

Environmental Technology Verification

Test Report of Mobile Source Emission Control Devices

PUREM North America, LLC
PMF GreenTec 1004205.00.0 Diesel Particulate Filter

Prepared by

Southwest Research Institute



RTI International



Under a Cooperative Agreement with
U.S. Environmental Protection Agency



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THE ENVIRONMENTAL TECHNOLOGY VERIFICATION
PROGRAM



ETV Joint Verification Statement

TECHNOLOGY TYPE:	MOBILE DIESEL ENGINE AIR POLLUTION CONTROL
APPLICATION:	CONTROL OF EMISSIONS FROM MOBILE DIESEL ENGINES IN HIGHWAY USE BY DIESEL OXIDATION CATALYSTS AND DIESEL PARTICULATE FILTERS
TECHNOLOGY NAME:	PMF GREENTEC 1004205.00.0
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, permittees, and other interested parties; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Air Pollution Control Technology Verification Center (APCT Center), one of six centers under the ETV Program, is operated by RTI International (RTI), in cooperation with EPA’s National Risk Management Research Laboratory. The APCT Center has evaluated the performance of an emissions control system consisting of a precious metal diesel oxidation catalyst and diesel particulate filter for highway diesel engines.

ETV TEST DESCRIPTION

All tests were performed in accordance with the *Test/QA Plan for the Verification Testing of Diesel Exhaust Catalysts, PM Filters, and Engine Modification Technologies for Highway and Nonroad Use Diesel Engines* and the *Test-Specific Addendum to ETV Mobile Source Test/QA Plan for PUREM North America LLC for the PMF GreenTec system*. These documents are written in accordance with the applicable generic verification protocol and include requirements for quality management, QA, procedures for product selection, auditing of the test laboratories, and test reporting format.

The mobile diesel engine air pollution control technology was tested at Southwest Research Institute. The performance verified was the percentage emission reduction achieved by the technology for particulate matter (PM), nitrogen oxides (NO_x), hydrocarbons (HC), and carbon monoxide (CO) relative to the performance of the same baseline engine without the technology in place. Operating conditions were documented and ancillary performance measurements were also made. A summary description of the ETV test is provided in Table 1.

Table 1. Summary Description of the ETV Test

Test type	Highway Transient Federal Test Procedure (FTP)
Engine family	XNVXH07.3ANE
Engine make–model year	Navistar – 1999 model DT466-B250F
Service class	Highway, heavy-duty diesel engine
Engine rated power	250 hp @ 2600 rpm
Engine displacement	7.3 L, eight-cylinder
Technology	PMF GreenTec 1004205.00.0
Technology description	Precious metal oxidation catalyst plus a powdered metal particulate matter filter.
Test cycle or mode description	One cold-start and three hot-start tests according to FTP test
Test fuel description	Ultra-low-sulfur diesel (ULSD) fuel with 15 ppm sulfur maximum
Critical measurements	PM, NO _x , HC, and CO
Ancillary measurements	CO ₂ , NO, NO ₂ (by calculation), soluble organic fraction (SOF) of PM, exhaust backpressure, exhaust temperature, and fuel consumption

VERIFIED TECHNOLOGY DESCRIPTION

The PUREM PMF GreenTec 1004205.00.0 is a precious metal oxidation catalyst plus a powdered metal particulate matter filter. This verification statement describes the performance of the tested technology on the diesel engine and fuels identified in Table 1, and applies only to the use of the PMF GreenTec 1004205.00.0 on highway engines fueled by ULSD (15 ppm or less) fuel.

VERIFICATION OF PERFORMANCE

The PMF GreenTec 1004205.00.0 achieved the reduction in tailpipe emissions shown in Table 2 compared to baseline operation without the PMF GreenTec system.

Table 2. Verified Emissions Reductions

Device type	Fuel	Mean Emissions Reduction (%)				95% Confidence Limits on the Emissions Reduction (%)			
		PM	NOx	HC	CO	PM	NOx	HC	CO
Degreened	ULSD	94	2.1	97	85	91 to 97	– ^a	– ^b	73 to 97
Aged	ULSD	95	2.8	93	86	92 to 98	1.1 to 4.4	– ^b	74 to 98

^a The emission reduction cannot be distinguished from zero with 95% confidence.

^b The emissions reduction could not be quantified or distinguished from 100% with 95% confidence.

The APCT Center QA officer has reviewed the test results and quality control data and has concluded that the data quality objectives given in the generic verification protocol and test/QA plan have been attained. EPA and APCT Center QA staff have conducted technical assessments of the test laboratory and of the data handling. These assessments confirm that the ETV tests were conducted in accordance with the EPA-approved test/QA plan.

This verification statement verifies the emissions characteristics of the *PMF GreenTec 1004205.00.0* for the stated application. Extrapolation outside that range should be done with caution and an understanding of the scientific principles that control the performance of the technology. This verification focuses on emissions. Potential technology users may obtain other types of performance information from the manufacturer.

In accordance with the generic verification protocol, this verification statement is valid, commencing on the date below, indefinitely for application of the *PMF GreenTec 1004205.00.0* within the range of applicability of the statement.

Original signed by S. Gutierrez 4/4/07

 Sally Gutierrez Date
 Director
 National Risk Management Research Laboratory
 Office of Research and Development
 United States Environmental Protection Agency

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 Air Pollution Control Technology
 Verification Center

Environmental Technology Verification Report

Mobile Source Emission Control Devices

**PUREM North America, LLC
PMF GreenTec 1004205.00.0
Precious Metal Diesel Oxidation Catalyst and
Diesel Particulate Filter System**

Prepared by

RTI International
Southwest Research Institute

EPA Cooperative Agreement No. CR831911-01-1

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April 2007

Notice

This document was prepared by RTI International (RTI) and its subcontractor, Southwest Research Institute (SwRI), with partial funding from Cooperative Agreement No. CR83191101-1 with the U.S. Environmental Protection Agency (EPA). The document has been submitted to RTI's and EPA's peer and administrative reviews and has been approved for publication. Mention of corporation names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products.

Foreword

The Environmental Technology Verification (ETV) Program, established by the U.S. Environmental Protection Agency (EPA), is designed to accelerate the development and commercialization of new or improved technologies through third-party verification and reporting of performance. The goal of the ETV Program is to verify the performance of commercially ready environmental technologies through the evaluation of objective and quality-assured data in order to provide potential purchasers and permittees an independent, credible assessment of the technology they are buying or permitting.

The Air Pollution Control Technology Verification Center (APCT Center) is part of the EPA's ETV Program, and is operated as a partnership between RTI International (RTI) and EPA. The APCT Center verifies the performance of commercially ready air pollution control technologies. Verification tests use approved protocols, and verified performance is reported in verification statements signed by EPA and RTI officials. RTI contracts with Southwest Research Institute (SwRI) to perform verification tests on engine emission control technologies.

Retrofit air pollution control devices used to control emissions from mobile diesel engines are among the technologies evaluated by the APCT Center. The APCT Center developed (and EPA approved) the *Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines* to provide guidance on the verification testing of specific products that are designed to control emissions from diesel engines.

The following report reviews the performance of the PUREM North America, LLC, PMF GreenTec 1004205.00.0 comprising a precious metal diesel oxidation catalyst and a diesel particulate filter. ETV testing of this technology was conducted in September-October 2006 at SwRI. All testing was performed in accordance with an approved test/QA plan that implements the requirements of the generic verification protocol at the test laboratory.

Availability of Report

Copies of this verification report are available from:

- RTI International
Engineering and Technology Unit
P.O. Box 12194
Research Triangle Park, NC 27709-2194
- U.S. Environmental Protection Agency
Air Pollution Prevention and Control Division (E343-02)
109 T. W. Alexander Drive
Research Triangle Park, NC 27711

Web sites: <http://www.epa.gov/etv/verifications/verification-index.html> (pdf format)
 <http://www.epa.gov/ncepihom/>

Table of Contents

Section	Page
Notice.....	ii
Foreword.....	iii
Availability of Report.....	iv
List of Figures.....	vi
List of Tables.....	vi
Acronyms/Abbreviations.....	vii
Acknowledgments.....	ix
Section 1.0 Introduction.....	1
Section 2.0 Product Description.....	2
Section 3.0 Test Documentation.....	3
3.1 Engine Description.....	3
3.2 Engine Fuel Description.....	3
3.3 Summary of Emissions Measurement Procedures.....	5
3.4 Deviations from the Test/QA Plan.....	6
3.5 Documented Test Conditions.....	6
Section 4.0 Summary and Discussion of Emission Results.....	11
4.1 Quality Assurance.....	14
Section 5.0 References.....	15

List of Figures

Figure	Page
Figure 1. Engine shown installed in emissions test cell with PUREM PMF GreenTec 1004205.00.0 shown left of engine.....	2
Figure 2. Schematic of emissions sampling system at SwRI.....	5
Figure 3. Torque map of 1999 Navistar B250F engine using ULSD fuel.....	7
Figure 4. Inlet Temperature Profile of Degreened PMF GreenTec 1004205.00.0.....	8
Figure 5. Inlet Temperature Profile of Aged PMF GreenTec 1004205.00.0.....	9

List of Tables

Table	Page
Table 1. Engine Identification Information	4
Table 2. Selected Fuel Properties and Specifications	4
Table 3. Test Engine Baseline Emissions Requirement for 1999 Navistar B250	6
Table 4. Engine Exhaust Backpressure and Average Device Inlet/Outlet Temperature	8
Table 5. Particulate Characterization — Soluble Organic Fraction (SOF) from Each Test.....	9
Table 6. Brake-Specific Fuel Consumption (by Carbon Balance)	10
Table 7. Summary of Fuel Consumption Reductions.....	10
Table 8. Emissions Data	11
Table 9. Composite Weighted Emission Rates (U.S. Common Units)	12
Table 10. Composite Weighted Emission Rates (Metric Units).....	13
Table 11. Summary of Verification Test Data (U.S. Common Units)	13
Table 12. Summary of Verification Test Data (Metric Units).....	13
Table 13. Summary of Verification Test Emission Reductions	14

Acronyms/Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
APCT Center	Air Pollution Control Technology Verification Center
ASTM	American Society for Testing and Materials
bhp	brake horsepower
bhp-hr	brake horsepower-hour
BSFC	brake-specific fuel consumption
C-B	carbon balance
CFR	Code of Federal Regulations
cm	centimeter(s)
CO	carbon monoxide
CO ₂	carbon dioxide
CVS	constant volume sampler
DOC	diesel oxidation catalyst
DPF	diesel particulate filter
EPA	U.S. Environmental Protection Agency
ETV	environmental technology verification
FEL	family emission limits
ft	foot (feet)
FTP	Federal Test Procedure
g	gram(s)
HC	hydrocarbon(s)
HD	heavy duty
hp	horsepower
in. Hg	inch(es) mercury
in.	inch(es)
kW	kilowatt(s)
kWh	kilowatt hour(s)
L	liter(s)
lb	pound(s)
lb-ft	pound foot (feet)

m	meter(s)
mm	millimeter(s)
N	newton(s)
N-m	newton-meter
NO	nitric oxide
NO ₂	nitrogen dioxide
NO _x	nitrogen oxides
OTAQ	Office of Transportation and Air Quality
Pa	pascal(s)
PDP	positive displacement pump
PM	particulate matter
ppm	parts per million by volume
PUREM	PUREM North America, LLC
QA	quality assurance
QC	quality control
rpm	revolutions per minute
RTI	RTI International
SOF	soluble organic fraction of the particulate matter
SOP	standard operating procedure
SwRI	Southwest Research Institute
ULSD	ultra-low sulfur diesel

Acknowledgments

The authors acknowledge the support of all of those who helped plan and conduct the verification activities. In particular, we would like to thank Michael Kosusko, project manager, and Paul Groff, quality assurance manager, both of the U.S. Environmental Protection Agency's (EPA's) National Risk Management Research Laboratory in Research Triangle Park, NC. We would also like to acknowledge the assistance and participation of all PUREM North America, LLC, personnel who supported the test effort.

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Section 1.0 Introduction

This report reviews the performance of the PMF GreenTec 1004205.00.0 diesel particulate filter (DPF) system comprising a precious metal diesel oxidation catalyst (DOC) and a DPF submitted for testing by PUREM North America, LLC (PUREM). Environmental technology verification (ETV) testing of this technology was conducted during a series of tests in September-October 2006 by Southwest Research Institute (SwRI), under contract with the Air Pollution Control Technology Verification Center (APCT Center). The APCT Center is operated by RTI International (RTI)[†] in partnership with the U.S. Environmental Protection Agency's (EPA) ETV program. The objective of the APCT Center and the ETV program is to verify, with high-quality data, the performance of air pollution control technologies, including those designed to control air emissions from diesel engines. With the assistance of a technical panel of experts assembled for the purpose, RTI has established the APCT Center program area specifically to evaluate the performance of diesel exhaust catalysts, particulate filters, and engine modification control technologies for mobile diesel engines. Based on the activities of this technical panel, the *Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*¹ was developed. This protocol was chosen as the best guide to verify the immediate performance effects of the PMF GreenTec 1004205.00.0. To determine these effects, emissions results from a heavy-duty highway diesel engine were compared to emissions results obtained operating the same engine with the same fuel, but with the PMF GreenTec DPF technology installed. The specific test/quality assurance (QA) plan addendum for the ETV test of the technology submitted by PUREM was developed and approved in August 2006.² The goal of the test was to measure the emissions control performance of the PMF GreenTec DPF technology and its emissions reduction relative to an uncontrolled engine.

A description of the PUREM technology is presented in Section 2. Section 3 documents the procedures and methods used for the test and the conditions under which the test was conducted. The results of the test are summarized and discussed in Section 4, and references are presented in Section 5.

This report contains only summary data and the verification statement. Complete documentation of the test results is provided in a separate test report³ and audit of data quality report.⁴ These reports include the raw test data from product testing and supplemental testing, equipment calibration results, and QA and quality control (QC) activities and results. Complete documentation of QA/QC activities and results, raw test data, and equipment calibration results are retained in SwRI's files for 7 years.

The verification statement applies only to the use of the PMF GreenTec 1004205.00.0 on highway engines. It is applicable to engines fueled only by ultra-low-sulfur diesel (ULSD) (15 ppm or less) fuel.

[†] RTI International is a trade name of Research Triangle Institute.

Section 2.0 Product Description

The PUREM PMF GreenTec 1004205.00.0 is a precious metal oxidation catalyst plus a powdered metal particulate matter filter. Exhaust gases are routed through the oxidation catalyst and then processed through a particulate matter (PM) filter to achieve emissions reductions.

PUREM provided a “degreened” PMF GreenTec 1004205.00.0 unit that had seen 100 hours of service on a 1998 International/Navistar B175F engine installed on an engine dynamometer. The 100 hours were accumulated by repeating a 300-second cyclic operation that contained 42 stepwise engine condition ramping commands, developed by PUREM to simulate the school bus duty cycle on an engine dynamometer. It had a February 2006 date of manufacture and was designated serial number 104.

PUREM provided an “aged” PMF GreenTec 1004205.00.0 unit that had seen 1050 hours of service on the same engine, also installed on an engine dynamometer. The 1050 hours were accumulated by repeating the same 300-second cyclic operation as above. This unit had a January 2006 date of manufacture and was designated serial number 053.

Both the degreened and aged DPF units were identical size, box-shaped housings, designed as mufflers weighing nominally 100 pounds, with a 3 ½-inch (90.5 mm) diameter flange at each opening. For evaluating emissions, each DPF in turn was mounted 80 inches (2 m) downstream of the turbocharger in its “as received” condition.



Figure 1. Engine shown installed in emissions test cell with PUREM PMF GreenTec 1004205.00.0 shown left of engine.

Section 3.0 Test Documentation

The ETV testing took place during September-October 2006 at SwRI under contract to the APCT Center. Testing was performed in accordance with:

- *Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*¹
- *Test/QA Plan for the Verification Testing of Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*⁵
- *Test-Specific Addendum to ETV Mobile Source Test/QA Plan for PUREM North America, LLC for the PMF GreenTec Diesel Particulate Filter.*²

The applicant reviewed the generic verification protocol and had an opportunity to review the test/QA plan prior to testing.

3.1 Engine Description

The ETV testing was performed on an eight-cylinder, 7.3 L, 1999 model year Navistar highway medium heavy-duty diesel engine (model B250F, SN: 0960428). The nameplate rating of this model engine is 187 kW (250 bhp) in “prime” power service at 2600 rpm. SwRI supplied the engine for verification testing. The test engine had 500 hours of operation accumulated on it.

Table 1 provides the engine identification details.

3.2 Engine Fuel Description

All emissions testing was conducted with ULSD fuel meeting the 40 CFR §86.1313-2007 specification for emissions certified fuel.⁶ Selected fuel properties from the supplier’s analyses are summarized in Table 2. All testing was conducted using fuel from a single batch, identified as EM-5989-F.

Table 1. Engine Identification Information

Engine serial number	0960428
Date of manufacture	February 23, 1999
Make	Navistar
Model year	1999
Model	DT466-B250F
Engine displacement and configuration	7.3 L, eight-cylinder
Service class	Highway, medium heavy-duty diesel engine
EPA engine family identification	XNVXH07.3ANE
Family emissions limits (g/hp-hr)	HC 1.34/CO 15.54/NOx 4.05/PM 0.105
Rated power (nameplate)	250 hp @ 2600 rpm
Rated torque (calculated from nameplate power)	500 lb-ft @ 1600 rpm
Certified emission control system	Electronic control system
Aspiration	Turbocharger and air cooler
Fuel system	Direct injection

Table 2. Selected Fuel Properties and Specifications

Item	Code of Federal Regulations (CFR) Specification ^a		Test Fuel
	ASTM	Type 2D	EM-5989-F
Cetane number	D613	40–50	44.4
Cetane index	D976	40–50	n/a
Distillation range:			
Initial boiling point, °C (°F)	D86	171–204 (340–400)	192 (377)
10% Point, °C (°F)	D86	204–238 (400–460)	214 (417)
50% Point, °C (°F)	D86	243–282 (470–540)	260 (500)
90% Point, °C (°F)	D86	293–332 (560–630)	311 (592)
End point, °C (°F)	D86	321–366 (610–690)	337 (638)
Gravity (American Petroleum Institute)	D287	32–37	35.2 ^b
Specific gravity	–	–	0.849 ^b
Total sulfur, ppm	D2622	7-15	10 ^c
Hydrocarbon composition:			
Aromatics (minimum), %	D5186	27	29.5 ^d
Paraffins, naphthenes, and olefins, %	D5186	^e	70.5 ^d
Flash point (minimum), °C (°F)	D93	54 (130)	77 (170)
Viscosity, centistokes @ 40 °C	D445	2.0–3.2	2.5

^a 40 CFR 86.1313-2007(b)(2) for the year 2007 and beyond for heavy-duty diesel engines.

^b Measured per ASTM D4052.

^c Measured per ASTM D5453. This method is an acceptable substitute for ASTM D2622.

^d Measured per ASTM D1319.

^e Remainder of the hydrocarbons

3.3 Summary of Emissions Measurement Procedures

The ETV tests consisted of baseline uncontrolled tests and tests with the control technology installed. Engine operation and emissions sampling adhered to techniques developed by EPA in 40 CFR, Part 86, Subpart N.⁷ Emissions were measured over triplicate runs of the highway transient test cycle for the baseline, degreened DPF, and aged DPF exhaust configurations.

The Navistar B250F engine was operated in an engine dynamometer test cell, with exhaust sampled using full-flow dilution constant volume sampling (CVS) techniques to measure regulated emissions of hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter (PM), plus nitric oxide (NO). The nitrogen dioxide (NO₂) levels are expressed as the difference between measured NO_x and NO levels for each run. In addition to results presented in this report, raw data were gathered at the rate of one series of measurements per second over each test to record the engine speed, torque value, concentration of selected emissions, exhaust temperature, and various pressures. Figure 2 depicts the sampling system and related components. The system is designed to comply with the requirements of 40 CFR, Part 86.⁷

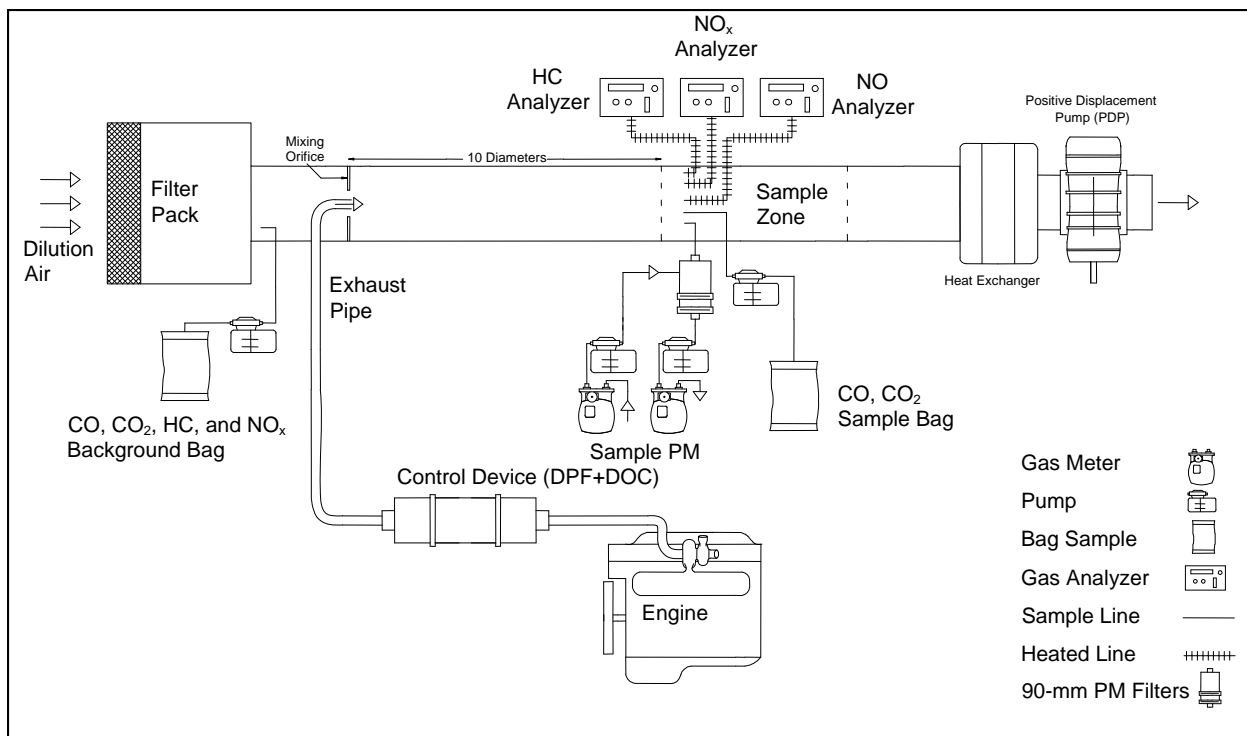


Figure 2. Schematic of emissions sampling system at SwRI.

The verification protocol requires that the emissions from engines used for verification testing must not exceed 110% of the certification standards for that engine category.⁸ For this engine, the family emission limits (FEL) supersede the certification standards. Also, the Office of Transportation and Air Quality (OTAQ) assumes 5% emissions reduction due to the use of ULSD fuel.

Therefore, the criteria established to indicate that the test engine was acceptable and that the verification testing could proceed were that the baseline emissions from the engine using ULSD fuel could not exceed 110% of (FEL-5%), or (1.045 x FEL). Table 3 presents the required baseline emission performance of the test engine. (Section 4.0 of this report contains the emissions data that show the performance of the selected engine was acceptable.)

Table 3. Test Engine Baseline Emissions Requirement for 1999 Navistar B250

	HC		CO		NOX		PM	
	g/kWh	g/hp-hr	g/kWh	g/hp-hr	g/kWh	g/hp-hr	g/kWh	g/hp-hr
FEL ^a	1.80	1.34	20.84	15.54	5.43	4.05	0.141	0.105
1.045 x FEL	1.88	1.40	21.78	16.24	5.68	4.23	0.147	0.110

^aFEL applies only to specific engine family.

3.4 Deviations from the Test/QA Plan

There were two deviations from the test/QA plan.

The statement of work called for use of a 1998 International B175 T444E heavy-duty diesel engine. The 1998 engine was deemed unacceptable because its NO_x level was uncharacteristically high, at 5.3 g/hp-hr, compared to its regulatory limit of 4.0 g/hp-hr. With a substitute engine from the same EPA highway engine family on-site, the 1998 engine was set aside. The substituted 1999 Navistar B250F engine clearly met the model year FEL. Engine performance was stable over the multiple days of testing, as transient cycle operation consistently met or “passed” the required performance and statistical criteria.

The other deviation occurred when a ¼-inch plug, which is typically located in the exterior wall of the DPF, was found on the floor following tests on the degreened DPF. The plug is designed as a temperature or pressure tap. That leak was repaired, and the degreened DPF was tested again on a subsequent day. Comparing those two sets of results suggests that the plug most likely became dislodged near the end of its first day of testing. However, because of the leak, the first set of emissions data was not used in calculating emissions reduction of the technology.

3.5 Documented Test Conditions

Engine Performance

Figure 3 shows torque map information measured on the 1999 Navistar B250F engine using the ULSD fuel.

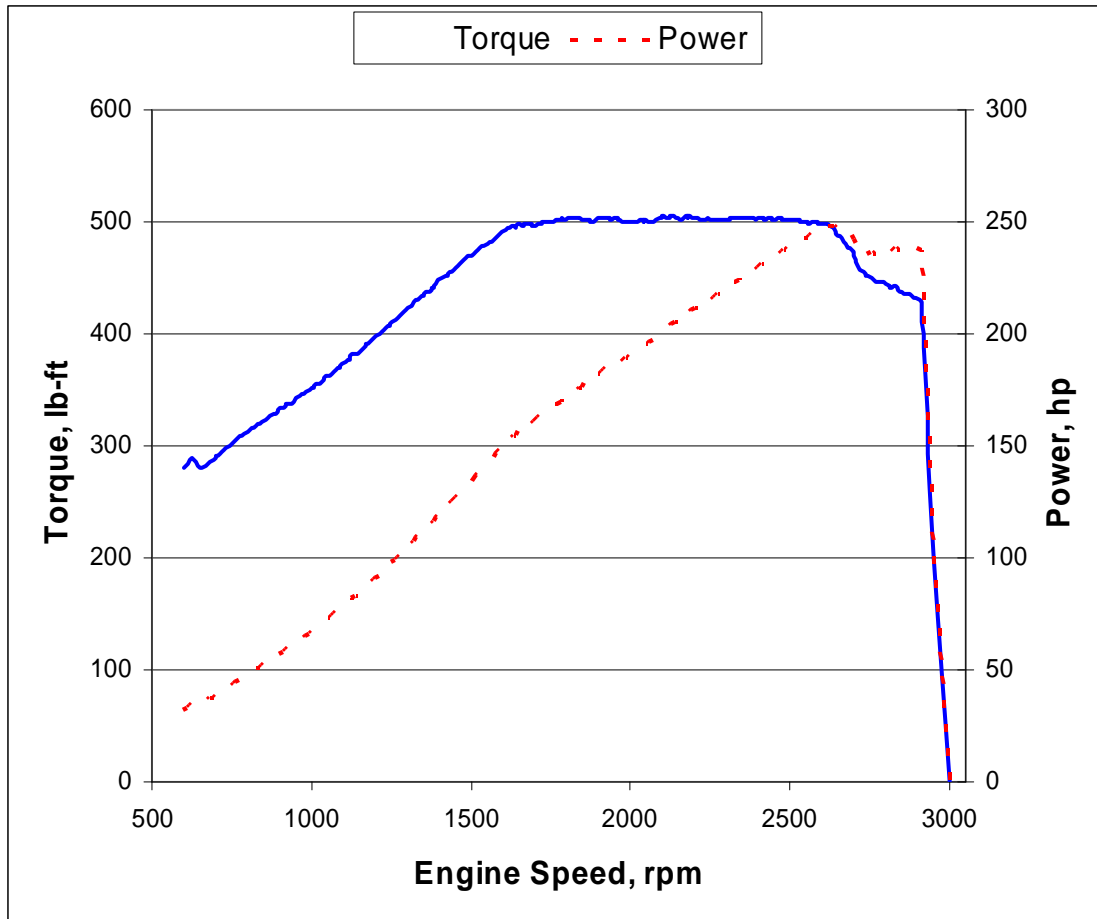


Figure 3. Torque map of 1999 Navistar B250F engine using ULSD fuel.

Engine Exhaust Backpressure and Exhaust Temperature

The engine backpressure for the 1999 Navistar B250F engine was set to 3.4 in. Hg \pm 0.2 in. Hg (11.5 kPa \pm 0. kPa) in accordance with the engine manufacturer specifications for the baseline configuration. The backpressure was adjusted to the same specification after installation of the degreased and aged devices. Maximum backpressure observed during testing, reported in Table 4, did not exceed the manufacturer's specifications.

Temperature measurements were made in the exhaust system of the Navistar engine at the inlet and outlet of the PMF GreenTec 1004205.00.0. Average inlet and outlet temperatures over the transient test cycle were 454 °F (235 °C) and 460 °F (238 °C), respectively.

Maximum values for exhaust backpressure and average values for device inlet and outlet temperatures are shown in Table 4. The inlet and outlet temperatures were measured within 1 inch (2.54 cm) of the flange openings. Figure 4 shows the inlet temperature over time for the degreased device and Figure 5 shows the inlet temperature over time for the aged device. In both figures, the hot-start profile is the average of the three hot-start tests.

Table 4. Engine Exhaust Backpressure and Average Device Inlet/Outlet Temperature

Test Number	Test Type	Test Date	Maximum Exhaust Backpressure		Average Device Inlet Temperature		Average Device Outlet Temperature		
			kPa	in. Hg	°C	°F	°C	°F	
Baseline with ULSD Fuel on a 1999 Navistar B250F Engine									
B250BL-C-3	Cold-start	10/04/06	9.5	2.8	n/a	n/a	n/a	n/a	
B250BL-H-2	Hot-start	10/04/06	9.4	2.8	n/a	n/a	n/a	n/a	
B250BL-H-3	Hot-start	10/04/06	9.4	2.8	n/a	n/a	n/a	n/a	
B250BL-H-4	Hot-start	10/04/06	9.4	2.8	n/a	n/a	n/a	n/a	
Degreened PMF GreenTec DPF with ULSD Fuel on a 1999 Navistar B250F Engine									
08W06/104-C2	Cold-start	10/06/06	8.4	2.5	223.1	433.6	197.7	387.9	
08W06/104-H4	Hot-start	10/06/06	9.2	2.7	238.0	460.4	248.8	479.8	
08W06/104-H5	Hot-start	10/06/06	9.6	2.8	240.3	464.5	251.0	483.8	
08W06/104-H6	Hot-start	10/06/06	9.9	2.9	239.6	463.3	251.7	485.1	
Aged PMF GreenTec DPF with ULSD Fuel on a 1999 Navistar B250F Engine									
01W06/053-C1	Cold-start	10/10/06	8.8	2.6	221.2	430.2	195.6	384.1	
01W06/053-H1	Hot-start	10/10/06	9.1	2.7	234.7	454.5	248.6	479.5	
01W06/053-H2	Hot-start	10/10/06	9.4	2.8	237.0	458.6	251.0	483.8	
01W06/053-H3	Hot-start	10/10/06	9.6	2.8	242.4	468.3	256.9	494.4	

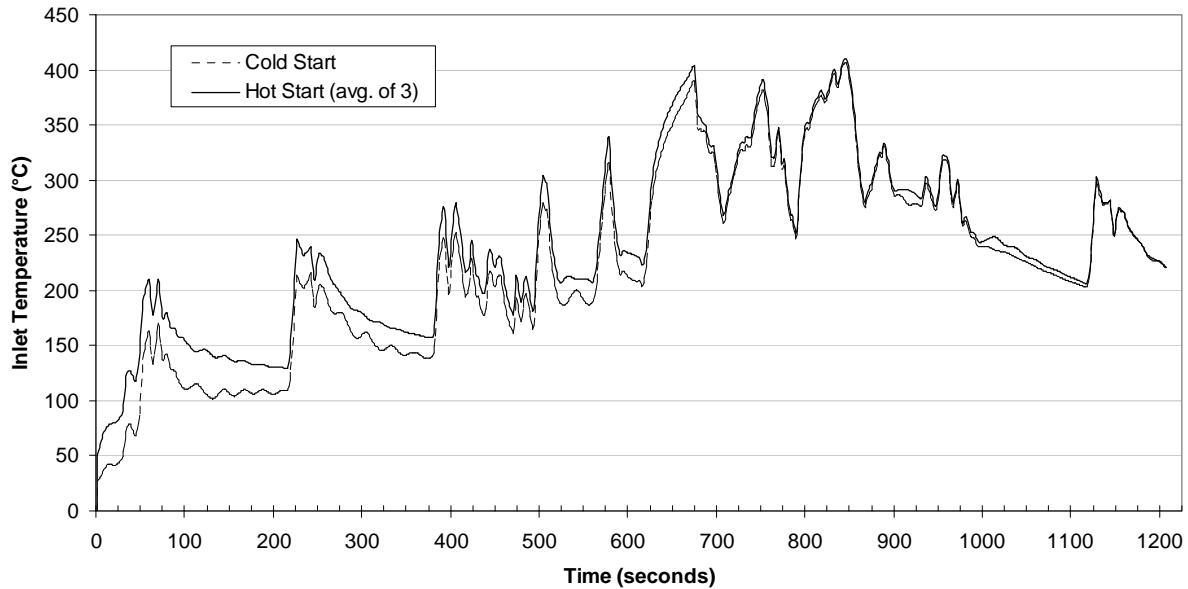


Figure 4. Inlet Temperature Profile of Degreened PMF GreenTec 1004205.00.0.

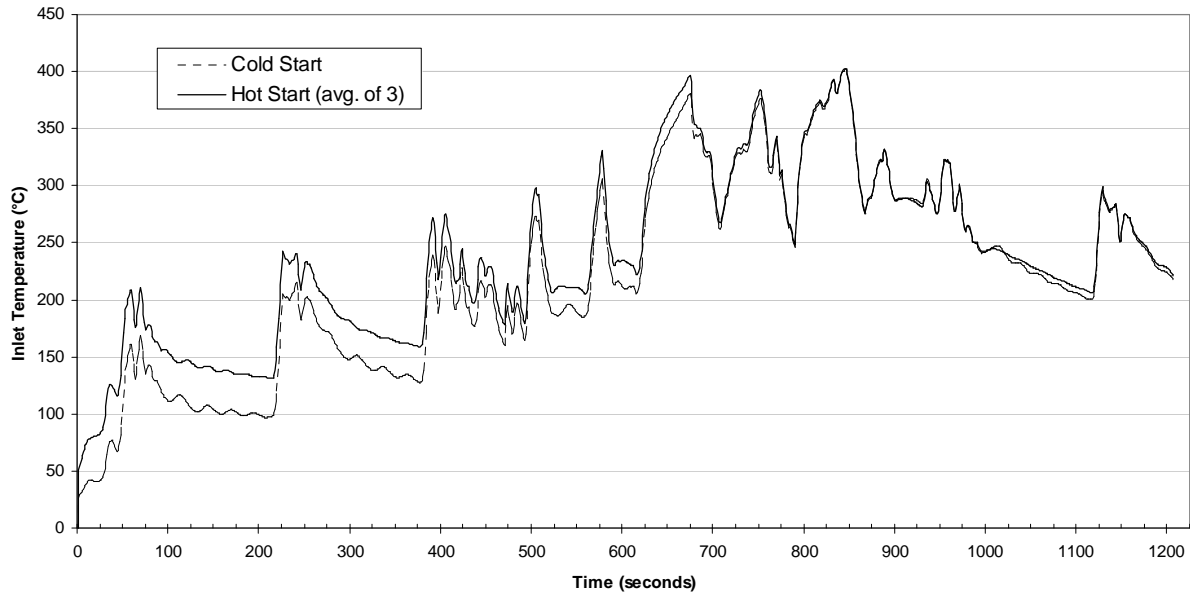


Figure 5. Inlet Temperature Profile of Aged PMF GreenTec 1004205.00.0.

On each test, the particulate material was tested for soluble organic fraction (SOF). Table 5 reports the results.

Table 5. Particulate Characterization — Soluble Organic Fraction (SOF) from Each Test

Test Description	Test Number	PM, g/hp-hr	SOF, % of PM
Baseline Without DPF	B250BL-C3	0.105	45
	B250BL-H2	0.096	28
	B250BL-H3	0.099	31
	B250BL-H4	0.097	32
With Degreened PMF GreenTec DPF	08W06/104-C2	0.014	28
	08W06/104-H4	0.005	91
	08W06/104-H5	0.004	55
	08W06/104-H6	0.005	89
With Aged PMF GreenTec DPF	01W06/053-C1	0.009	39
	01W06/053-H1	0.005	89
	01W06/053-H2	0.004	90
	01W06/053-H3	0.005	93

The fuel consumption was not measured directly during the engine testing. Rather, a calculated “carbon-balance” (C-B) fuel consumption rate was determined based on the measured exhaust flow rate and the carbon content (i.e., the CO and the CO₂) in the exhaust gas analysis. The weighted BSFC calculations are similar to the weighted emissions calculations explained in Section 4.0. Table 6 shows the weighted BSFC calculations. Table 7 summarizes the results of

these calculations and compares the fuel consumption during the baseline runs with that measured during the tests with the PMF GreenTec DPF units installed.

Table 6. Brake-Specific Fuel Consumption (by Carbon Balance)

Test Number	Test Type	Test Date	BSFC		Weighted BSFC	
			lb/bhp-hr	kg/kWh	lb/bhp-hr	kg/kWh
Baseline with ULSD Fuel on a 1999 Navistar B250F Engine						
B250BL-C-3	Cold-start	10/4/2006	0.474	0.288		
B250BL-H-2	Hot-start	10/4/2006	0.457	0.278	0.459	0.279
B250BL-H-3	Hot-start	10/4/2006	0.450	0.274	0.453	0.276
B250BL-H-4	Hot-start	10/4/2006	0.454	0.276	0.457	0.278
Mean					0.456	0.277
Degreened PMF GreenTec DPF with ULSD Fuel on a 1999 Navistar B250F Engine						
08W06/104-C2	Cold-start	10/6/2006	0.471	0.286		
08W06/104-H4	Hot-start	10/6/2006	0.452	0.275	0.454	0.276
08W06/104-H5	Hot-start	10/6/2006	0.448	0.272	0.451	0.274
08W06/104-H6	Hot-start	10/6/2006	0.453	0.275	0.456	0.277
Mean					0.454	0.276
Aged PMF GreenTec DPF with ULSD Fuel on a 1999 Navistar B250F Engine						
01W06/053-C1	Cold-start	10/10/2006	0.439	0.267		
01W06/053-H1	Hot-start	10/10/2006	0.460	0.280	0.457	0.278
01W06/053-H2	Hot-start	10/10/2006	0.440	0.268	0.440	0.267
01W06/053-H3	Hot-start	10/10/2006	0.442	0.269	0.446	0.271
Mean					0.447	0.272

Table 7. Summary of Fuel Consumption Reductions

Device type	Fuel	% Reduction	95% Confidence Limits
Degreened	ULSD	0.56	– ^a
Aged	ULSD	2.0	– ^a

^a The fuel consumption reduction cannot be distinguished from zero with 95% confidence.

Section 4.0 Summary and Discussion of Emission Results

Table 8 reports the emissions from the tests that were conducted: baseline, with a degreened PMF GreenTec DPF installed, and with an aged PMF GreenTec DPF installed. The concentration measurements were converted to units of total grams per test for all species. The “bhp from work” (the integrated measured power during each test period) values are also shown in these tables.

Table 8. Emissions Data

Test Number	Test Type	PM	NO _x	NO	NO ₂ ^a	NO ₂ /NOX	HC	CO	CO ₂	Work
		g					%	g	g	kg
Baseline with ULSD Fuel on a 1999 Navistar B250F Engine										
B250BL-C-3	Cold-start	1.63	66.3	62.3	3.98	6.00	2.99	26.5	10.5	11.6 (15.5)
B250BL-H-2	Hot-start	1.53	60.1	58.3	1.80	3.00	1.09	18.8	10.4	11.8 (15.9)
B250BL-H-3	Hot-start	1.56	60.7	57.0	3.64	6.00	1.20	18.7	10.2	11.7 (15.7)
B250BL-H-4	Hot-start	1.51	60.1	56.5	3.60	6.00	1.57	20.5	10.1	11.6 (15.6)
Degreened PMF GreenTec DPF with ULSD Fuel on a 1999 Navistar B250F Engine										
08W06/104-C2	Cold-start	0.224	63.1	48.0	15.2	24.0	0.373	7.75	10.6	11.7 (15.7)
08W06/104-H4	Hot-start	0.0770	60.2	39.8	20.5	34.0	0.000	2.79	10.2	11.7 (15.7)
08W06/104-H5	Hot-start	0.0700	58.8	39.4	19.4	33.0	0.000	2.02	10.2	11.8 (15.8)
08W06/104-H6	Hot-start	0.0850	59.2	39.7	19.5	33.0	0.000	2.28	10.2	11.7 (15.7)
Aged PMF GreenTec DPF with ULSD Fuel on a 1999 Navistar B250F Engine										
01W06/053-C1	Cold-start	0.137	62.8	47.7	15.1	24.0	0.696	9.25	9.80	11.6 (15.6)
01W06/053-H1	Hot-start	0.0840	58.9	39.5	19.4	33.0	0.000	1.82	10.3	11.7 (15.6)
01W06/053-H2	Hot-start	0.0570	58.4	39.1	19.3	33.0	0.000	1.71	9.88	11.7 (15.6)
01W06/053-H3	Hot-start	0.0770	58.9	38.9	20.0	34.0	0.000	1.82	10.1	11.8 (15.8)

^a NO₂ calculated as NO_x - NO.

For each pollutant/hot-start test combination, the transient composite-weighted emissions per work (bhp-hr) were then calculated following the fractional calculation for highway engines as follows:

$$(E_{COMP})_m = \frac{\frac{1}{7} \cdot E_{COLD} + \frac{6}{7} \cdot (E_{HOT})_m}{\frac{1}{7} \cdot W_{COLD} + \frac{6}{7} \cdot (W_{HOT})_m} \quad (\text{Eq. 1})$$

where

- E_{COMP} = composite emissions rate, g/bhp-hr
- m = one, two, or three hot-start tests
- E_{COLD} = cold-start mass emissions level, g
- E_{HOT} = hot-start mass emissions level, g
- W_{COLD} = cold-start brake horsepower hour, bhp-hr
- W_{HOT} = hot-start brake horsepower hour, bhp-hr.

These composite-weighted emissions rates are shown in Tables 9 and 10 and were used to calculate the mean and standard deviations for the baseline and controlled emissions rates. These data were in turn used to calculate mean emissions reductions and 95% confidence limits. These calculations are based on the generic verification protocol¹ and test/QA plan.²

Table 9. Composite Weighted Emission Rates (U.S. Common Units)

Test Number	Exhaust PM	NO _x	NO	NO ₂ ^a	NO ₂ /NOX	HC	CO	CO ₂
	g/bhp-hr				%	g/bhp-hr		
Baseline with ULSD Fuel on a 1999 Navistar B250F Engine								
B250BL-H-2	0.0976	3.86	3.73	0.134	3.47	0.0862	1.26	658
B250BL-H-3	0.0998	3.91	3.68	0.235	6.00	0.0928	1.26	650
B250BL-H-4	0.0979	3.91	3.68	0.235	6.00	0.114	1.37	654
Degreened PMF GreenTec DPF with ULSD Fuel on a 1999 Navistar B250F Engine								
08W06/104-H4	0.00624	3.86	2.61	1.26	32.5	0.00339	0.223	653
08W06/104-H5	0.00582	3.76	2.57	1.19	31.6	0.00337	0.179	649
08W06/104-H6	0.00670	3.82	2.61	1.21	31.6	0.00340	0.196	655
Aged PMF GreenTec DPF with ULSD Fuel on a 1999 Navistar B250F Engine								
01W06/053-H1	0.00587	3.81	2.60	1.21	31.6	0.00637	0.185	656
01W06/053-H2	0.00438	3.78	2.58	1.20	31.6	0.00637	0.179	632
01W06/053-H3	0.00543	3.78	2.55	1.23	32.5	0.00631	0.183	640

^a NO₂ calculated as NO_x - NO.

Table 10. Composite Weighted Emission Rates (Metric Units)

Test Number	Exhaust PM	NO _x	NO	NO ₂ ^a	NO ₂ /NOX	HC	CO	CO ₂
	g/kWh				%	g/kWh		
Baseline with ULSD Fuel on a 1999 Navistar B250F Engine								
B250BL-H-2	0.131	5.17	5.000	0.180	3.47	0.116	1.69	882
B250BL-H-3	0.134	5.24	4.933	0.315	6.00	0.124	1.69	871
B250BL-H-4	0.131	5.24	4.93	0.315	6.00	0.153	1.84	877
Degreened PMF GreenTec DPF with ULSD Fuel on a 1999 Navistar B250F Engine								
08W06/104-H4	0.00836	5.17	3.50	1.69	32.5	0.00454	0.299	875
08W06/104-H5	0.00780	5.04	3.45	1.60	31.6	0.00452	0.240	870
08W06/104-H6	0.00898	5.12	3.50	1.62	31.6	0.00456	0.263	878
Aged PMF GreenTec DPF with ULSD Fuel on a 1999 Navistar B250F Engine								
01W06/053-H1	0.00787	5.11	3.49	1.62	31.6	0.00854	0.248	879
01W06/053-H2	0.00587	5.07	3.46	1.61	31.6	0.00854	0.240	847
01W06/053-H3	0.00728	5.07	3.42	1.65	32.5	0.00846	0.245	858

^a NO₂ calculated as NO_x - NO.

The mean composite weighted emission rates from Tables 11 and 12 are the key values for the verification test. Table 13 summarizes that information. The first line shows the baseline engine results; the emissions in all categories are below the Table 3 threshold.

Table 11. Summary of Verification Test Data (U.S. Common Units)

Device type	Fuel	Mean Composite Weighted Emission Rate				
		PM	NO _x	HC	CO	CO ₂
		g/bhp-hr				
Baseline	ULSD	0.0984	3.90	0.0976	1.30	654
Degreened	ULSD	0.00625	3.81	0.00339	0.199	653
Aged	ULSD	0.00523	3.79	0.00635	0.182	643

Table 12. Summary of Verification Test Data (Metric Units)

Device type	Fuel	Mean Composite Weighted Emission Rate				
		PM	NO _x	HC	CO	CO ₂
		g/kWh				
Baseline	ULSD	0.132	5.22	0.131	1.74	877
Degreened	ULSD	0.00839	5.11	0.00455	0.267	875
Aged	ULSD	0.00711	5.15	0.00864	0.248	875

Table 13 summarizes the emissions reductions that were achieved by the use of the PMF GreenTec DPF. These are the “verified emissions reductions” reported in Table 2 of the ETV Joint Verification Statement.

Table 13. Summary of Verification Test Emission Reductions

Device type	Fuel	Mean Emissions Reduction (%)				95% Confidence Limits on the Emissions Reduction (%)			
		PM	NOx	HC	CO	PM	NOx	HC	CO
Degreened	ULSD	94	2.1	97	85	91 to 97	– ^a	– ^b	73 to 97
Aged	ULSD	95	2.8	93	86	92 to 98	1.1 to 4.4	– ^b	74 to 98

^a The emission reduction cannot be distinguished from zero with 95% confidence.

^b The emissions reduction could not be quantified or distinguished from 100% with 95% confidence.

4.1 Quality Assurance

The environmental technology verification of the PMF GreenTec 1004205.00.0 with ULSD fuel for heavy-duty highway diesel engines was performed in accordance with the approved test/QA plan and the test-specific addendum.² An audit of data quality included the review of equipment, personnel qualifications, procedures, record keeping, data validation, analysis, and reporting. Preliminary, in-process, and final inspections, and a review of 10% of the data showed that the requirements stipulated in the test/QA plan⁵ were achieved. The SwRI, APCT Center, and EPA quality managers reviewed the test results and the QC data and concluded that the data quality objectives given in the generic verification protocol were attained. EPA and RTI QA staff conducted audits of SwRI's technical and quality systems in April 2002 and found no deficiencies that would adversely impact the quality of results. The equipment was appropriate for the verification testing, and it was operating satisfactorily. SwRI's technical staff was well qualified to perform the testing and conducted themselves in a professional manner.

Section 5.0 References

1. RTI International. 2002. *Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*. Research Triangle Park, NC, January. Available: http://www.epa.gov/etv/pdfs/vp/05_vp_devrev.pdf
2. RTI International. 2006. *Test-Specific Addendum to ETV Mobile Source Test/QA Plan for PUREM North America, LLC for the PMF GreenTec Diesel Particulate Filter*. Research Triangle Park, NC, August 9.
3. Southwest Research Institute. 2006. *Environmental Technology Verification of PMF GreenTec Diesel Particulate Filter*. Final Report. San Antonio, TX, November.
4. Southwest Research Institute. 2006. *Audit of Data Quality for Environmental Technology Verification of PMF GreenTec Diesel Particulate Filter*. San Antonio, TX, November.
5. RTI International. 2002. *Test/QA Plan for the Verification Testing of Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*. Research Triangle Park, NC, April. Available: http://www.epa.gov/etv/pdfs/vp/05_tp_diesel.pdf.
6. 40 CFR §86.1313-2007 (Protection of Environment: Control of Emissions from New and In-Use Highway Vehicles and Engines, Fuel Specifications), Table N07-2. Available: <http://www.epa.gov/epahome/cfr40.htm> (updated September 6, 2006).
7. 40 CFR, Part 86 (Protection of Environment: Control of Emissions from New and In-Use Highway Vehicles and Engines), Subpart N.
8. RTI International. 2003. *Generic Verification Protocol for Determination of Emissions Reductions from Selective Catalytic Reduction Control Technologies for Highway, Nonroad, and Stationary Use Diesel Engines*. Research Triangle Park, NC, September. Available: http://www.epa.gov/etv/pdfs/vp/05_vp_emissions.pdf.