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IN-USE EVALUATION OF EMISSIONS FROM NON-ROAD DIESEL EQUIPMENT USING BIODIESEL FUEL

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ACRONYMS AND ABBREVIATIONS

B100	100% biodiesel fuel
B50	50% biodiesel – ULSD blend
CO	carbon monoxide
CO_2	carbon dioxide
EF&EE	Engine, Fuels, & Emissions Engineering
NOx	oxides of nitrogen
NREL	National Renewable Energy Laboratory
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
PM	particulate matter
QA	quality assurance
RAVEM	Ride-Along Vehicle Emission Measurement
Southern	Southern Research Institute
ULSD	ultra low sulfur diesel

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EXECUTIVE SUMMARY

Diesel engines can be highly energy efficient and durable, yet emissions from them have historically contributed to a number of serious air pollution problems. Several local and state initiatives and laws have been introduced which focus on reducing pollution from diesel engines. As more voluntary programs are initiated, regulations are enacted, and emission reductions are sought, additional information regarding the various strategies for emission reductions is needed. The goal of this project was to evaluate the in-use performance of biodiesel blends in non-road diesel construction equipment to determine the potential impacts of biodiesel usage. The evaluation consisted of testing a single piece of construction equipment operating over a simple duty cycle using a series of fuel types: ultra-low sulfur diesel (ULSD); a 50% biodiesel-ULSD blend (B50); and 100% biodiesel (B100).

Testing took place during September 10 – 12, 2007 at the Destiny USA Carousel Mall site in Syracuse, NY. The testing approach was based on the *Generic In-Use Test Protocol for Non-Road Equipment* [Southern Research Institute, 2007]. A Volvo L90F front end loader with a D6E LAE3 engine served as the test vehicle. The three fuel types were evaluated under a simple duty cycle simulating equipment operation in an actual work environment. Gaseous emissions (CO_2, CO, and NOx) and PM emissions were measured by Engine, Fuels, & Emissions Engineering's RAVEM system using both integrated and modal sampling. Table ES-1 summarizes the mean results and the 95 percent confidence intervals for the in-use testing in terms of g/test and g/min.

Table ES-1. Emissions Results from In-Use Testing

		Integrated Emissions				Modal Emissions	
		PM	**CO_2**	**CO**	**NOx**	**CO_2**	**NOx**
B100	**g/test**	0.45 ± 0.16	8100 ± 400	15 ± 3	110 ± 50	8300 ± 700	110 ± 10
	g/min	0.027 ± 0.009	470 ± 20	0.86 ± 0.16	6.2 ± 3.1	490 ± 40	6.5 ± 0.5
B50	**g/test**	0.78 ± 0.23	8700 ± 200	29 ± 5	89 ± 7	8700 ± 200	94 ± 7
	g/min	0.046 ± 0.013	510 ± 10	1.7 ± 0.3	5.3 ± 0.4	510 ± 10	5.5 ± 0.4
ULSD	**g/test**	1.4 ± 0.2	9200 ± 200	35 ± 6	84 ± 2	9000 ± 100	87 ± 3
	g/min	0.082 ± 0.014	540 ± 10	2.1 ± 0.3	5.0 ± 0.1	530 ± 10	5.1 ± 0.2

Table ES-2 displays the percentage reduction in emissions for B100 and B50 fuels when compared with results from tests using ULSD. For comparison, the percentage reductions are shown as calculated using the g/test data and the g/min data. Percentage reductions in PM, CO_2, and CO emissions are based on the integrated data, whereas the reduction in NOx emissions is based on the modal data.

Table ES-2. Percentage Reduction in Emissions when Compared with ULSD Fuel

		PM	CO_2	CO	NOx
B100	**g/test**	68 ± 20	12 ± 4	59 ± 18	-28 ± 10
	g/min	68 ± 20	12 ± 4	59 ± 18	-28 ± 10
B50	**g/test**	44 ± 23	5.5 ± 3.1	19 ± 22[a]	-8.5 ± 9.2[a]
	g/min	44 ± 23	5.5 ± 3.1	19 ± 22[a]	-8.5 ± 9.2[a]

[a] Results are not statistically significant
NOTE: The data presented in Table ES-1 may not reconcile exactly with the percentage reductions reported in Table ES-2 due to rounding conventions and the use of significant figures

The percentage reductions in CO and NOx emissions for B50 compared with ULSD were not found to be statistically significant. It should also be noted that the CO_2 reductions do not account for full life cycle emissions associated with the conversion from petroleum based fuel to a renewable fuel. The CO_2 reductions reported here are for the exhaust stack only and do not necessarily indicate a net greenhouse gas emission reduction through the use of biodiesel.

The results of this test program show a larger effect of biodiesel fuel on PM and NOx emissions than that predicted by various EPA studies [US EPA Diesel Retrofit Technology Verification, 2007; US EPA Report EPA420-P-02-001, 2002]. These test results, however, are consistent with the findings of an NREL study [NREL Report NREL/CP-540-37508, 2005] showing the influence of engine age on the NOx penalty associated with the use of biodiesel. The NREL study reports that when tested on the same biodiesel blends, newer 2004 compliant engines emitted more NOx than engines from 1998 and older. The results in this report on the 2007 Volvo are consistent with the NREL findings.

1.0 INTRODUCTION

Diesel engines can be highly energy efficient and durable, yet emissions from diesel engines have historically contributed to a number of serious air pollution problems. To address the issues associated with diesel engines, several local and state initiatives and laws have been introduced which focus on reducing pollution from diesel engines. As more voluntary programs are initiated, regulations enacted, and emission reductions sought, information regarding the various strategies for emission reductions is needed more and more. This project seeks to provide detailed information to interested stakeholders, including end-users, regulators and others, regarding the performance of biodiesel fuel on high-priority non-road equipment operated in New York State (NYS). The project is part of a broader Clean Diesel Initiative at the New York State Energy Research & Development Authority (NYSERDA) that supports development of products and technologies to reduce emissions from diesel engines, funding for school bus and other retrofits across NYS, and demonstration and evaluation of various emission reduction strategies. The project also serves to provide Destiny USA information to determine the impacts of its conversion of construction equipment operation to biodiesel at the Syracuse, New York Carousel Mall construction site as part of their green construction and sustainability programs.

The primary goal of this project was to evaluate the in-use performance of biodiesel blends on non-road diesel construction equipment operated by Destiny USA, to determine the potential impacts of biodiesel usage. The evaluation consisted of testing of a single piece of construction equipment operating over a simple duty cycle using a series of three fuel types: ultra-low sulfur diesel (ULSD); a 50% biodiesel-ULSD blend (B50); and 100% biodiesel (B100). This report describes the experimental design and test procedures, and presents the results of the evaluation.

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2.0 EXPERMENTAL DESIGN AND TEST PROCEDURES

2.1. TEST EQUIPMENT

The non-road diesel construction equipment used for this study was a 2007 Volvo L90F front end loader with a Volvo D6E LAE3 engine that conforms to the 01/2007 model year USEPA/CARB Tier 3 emissions certification standard for large non-road engines. The loader was outfitted with a 2½ yard hydraulic bucket that operates at a maximum pressure of 3,770 psi with loads as prescribed in SAE J818. The engine incorporates a load-based speed control, which is an electronic control that improves fuel economy and driver satisfaction by balancing performance and increasing fuel economy. The speed control system communicates with the operator and indicates when the engine is over-speeding in the engaged gear, which encourages the driver to operate in a top gear. Figure 2-1 shows the Volvo loader instrumented for the testing and Table 2-1 lists the engine specifications.

Figure 2-1. Volvo L90F Instrumented for In-Use Testing

Table 2-1. Volvo L90F Specifications

Engine	Volvo D6E LAE3
Configuration	Inline 6 cylinder
Max Horsepower	169 hp
Max Torque	550 lb-ft
Peak Torque RPM	1600
Displacement	348 cu. in (5.7L)
Emission Technology	Air-to-Air Intercooled EGR
Emission Level	Tier 3 Compliant
Maintenance Interval	500 hours
Oil Sump Capacity	41 quarts

2.2. TEST FUEL

All test fuel for the in-use testing was supplied by Destiny USA through their fuel contractor, Ascent Aviation Group Inc., located in Parish, New York. All equipment at the test site normally operates on a soy-based B100 fuel. Two additional fuels (B50 and ULSD) were delivered to the test site during the first day of testing in 55 gallon drums. Appendix A shows a fuel analysis for each fuel type that was evaluated during this test program.

2.3. ANALYTICAL EQUIPMENT DESCRIPTION

The Engine, Fuels, & Emissions Engineering (EF&EE) Ride-Along Vehicle Emission Measurement (RAVEM) system provided measurements of emissions concentrations. The RAVEM system is based on proportional partial-flow constant volume sampling from the vehicle exhaust pipe. The RAVEM's sampling system extracts and dilutes a small, constant fraction of the total exhaust flow. The dilution air requirements and dilution tunnel size can thus be reduced to levels compatible with portable operation. The isokinetic proportional sampling system continuously adjusts the sample flow rate so that the flow velocity in the sample probe is equal to that of the surrounding exhaust. Since the velocities are equal, the ratio of the flow rates in the exhaust pipe and the sample probe is equal to the ratio of their cross-sectional areas. A diagram of the RAVEM system is shown in Figure 2-2.

Pollutant concentration measurements in the RAVEM system follow the methods specified by the U.S. EPA (US CFR Vol 40 Part 86) and ISO standard 8178.

Concentrations of NOx, CO_2, and CO in the dilute exhaust gas are recorded second-by-second during each test (modal testing). In addition, integrated samples of the dilute exhaust mixture and dilution air are collected during each test and analyzed afterward for NOx, CO_2, and CO.

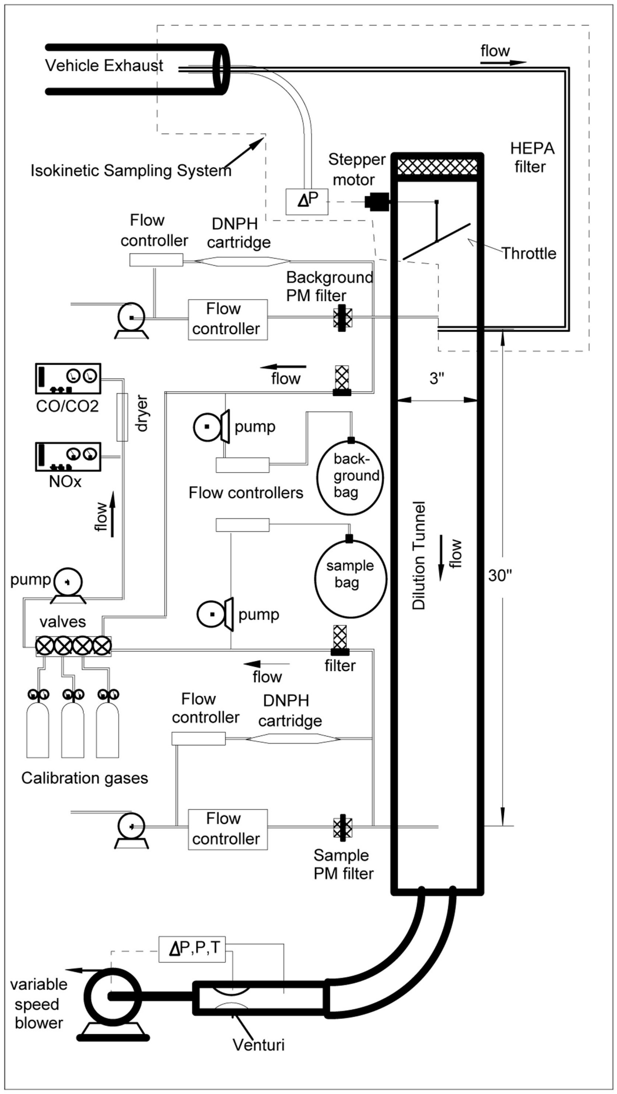

Figure 2-2. Diagram of the RAVEM System

(courtesy of EF&EE)

The RAVEM sampling system was configured for collecting raw exhaust samples directly from the outlet of the off-road equipment exhaust stack. Exhaust samples were collected with a heated probe and umbilical that transferred the sample to the dilution system for subsequent analysis and gaseous bag sample and PM filter collection. Exhaust flow was measured with a pitot and dilution air flow was adjusted according to the exhaust flow. The exhaust flow measurement and sample collection probes were located at the top of the engine exhaust stack.

EF&EE used a five gallon day tank to fuel the engine for all test runs. This allowed for direct measurement of the fuel used during each test run. Fuel usage was also calculated to serve as a cross-check of the measured values.

Fuel usage calculations were based only on the measured CO_2 and CO emissions, and the estimated percent carbon in the fuel.

2.4. TESTING APPROACH AND DUTY CYCLE

Tests were performed on September 10 – 12, 2007 at the Destiny USA Carousel Mall site in Syracuse, New York. The test site was located inside a fenced area stocked with a mounded sand mixture. The sand mixture allowed for simulation of equipment operation in an actual working environment. The loader was operated by the same Destiny USA contract employee during all tests.

The testing approach was based on the *Generic In-Use Test Protocol for Non-road Equipment* [1] (generic protocol) developed by Southern Research Institute (Southern) for NYSERDA. The generic protocol provides overall test campaign designs, procedures for developing duty cycles, instrument specifications, step-by-step test procedures, and analytical techniques. A site-specific protocol was written to provide information about the individual test site, non-road diesel construction equipment, and other details unique to the particular test campaign.

The three fuel types (B100, B50, and ULSD) were evaluated under a well-defined simple duty cycle. Duty cycles are detailed descriptions of the non-road equipment maneuvers during testing. Non-road equipment maneuvers may be described as individual “events” such as backing, travel forward, bucket extension, or digging, etc. Composite events consist of a combination of individual events over varying time periods. A rubber-tired loader, for example, may combine simple forward travel, reverse travel, bucket extension, tilting, and lifting events over a repeatable time period into a single “load bucket” composite event. A *simple* duty cycle is an arbitrary arrangement of simple or composite events of specified duration performed in sequence under controlled conditions. The simple duty cycle should:

- be representative of typical work activity
- last between 1/4 and 1 hour to allow for sufficient PM filter loading for gravimetric analysis, and to allow a reasonable number of test runs during a typical day
- be repeatable as determined by appropriate cycle criteria

Tests utilized a simple duty cycle that Southern had previously developed for the NYSERDA Clean Diesel Technology in-use test program. Southern personnel developed the duty cycle by observing construction equipment in normal operation. Test personnel logged the events that comprised equipment maneuvers and organized them into a representative, repeatable cycle. Table 2-2 lists the events logged during the in-use equipment observation.

Table 2-2. Events Logged During In-Use Equipment Operations

Event ID	Description
A.1	Begin at starting Point A, approx. 50 feet from salt/sand pile
A.2	Forward Travel Unloaded: Begin at Point A and travel forward in 2nd gear to pile (Point B)
A.3	Fill: At Point B, crowd the pile and fill bucket
A.4	Reverse Travel Loaded: Reverse gear, travel backward loaded with bucket at mid-height back to Point A
A.5	Forward Travel Loaded: From Point A, travel forward in 2nd gear back to pile with bucket at mid-height
A.6	Dump: Raise bucket to full height at pile and dump
A.7	Reverse Travel Unloaded: Travel backward unloaded to Point A, lowering bucket and coming to a full stop
B	Idle with bucket down
Series A	Composite of events A.1 – A.7

The events specified in Table 2-2 were organized into a duty cycle. The total cycle length was set at 17 minutes, which allowed for sufficient filter loading for gravimetric analysis. Table 2-3 lists the duty cycle events in their order of occurrence.

Table 2-3. Duty Cycle for In-Use Testing

Event ID	Description	Approx. Duration (mm:ss)
B	Idle with bucket down for 1 minute	01:00
Series A	Perform Series A (1 of 7 times)	00:33
Series A	Perform Series A (2 of 7 times)	00:33
Series A	Perform Series A (3 of 7 times)	00:33
Series A	Perform Series A (4 of 7 times)	00:33
Series A	Perform Series A (5 of 7 times)	00:33
Series A	Perform Series A (6 of 7 times)	00:33
Series A	Perform Series A (7 of 7 times)	00:33
B	Idle with bucket down for 1 minute	01:00
Series A	Perform Series A (1 of 7 times)	00:33
Series A	Perform Series A (2 of 7 times)	00:33
Series A	Perform Series A (3 of 7 times)	00:33
Series A	Perform Series A (4 of 7 times)	00:33
Series A	Perform Series A (5 of 7 times)	00:33
Series A	Perform Series A (6 of 7 times)	00:33
Series A	Perform Series A (7 of 7 times)	00:33
B	Idle with bucket down for 1 minute	01:00
Series A	Perform Series A (1 of 7 times)	00:33
Series A	Perform Series A (2 of 7 times)	00:33
Series A	Perform Series A (3 of 7 times)	00:33
Series A	Perform Series A (4 of 7 times)	00:33
Series A	Perform Series A (5 of 7 times)	00:33
Series A	Perform Series A (6 of 7 times)	00:33
Series A	Perform Series A (7 of 7 times)	00:33
B	Idle with bucket down for remainder of cycle	02:30
	Total Duty Cycle	**17:00**

To ensure the test runs were repeatable, test personnel set a criterion that the elapsed times for the total duty cycle length for each test run must be within ± 5 percent of each other. This criterion was met for all runs for all fuels (B100, B50, and ULSD), indicating that the test runs were not highly variable.

2.5. FUELING PROCEDURE

B100 tests were conducted first, followed by B50 and ULSD tests. Between the tests for each fuel type, the day tank and day tank fuel lines were drained and refilled with the next test fuel. A small amount of residual fuel from the previous tests remained in the injector pump. As such, the vehicle was conditioned by performing several iterations of loading and dumping. This was also used to warm up the vehicle. Following the conditioning, the day tank was refilled and weighed. Following each test, the day tank was weighed and refilled, if necessary, to prepare for the next test run.

3.0 IN-USE TESTING

3.1. TEST DETAILS

Tests were performed on September 10 – 12, 2007 at the Destiny USA Carousel Mall site in Syracuse, New York. Table 3-1 summarizes test run details.

Table 3-1. Test Run Information

Fuel Type	Date	Run Number	Notes
B100	9/10/2007	1	Run voided – test results exceeded the analyzer span
		2	Run voided – test results exceeded the analyzer span
		3	Run voided – test results exceeded the analyzer span
		4	Run voided – test results exceeded the analyzer span
	9/11/2007	5	No integrated bag emissions for this run – sample line was loose
		6	
		7	
B50	9/11/2007	1	
		2	
		3	
	9/12/2007	4	Run voided – RAVEM generator malfunctioned
		5	PM results voided – PM filter tore during testing
ULSD	9/12/2007	1	
		2	
		3	
		4	PM results voided – PM filter housing opened during the test
		5	

The first four B100 tests were invalidated because the peak emissions results exceeded the analyzer span. This was caused by the sampling probe. The size of the probe caused an inability to maintain isokinetic sampling under some of the engine operating conditions. The probe size was changed and the B100 fuel was retested the following day. All subsequent tests were conducted with this single probe.

Gaseous emissions data are presented for both integrated bag samples and for second-by-second modal results. The results from the integrated bag samples are considered more accurate for CO and CO_2 due to analyzer drift over the length of the test runs, while the modal results are considered more accurate for NOx due to reactions in the sample bag that can remove some of the NOx present.

There are several ways to quantify and assess the differences in emissions associated with in-use testing. For example, units of g/test, g/min, or g/gal may be useful. However, these metrics do not show the relationship between emissions and energy used during a test. Units of g/bhp-hr would show the relationship of emissions to work performed. Measuring the energy used (i.e. work performed) during a test requires determining how engine speed and torque vary during the course of the test.

For this test campaign, measurement of the energy used was not possible because torque measurements could not be determined. As such, emission results are presented in terms of g/test and g/min. Analysts also intended to present results in g/gal, however the measured and calculated fuel consumption values were questionable. Measurement of the five gallon day tank took place on a makeshift table outdoors in variable ambient conditions, introducing potential inaccuracies in the measurements. Calculated fuel consumption was based on the estimated percent carbon in the fuel and the measured CO_2 and CO emissions. Hydrocarbons were not measured and as such were not included in the fuel consumption calculations; however this would only marginally affect the fuel consumption computation. In some cases the measured and calculated fuel consumption values contradicted one another, leading analysts to invalidate this data. Fuel consumption data does not, however, affect any other reported results, so all results in this report are deemed valid.

3.2. TEST RESULTS

Table 3-2 summarizes the mean results and the 95 percent confidence intervals for the in-use testing in g/test and g/min.

Table 3-2. Emissions Results from In-Use Testing

		Integrated Emissions				Modal Emissions	
		PM	**CO_2**	**CO**	**NOx**	**CO_2**	**NOx**
B100	**g/test**	0.45 ± 0.16	8100 ± 400	15 ± 3	110 ± 50	8300 ± 700	110 ± 10
	g/min	0.027 ± 0.009	470 ± 20	0.86 ± 0.16	6.2 ± 3.1	490 ± 40	6.5 ± 0.5
B50	**g/test**	0.78 ± 0.23	8700 ± 200	29 ± 5	89 ± 7	8700 ± 200	94 ± 7
	g/min	0.046 ± 0.013	510 ± 10	1.7 ± 0.3	5.3 ± 0.4	510 ± 10	5.5 ± 0.4
ULSD	**g/test**	1.4 ± 0.2	9200 ± 200	35 ± 6	84 ± 2	9000 ± 100	87 ± 3
	g/min	0.082 ± 0.014	540 ± 10	2.1 ± 0.3	5.0 ± 0.1	530 ± 10	5.1 ± 0.2

Table 3-3 displays the percentage reductions and their 95 percent confidence intervals for emissions of the B100 and B50 fuels when they are compared with ULSD fuel. The table shows the percentage reduction as calculated using the g/test data and with the g/min data, for comparison. Emission reductions for PM, CO, and CO_2 are based on data from the integrated samples, while NOx reductions are based on data from the modal testing. NOx is reported from the modal testing because the modal results are generally considered more accurate than the integrated results, due to reactions in the sample bag that can remove some of the NOx present.

Table 3-3. Percentage Reduction in Emissions when Compared with ULSD Fuel

		PM	CO_2	CO	NOx
B100	g/test	68 ± 20	12 ± 4	59 ± 18	-28 ± 10
	g/min	68 ± 20	12 ± 4	59 ± 18	-28 ± 10
B50	g/test	44 ± 23	5.5 ± 3.1	19 ± 22[a]	-8.5 ± 9.2[a]
	g/min	44 ± 23	5.5 ± 3.1	19 ± 22[a]	-8.5 ± 9.2[a]

[a] Results are not statistically significant
NOTE: The data presented in Table 3-2 may not reconcile exactly with the percentage reductions reported in Table 3-3 due to rounding conventions and the use of significant figures

It should be noted CO_2 reductions do not account for full life cycle emissions associated with the conversion from petroleum based fuel to a renewable fuel. The CO_2 reductions reported here are for the exhaust stack only and do not necessarily indicate a net greenhouse gas emission reduction through the use of biodiesel.

The following figures show graphical summaries of the emissions reductions shown in Table 3-3. The reductions based on g/test data and g/min data are presented side-by-side for comparison.

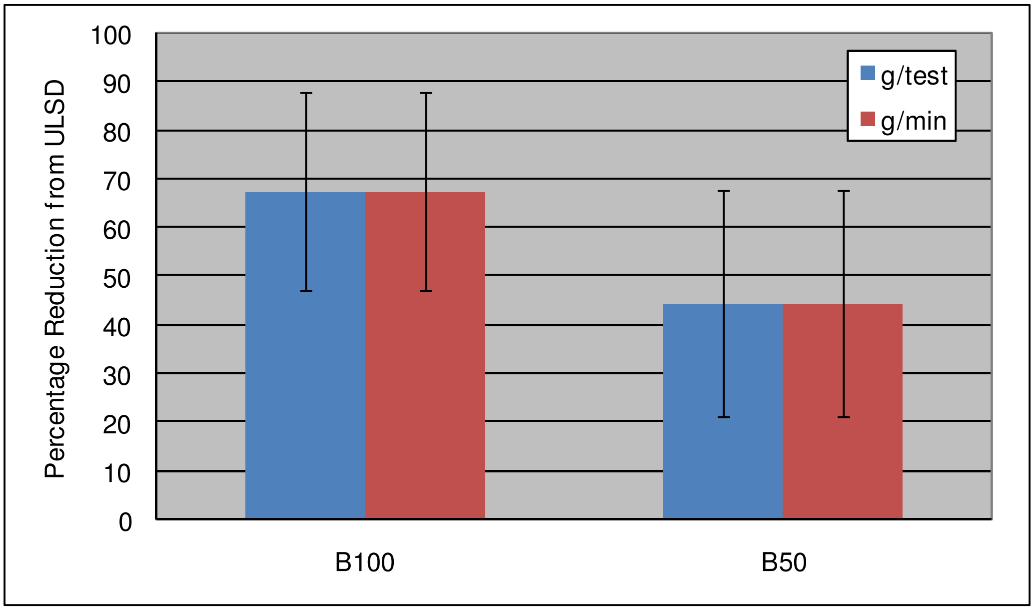

Figure 3-1. Reduction in PM Emissions when Compared to ULSD Fuel

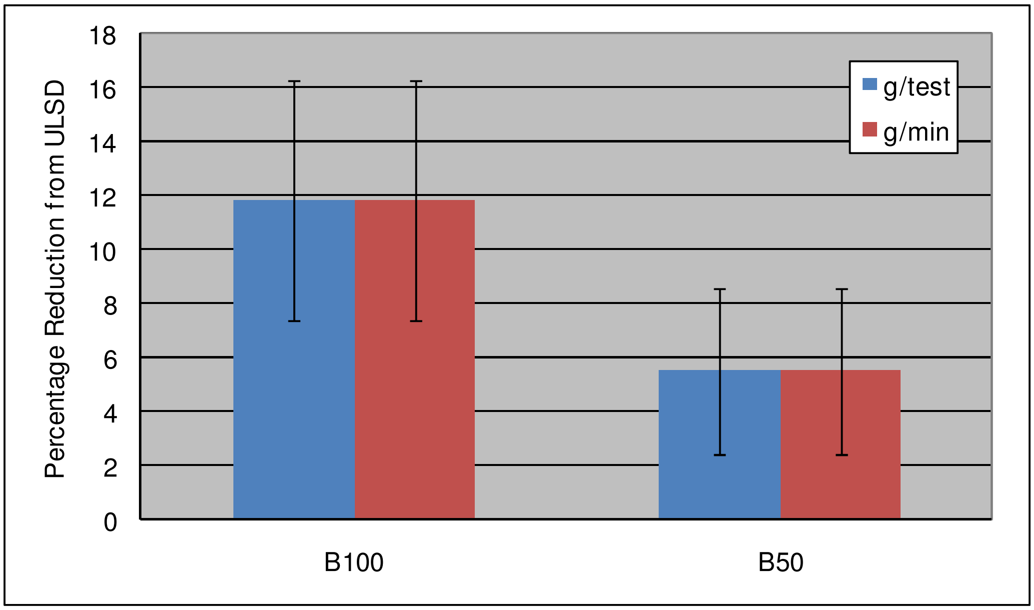

Figure 3-2. Reduction in CO_2 Emissions when Compared to ULSD Fuel

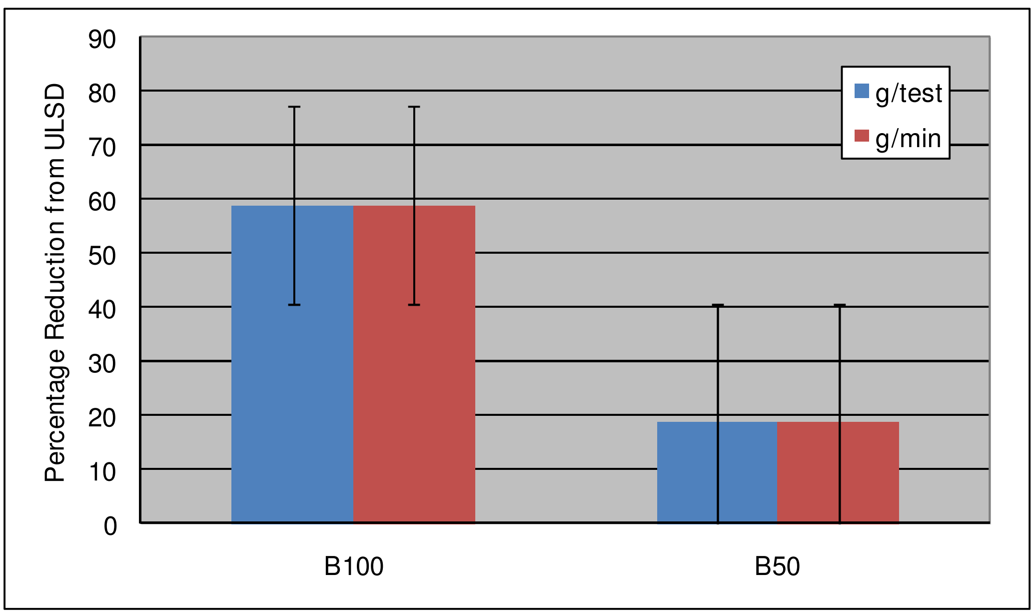

Figure 3-3. Reduction in CO Emissions when Compared to ULSD Fuel

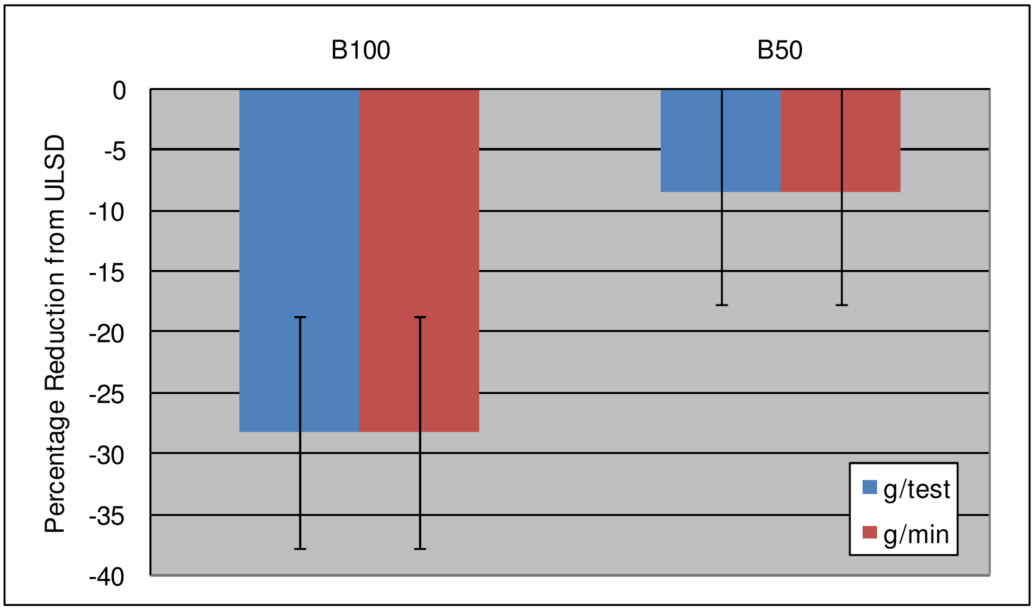

Figure 3-4. Reduction in NOx Emissions when Compared to ULSD Fuel

Substantial reductions resulted from use of the biodiesel fuel for all pollutants, with the exception of NOx, where there were increases. This was expected, as previous studies have shown that use of biodiesel may result in NOx increases. The in-use results for this non-road equipment, however, show a larger effect of biodiesel on PM and NOx emissions than that predicted by EPA studies based on the heavy-duty transient test procedure. The EPA's *Diesel Retrofit Technology Verification: Verified Technologies List* [2] recognizes the following percent reductions associated with use of biodiesel fuel:

- PM: 0 to 47%;
- CO: 0 to 47%;
- NOx: -10 to 0 %
- HC: 0 to 67%

Figure 3-5 shows the results of another EPA analysis of biodiesel impacts on exhaust emissions [3].

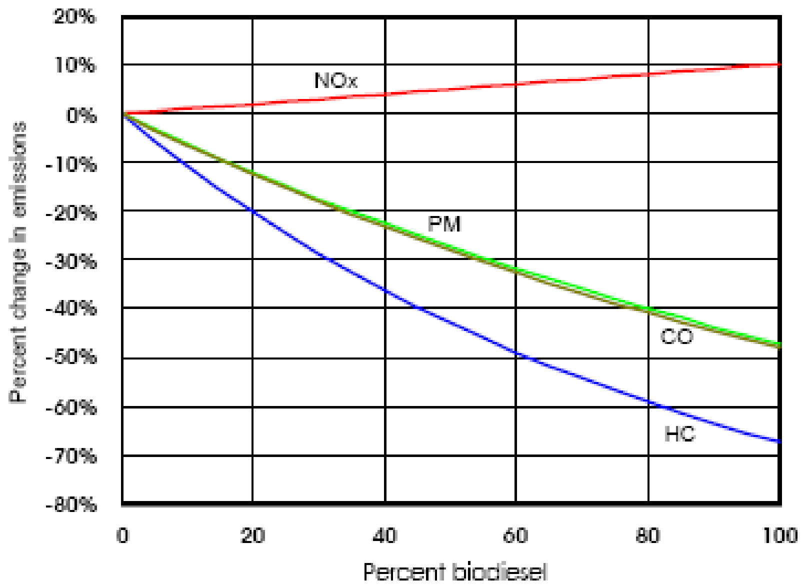

Figure 3-5. EPA Analysis: Impacts of Biodiesel for Heavy-Duty Highway Engines

A study completed by the National Renewable Energy Laboratory (NREL) shows how engine age influences the NOx penalty associated with the use of biodiesel fuel. Figure 3-6 shows the results of that study [3, 4].

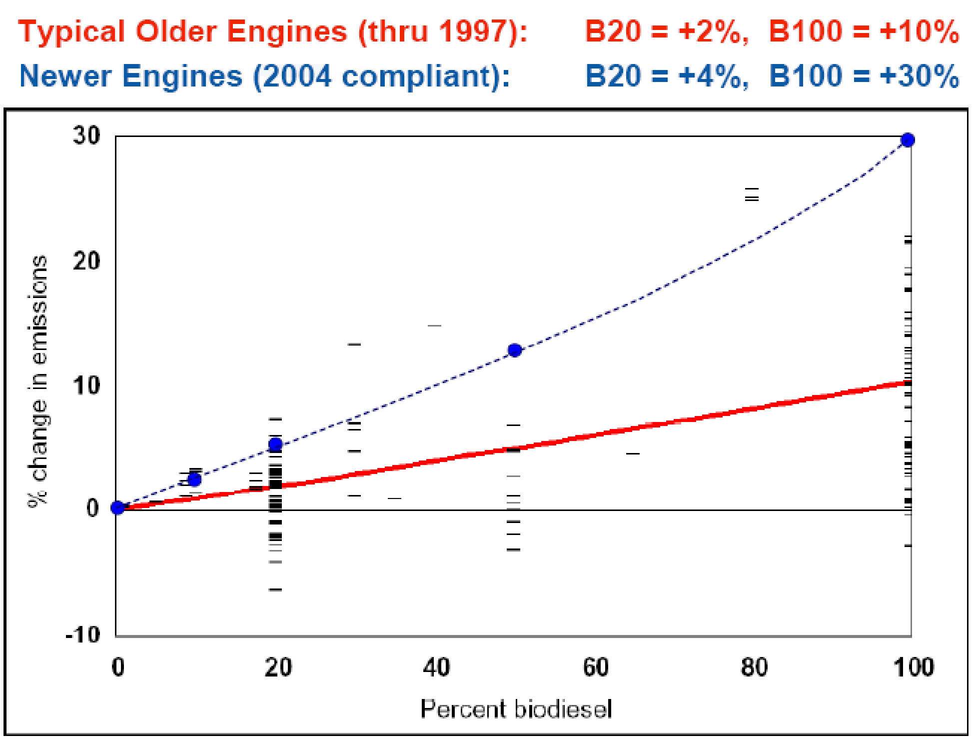

Figure 3-6. Influence of Engine Age on Biodiesel's Effect on NOx Emissions

The NREL study reports that when tested on the same biodiesel blends, newer 2004 compliant engines emitted more NOx than engines from 1998 and older. The NOx penalty observed with the 2007 Volvo used in this test campaign (28 percent with B100 fuel; 8.5 percent with B50 fuel) is consistent with the results shown in the NREL study for newer engines.

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4.0 DATA QUALITY ASSESSMENT

The emissions and performance determinations described in this report require numerous contributing measurements, sensors, instruments, analytical procedures, and data loggers. This section documents general specifications which helped ensure repeatability within the test campaign and comparability with other programs.

4.1. MEASUREMENT QUALITY OBJECTIVES

Table 4-1 lists the instrument and sensor accuracy specifications used in the test campaign. It also indicates the instrument manufacturer, model, and specification verification dates.

Table 4-1. RAVEM Specifications

Parameter	Logging Frequency	Accuracy	Repeatability	Manufacturer	Model(s)	Meets Spec.	Date/When Verified
Instrumental analyzer concentration	1 Hz	2.0 % of point	1.0 % of point	EF&EE	RAVEM	☒	9/11/2007
Gravimetric TPM balance	n/a[a]	0.1 % (see §1065.790)	0.5 µg	EF&EE	RAVEM	☒	At each weighing
Main flow rate	2 Hz	1.0 % FS[b]	n/a	EF&EE	RAVEM	☒	9/11/2007
Sample flow rate				EF&EE	RAVEM	☒	9/11/2007

[a]Not applicable (n/a)
[b]Full scale (FS)

Table 4-2 lists recommended calibration intervals and performance checks. Personnel performed some of the performance checks, such as leak checks, analyzer zero and spans, etc. before and after each test run while others were performed either in the field or laboratory.

Table 4-2. Recommended Calibrations and Performance Checks

System or Parameter	Description / Procedure	Frequency	Meets Spec.?	Date/When Completed
RAVEM	Comparison against laboratory CVS system	At purchase / installation; after major modifications	☒	Aug 07
	Zero / span analyzers (zero ≤ ± 2.0 % of span, span ≤ ± 4.0 % of point)	Before and after each test run	☒	9/10/07 – 9/12/07
	Inspect sample lines, filter housings, and sample bags for visible moisture (none is allowed)	After each test run	☒	9/10/07 – 9/12/07
	Perform analyzer drift check (≤ ± 4.0 % of cal gas point)		☒	9/10/07 – 9/12/07
	TPM background check and dilution tunnel blank	Once per test day	☒	9/10/07 – 9/12/07
	Dilution tunnel leak check		☒	9/10/07 – 9/12/07
	Sample bag leak check (< 0.5 % of normal system flow rate)		☒	9/10/07 – 9/12/07
	TPM filter face temperature (not to exceed 47 ^{o}C or 117 ^{o}F)	Continuously during sampling	☒	9/10/07 – 9/12/07
TPM gravimetric balance	NIST-traceable calibration	Within 12 months	☒	At each weighing
	Reference sample weights	Within 12 hours of filter weighing	☒	At each weighing

4.2. AUDIT OF DATA QUALITY

This test campaign was supported by an audit of data quality. An independent reviewer examined the test results. The analyst or author who produced a result table or text submitted it and the associated raw data to the reviewer. Review procedures included:

- review of technical systems audits (calibrations, QA checks, etc.) generated during field tests
- audits of data quality and analysis techniques
- manual cross-checking a portion of source data and calculation of final results

Southern's QA checks indicate that data collection was appropriate, analyses are correct, and the final results are acceptable for reporting. QA documents are maintained on file by Southern.

5.0 REFERENCES

[1] *Generic In-Use Test Protocol for Non-Road Equipment,* Southern Research Institute, Morrisville NC 2007

[2] *Diesel Retrofit Technology Verification: Verified Technologies List,* U.S. Environmental Protection Agency, December 2007, < http://www.epa.gov/otaq/retrofit/verif-list.htm>

[3] *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions*, U.S. Environmental Protection Agency, Draft Technical Report EPA420-P-02-001, October 2002, <http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf>

[4] *Regulated Emissions from Biodiesel Tested in Heavy-Duty Engines Meeting 2004 Emission Standards, SAE Report NREL/CP-540-37508*, Robert L. McCormick, et al, National Renewable Energy Laboratory, May 2005, <http://www.nrel.gov/vehiclesandfuels/npbf/pdfs/37508.pdf>

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APPENDIX A
FUEL ANALYSIS

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FORM G&O 100

NORTH CAROLINA DEPARTMENT OF AGRICULTURE AND CONSUMER SERVICES
STANDARDS DIVISION
Stephen Benjamin, Director
ANALYTICAL RECORD OF SAMPLE TAKEN

COUNTY ______
INSP № 440172

DATE 11/27/07

*Special

DEALER Butch Crews ADDRESS
STATION NAME CITY

BRAND NAME	SAMPLE A	SAMPLE B	SAMPLE C	SAMPLE D	SAMPLE E
	B100 Biodiesel	B50 Biodiesel	ULSD Hwy		
Sample Taken From					
Gallons Sampled					
Initial Boiling Point	°C	181 °C	172 °C	°C	°C
	Evaporated / Recovered	Evaporated / Recovered	Evaporated / Recovered	Evaporated / Recovered	Evaporated / Recovered
10% Volume @	°C / °C	°C / 237 °C	°C / 210 °C	°C / °C	°C / °C
50% Volume @	°C / °C	°C / 312 °C	°C / 267 °C	°C / °C	°C / °C
90% Volume @	°C / °C	°C / 338 °C	°C / 323 °C	°C / °C	°C / °C
End Point	°C	348 °C	347 °C	°C	°C
Percent Recovered					
Percent Residue					
Percent Loss					
Drivability Index					
Octane Index (R + M) / 2	RON / MON	RON / MON	RON / MON	RON / MON	RON / MON
Vapor Pressure (PSI)					
Total Ethanol (Vol. %)					
Total MTBE (Vol. %)					
Total Oxygen (Weight %)					
Cetane Number (D-613)					
Cetane Number (NIR)					
Calculated Cetane Index					
Water/Sediment	Pass	Pass	Pass		
Flash Point (Tag Closed Cup)	°F	°F	°F	°F	°F
API Gravity (60°F)	28.5	32.5	35.5		
Viscosity @ 40°C 100°C	Cst / Cst	Cst / Cst	Cst / Cst	Cst / Cst	Cst / Cst
Viscosity Index					
Apparent Viscosity (cP)	@ °C	@ – °C	@ – °C	@ – °C	@ – °C
Dye (PPM) / Color (D156)					
Sulfur (ppm)	0.6	5.3	8.2		
Flash Point (D93)	>300°F	166°F	138°F		
POSTED SPECIFICATIONS					
SAMPLE: PURCHASE ______ DONATED ______	Sample: App __ Con __ / Label: App __ Con __	Sample: App __ Con __ / Label: App __ Con __	Sample: App __ Con __ / Label: App __ Con __	Sample: App __ Con __ / Label: App __ Con __	Sample: App __ Con __ / Label: App __ Con __

Special samples-results for information only

REMARKS Phone 806-3456 x 29
fax 806-2306

I certify that all samples listed above are representative of the product(s) named.

Signed [signature]
North Carolina Department of Agriculture and Consumer Services

Signed [signature]
Dealer or Employee

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APPENDIX B

DETAILED RESULTS TABLES

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Table B-1. Test Run Data for 100% Biodiesel in a Volvo L90F Front End Loader

Test File	Start Date/Time	Test Conditions	Measured Fuel (g)	Bag Emissions (g/test)				Calc Fuel (g)	Modal g/test		Calc Fuel (g)
				PM	CO_2	CO	NOx		CO_2	NOx	
R3T1287	9/11/2007 13:01	B100 Fuel	n/a	0.50	Integrated bag emissions data unavailable				8,575	109.1	3,037
R3T1291	9/11/2007 14:34	B100 Fuel	3,303.0	0.38	8,107	15	101.5	2,880	8,163	109.3	2,891
R3T1292	9/11/2007 15:03	B100 Fuel	3,247.0	0.48	8,050	14	109.8	2,859	8,047	114.6	2,850

Table B-2. Test Run Data for 50% Biodiesel in a Volvo L90F Front End Loader

Test File	Start Date/Time	Test Conditions	Measured Fuel (g)	Bag Emissions (g/test)				Calc Fuel (g)	Modal g/test		Calc Fuel (g)
				PM	CO_2	CO	NOx		CO_2	NOx	
R3T1293	9/11/2007 15:51	B50 Fuel	3,400.0	0.87	8,768	32	92.2	2,940	8,776	98.9	2,926
R3T1294	9/11/2007 16:24	B50 Fuel	3,391.0	0.68	8,661	26	92.7	2,901	8,604	94.6	2,869
R3T1295	9/11/2007 16:54	B50 Fuel	3,368.0	0.78	8,735	31	83.6	2,928	8,477	87.5	2,826
R3T1298	9/12/2007 8:51	B50 Fuel	3,282.0	Void	8,463	26	89.4	2,835	8,741	94.5	2,914

Table B-3. Test Run Data for ULSD in a Volvo L90F Front End Loader

Test File	Start Date/Time	Test Conditions	Measured Fuel (g)	Bag Emissions (g/test)				Calc Fuel (g)	Modal g/test		Calc Fuel (g)
				PM	CO_2	CO	NOx		CO_2	NOx	
R3T1299	9/12/2007 9:29	ULSD Fuel	n/a	1.37	9,015	42	83.4	2,857	8,952	85.8	2,816
R3T1300	9/12/2007 10:01	ULSD Fuel	3,003.0	1.33	9,058	29	83.5	2,864	8,879	84.6	2,793
R3T1301	9/12/2007 10:29	ULSD Fuel	3,062.0	1.29	9,161	34	82.9	2,898	8,985	85.9	2,826
R3T1302	9/12/2007 11:01	ULSD Fuel	3,232.0	Void	9,387	37	85.1	2,971	9,089	86.0	2,859
R3T1303	9/12/2007 11:38	ULSD Fuel	3,117.0	1.62	9,191	35	86.3	2,909	9,014	90.2	2,835

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