0	Percent		Percent	Z uo	Questi	NA								MD	INIV								0	Total Yes				
Sales Increase per year	#DIV/01	Percent Year on Year		Number		Sales Trend	#DIV/0!	#DIA/0i	#DIA/0i	#DIA/0i	#DIA/0i	#DIV/0!	#DIV/O!	#DIV/OI	#DIANO:	#DIV/0!	#DIV/MI	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	١					
Total Fuel sold in 2002	0	Gallons		Number		2002 Region 5	0	0	0	0	0	0	0 0	0	0	0 0	0	0	0	0	0	0	0						
Total Fuel sold in 2002	0	Gallons		Number	Question 1	2002 Region				188								0							_				
Total Fuel sold in 20002	0	Gallons		Number	Ques	2002 Region 3	0		0	0	0							0							ODE No.s	Co to Marinas and	Timas and	St Tor new an	
Total Fuel sold in 2002	0	Gallons		Number		2002 Region	0		0	0	0	0	0	0	0	0	0	0 0		0	0	0	0		Next ID COD	Cato Me	U0 10 IVI	distributors list for new in-	
Total Fuel Total Fuel sold in 2002	0	Gallons		Number		2002 Region 1	,	0		0	0	0	0	0	0	0	0	0 0		0	0	0	0						
	18	Number of Respondents		Entered Data		Distributor																		40	01	Total Respondents	distributors who do not	responses are thrown	out due to questions.
DISTRIBUTION SEGMENT SUMMARY	2	No of Surveys Distributed				а		D-1	D-2	200	2	D-6	D-7	D-8	D-9	D-10	D-11	D-12	D-13	D-14	710	D-17	D-18						

# APPENDIX D

## MARINA SUMMARY BY REGION

Name	tsesol leseld qmuc syud leseld mor∃	1		NA NA		NA Fleming	NA NA	0		20000 200000 2000000		%	12	
1 for Yes	17 17	Gr		-		-	-	-			4	% 100.0%	t Percent	
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1 Ofor No for Yes	estion	gn				-	-	0			-			
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ge Number	tion	-	-		-	0	30	0	45	0	0	23	15.1%	ot % of tot
Percentage	tion		-		%0	%8	%8	14%	70%	%0	1%	92	82	s's % of tot
Number	noti	sən	-		6	25	26	-	400	13	46	als 576	492	respons's
Entered Data		User surveys	distributed	ugatuck	0		31	0	280			Segment Totals	1	
		=	<b>a</b>	Region 5 - Saugatuck	M-29	M-30	M-54	M-55	M-56	6.5	Y-7	Responses	Surveys Dist	

Name Name	Closest Diesel Buys Diesel From					M-3		00000	M-44 NA	M-4 NA	NA	******	2000	99000	80000		50650			
5 ½	41		***			393635			****	****	25535				****				%	in the
1 Ofor No	Question																	4,	100.0%	Percent
O for No for Yes	Question 16					0			-	0	-				0			2	40.0%	Percent
O for No for Yes	nottseuD år					0			0	0	0				0			0		
O for No 1 for Yes	noiteeuD 14					0			0	0	0				0			0		
Number	Question 13					0			0	0	0				0			-		
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Number	noiteau	O		0	0	0	3	0	0	2	7	0	0	0	0	12	0	-	37	2.4%
Percentage	nestion	IF		7%	%0	1%	1%	%0	%0	20%	%0	%0	%0	3%	%0	7%	100%	7%	139	783 83
Number	nestion	סי		28	480	89	70	20	90	151	22	190	∞	34	8	350	20	45	1713	
Entered Data	User surveys	distributed	nd Haven	Service Barrier			34			147	25	144				154			Segment Totals	504
		e	Region 3 - Grand Haven	M-2	M-3	M-4	M-45	M-46	9-W	Y-1	Y-2	M-31	M-33	M-35	M-42	M-44	¥-8	65)	Responses	Surveys Dist

Mumbor	Derrentade	Number	0 for No	Number	Number	Number	Dollars	0 for No	O for No 1	Number	O for No 1 for Yes	for No 1	Ofor No 1 for Yes	O for No 1 for Yes	Name	Name
_	Boulland		1 for Yes						1			u	u		1	1
	nestion	notizeu 5	nestion	notizeu 8	T	noiteaus 8	noltseu£	11 2nestlon	notseu£	Questlor 13	Question	Questio:	Questio 16	Questio	Closes Diesel	Buys Diese
-	O	0	0	0	0	5	,	,				THE REAL PROPERTY.				
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	20%	0	0					0								
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	20%	0	0					NA C	-	0	6	0	-	-	M-12	D-9
	40%	36	-		1	1	0000000		-	3						****
	%001	0	0					W.	<	00	-	-	7	7		
1070	593	11	7			THE	47.4						100 00%	100.0%		
916	223	14.9%	100.0%				31.000						Percent	Percent		
-	respons's % of tot  f tot	f tot pwr b	Percent				NG NG									

					Name	skr wo.	DI		NA	NA				NA			NA		2000				
					Name	fess fess qm	DI		M41	M-36				M-40			M-36						
Permit user survey	85.0%		Percent	allowing user survey	0 for No 1 for Yes	T	ant		-	-				-			0				3	75.0%	Percent
Host a Seminar	55.0%		Darrent	willing to host Seminar	1 0 for No 1 for Yes	note		,	-	0				0			0				-	25.0%	Percent
Aware of Pending Legislat'n	5.0%		Darrant	aware of pending legislat'n	0 for No 1 for Yes	nolli	t sent	,	0	0				0			0						
Heard of Biodiesel	25.0%		1	Percent aware of Biodiesel	0 for No 1 for Yes	ton	ı. sən	0	,		,			0			0						
Estimated Annual Spilled Diesel	7.7		1	Avg. Gallons spilled per year	Number	not	: l seni	0	,	, ,	7			0	,			,					
Spilled Diesel	-		1	Number of Spills	0 for No 1 for Yes	tion	sen:	0															
Diesel work Boats	2			Diesel work Boats	0 for No 1 for Yes	uop	sen	0	·	0	0	0	0	NK	0		0		9	0		THE REAL PROPERTY.	
Price in 2002	51.631			Avg \$ per Gallon	Dollars	noi	6 sen	O							200000000000000000000000000000000000000							200	\$1.690
Fuel Sold Fuel Sold Fuel Sold in 2000	212965			Gallons	Number	uoj	8 ser	סו															
Fuel Sold in 2001	GIETR	2000		Gallons	Number	uoj	T T	מו							22222								
Fuel Sold in 2000	70005	2000		Gallons	Number	uoj	iest 8	סו															
Marinas selling Diesel	40.00	13.078		Marinas Selling Diesel	0 for No	uo	tee:	מי		0	0	-	0	0	0	0	0	0	-	0	0	2	16.7%
Non-Sail Diesel engines	907	130	5.3%	Number	Number	uo	itae 5	מח		9	4	0	0	0	0	0	0	4	0	0	0	14	3.6%
Sail in Marina		1666	30.9%	Number	Percentage	uo	llse S	gn		7%	20%	43%	30%	%19	%0	%0	16%	%09	35%	36%	52%	246	390 142 3.
No. Boats in Marinas		5391	2568	Number	Number	uo	İtse	gn		160	46	96	20	42	4	12	91	180	20	=	29	\$ 636	
MARINA SEGMENT TOTALS by Marina and Region		20	62	Number of Respondants	Entered Data		Tlear curveus	distributed	itehall	75	36				0							Segment Totals	111
MARINA TO' by Marina		25	1385	No of Surveys Distributed				a	Region 1 - Whitehall	M-13	M-14	M-36	M-38	M-39	M-49	M-50	M-51	M-40	M-41	C-8	Y-13	Responses	Surveys Dist

	T		ID CODE	Number	Number	Number	1-24	YorN	Number	Number	Number
	Q	MISC HAND COUNTED BOATS	Region ID	Total number of boats	Total Number of Sailboats	Esttimated number of diesel Engines	Esttimated number of diesel Engines	Marine Deisel Pump	Diesel work boats	Fuel Sold/Used - 2002	Fuel Price - 2002
CINI	erion	2 Muskegon									
N	1-17	Bluffton Bay Marina	2	80	16			0	0		
N	1-24	Pointe Marine	2	116	32			0	0		
N	1-26	Torresen Marine Inc.	2	140	112			0	0		
١	143	Buds North Shore Marina	2	29	2			0	Q		
		Anchor Marina	2	22	2			0	0		
		Great Lakes Marina & Storage	2	400	120	102	0	1	3		
		Harbour Town Marina	2	200	95	81	0	1	0	100	
N	1-21	Hartshorn Marina	2	152	98	83	0	0	0		
I	<b>1-22</b>	Lakeshore Yacht Harbour, Inc	2	35	16	\$4	0	0	0		
		Terrace Point Marina	2	35	18	15	Q	0	0		
I	-	Anderson Marina	2	12	0	0	0	0	0	+110	
-	-	North Pier Condo		13	2			25.57			
-	_	Muskegon Yacht Club	2	70	65	55	0	0	0		T TO
1		Muskegon Conservation Club	2	86	17	14	0	0	0		
1		Balcom Cove		6	1			0	0	91	
-				No. AL				7 7 9			
1		Totals of non-reponding marinas	only	1009	432	368	0	2	3	36,403	1.589
		Salah Marine Beak ABelow									
NI VA	1	Fishermans Landing	2	12	5						
	2		2	13	0						
1	3		2	7	2						
1	4		2	10	1						
1	5		2	20	1						
1	6		2	2	0						
1	7		2	70	69						
+	8		2	17	1						
	9	A Section of the second	2	3	1						
1	10	The Market Marke			S. Andr						
)			2	154	80	68	0				

			ID CODE	Number	Number	Number		YorN	Number	Number	Number
	QI	MISC HAND COUNTED BOATS	Region ID	Total number of boats	Total Number of Sailboats	Esttimated number of diesel Engines	Esttimated number of diesel Engines	Marine Delsel Pump	Diesel work boats	Fuel Sold/Used - 2002	Fuel Price - 2002
	Region Wastell	3 - Grand Haven River Haven Million		<b>111170111</b>				0	0		
ŀ	M-#3 Y-1	Grand Haven Yacht Club	3	151	76			0	0		
ŀ		Rivers Edge Yacht Club	3	22	0			0	0		
		Keenan Marina	3	190	0			0	0		
	M-44	North Share Yacht Club	3	350	7				Ō.		
Ì		Grand Haven Municipal Marina	3	28	2	2	Q			77.04	
		Grand Isle Marina	3	480	1		0				
		Grand Valley Marina II	3	68	1		0				-
Ļ		Dicks Landing	3	50	0	0	0	-	-		
1	M-6	Wharf Marina Inc.	3	90	0	0	0	0	0		-
0	14 22	Daradias Cava Marina Inc	3	8	0	0	0			-	+
1	M-33	Paradise Cove Marina Inc.	Belle 1010 (010) (010)		0	U.	V				
	M.35	Village Cove Marina	3	34	1		0		-	10	
- Gunnodent-not	M-42	Barrett Boats Works	3	80	0	0	0	0	0		-
	Y-8	Spring Lake Yacht Club	3	50	50	43	0		N. T.		
	C-9	Holidy Inn Marina	3	42	1		0	No	0		
		Rycenga Marina		38	0	0	0	No	0		
		River Boat		1	0	0				0	
	400	Totals of non-reponding marinas		969	56	48	0	0	0	0	0
		Non-marma Boots-Below				000000000	H 1000000000	00000000	4000000 K 0000000	K 00000000	
	1	Petty's Bayou	3		4						
	2	Condo at Barrets	3	30	0						
	3	7	3	8	0						
	4		3	12	2						
-	6		3 3	21	2						
	7		3	7	0						
	8		3	17	0						
	9		3	24	0						
	10		3	-	0						
Ī	11		3	16	0						
Ī	12		3	36	0						
	13		3	5	0						
	14	e la company de	3	41	1						
	15		3	12	1						
	16		3	28	0						
	17		3	20	0						
	18		3	22	1						
	19		3	25 13	0						
	20	Com for Contract also also	3		13						
	21	Sum for Spring Lake alone	3	417	13						
	22		3								
	23		3								
	24		3								
	25		3	5	1						
	27			14	0						
ł	28		3		-						
-	0 28		100000000000000000000000000000000000000	436	14	12	0				
				100			-	100000000000000000000000000000000000000	- Control of the Cont		-
_'		STATE OF THE STATE	3	1				. V.			

8			ID CODE	Number	Number	Number		YorN	Number	Number	Number
	QI	MISC HAND COUNTED BOATS	Region ID	Total number of boats	Total Number of Sailboats	Esttimated number of diesel Engines	Esttimated number of diesel Engines	Marine Deisel Pump	Diesel work boats	Fuel Sold/Used - 2002	Fuel Price - 2002
de Sala	Region	24: (Folkum)									
		Anchorage Marina	4	187	93				0		
		Yacht Basin Marina	4	329	132				0		
T		Cresent Shores Marina	4	120	60	51	0	0	0		
Ì		Eldeans Shipyard	4	280	196	167	0	1	0		
1		Parkside Marina	4	80	40	34	0	0	NA_		
our respondent most								144			
1											
	JULY 1								100		
1	Y-4	Macatawa Bay Yacht Club	4	74	74	63	0	0	NA	Loukin	
1		Company and the same	4								
1			4		1-1500						
		Totals of non-reponding marinas		554	370	315	0	1	0	58737	0
17777		Non-marina Boars - Below				5					
25	1			14	9						
	2	tion to the control of the control o	4	10	10						
	3		4	14	3						
	4	Property and a second	4	33	6						
Ì	5		4	5	5						
-	6	7.3	4	18	13						
-	7	100000000000000000000000000000000000000	4	8	0						
_	8		4	10	0						
	9		4	15	3						
	10		4	58	4						
-	11	(C) 100 C) (C)	4	27	4						
	12		4	36	7						
	13		4	12	1						
	14	7.5	4	12							
-	15		4								
	13		800000000000000000000000000000000000000	260	65	55	0				
<u>_</u>		II and the second secon	II.	200	VU	00		1000000000		element de la constant	
0			4		A SHEET WAY	C JOSEPH	The state of	NO PERSONAL PROPERTY.	1796		

****			ID CODE	Number	Number	Number		YorN	Number	Number	Number	
	QI	MISC HAND COUNTED BOATS	Region ID	Total number of boats	Total Number of Sallboats	Esttimated number of diesel Engines	Esttimated number of dlesel Engines	Marine Deisel Pump	Diesel work boats	Fuel Sold/Used - 2002	Fuel Price - 2002	
		n 5 - Saugatuck										
	M-56	Tower Marina	5	400	80				0			
		Point Pleasant Marine	5	9	0			0	0			
	M-\$4	Saugatuck Yacht Services	5	76	6			1	0			1
	M-55	Landings at Saugatuck	- 5	7				0	0			
	M-30	Sergeant Marina	5	25	2	2	0					
			5									
	Y-7	Singapore Yacht Club	3	46	3	3	0				-	
L	C-9	Condo next to Sergeant Marina	5	13	0	0					-	
L			5						_		-	
	A	Totals of non-reponding marinas		84	5	4	0	0	0	0	0	
		Non-marina Boats Below	the state of the last of the last			100000000000	0000000000	100000000			el Production	
L	1		5	11	0							
L	2		5	5	0							
L	3		5	21	0							
L	4		- 5	5	0							
L	5		5	12	1							
L	6		5	5	0							
L	7		5	5	0							
L	8	-	5	12	2							
L	9		5	8	1							
L	10		5	15	1							
L	11		5	18	7							
L	12		5	9	0							
1	13		5	22	1							
1	14		5	9	1	100000000000000000000000000000000000000						
1	15		5	22	2							
-	16		5	4	0							
-	17		5	16	0							1
1	18		5	5	0							
1	19		\$	204	1/	14	^					
0	4-	-		204	16	14	0			8 28 18 18 18 18 18		
-	-	-	5		-	-	1	+	-	-	_	
L			1									101

# APPENDIX E

## RECREATIONAL BOATER SUMMARY BY REGION

			Percent Diesel in power	No.of Boats	No.of Sailboats	Diesel Engines - Sail	Diesel Engines - non-Sail	Sell Diesel Fuel	Diesel Work Boats	Fuel Sold/Used	Fuel price	Percent Diesel in Sail
	Γ		5.3%	4337	276	235	0		0	0	0	85.2%
		MISC HAND COUNTED BOATS - TOTALS	Percent	Total No of Boats Counted	Total No of Sallboats Counted	Calculated Number	Calculated Number	1 for yes 0 for no	Number	Diesel Fuel Sold Gallons	Price	Percent
				2862		ts in marinas						
				1475	_	ts at private do						
¥	- I		ID CODE	Number	Number	Number	Number	YorN	Number	Number	Number	4
	9	MISC HAND COUNTED BOATS	Region ID	Total number of boats	Total Number of Saliboats	Esttimated number of diesel Engines	Esttlmated number of diesel Engines	Marine Diesel Pump	Diesel work boats	Fuel Sold/Used - 2002	Fuel Price - 2002	
	Region	O-Whitehall							200		SACK TO	
		Elienwood Landing Marine		160				0	0			
	M-14	Montague Marina		46	23			Ö	0			
		Lyons Den Marina		4	0			0	0			
		Whitehall Landing Inc.		180	108			0	0			
		Cross Winds Marine Service		96	41	35	0	1	0			-
ina		South Shore Marina		20	6	5	0	0	0	-	-	1
Non-responding marinas		White Bay Marina & Resort		42	28	24	0	0	NR	+	-	1
18 r		Armstrong Marina		12	0	0	0	0	0	-	-	-
Đ l		Harbor Hill Landling		16	7	3 6	0	1	0	-	-	-
pods	M-41 C-8	Whitehall Municipal Marina Driftwood Dunes Condos		11	4	3	0	0	0	+	+	-11
-re	_	White Lake Yacht Club		29	15	33	0	0	0	1	1	1
S o	1-13	Willie Lake Tacili Ciuo		2)	1 .5			-	1 -		+	1
~												11
		Totals of non-reponding marina	s only	246	104	89	0	2	0	21,718	1.64	
	1	Non-marina Boats - Belov										]
	1			90	4							
	2			49	6							11
	3			27	3							41
	4			14	3							41
_	5			7	7							41
	6			20	8							41
_	7			50	50							
_	9			39 37	3							11
	10			30	6							11
_	11			25	1	1						11
-	12			21	3							11
	13			12	2							11
	14			1	-							11
	15				1							1
0	1			421	101	86	0					
v												

***			ID CODE	Number	Number	Number		YorN	Number	Number	Number	
	Q	MISC HAND COUNTED BOATS	Region ID	Total number of boats	Total Number of Sallboats	Esttimated number of diesel Engines	Esttimated number of diesel Engines	Marine Deisel Pump	Diesel work boats	Fuel Sold/Used - 2002	Fuel Price - 2002	
	Region	2 Muskegon										
	M-17	Bluffton Bay Marina	2	80	16			0	0			
		Pointe Marine	2	116	32			0	0			
		Torresen Marine Inc.	2	140	112			0	0			
	M-43	Buds North Shore Marina	2	29	2			0	0			
		Anchor Marina	2	22	2			0	0			
		Great Lakes Marina & Storage	2	400	120	102	0	1	3			
S		Harbour Town Marina	2	200	95	81	0	1	0			
marinas	M-21	Hartshorn Marina	2	152	98	83	0	0	0			
nar		Lakeshore Yacht Harbour, Inc	2	35	16	14	0	0	0			
		Terrace Point Marina	2	35	18	15	0	0	0			
II DI	M-47	Anderson Marina	2	12	0	0	0	0	0			
por	C-7	North Pier Condo		13	2	2						
res	Y-6	Muskegon Yacht Club	2	70	65	55	0	0	0			
Non-responding		Muskegon Conservation Club	2	86	17	34	0	0	0			
Z		Balcom Cove		6	1			0	0			
		Totals of non-reponding marinas	only	1009	432	368	0	2	3	36,403	1.589	
		Non-marina Bouts - Below										
COAL	1	Fishermans Landing	2	12	5							
	2		2	13	0							
Ī	3		2	7	2							
Ī	4		2	10	1							
	5		2	20	1							
	6		2	2	0							
	7		2	70	69							
	8		2	17	1							
	9		2	3	1							
	10											
0				154	80	68	0					
		1	2	The second second				1				
	1											

	L		ID CODE	Number	Number	Number		YorN	Number	Number	Number
QI		MISC HAND COUNTED BOATS	Region ID	Total number of boats	Total Number of Sailboats	Esttimated number of diesel Engines	Esttimated number of diesel Engines	Marine Delsel Pump	Diesel work boats	Fuel Sold/Used - 2002	Fuel Price - 2002
RG	ion 3	- Grand Haven									1000
M-		ver Haven Marina	3	70	7			0	0		
Y.		and Haven Yacht Club	3	151	76			0	0		
Y		vers Edge Yacht Club	3	22	0			0	0		
		enan Marina	3	190	0			0	0		
-		orth Shore Yacht Club	3	350	7				0		
M	$\overline{}$	rand Haven Municipal Marina	3	28	2	2	0				
M		rand Isle Marina	3	480 68	1		0				
M		rand Valley Marina II	3	50	0	0	0				
M-		icks Landing Tharf Marina Inc.	3	90	0	0	0	0	0		
IVI	-0 M	nari Marina inc.		90	-				-	100	
M- M- M- M- Y	-33 Pa	aradise Cove Marina Inc.	3	8	0	0	0			7	
1	35 1/	illage Cove Marina	3	34	1		0		-		
M	-42 B	arrett Boats Works	3	80	0	0	0	0	0		
V	-8 S	pring Lake Yacht Club	3	50	50	43	0		1		
_	-9 H	folidy Inn Marina	3	42	1		0	No	0		
		ycenga Marina		38	0	0	0	No	0		
	R	liver Boat		1	0	0			200	0	
1	T	otals of non-reponding marinas	only	969	56	48	0	0	0	0	0
		Non-marina Boats - Below				000000000	H 1000000000	00000000		s 000000000	90 100 00 00 00 00 00 00 00 00 00 00 00 0
-	1	Petty's Bayou	3		4						
-	2	Condo at Barrets	3	30	0						
	3		3	8	0						
	4		3	12	2						
_	5		3	21	2						
	7		3	7	0						
+	8		3	17	0						
+	9		3	24	0						
	10		3	9	0						
	11		3	16	0						
	12		3	36	0						
	13		3	5	0						
	14	THE RESERVE OF BUILDING	3	41	1						
	15		3	12	1						
	16		3	28	0						
	17		3	20	0						
-	18		3	22	1						
	19		3	25	1						
	20	Conference to the state of	3	13	0						
	21	Sum for Spring Lake alone	3	417	13						
	22		3								
+	23		3								
-	24		3								
+	26		3	5	1						
	27	Cntd from River Haven Marin		14	0						
+		Cited Holli Kiver Playell Marini		14	-						
+		Property of the second	2					****		****	19191 19191 19191
0	28		3	436	14	12	0				

****			ID CODE	Number	Number	Number		YorN	Number	Number	Number	
	Q	MISC HAND COUNTED BOATS	Region ID	Total number of boats	Total Number of Sailboats	Esttimated number of diesel Engines	Esttimated number of diesel Engines	Marine Deisel Pump	Diesel work boats	Fuel Sold/Used - 2002	Fuel Price - 2002	
	Region	4. Holland			644.461							
	M-7	Anchorage Marina	4	187	93				0			
		Yacht Basin Marina	4	329	132				0			
S		Cresent Shores Marina	4	120	60	51	0	0	0			
ring		Eldeans Shipyard	4	280	196	167	0	1	0			*******
ma	M-11	Parkside Marina	4	80	40	34	0	0	NA			
Non-responding marinas												
ndi												
sbo											-	
-re	Y-4	Macatawa Bay Yacht Club	4	74	74	63	0	0	NA			
5			4						-	-		
_			4	***	200	1	^	-	-	50727		
727500	15.4000 (Chr) (	Totals of non-reponding marinas	sonly	554	370	315	0	1	0	58737	0	
题		Non-marina Boats - Below	the state of the state of the state of	14	9	<b>1</b> 10000000000	10000000000	110000000			100000000	
H	1	-	4	14	10							
H	2		4	14	3							
┝	3		4	33	6							
H	5		4	5	5							
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H	7	<del> </del>	4	8	0							
H	8		4	10	0							
H	9		4	15	3							
H	10		4	58	4							
1	11		4	27	4							
T	12		4	36	7							
	13		4	12	1							
	14		4									
r	15		4		1							
0	_			260	65	55	0					
-			4									
	T					-						

*		ID CODE	Number	Number	Number		YorN	Number	Number	Number	
QI	MISC HAND COUNTED BOATS	Region ID	Total number of boats	Total Number of Sallboats	Esttimated number of diesel Engines	Esttimated number of diesel Engines	Marine Deisel Pump	Diesel work boats	Fuel Sold/Used - 2002	Fuel Price - 2002	
	n 5-Sangatnek 🦸										
	Tower Marina	5	400	80				0			
	Point Pleasant Marine	5	9	0			0	0			
	Saugatuck Yacht Services	5	76	6				0			
M-55	Landings at Saugatuck	5.	7				0	0			
M-30	Sergeant Marina	- 5	25	2	2	0					
		5									
Y-7	Singapore Yacht Club	5	46	3	3	0				-	
C-9	Condo next to Sergeant Marina	5	13	0	0						
		5									
	Totals of non-reponding marinas	only	84	5	4	0	0	0	0	0	
	Non-marina Boats - Below										
1		5	11	0							
2		5	5	0							
3		5	21	0							
4		5	5	0							
5		- 5	12	1							
6		5	5	0							
7		5	5	0							
8		5	12	2							
9		5	8	1							
10		5	15	1							
11		5	18	7							
12		5	9	0							
13		5	22	1							
14		5	9	1							
15		5	22	2							
16		5	4	0							
17		5	16	0							
18		5	5	0							
19		5									
0			204	16	14	0					
		5									

# APPENDIX F

# DISTRIBUTERS SURVEY QUESTIONAIRE

#### **DIESEL FUEL SURVEY - DISTRIBUTORS**

Annis Water Resources Institute of Grand Valley State University

Please return to Annis Water Resources Institute in the enclosed Envelope March 3, 2003

Form D-17

The following survey questions apply to marine or dyed diesel fuel shipments to retailers and resellers of diesel fuel in the Western Michigan Tri-Plex, a triangular area bounded by Saugatuck/Douglas on the South, Whitehall/Montague on the North, and Grand Rapids on the East. This area includes: the Kalamazoo River, Lake Macatawa, the Grand River, Spring Lake, Muskegon Lake, White Lake and near contiguous areas.

1 How much marine diesel fuel have you shipped into

1	How much marine diesel fuel have you shipped into following areas?	200	01	2002	
	White Lake/Montague				Please enter total Gallons per year
	Muskegon Lake				Please enter total Gallons per year
	Grand Haven/Spring Lake/Ferrysburg				Please enter total Gallons per year
	Lake Macatawa				Please enter total Gallons per year
	Saugatuck/Douglas		145	B. C.	Please enter total Gallons per year
2	Does your marine diesel meet an ASTM or other standard?				Please enter the standard No.
3	Do sell you CARB or low Sulfur diesel?	Yes	No	Circle one	
4	Who do you buy your Marine Diesel from?				
5	Have you had any reportable spills of marine diesel fuel in the last years? (This response will be held in closest confidence)	two Yes	No	Circle one	
6	What was the approximate size of the spills?			Please enter the	number of Gallons per
7	Have you heard of diesel fuel made from Soy oil?	Yes	No	Circle one	
8	Are you aware of any pending legislation that would require the u diesel fuel made from soy oil as an additive to petroleum based difuel?		No	Circle one	
9	Comments				

# APPENDIX G

# COMMERCIAL OPERATORS SURVEY QUESTONAIRE

# **DIESEL FUEL SURVEY - Commercial Operators**

				P-1
Ple	ase return to Annis Water Resources Institute in the enclosed  Envelope by	anuary 10	0, 2003	
1	How many diesel powered vessels are operated by your business?		Prig	Please enter a number
2	Do you have a diesel fuel storage tank and pump?	Yes	No	Circle one
3	Do you sell diesel fuel from your facilities?	Yes	No	Circle one
4	If you do not have a diesel fuel storage tank and pump, where do you buy diesel fuel?		1	
5	How much total diesel fuel did your diesel powered vessels use in 2002 ?			Please enter total gallons used in 2002
6	If you sell diesel fuel, how much did you sell in 2002?			Please enter total gallons sold in 2001
7	Who do you buy your diesel fuel from?			
8	Have you had any spills of diesel fuel in the last two years? (reported or incidental spills)	Yes	No	Circle one
9	What estimated volume of diesel fuel is spilled per year in your facility? (reported and incidental spills)			Please enter the nmber of gallons per year
10	Have you heard of diesel fuel made from Soy oil or biodiesel?	Yes	No	Circle one
11	Are you aware of any pending legislation that would require the use of biodiesel as an additive to petroleum based diesel fuel?	Yes	No	Circle one

# APPENDIX H

# MARINA SURVEY QUESTIONAIRE

#### **DIESEL FUEL SURVEY - MARINAS** Annis Water Resources Institute of Grand Valley State University Form Y-11 Please return to Annis Water Resources Institute in the enclosed Envelope by May 2, 2003 Please Enter the number 1 How many boats were in slips/moored in your marina in 2002? of boats 2 What percentage of the boats in your marina last season were sailboats Please Enter a percentage Please enter a number 3 Did any power boats in your marina have inboard diesel engines? Circle one Yes No 4 Do you sell diesel fuel in your marina? 5 If you do not sell diesel fuel, where is the closest fuel dock that carries diesel fuel? (If you do not sell diesel fuel you may skip questions 6 thru 10 BUT PLEASE COMPLETE AND RETURN THE SURVEY TO US) Please enter total gallons 6 How much diesel fuel did you sell in 2002? sold in 2002 Please enter total gallons 7 How much diesel fuel did you sell in 2001? sold in 2001 Please enter total gallons 8 How much diesel fuel did you sell in 2000? sold in 2000 Please enter dollars per 9 What average price did you charge for diesel fuel in 2002? gallon 10 Who do you buy your diesel fuel from? Circle one 11 Does your marina own/operate any diesel powered workboats? Yes No Circle one Yes No 12 Have you had any spills of diesel fuel in the last two years? 13 What estimated volume of diesel fuel is spilled per year in your Please enter the nmber of marina? (reported and incidental spills) gallons per year 14 Have you heard of diesel fuel made from Soy oil or biodiesel? Yes No Circle one 15 Are you aware of any pending legislation that would require the use of diesel fuel made from soy oil as an additive to petroleum based diesel Circle one Yes No fuel? 16 Would you host a biodiesel seminar for the boaters in your marina if Yes No Circle one one were made available to you? 17 Would you permit Annis Water Resources Institute of Grand Valley State University to distribute a questionnaire to the slip holders in your Yes No Circle one marina and place a box in your office to collect responses during a portion of the 2003 season?

# APPENDIX I

# **BOAT SURVEY QUESTIONAIRE**

# **DIESEL FUEL SURVEY - BOATERS** Annis Water Resources Institute of Grand Valley State University Form M-56 Please place completed survey form in the collection box in the marina office by July 1, 2003 Yes No Circle one 1 Is your boat a sail boat? Is your boat powered by a diesel engine? (If your answer to this question is NO, you may skip questions 3 thru 16 -your response is Yes No Circle one still valuable to GVSU) Please enter a 3 Where do you normally buy your diesel fuel? marina/dealer name Please enter number 4 How much diesel fuel do you use in a typical season? of gallons Please enter dollars 5 What average price did you pay for diesel fuel in 2002? per gallon Please enter dollars 6 What average price did you pay for diesel fuel in 2001? per gallon Yes No Circle one 7 Does your marina own/operate any diesel powered workboats? Don't know 8 If there were there any spills of diesel fuel from your boat in the last Please enter a two years, how many? (Not major EPA spills but those overflows or number mishaps at the fuel dock while fueling, etc.) How many times a season do you clean black discoloration from the Please enter a number transom of your boat? 10 Do you have complaints or health issues related to the odor of the Circle one Yes No exhaust from your diesel engine? Circle one 11 Have you heard of diesel fuel made from Soy oil or biodiesel? Yes No Page 1

#### **DIESEL FUEL SURVEY - BOATERS**

#### Annis Water Resources Institute of Grand Valley State University

Form M-56

Please place completed survey form in the collection box in the marina office by July 1, 2003

Biodiesel is a renewable fuel that can be made from domestically grown vegetable oils - Soy, Corn, Sunflower, Safflower, pumpkin, coconut, and many other oil seeds. Over 20 million gallons of biodiesel are produced annually within the United States. Biodiesel has been used in diesel engines in numerous applications across the U.S for up to ten years. The use of biodiesel reduces air pollution, reduces our dependency on foreign oil, and creates jobs in agriculture and manufacturing in west Michigan and the U.S. Biodiesel burns cleaner than petroleum diesel. It will not leave black exhaust deposits on surfaces near the exhaust pipe and does not have an offensive odor. Many states are considering (Michigan being one), or have legislated, that all diesel fuel sold in the state contain biodiesel as an additive. However, research has determined that diesel engines operate as well on 100 % biodiesel as when operated on petroleum diesel and without increased maintenance costs. Currently, the distribution and manufacturing system is not in place to make biodiesel price competitive with petroleum diesel.

12	If both biodiesel and petroleum diesel (petrodiesel) were available at your normal fuel dock at the same cost which would you buy?	Biodi	esel	Petrodiesel
13	Would you pay more for biodiesel than petroleum diesel if both were available at your normal fuel dock?	Yes	No	Circle one
14	If your answer to question 13 was yes, how much more would you be willing to pay for biodiesel over petroleum diesel if both were available at your normal fuel dock?			Please enter a dollar value
15	Would you go to another marina to buy biodiesel if it were 16 cents a gallon more and not available at your normal fuel dock?	Yes	No	Circle one
16	Would you go to another marina to buy biodiesel if it were 48 cents a gallon more and not available at your normal fuel dock?	Yes	No	Circle one
17	Would you attend a free biodiesel seminar if one were made available to you in your marina?	Yes	No	Circle one
18	Would you attend a free biodiesel seminar if it were held in another marina within 4 miles of your marina?	Yes	No	Circle one
19	Comments			

# APPENDIX J

#### **DISTRIBUTORS**

				DISTRIBUTORS	TORS			
	1	8	Dietributor	Street	Street	Zip	Phone	Contact
Mailing	Kesponse	a	DISHTIDATOL		71. 10	YUYUY	10404 (515) 827-6523	
22-Nov-02	2-Dec-02	D-1	Alt Oil Co.	1374 W. Randall St	Coopersville, MI	43404	CC00-100 (010)	
Now 00		D-2	I emmen Oil Co.	13 Randall Rd.	Coopersville, MI	49404	49404 (231/616?) 865-67340	
70-A0NI-77		73	Tri City Oil Co	523 Pine St.	Ferrysburg, MI	49409	49409 (616) 842-8650	
70-A0N-77		3 2	Busch Oil Co	812 W. Main	Fremont, MI	49412	49412 (231) 924-4900	
70-A0N-77		5	Owietal Flach	1754 Alnine Ave.	Grand Rapids, MI	49504	49504 (616) 393-4851	
70-A0N-77		3 2	Voca Oil Co	4875 Starr St. S.E.	Grand Rapids, MI	49546	49546 (800) 356-3560	
77-Nov-02		3	Wasse Inc	196.S. Division	Hesperia, MI	49421	49421 (877) 469-3726	
22-Nov-02		1 2	Wescu IIIc.	715 I incoln Ave	Holland, MI	49423	49423 (616) 392-2333	
22-Nov-02		2-1	Boeve Ou CO.	nd Blad	Holland MI	49424	49424 (800) 545-0706	
22-Nov-02		D-9	Merle Boes Inc.	מתי הזונה	D. 11.	70707	7676 022 (212)	7
-Nov-02	22-Nov-02 26-Nov-02	D-10	Boschman Oil Co.	3822 Chicago Dr.	Hudsonville, MI	49470	49470 (010) 009-2030	
Now 00	-	11-4	Famers Co-on Service Station	3300 Prospect St.	Hudsonville, MI	49426	49426 (616) 669-6379	
70-A0NI-77		21.0	Dlamey Cartle Oil Co	2685 Holton Rd.	Muskegon Mi.	49445	49445 (231) 744-1601	
77-N0V-02		21-12	Diamely Cashe on Co.	1931 Holton Rd	Muskegon Mi.	49445	49445 (231) 744-1957	
22-Nov-02		CI-CI	Diemier On Co.	1752 Madison St	Muskegon Mi	49442	49442 (800) 968-6457	
22-Nov-02		D-14	Spartan Oil Corp.	TO TO INTERNATION OF THE PARTY	Po-motore M	40400		
06-Dec-02		D-15	Shell Products US	17806 North Shore Dr.	Ferrysourg, MI	49407		
06-Dec-02		D-16	Mobile/Citgo Terminal	524 Third St.	Ferrysburg, MI	49409		
20 -71 30		D-17	Van Manen Petroleum Group, Finel Management Systems, Inc.	305 Lake Michigan Drive	Grand Rapids, MI 49544	49544	(616) 453-6344	

# APPENDIX K

#### **MARINAS**

		100		MARINAS	AS			
		1	Marina	Street	Street	Zip	Phone	Contact
Mailing	Kesponse	a i		10 Water St	Douglas, MI	49406	(616) 857-2960	
10-Dec-02		M-1	Naughtin's Marine		Grand Haven, MI	49417	(616) 842-2550	
06-Dec-02		M-2	M-2 Grand Haven Municipal Marina	-	Grand Haven MI	49417	(616) 842-9330	
06-Dec-02		M-3	M-3 Grand Isle Marina	I Crand Isle Dr.	Chaill Haven, 1911	40417	(616) 842-4670	
06-Dec-02		M-4	M-4 Grand Valley Marina II	1211 Jackson St.	Grand Haven, IVII	47411	210, 210 (010)	
XXXXXX		M-5			IM would the own	71101	(616) 842-5370	
06-Dec-02		9-W	M-6 Wharf Marina Inc.	501 N. Third St.	Grand Haven, IVII	10101	(616) 342 3313	
10 Dec-02		M-7	M-7 Anchorage Marina	1800 Ottawa Beach Rd.	Holland, MI	47464	(010) 399-1002	
10-Dec-02		W-8	M-8 Cresent Shores Marina	561 Cresent Dr.	Holland, MI	49423	1066-768 (919)	
10-Dec-02	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	6-W	M-9 Eldeans Shipyard	2223 South Shore Dr.	Macatawa, MI	49434		
XXXXXX		M-10				10101	0000 000 0000	
10-Dec-02		M-11	M-11 Parkside Marina	2314 Ottawa Beach Rd.	Holland, MI	47464	0202-666 (010)	
10-Dec-02		M-12	M-12 Yacht Basin Marina	1862 Ottawa Beach Rd.	Holland, MI	+7464	(010) 100-2200	
06-Dec-02	No. of the last of	M-13	M-13 Ellenwood Landing Marine	8560 Ellenwood Dr.	Montague, MI	49431	(231) 693-900	
06-Dec-02	13-Dec-02	M-14	M-14 Montague Marina	4770 Goodrich St	Montague, MI	49437	(231) 893-4737	
06-Dec-02	_	M-15						
XXXXXX		M-16				40441	750 0406	-
29-Nov-02	13-Dec-02	M-17	M-17 Bluffton Bay Marina	3040 Lakeshore Dr.	Muskegon, MI	49441	0640-661 (167)	
AAAAAA		M-18			Muskegon, MI	49441	Coop of Coop	
O Mon 00	2000	M-19	M-19 Great Lakes Marina & Storage	1920 Lakeshore Dr.	Muskegon, MI	49441	(231) 759-8230	
20-VOVI-02		N 20	M 20 Harbour Town Marina	3429 Fulton St	Muskegon, MI	49441	(231) 755-2218	
29-Nov-02		10 7.	Harbon Marina	920 W Western Ave.	Muskegon, MI	49441	(231) 724-6776	
29-Nov-02		17-IVI	M-21 Italishom Marma	1200 Lakeshore Dr.	Muskegon, MI	49441	(231) 726-5770	
29-Nov-02		M-22	Diggen Vey Marina	3545 Marina View Pt.	Muskegon, MI	49441	(231) 755-7511	
XXXXXX		7-INI	M-23 Ligodi Ney manne	350 Cihak St	Muskegon, MI	49441	(231) 744-3236	
29-Nov-02		77-IVI	M 26 Transca Doint Marina	770 Terrace Point Rd.	Muskegon, MI	49440	(231) 722-4448	
29-Nov-02	200	M-22	ACTION M. 26 Transcen Marine Inc	3126 Lakeshore Dr.	Muskegon, MI	49441	(231) 759-8596	
20-NOV-02	09-Dec-02	14.20	TOTICS OF IMARING THE					
XXXXXX		M-2/	T. W. A. Merica	6760 Diverside Dr	Sangatuck, MI	49453	(616) 857-1518	
10-Dec-02	NSN	M-28	M-28 Deep Harbor Marina	OZOJ Mychington Ct	Sangafuck MI	49453	(616) 857-4759	
10-Dec-02	09-Apr-03	M-29	09-Apr-03 M-29 Point Pleasant Marine	201 Washington of	Sangafuck MI	49453		
10-Dec-02		M-30	M-30 Sergeant Marina	31 Bullet St.	Caugamon, ita	40156	1	
06-Dec-02	13-Dec-02	M-31	M-31 Keenan Marina	526 Pine St.	Spring Lake, MI	47430		
XXXXXX	The state of the s				Chainer I ake MI	49456	(616) 842-3713	177
OF Day 00		N 33	M 22 Daradice Cove Marina Inc.	17540 N. Friutport Rd.	Spring Lake, 1vii	2000	П	-

# APPENDIX L

#### **COMMERCIAL OPERATORS**

				Yacht Clubs			
Mailing	Decnonce	=	Yacht Club	Street	Street	Zip	Phone Contact
6-Dec-02	2-Jan-03	Y-1	Grand Haven Yacht Club	501 1/2 N. 3rd Street OR P.O Box 745 (Winter)	Grand Haven, MI	49417	16) 846-6679
00	20 20 21	V	Divers Edge Vacht Club	14999 Mercury Dr.	Grand Haven, MI	49417	49417 (616) 846-0408
6-Dec-02	17-Dec-07	1-7 V 2	Day Chore Vacht Club	1862 Ottawa Beach Rd	Holland, MI	49424	49424 (616) 399-9844
10-Dec-02		C-Y	Day Shore I acht Chub	2157 & Chore Dr	Holland, MI	49423	49423 (616) 335-5815
10-Dec-02		Y-4	Macatawa Bay Taciit Ciuo	ZIOI D. DROKO DA:			
XXXXXX		Y-5			IM monostoning	49441	(731) 755-1414
29-Nov-02		9-X	Muskegon Yacht Club	3198 Edgewater	Millskegoll, Ivil	40453	
10-Dec-02		Y-7	Singapore Yacht Club	40 Butler St	Saugatuck, IVI	75101	775 (616) 847-8377
6-Dec-02		¥-8	Spring Lake Yacht Club	17500 W. Spring Lake Rd.	Spring Lake, MI	70477	49450 (010) 041 0524 4047 (721) 902 4737
6-Dec-02		6-X	Maple Beach Yacht Club	4770 Goodrich St.	Montague, MI	10464	0001 325 (100)
20-Mov-02		Y-10	Harbour Town Yacht Club	3429 Fulton Ave.	Muskegon, MI	49441	
O DO ON		V-11	Sanoatuck Yacht Club	833 Park St.	Saugatuck, MI	49453	(269) 837-8663
10-Dec-02		V 13	Muskegon Conservation Club 1921 Lake St.	1921 Lake St.	Muskegon, MI	49441	(231) 744-8326
29-Nov-02	-	71-1	IMITANO IN COLOR IN COLOR	Carry Countly Chara Dr	Whitehall MI	49461	
6-Dec-02		Y-13	White Lake Yacht Club	6/// South Shore Di	Willicians, 1911		
		Y-14					
100		Y-15					
		Y-16					
		Y-17					
100		Y-18					
		Y-19					
100	100 mg	Y-20					
		Y-21					
		Y-22					
		V-23					

				CONDOMINIONS		i	-	
Mailing	Response	a	Condominium	Street	Street	Zip	Phone	Contact
		5						
		C-2						
100000		C-3						
		2					0000	
6-Dec-02		C-5	Spring Col Condominiums	223 River Front	Spring Lake, MI	49456	49456 (616) 844-5039	
		G-6						
29-Nov-02		C-7	North Pier Condominiums	Sig Rudholm S & A Development 2588 Barclay Suite B	Muskegon, MI	49441	Muskegon, MI   49441   (231) 733-1236 Remax	Кетах
8		0.5	Driftwood Dunes Condominiums 6180 Murray Rd.	6180 Murray Rd.	Whitehall, MI	49461		
6-Dec-02		300	Holiday Inn Marina	940 W. Savidge St.	Spring Lake, MI	49456		
P-Dec-07		3	Sum	Black Lake	Holland Mi			
		25		Lake St	Saugatuck MI	49406		
		C-12						
000		C-13						
		C-14						
		C-15					S S S S S S S S S S S S S S S S S S S	
		C-16						
		C-17				1		
		C-18						

	M-34				75707	10456 (616) 947 0340
	M-35	M-35 Village Cove Marina	900 W. Savidge St.	Spring Lake, MI	49450	(010) 04/-9340
	M-36	M-36 Cross Winds Marine Service	302 S. Lake Street	Whitehall, MI	49461	(231) 894-4549
	M-37			The second second		2000 000 1100
	M-38	M-38 South Shore Marina	6806 South Shore Dr.	Whitehall, MI	49461	(231) 893-3935
	M-39	M-39 White Bay Marina & Resort	220 S, Lake St.	Whitehall, MI	49461	(231) 893-5253
12 Dec 02	M-40	13 Dec. 02 M-40 Whitehall Landing Inc.	410 S. Lake St.	Whitehall, MI	49461	(231) 894-5622
17-700-01	M-41		405 E. Colby (City Hall)	Whitehall, MI	49461	(231) 894-4048
	M-42		821 Savidge St	Spring Lake, MI	49456	(616) 842-1202
13. Dec-02	M-43	Aarina, Inc.	2975 Memorial Dr.	Muskegon, MI	49445	(231) 744-5763
12-Lan-03	M-44	re Marina. Inc.	18275 Berwyck	Spring Lake, MI	49456	(616) 842-1488
13 Dec-07	M.45	13 Dec no M 45 River Haven Marina	15006 120th Ave.	Grand Haven, MI	49417	
13-700-01	M-46	M-46 Dicks Landing	10367 N. Cedar Dr.	Grand Haven, MI	49417	(616) 842-1078
NSN	M.47	M-47 Anderson Marina	3088 Memorial Dr.	Muskegon, MI	49445	
13 Dec-02	M-48	13 Dec-02 M-48 Anchor Marina	2438 Memorial Dr.	Muskegon, MI	49445	(231) -?????
13-Dec-02	M-49	13-Dec-02 M-49 Lyons Den Marina	1639 S. Lake St.	Whitchall, MI	49461	(231) 893-9925
TO TOTAL	M-50	M-50 Armstrong Marina	200 S. Lake St.	Whitehall, MI	49461	THE PARTY OF THE P
	M-51	M-51 Harbor Hill Landing	8166 Old Channel Trail	Montague, MI	49437	
	M-52	M-52 South Shore Marine	1691 South Shore Dr.	Macatawa, MI	49434	
	M-53	M-53 Skinner Buds Marina	Ottawa Beach Rd.	Holland, MI	49424	
00 Amr 03	M. 54	17-Dec-02	Holland Rd.	Saugatuck, MI	49453	(616) 857-1481
00 Amr 03	M-55	17-Dec-02 03-Apri-03 M-55 I andinos at Sangatuck Marina		Saugatuck, MI	49453	(616) 857-45550
02-19n-03	M-56	02-ran_03 M-56 Tower Marina		Douglas, MI	49406	
02-Jan 02	200	1000	Cion in Canaatuck but didn't find	find		

# APPENDIX M

#### **COMMENTS FROM SURVEY RESPONSES**

#### The Marine Market for Biodiesel Fuel in the West Michigan Tri-Plex.

#### COMMENTS FROM THE DISTRIBUTOR SURVEY

 "We have used biodiesel from Soy oil for one year. We've had good response from the Farming Industry: Any information on this report would be of great important to our industry." Alt Oil Company.

#### COMMENTS FROM THE MARINA SURVEY

1. "Thank you for this opportunity" Ellenwood Landing Condominisms,

#### COMMENT FROM THE USER SURVEY

- "Major concern would be the effects of Biodiesel fuel on the injector system & residue from combustion," Sailboat owner on Lake Macatawa.
- "I like the idea of biodiesel. We use so little I don't know how significant a
  contribution we would make to the environment, but we must start someplace. I
  would like to see it become available. Is it as stable as existing fuel?" Sailboat
  owner on Lake Macatawa.
- "I used soydiesel 6 years ago- writer for Sailing Magazine wrote about Soy in a issue." C. B. sailboat owner on Lake Magazawa.
- "I am concerned about the 'life' of the fuel, since I only use about 10% of my tank each year – and, what happens to it when it gets old?" Sailboat owner on Lake Macatawa
- "The real issue to me is Will the life of my \$8000.00 diesel engine be harmed, extended, or not effected by bio-diesel? When Torreson marine master mechanics say its better, then I'll consider it. Sailbost owner on Lake Macatawa
- (I would buy biodiesel at the same price at my normal fuel dock.) "Assuming that
  I determined that it was safe for my (Yanmar) engine." Sailboat owner on Lake
  Macatawa.
- 7. "Don't currently use diesel. We were present for your outstanding Presentation at the Grand Rapids Power Squadron meeting. Very Interesting." Power boat owner on Lake Macatawa (The presentation referred to was made by Bill Stough of the Sustainable Research Group and the Grand Rapids biodiesel demonstration project manager Corky Overmyer)

Annis Water Resources Institute Grand Valley State University 1

#### The Marine Market for Biodieset Fuel in the West Michigan Tri-Pies.

#### COMMENT FROM THE USER SURVEY (Cont'd)

- "I don't want to seem callous with my NO responses, but I have a boat that does
  not use diesel fuel. I don't have a big interest in attending seminars concerning it.
  I am concerned with environmental quality however, and I encourage you in your
  study." Power boat owner on Lake Macatawa
- "Because we use so little fuel and diesel fuel tends to grow organisms, we are concerned about what will happen in our tank with biodiesel. We do not use anywhere near a full tank of diesel per year. What plant growth will biodiesel grow in one year's time." Sailbost owner on Lake Macatawa
- 10. "We use biodiesel on our farm and have no problems with it." Power boat owner on Lake Macatawa and user of 3000 gallons of diesel feel annually in his boat
- 11. "Re #12 this is assuming biodiesel is as good as petrodiesel for engine life and as efficient from an operational standpoint." Power boat owner on Lake Macatawa and user of 10,000+ gallons of diesel fuel per year (#12 refers to question 12 on the User Survey questionnaire relating to fuel preference if both petrodiesel and biodiesel were available at the same price and location.)
- "I would like to see biodiesel become available." Sailboat owner on Lake Macatawa
- "I drive a diesel automobile If your study covers cars/trucks as well, call me at 616-786-xxxx – A.B." Power boat owner on Lake Macatawa
- 14. "I would consider changing from gasoline to diesel power if my engine needed to be replaced. I'd probably seriously consider it if the conversion cost was within \$2000 of the cost of a gasoline engine." Power boat owner on Lake Macatawa.
- "Very impressive with what I've read about Biodiesel. Would like more information." Sailboat owner on Lake Macatawa
- 16. "15 & 16 are more involved than YES or NO depending on weather conditions and the condition of crew. Prudence would enter equation. 17 & 18 It would depend upon on the time schedule and my availability." Sailboat owner on White Lake (15 & 16 and 17 & 18 refer to questions on the Boaters survey relating to price sensitivity for the purchase of biodiesel and seminar attendance respectively.)
- 17. "I have avoided diesels because of the exhaust odor. I would strongly reconsider based on the above info box." Power boat owner on White Lake (Refers to biodiesel information included on the Boaters survey questionnaire.)

Annis Water Resources Institute Grand Valley State University 2

#### The Marine Market for Biodlesel Fuel in the West Michigan Tri-Pics.

#### COMMENT FROM THE USER SURVEY (Cont'd)

- 18. "My sailboat motor is a 4 cycle unit and uses ordinary gasoline like an automobile. However, I am interested in your efforts to reduce our need for foreign oil and also to clean up our atmosphere." D. R. sailboat Owner on Musicegon Lake
- 19. "My next boat will probably be diesel powered. As a sailor I would be willing to pay half again as much for the biodiesel." Sailboat owner on Muskegon Lake
- 20. "Our boat is a trawler and very fuel efficient. (+/- 4 miles/Gal) We tank-up once a year whether it needs it or not. Biodesel is destructive to fuel lines/scals, etc. if these problems as solved I would consider (see 12)." Power boat owner on Spring Lake (refers to question 12 on the boater's survey relating to buying of biodiesel at the same cost and location as petrodiesel.)
- "Biodiesel would be great but being a sailor we use very little each season. Good on you GVSU!" Sailboat owner on the Grand River
- 22. "I am a strong supporter of biodiesel and will buy if conveniently located to my route of travel." R. A. power boat owner New Buffalo MI (R.A. stores his boat in winter in the Saugatuck area.)
- 23. "I think biodiesel is one of the avenues we should explore & I commend your efforts." Saugatuck Power boat owner
- 24. "Owned a diesel fueled VW rabbit for 20 years loved the fuel economy. Prefer gasoline engine on boat quieter-" Saugatuck suilboat owner
- 25. "We have a small tank & fill with a 5 gal can" Saugatuck sailboat owner
- "Biodiesel solved my only objection to owning a diesel engine." Saugstuck sailboat owner
- "Biodiesel has the nasty habit of destroying hoses as presently made safety at sea is 1"." Saugatuck powerboat owner
- "Your talking about BiO from Soybeans, what about hazelmuts they produce more oil per acre than soy." Saugatuck power boat owner
- 29. "Great Idea hope you are successful." Saugatuck sailboat owner
- 30. "I would support legislation to require the use of biodiesel fuel." Saugatuck power boat owner

Arms Water Resources Institute Grand Valley State University 3

### The Marine Market for Bindiesal Fuel in the West Michigan Tri-Piex.

#### COMMENT FROM THE USER SURVEY (Cont'd)

- "I would love a cleaner fuel that is made in the USA. I would also like to invest in the company that makes it." B.F. 616-813-xxxx Grand Haven power boat owner.
- 32. "I just found your survey on my boat yesterday. [7/18/03] This is too late for your timeline but I wanted to respond anyway to support your program in a small way." Grand Haven power boat owner

Annia Water Resources Institute Grand Valley State University 4

				COMMERCIAL USER	L USER			
Median	Demonst	E	Pommerdal Dur	Street	40	270	Phone	1
The no	Broken	2	Beet City Princess	702 416 52	Mukegm, MI	Ħ.	(231) 744-1619	
20000000	60 lan 60	2	Toroner Marine Inc.	3136 Likethorn Dr.	Muskqum, MI	3		
17-D00-126	- 1		1 she Michigan Contraction Inc.	265 Kolles Park Dr.	Hotland M.	49624		
11-UR-92		2 3	Over of Communich	716 Water St.	Smoothelt MI	49453	(269) 157-4761	
77-50-77			1 W.T. and No.	6000 libra Starf Hav	Sammuck MI	58	(269) 857-323	
17-Dec 02		2 2	I do Controdos Ca	1481 Hue Star Hwy	Smeatack MI	40453	(269) 857-4802	
77700-07	74-090-47	2	TOTAL CONTRACTOR OF	170 Parent Day	Hoffmed Mil	PCP69	(616) 772-4000	
17-Dec-02		2	Braziline Confined Co	OCI Present Pe	Halland Mil	100	000 MF018	
17-Dec-62		Z	DA CONTRIGOR	CO C LEDAN Aven	Holland Mi	ADGA	80.98.08	
1-Dec-2		2	Doesema Marme me	11676 Burn St	Halland Mr	MORE	MIG 399-1784	
D-Decdi		웃	Karco	Lingua paray as	507	4000	4016, 106, 6010	
D-Dec 62	日中日	Z	Owen Marine Construction	4[5]] [28th Am.	HOUSE POL	1000	STORY OF STREET	
73.Dec.00			Andrie Inc	561 E. Western Avr.	Muskepta, MI	₹	(21) 728-2276	
T. Describ Now	NON	2	Balcom Marine Cir & Contractors 2964 Laberhate Dr.	2964 Labrahase Dr.	Muskapa, MI	¥	(231) 755-1332	
Ta Pan M NO	702	2	Divitorse Marine & Exampling	6775 Harrey St	Muskrem, MI	1	210 796-1601	
The Mark		12		1920 Lakeshore Dr.	Muskapa, MI	₹	(211) 759-6730	
1000000	71 Des 70	2 2	Office Declair & Contractor 4186 Herry St	4186 Henry St.	Muskegon, MI	404	(211) 798-2151	
Dan O			Shouline Dock & Sexual	833 Eagent Ave	Muskepon, MI	1940	(231) 759-8888	
S Park		12	South Share Marina	6806 S. Shore Dr.	Whitehall MI	1980	(211) 898-3935	
The m	m-ladi	5	Lakerhorn Martine Services	5849 Dowling St.	Montague MI	40437	(231) 894-3649	
the state of		2	AWRIVANIE		Chand Haven CO			
		2	AWRUlachon		Labe Wichigm Cir.			
		2	Grand Haven Coast Orani					1
		2	CLEAL/NOAA Mushegon		Muscepu			1
		2	Marina Streeter		Grand Hoven			

# APPENDIX N

#### **SURVEY MASTER LIST**

			SURVEY MASTER LIST			
	=	Marina	Street	City	Zip	Phone
	M 26 W	M 25 Cross Winds Marine Service	302 S. Lake Street	Whitehall, MI	49461	49461 (231) 894-4549
	M-38	South Shor	6806 South Shore Dr.	Whitehall, MI	49461	49461 (231) 893-3935
	M 20	White Ray	220 S, Lake St.	Whitehall, MI	49461	49461 (231) 893-5253
	N AO	Whitehall I	410 S. Lake St.	Whitehall, MI	49461	49461 (231) 894-5622
	M-W		405 E Colby - (City Hall)	Whitehall, MI	49461	49461 (231) 894-4048
1	M-41		8560 Ellenwood Dr.	Montague, MI	49437	49437 (231) 893-9663
NI	CI-IM	Mantame	4770 Goodrich St	Montague, MI	49437	49437 (231) 893-4737
OI	M-14	Montague Tuest Den	1639 S. Lake St.	Whitehall, MI	49461	49461 (231) 893-9925
EC	M-43	Lyons Den	200 S. Lake St.	Whitehall, MI	49461	
ы	N-W	Horbor Hil	8166 Old Channel Trail	Montague, MI	49437	
	IC-IM		6180 Murray Rd.	Whitehall, MI	49461	
	2 2		6777 South Shore Dr	Whitehall, MI	49461	
	CI-1		6806 S. Shore Dr	Whitehall MI	49461	49461 (231) 893-3935
	r-10	T oleachore	5849 Dowling St.	Montague MI	49437	49437 (231) 894-5649

		SURVEY MASTER LIST			
A	Marina	Street	City	Zip	Phone
C-7	North Pier Condominiums	Sig Rudholm Sig Rudholm 2588 & A Development 2588 Barclay Suite B	Muskegon, MI	49441	(231) 733-1236 Remax
71.17	Bluffon Bay Marina	3040 Lakeshore Dr.	Muskegon, MI	49441	(231) 759-0496
M 10	Great Lakes	1920 Lakeshore Dr.	Muskegon, MI		(231) 759-8230
M 20	Harbour To	3429 Fulton St	Muskegon, MI	49441	(231) 755-2218
M-21		920 W. Western Ave.	Muskegon, MI	49441	49441 (231) 724-6776
M-22	Lakeshore	1200 Lakeshore Dr.	Muskegon, MI	49441	(231) 726-5770
M-24		350 Cihak St.	Muskegon, MI	49441	49441 (231) 744-3236
M-25		770 Terrace Point Rd.	Muskegon, MI	49440	(231) 722-4448
	Torresen M	3126 Lakeshore Dr.	Muskegon, MI	49441	49441 (231) 759-8596
1		2975 Memorial Dr.	Muskegon, MI	49445	(231) 744-5763
	Anderson M	3088 Memorial Dr.	Muskegon, MI	49445	49445 (616) 755-2381
M 48	Anchor Ma	2438 Memorial Dr.	Muskegon, MI	49445	(231) ???-?????
1	Muskegon	3198 Edgewater	Muskegon, MI	49441	(231) 755-1414
V-12		1921 Lake St.	Muskegon, MI	49441	49441 (231) ???-????
P-12		702 4th St.	Muskegon, MI	49441	(231) 744-1619
P-2	Torresen Marine Inc.	3126 Lakeshore Dr.	Muskegon, MI	49441	
D-17	Andrie Inc	561 E. Western Ave	Muskegon, MI	49441	(231) 728-2226
D-14	Dykhouse Marine & Excavating	6775 Harvey St	Muskegon, MI	49441	49441 (231) 798-1601
D 15	Great I ales Marina & Storage	1920 Lakeshore Dr.	Muskegon, MI	49441	(231) 759-8230
61-1 91 d		14186 Henry St.	Muskegon, MI	49441	(231) 798-2351
P-17	Shoreline	833 Eugene Ave	Muskegon, MI	49441	(231) 799-8888
P-21	AWRI/Jackson	)	Lake Michigan Ctr.	i	
D 23	1		Muskegon	100	

_			SURVEY MASTER LIST			
_	=	Marina	Street	City	Zip	Phone
t	N C	Grand Haven Municinal Marina	421 Columbus St.	Grand Haven, MI		49417 (616) 842-2550
	M 2	Grand Isle Marina	1 Grand Isle Dr.	Grand Haven, MI	49417	49417 (616) 842-9330
	C-IM	Grand Valley Marina II	1211 Jackson St.	Grand Haven, MI	49417	49417 (616) 842-4670
	M-45		15006 120th Ave.	Grand Haven, MI	49417	49417 (616) 842-2458
	M-46	Dicks Land	10367 N. Cedar Dr.	Grand Haven, MI		49417 (616) 842-1078
	9-W	_	501 N. Third St.	Grand Haven, MI	49417	49417 (616) 842-5370
	- N	Grand Haven Yacht Club	501 1/2 N. 3rd Street	Grand Haven, MI	49417	49417 (616) 846-6679
-	4.2	Rivers Edge Yacht Club	14999 Mercury Dr.	Grand Haven, MI		49417 (616) 846-0408
NO	M.31	Keenan Ma	526 Pine St.	Spring Lake, MI	49456	49456 (616) 846-3830
	M 22		17540 N. Friutport Rd.	Spring Lake, MI	49456	49456 (616) 842-3713
1	M.35		900 W. Savidge St.	Spring Lake, MI	49456	49456 (616) 847-9340
1	CVW	M 42 Barrett Boat Works	821 Savidge St	Spring Lake, MI	49456	49456 (616) 842-1202
6	M M	North Chor	18275 Berwyck	Spring Lake, MI	49456	49456 (616) 842-1488
	N N		17500 W. Spring Lake Rd.	Spring Lake, MI	49456	49456 (616) 847-8322
_	00	Holiday Inn Marina	940 W. Savidge St.	Spring Lake, MI	49456	
-	P-20	AWRI/Angus		Grand Haven CG		
	P-22	Grand Haven Coast Guard		Grand Haven		
-		Marina Steamer		Grand Haven		

			SURVEY MASTER LIST			
	E	Marina	Street	City	Zip	Phone
	m ::	n 11. Marino	2314 Ottawa Beach Rd.	Holland, MI	49424	49424 (616) 399-2020
	M-II	Farkside Mai	1962 Ottown Beach Rd	Holland, MI	49424	49424 (616) 786-2205
	M-12	Yacht Basın Marina	1002 Ottawa Dodou no.	Unlland MI	40424	49424 (616) 399-1802
	M-7	Anchorage Marina	1800 Ottawa Beach Kd.	monand, m	20,00	120 200 0051
	M.8		561 Cresent Dr.	Holland, MI	49473	1666-766 (010) 578-84
t	OWI	Tildom Chinand	2223 South Shore Dr.	Macatawa, MI	49434	
N	WN	Elucans Simpland	1167 C Chara Dr	Holland, MI	49423	49423 (616) 335-5815
0	Y-4	Macatawa Bay Yacht Club	2137 3. SHORE DI.	11 11 T	VCVOV	879C_C05 (313) ACAOA
IE	p.3	I ake Michigan Construction Inc	265 Kollen Park Dr.	Holland MI	+7+6+	010) 272 4000
E	2.4	Deschline Construction Co	375 Donann Dr.	Holland MI	49424	49424 (616) 772-4000
Я	7 6	December Construction	561 Crescent Dr.	Holland MI	49424	49424 (616) 494-0970
	2-1 8-1	DA Constituction	68 C 160th Ave	Holland MI	49424	49424 (616) 396-3256
	P-9	<b>Дое</b> дета матие ис	19790 10 10 10 10 10 10 10 10 10 10 10 10 10	Holland MI	49424	49424 (616) 399-1784
	P-10	King Co	13520 Вапу эт.	ווטוומווט ווי זיי	VCVOV	0100-001 (215) 100-0010
	D 11	Owen Marine Construction	41511 128th Ave.	Holland MII	42464	100 000 (010)

			SURVEY MASTER LIST			
			Chroot	City	Zip	Phone
	<b>a</b>	Marina	חוו הה		40150	0771 739 (030)
T	00.51	n + Manant Marine	201 Washington St.	Saugatuck, MI	49400	49433 (207) 60444
	67-W	Point Fleasant Marine	10 TH 11 TH	Canoatick M	49453	49453 (269) 857-9430
h hy	M-30	Sergeant Marina	31 Butter M.	Daugainan J.	40469	778 779 (070)
	DC THI		833 Park St.	Saugatuck, MI	49400	49433 (202) 607-000
	Y-11	Saugaluck Tacill City	0 5 60	Compating MI	49453	49453 (269) 857-2442
	V-7	Singapore Yacht Club	40 Butler St	Daugarnan, 1711	1016	911 730 (070)
		O I VI LLA Common	868 Holland Rd.	Saugatuck, MI	49403	49433 (209) 021-1-10
	M-54	Saugatuck racm Services	000 1101000	The Journal M	49453	49453 (769) 857-4550
	MEE	I andings at Sangatuck Marina	726 Water Street	Daugainen, 1911	201	2000000
		Lanungs	111 Detere St	Douglas, MI	49406	49406 (269) 857-2131
B	M-56	Tower Marina	211 I utua Di.	Ourantial MI	10453	49453 (769) 857-4261
	10	Char of Campathick	716 Water St.	Saugatuck 1911	CCTCT	100 000
	1	Stat of Saugatush	CANA Dina Charf Hury	Sangatuck MI	49453	49453 (269) 857-3228
	P-5	L.W. Lamb Inc	0090 DIUC SIAIL LIMY	0.11	40153	40.452 (750) 857.4837
	200	I also Construction Co	3481 Blue Star Hwy	Saugatuck IMI	47400	(207) 021 (02)