SRI/USEPA-GHG-QAP-39
December 2004

Test and Quality Assurance Plan

White Sands, LLC. - CleanBoost Combustion Catalyst Diesel Fuel Additive

Prepared by:

Greenhouse Gas Technology Center
Southern Research Institute

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

EPA REVIEW NOTICE

This report has been peer and administratively reviewed by the U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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A U.S. EPA Sponsored Environmental Technology Verification (ETV) Organization

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This Test and Quality Assurance Plan has been reviewed and approved by the Greenhouse Gas Technology Center Project Manager and Center Director, the U.S. EPA APPCD Project Officer, and the U.S. EPA APPCD Quality Assurance Manager.

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Test Plan Final: December 2004

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List of Acronyms and Abbreviations

ADQ	audit of data quality
APPCD	Air Pollution Prevention and Control Division
Bhp-hr	brake horsepower-hour
BSFC	brake specific fuel consumption
CFR	Code of Federal Regulations
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
COV	coefficient of variation
CVS	constant volume sampling
DEER	Department of Engine and Emissions Research
DQIG	data quality indicator goals
DQO	data quality objective
EPA-ORD	Environmental Protection Agency Office of Research and Development
ETV	Environmental Technology Verification
Fe	iron
FS	full scale
FTP	Federal Test Procedure
GHG Center	Greenhouse Gas Technology Center
GVP	ETV Generic Verification Protocol
NIST	National Institute of Standards and Technology
NO_2	nitrogen dioxide
NO_X	blend of NO, NO_2, and other oxides of nitrogen
PEA	performance evaluation audit
PM	particulate matter
PM2.5	particulate matter with diameter of 2.5 microns or less
ppmv	parts per million by volume
QA/QC	quality assurance / quality control
QMP	quality management plan
QPP	quality policy and procedures
QSM	quality systems manual
SOP	standard operating procedure
SwRI	Southwest Research Institute
THC	total hydrocarbons (as carbon)
TQAP	test and quality assurance plan
TSA	technical systems audit

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1.0 INTRODUCTION

1.1 BACKGROUND

The U.S. Environmental Protection Agency's Office of Research and Development (EPA-ORD) operates the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The ETV program's goal is to further environmental protection by substantially accelerating the acceptance and use of improved and innovative environmental technologies. Congress funds ETV in response to the belief that there are many viable environmental technologies that are not being used for the lack of credible third-party performance data. The performance data developed under this program will allow technology buyers, financiers, and permitters in the United States and abroad to make more informed decisions regarding environmental technology purchase and use.

The Greenhouse Gas Technology Center (GHG Center) is one of six ETV organizations. EPA's partner verification organization, Southern Research Institute (Southern), manages the GHG Center. The GHG Center conducts verification testing of promising GHG mitigation and monitoring technologies. It develops verification protocols, conducts field tests, collects and interprets field and other data, obtains independent peer-review input, and reports findings. The GHG Center conducts performance evaluations according to externally reviewed verification Test and Quality Assurance Plans (TQAPs) and established protocols for quality assurance (QA).

Volunteer stakeholder groups guide the GHG Center's verification activities. These stakeholders advise on specific technologies most appropriate for testing, help disseminate results, and review TQAPs and technology Verification Reports. National and international environmental policy, technology, and regulatory experts participate in the GHG Center's Executive Stakeholder Group. The group also includes industry trade organizations, environmental technology finance groups, governmental organizations, and other interested parties. Industry-specific stakeholders peer-review key documents prepared by the GHG Center and provide verification testing strategy guidance in those areas related to their expertise.

One sector of significant interest to GHG Center stakeholders is transportation - particularly technologies that result in fuel economy improvements. The Department of Energy reports that in 2001, "other trucks" (all trucks other than light-duty trucks) consuming diesel fuel emitted approximately 72.5 million metric tons of carbon dioxide (CO_2). These emissions increase to 107.5 million metric tons when considering all diesel vehicles in the transportation sector. Small fuel efficiency or emission rate improvements are expected to have a significant beneficial impact on nationwide greenhouse gas emissions.

White Sands, LLC. of Bluffdale, Utah markets the CleanBoost combustion catalyst, a fuel additive that can be used in mid to heavy duty diesel engines as well as various other applications fueled with biodiesel and heating oil. The CleanBoost additive can act as a detergent in older engines removing carbon deposits and improving performance, and can catalytically improve fuel combustion in newer engines. According to White Sands, improved fuel economy and reduced emissions are the primary benefits of using this technology.

White Sands wishes to verify performance of the CleanBoost technology for reductions in fuel consumption and emissions on a heavy-duty diesel engine. CleanBoost is a suitable verification candidate considering its potentially significant beneficial environmental quality impacts and ETV stakeholder interest in verified transportation sector emission reduction technologies.

This test will be conducted following guidelines provided in a ETV Generic Verification Protocol (GVP) developed by the Air Pollution Control Technology Verification Center: *"Environmental Technology Verification Protocol – Determination of Emissions Reductions Obtained by Use of Alternative or Reformulated Liquid Fuels, Fuel Additives, Fuel Emulsions, and Lubricants for Highway and Nonroad Use Diesel Engines and Light Duty Gasoline Engines and Vehicles"*. The GVP makes use of the Federal Test Procedure (FTP) as listed in 40 CFR Part 86 for highway engines as a standard test protocol to evaluate fuel modifications (FMs). This verification will include evaluation of the CleanBoost technology as an immediate-effect FM only and will not include evaluation as a cumulative-effect FM. Performance will be assessed using the GVP test sequence by comparing the fuel consumption and emission rates measured on a heavy-duty test engine before and after application of the CleanBoost additive. Verification testing will be directed by the GHG Center. The tests will take place at Southwest Research Institute's (SwRI) Department of Engine and Emissions Research (DEER) in San Antonio, TX. The test program is described in the following sections. Any deviations from the GVP are noted in Section 13 of this TQAP.

This TQAP specifies verification parameters and the rationale for their selection. It contains the verification approach, data quality objectives (DQOs), and Quality Assurance/Quality Control (QA/QC) procedures. It will also guide test implementation, document creation, data analysis, and interpretation.

This TQAP has been reviewed by White Sands, SwRI, and the EPA-ETV QA Manager. The EPA-APPCD Project Officer provided final approval of the TQAP. The TQAP meets the requirements of the GHG Center's Quality Management Plan (QMP) once approved and signed by the responsible parties listed on the front of this document. The TQAP is available on GHG Center internet site at www.sri-rtp.com and the ETV program site at www.epa.gov/etv.

The GHG Center will prepare a verification report and verification statement upon field test completion. The same organizations listed above will review the verification report and statement, followed by EPA-ORD technical review. The GHG Center Director and EPA-ORD Laboratory Director will sign the verification statement when this review is complete and the GHG Center will post the final documents as described above.

1.2 SWRI TESTING QUALIFICATIONS

The GHG Center has selected SwRI to conduct the testing for this verification. The following describes the accreditations and registrations of SwRI relevant to this TQAP.

The SwRI DEER is registered to International Organization for Standardization 9002 "Model for Quality Assurance in Production and Installation." This independently assessed quality system provides the basis for quality procedures that are applied to every project conducted in the DEER. DEER is accredited to ISO/IEC Guide 25 "General Requirements for the Competency of Calibration and Testing Laboratories" and EN 45001, "General Criteria for the Operation of Test Laboratories." The American Association for Laboratory Accreditation Certificate Number 0702-01 accredits DEER to perform evaluations of automotive fluids, fuel emissions, automotive components, engine and power-train performance and durability using stationary engine dynamometer test stands (light-duty, non-road, and heavy-duty) and vehicle dynamometer facilities, and automotive fleets (see http://www.a2la2.net/scopepdf/0702-01.pdf). The certificate accredits DEER to use specific standards and procedures, including dynamometer procedures for hydrocarbons, carbon monoxide, oxides of nitrogen, and particulate matter. DEER has also: (1) achieved Ford Tier 1 status for providing engineering services, (2) received the Ford Q1 Quality Award and the Ford Customer-Driven Quality Award, and (3) maintains its status as a Caterpillar-certified supplier.

For prior ETV tests, EPA has reviewed the DEER quality system and verified that the information conforms to the specific required elements of the [*EPA Requirements for Quality Assurance Project Plans]*, the ETV QMP, and the general requirements of the GVP.

1.3 ORGANIZATION OF THIS TQAP

This TQAP addresses ETV technology testing at SwRI under the applicable GVPs. It is deliberately organized to parallel the structure of EPA QA/R-5. Since all laboratory data will be generated by SwRI, much of this TQAP also parallels the SwRI *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 (Version 1.0, April 8, 2002; SwRI QPP)* which was developed based on the GVPs. The referenced SwRI QPP was developed for ETV testing under the current GVPs and is posted on the ETV website. Differences between the SwRI QPP and this TQAP reflect organizational differences and the specific role of the GHG center as the verification organization on this test. This TQAP also contains test-specific details of the CleanBoost technology, its implementation, verification parameters, schedule, and test design. These details are generally inserted in the appropriate sections of the main text rather than in a test-specific attachment to the existing SwRI QPP.

This TQAP also describes testing under the framework of the GVPs and the relevant FTP (from 40 CFR 86 Subpart N for highway engines), and both documents will be cited as applicable by reference where such citation is clear. This TQAP also describes how the FTP will be specifically implemented for this verification.

1.4 REFERENCED SWRI QUALITY DOCUMENTS

Several relevant internal SwRI documents will be incorporated by reference in this TQAP, including the (1) DEER Quality System Manual (QSM), (2) Quality Policy and Procedures (QPPs), and (3) Standard Operating Procedures (SOPs). These internal quality documents, unlike the GVP and FTP references, are considered proprietary to SwRI and are not publicly available. However, they will be made available for review during the on-site assessment of the DEER technical and quality systems, and for test-specific on-site audits by the GHG or EPA QA personnel. Several of the referenced SOPs were previously reviewed by GHG Center staff as part of a previous verification test and found adequate by the GHG Center QA manager as discussed in the TSA report for that test. Certain sections of this document reference specific SwRI quality documents that describe DEER's conformance with specific QPP-required elements. These references do not supersede the applicable GVPs and FTP citations, but are included to document the specific implementations of these directions by SwRI staff.

2.0 TEST DESCRIPTION AND TEST OBJECTIVES

2.1 TECHNOLOGY DESCRIPTION

The CleanBoost combustion catalyst is a diesel fuel additive that can be used in heavy duty diesel engines used in the transportation sector, as well as various other applications using diesel, biodiesel, and heating oil. CleanBoost consists of organo-ferrous compounds in a petroleum solvent (naphtha) base. The additive performs several functions, according to White Sands. In older engines, the additive can have a detergent effect, removing carbon soot deposits in the engine, thus improving engine performance. In well-maintained engines, the additive acts catalytically to improve the fuel combustion. White Sands claims that the catalytic action helps break down long chain hydrocarbons into smaller, more readily combustible molecules, lowers the temperature of combustion, provides more complete combustion, and reduces soot formation and buildup. The additive is utilized at a mixing ratio of 1:3000, and requires a short break in time to obtain the full effect in most engines due to the detergent action of the additive. White Sands claims that enhanced fuel economy and reduced emissions are the benefits of using this technology.

The technology was tested in May 2004 by SwRI using the SAE J1321 fuel consumption test procedure. Results of the testing indicate an average 3% increase in fuel economy resulting from the use of the CleanBoost additive on a diesel long-haul truck. Additional testing and case studies indicate emission reductions from use of CleanBoost on the order of 20% for CO and 14% for hydrocarbons. Reductions in opacity and particulate emissions have also been observed, with no increases in NO_X emissions. Case studies on use of CleanBoost with biodiesel blends have indicated significant reductions in NO_X emissions.

2.2 TEST DESCRIPTION

2.2.1 Overview

This TQAP describes testing of the CleanBoost technology following the guidelines detailed in the previously referenced GVPs. Section 5.1 of the fuel additives GVP provides a detailed analysis of test design and data analysis for fuel modification technologies. In it, the inadequacy of a simple comparison of a baseline test with tests conducted with treated fuels is described. Specifically, the GVP describes how an ETV test for fuel modifications must be designed to evaluate emission reductions with a likely changing baseline emissions profile. To address this, the GVP provides test sequences between base fuels and treated fuels. The test sequences vary according to fuel additive type and purpose, but in general require a series of baseline tests, followed by a series of tests with treated fuel, followed by a second series of baseline tests.

This general approach was used by the GHG Center previously on a similar verification (Test and Quality Assurance Plan—ConocoPhillips Fuel-Efficient High-Performance SAE 75W90 Rear Axle Gear Lubricant, SRI/USEPA-GHG-VR-29) and will be followed for this verification. During the previous verification, baseline fuel economy testing was conducted before and after the testing conducted with the candidate technology (in that case, an axle lubricant). In general, test results from the before and after baseline tests were used to develop a normalized baseline fuel economy, which was then compared to fuel economy achieved with the candidate technology. This approach will be used for this verification to evaluate changes in engine emissions and fuel economy attributable to CleanBoost. Appendix B provides a detailed description of this approach and how this analysis was conducted for the previous verification.

During this verification, the exhaust from the engine will be analyzed for emissions of NO_X, PM, PM2.5, THC, CO, CO_2, CH_4, and Fe (since CleanBoost contains ferrous compounds). Additional measurements and calculations will be used to determine fuel economy of the engine over a specified test cycle. The test procedure will consist of the following, at a minimum, based on the requirements of 40 CFR 86 Subpart N (detailed descriptions of each test phase are provided in Sections 2.2 through 2.4):

1. Install test engine on dynamometer, change engine fluids and stabilize.
2. Flush fuel system and operate the test engine for 25 hours on ULSD reference diesel fuel.
3. Perform engine mapping and preconditioning, followed by an overnight soak.
4. Complete heavy-duty transient FTP cycles consisting of one cold-start and three hot-start tests each. Sample engine exhaust.
5. Evaluate the engine operational parameters, emissions, and fuel consumption.
6. Complete additional FTP cycles as needed to improve data quality and credibility.
7. Prepare CleanBoost treated reference fuel at recommended dosage rate.
8. Flush fuel system and operate the test engine for 25 hours on treated fuel.
9. Perform engine mapping and preconditioning, followed by an overnight soak.
10. Complete heavy-duty transient FTP cycles consisting of one cold-start and three hot-start tests each. Sample engine exhaust.
11. Evaluate the engine operational parameters, emissions, and fuel consumption.
12. Complete additional FTP cycles as needed to improve data quality.
13. Change engine fluids and flush fuel system and operate the test engine for 25 hours on baseline reference fuel.
14. Perform engine mapping and preconditioning, followed by an overnight soak.
15. Complete heavy-duty transient FTP cycles consisting of one cold-start and three hot-start tests each. Sample engine exhaust.
16. Evaluate the engine operational parameters, emissions, and fuel consumption.
17. Complete additional FTP cycles as needed to improve data quality.
18. Evaluate baseline and treated fuel test results for statistically significant changes in operational parameters, emission rates, and fuel consumption.
19. Evaluate data quality as specified in this test plan.

The verification test generally requires operation of a test engine on an engine dynamometer. The engine dynamometer simulates operating conditions of the engine by applying loads to the engine and measuring the amount of power that the engine can produce against the load. The engine is operated on the dynamometer over a simulated duty cycle that mimics a typical on-road heavy-duty vehicle. This is the "transient" cycle heavy-duty FTP specified in 40 CFR 86.1333.

Exhaust emissions from the engine are collected through a constant volume sampling (CVS) system and then analyzed to determine emission concentrations. An adjustable-speed turbine blower in the CVS dilutes the exhaust with ambient air while the vehicle operates on the dynamometer. This dilution prevents the exhaust moisture from condensing and provides controllable sampling conditions. A sample pump and a control system transfers diluted exhaust to emission analyzers, sample bags, or particulate sampling systems (filters). Samples are collected at constant sampling rates.

During each test run, the following parameters are measured:

Dynamometer Operations:

- Speed
- Torque (load)
- Test cell temperature, humidity, and pressure

Constant Volume Sampling System Conditions:

- System pressure and temperature
- Volumetric flow rate

Engine exhaust components:

- CO, CO_2, NO_X, and THC concentrations
- PM, PM2.5, and Fe concentrations

2.3 TEST ENGINE AND FUEL SELECTION AND SPECIFICATIONS

2.3.1 Test Engine

The diesel engine to be used in this test program is a Cummins ISB 305 turbocharged engine manufactured in 2004. This engine was selected for testing because it represents a large segment of heavy-duty diesel engines currently on the road for which the CleanBoost technology is intended. CleanBoost will also be applicable to other types of heavy duty diesel engines. The test engine is located at the SwRI facility and SwRI has verified that the engine is new and is operating reasonably within original OEM specifications.

The ISB 305 is a 5.9 liter displacement inline six-cylinder diesel engine. The engine is rated at 305 brake horsepower (bhp) at 2900 rpm and has a peak torque of 600 lb-ft at 1600 rpm. Prior to this verification test, the engine will be used for the CleanBoost fuel additive testing required under Section 211(b) of the Clean Air Act. As part of the requirements of the 211(b) test, the engine will be operated for a duration of 125 hours for engine break-in.

2.3.2 Test Fuel

Testing will use certified ultra low sulfur diesel (ULSD) test fuel with sulfur content below 15 ppm. This reference fuel was selected because, with future ULSD mandates looming, it represents a potential majority of the intended CleanBoost market. With the exception of low sulfur content, this fuel has the same properties of EPA standard No.2 diesel. SwRI will provide the ULSD for this test, along with a certificate of analysis. The GHG Center will review fuel analyses and verify the fuel to be within specifications before the start of testing.

2.4 BASELINE ENGINE PREPARATION

2.4.1 Engine Oil Change

At the conclusion of the Section 211(b) testing, the engine's oil will be changed prior to baseline testing using the standard manufacturer oil change procedure. This ensures that the engine oil will not impact the performance of the engine from the baseline to treated fuel test. A suitable grade of engine oil will be used based on manufacturer specifications.

The technicians performing this maintenance will document the oil changes, including the date and quantity and type of oil used. Documentation will be signed by the technicians and copies provided to the field team leader. The same engine oil will be used throughout the initial baseline and treated fuel testing. Prior to the final baseline testing (after completion of the testing with treated fuel) a second oil change will be conducted to minimize baseline engine drift.

2.5 FUEL MODIFICATION WITH THE CLEANBOOST TECHNOLOGY

The test fuel will be treated by administering the CleanBoost fuel additive to the baseline ULSD reference fuel after baseline testing is complete. A White Sands representative will be present to confirm that proper additive dosing is performed, that the proper break-in is completed, and to provide oversight and consultation during the administering of the CleanBoost technology. Flushing of the engine with treated fuel will begin after White Sands approves the CleanBoost dosing. All dosing and additive administration activities will be decided the GHG Center field team leader.

2.6 ENGINE TESTING PROCEDURES

The test engine will be installed on the engine dynamometer after engine preparations are completed. The engine test procedure is described in the following sections.

2.6.1 Break-in Periods

The baseline engine will go through a break-in period to ensure proper break-in of the new engine oil and sufficient flushing with the baseline reference fuel. This allows the engine to stabilize and eliminates any effects of oil break-in or previous fuel carryover on engine performance. A break-in period of 25 hours is specified here since only fresh oil is added to the engine and no other mechanical changes will be performed on the baseline engine.

Break-in is completed by operating the engine at specified conditions for a specified time period. The cycle operates at various engine conditions, including idle, peak torque, rated speed, and high idles. The actual break-in time for the baseline tests will be documented by SwRI.

After the baseline testing is completed and the fuel additive is administered, a second 25-hour break-in period will be conducted to fully flush the baseline fuel from the test engine and to stabilize engine operation on the treated fuel. The actual break-in time, operating conditions, and test cycle will be documented by SwRI. The break-in/flushing process will be repeated a third time using reference baseline fuel after completion of the testing with the treated fuel (before starting the second set of baseline tests).

2.6.2 Engine Mapping

Engine mapping is completed to generate a torque curve for the test engine by running the engine at full throttle at increasing engine speed from curb idle through the manufacturer's rated speed. The engine torque is measured at each speed. The torque curve is subsequently used to generate data for the transient test cycle for that specific engine. The engine mapping procedure follows the procedure specified at 40 CFR 86 Subpart N, Sections 86.1332 and 86-1333.

Engine mapping will be completed after the break-in procedure is completed for both the baseline and treated fuels. The baseline map obtained will be compared to the manufacturer-specified engine map. Significant differences between the two maps will be investigated. Corrective actions will be implemented once the cause of the discrepancy is identified. The required corrective action will be completed prior to accepting the engine for further testing. The engine may be labeled as unacceptable for the test if fundamental problems with the engine are identified based on the engine map. A new test engine would then be located.

In order to allow a fair comparison of engine performance with the baseline and treated fuels, the torque curve developed during the baseline mapping will be used to develop the FTP duty cycle for all testing periods. Mapping results will be reported for both the baseline and treated test fuels so that potential users can see changes in engine performance using the treated fuel (e.g., power output may be different with the modified fuel at the same engine speed levels as the baseline fuel).

2.6.3 Test Cycle

The test engine is operated on the dynamometer over the transient heavy-duty FTP driving cycle the specified in 40 CFR 86.1333 that simulates the operation of a typical on-road heavy-duty vehicle. The FTP cycle takes into account the operation of a variety of heavy-duty trucks and buses, and includes simulation of traffic on roads and expressways in and around cities. The average speed is about 30 km/h and the equivalent distance traveled is 10.3 km. The cycle lasts 1200 s [dieselnet: http://www.dieselnet.com/standards /cycles/ftp_trans.html].

The test cycle is specified as a normalized cycle. The data points specified in the FTP are the percent of maximum torque and speed over time. The specific transient cycle for the test engine is calculated based on these values and the engine mapping values. One complete FTP cycle consists of two test segments. The first is a "cold-start test" completed after the engine has been "soaked" (not operating) for a specified time period (overnight). The second period is a "hot-start" test. This is the same cycle as the cold start test, begun 20 minutes after the completion of the cold-start test, while the engine is still "hot".

The specific FTP cycle used for both the baseline and treated engines will be calculated for this verification test using the initial baseline engine mapping results. This ensures that identical test cycles are utilized.

Testing of each engine configuration will consist of a single cold-start test, followed by the required 20-minute soak period, and a minimum of three subsequent hot-start tests. A 20-minute soak period is required between each hot-start test.

2.6.4 Engine Preconditioning

The test engine will be preconditioned after engine mapping is completed. Preconditioning is completed by running the engine through the FTP test cycle that it will be seeing for the actual test procedure. Both the baseline and treated engine will be preconditioned for this test by running the engine through the transient FTP cycle three times. The transient cycles, each 20 minutes long, are run concurrently without any intermittent soak period. Once the preconditioning runs are completed, the engine is turned off and allowed to “soak” overnight. The length of the soak period between the end of preconditioning and beginning of test runs will be recorded and will be approximately the same for both the baseline and treated test engine.

2.6.5 Emissions and Fuel Consumption Testing

The emissions and fuel consumption tests will be completed after the overnight soak following the preconditioning runs. The test runs will consist of operating the test engine over the specified FTP test cycle for one cold-start test, and a minimum of three hot-start tests for both the baseline and treated engine. Additional hot-start tests may be added depending on the data quality of the initial test runs and upon agreement between all parties and funding agencies involved in the test campaign. Total minimum test duration is two hours and twenty minutes, consisting of one cold-start test, three hot-start tests, and three soak periods.

The composite brake-specific fuel consumption (BSFC) evaluated during the test is a measure of engine efficiency and is a primary verification parameter for this test series. BSFC is the ratio of the engine fuel consumption to the engine power output and has units of grams of fuel per kilowatt-hour (g/kWh) or pounds mass of fuel per brake horsepower-hour (lb/Bhp-hr). The calculation of composite BSFC is shown at 40 CFR 86.1342-90. The equation and supporting parameters are:

$$BSFC = \frac{\frac{1}{7}(M_c) + \frac{6}{7}(M_h)}{\frac{1}{7}(Bhp - hr_c) + \frac{6}{7}(Bhp - hr_h)} \qquad \text{Equation 1}$$

where:

BSFC = brake-specific fuel consumption in pounds of fuel per brake horsepower-hour, lbs/Bhp-hr

M_c = mass of fuel used by the engine during the cold start test, lbs

M_h = mass of fuel used by the engine during the hot start test, lbs

$Bhp\text{-}hr_c$ = total brake horsepower-hours (brake horsepower integrated with respect to time) for the cold start test

$Bhp\text{-}hr_h$ = total brake horsepower-hours (brake horsepower integrated with respect to time) for the hot start test

The Bhp-hr values for each test are calculated using the engine torque and speed data measured on the dynamometer. The mass of fuel, M, used during each test is calculated via a carbon balance method using the emission rates and fuel properties determined during testing. These rather complex calculations are specified in 40 CFR 86.1342-90 and not repeated here. Generally, the calculations rely on the measured engine exhaust mass emissions of THC, CO, and CO_2 and the measured test fuel carbon weight fraction, specific gravity, and net heating value.

These fuel properties are cited on the fuel certificate of analyses and are determined using the following methods:

- Specific gravity – ASTM D1298
- Carbon weight fraction – ASTM D3343
- Net heating value – ASTM D3348

During the previous ConocoPhilips verification, separate volumetric and gravimetric cross-checks were conducted on the fuel consumption determinations. Specifically, fuel consumption was determined volumetrically and gravimetrically during each test for comparison with the carbon balance fuel consumption determinations. The test and quality assurance plan (SRI/EPA-GHG-QAP-28) specified that a coefficient of variation (COV) of greater than ±0.3 would indicate a potential bias in the carbon balance method. Results presented in the verification report (SRI/EPA-GHG-VR-29) showed that the COVs averaged 0.15 for both the volumetric and gravimetric checks. Both cross-checks had absolute differences higher than the carbon balance method (average 0.16 and 0.23 mpg higher for the volumetric and gravimetric checks, respectively), but since both were consistently high and the COVs were favorable, no further investigations were conducted. Since the same carbon balance procedures and instrumentation will be used for this verification, these cross-checks will not be repeated here.

Engine exhaust gas will be analyzed during each test to determine mass emissions of NO_x, PM, PM2.5, THC, CO, CO_2, CH_4, and Fe. Engine and dynamometer operating conditions will be recorded. Sampling system, emission analyzer, and test cell operations will also be monitored.

Each test run will be followed by evaluation of data quality in accordance with the requirements of Section 3. Achievement of all data quality indicator goals and FTP requirements will allow the field team leader to declare a run valid. A test run where required data quality indicator goals are not met will cause the test run to be invalidated and repeated immediately (if a hot-start).

2.7 TEST ORGANIZATION AND RESPONSIBILITIES

Project management responsibilities are divided among the EPA, Southern, and SwRI staff as shown in Figure 2-1 and described in the following sections.

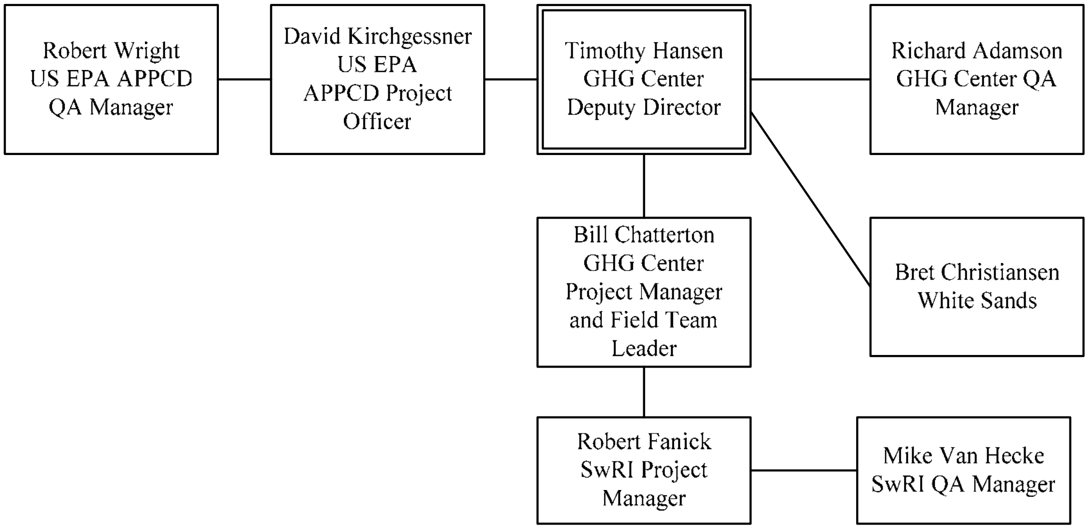

Figure 2-1. Project Organization

2.7.1 EPA

2.7.1.1 Project Management

The EPA Project Manager, David Kirchgessner, has overall EPA responsibility for the GHG Center. He is responsible for obtaining EPA's final approval of project TQAPs, and the verification statement and report from the ORD Director and the ETV Program Manager.

2.7.1.2 Quality Manager

The EPA Quality Manager for the GHG Center is Robert Wright of EPA's Air Pollution Prevention and Control Division (APPCD). His responsibilities include:

- Communicate quality systems requirements, quality procedures, and quality issues to the EPA Project Manager and the GHG Project Manager;
- Review and approve GHG Center quality systems documents to verify conformance with the quality provisions of the ETV quality systems documents;
- Conduct performance evaluations and audits of verification tests, as appropriate;
- Provide assistance to GHG Center personnel in resolving QA issues;
- Review and approve this TQAP;
- Review and approve the verification report and statement for each technology tested under this TQAP; and

2.7.2 Southern Research Institute

2.7.2.1 GHG Center Deputy Director

Southern's GHG Center has overall planning responsibility and will ensure successful verification test implementation. The GHG Center will:

- coordinate all activities;
- develop, monitor, and manage schedules; and
- ensure the achievement of high-quality independent testing and reporting.

Mr. Timothy Hansen is the GHG Center Deputy Director. He will ensure that staff and resources are sufficient and available to complete this verification. He will review the TQAP to ensure consistency with ETV operating principles. He will oversee GHG Center staff activities and provide management support where needed. Mr. Hansen will sign the verification statement along with the EPA-ORD Laboratory Director.

2.7.2.2 GHG Center Project Manager

Mr. Bill Chatterton will serve as the Project Manager for the GHG Center. His responsibilities include:

- drafting the TQAP and verification report;
- overseeing the field team leader's data collection activities, and
- ensuring data quality objectives (DQOs) are met prior to completion of testing.

The project manager will have full authority to suspend testing should a situation arise that could affect the health or safety of any personnel. He will also have the authority to suspend testing if the DQIGs described in Section 3.0 are not being met. He may resume testing when problems are resolved in both cases. He will be responsible for maintaining communication with White Sands, SwRI, EPA, and stakeholders.

2.7.2.3 GHG Center Field Team Leader

Mr. Chatterton will also serve as the Field Team Leader. He will supervise all SwRI testing activities to ensure conformance with the TQAP. Mr. Chatterton will assess test data quality and will have the authority to repeat tests as determined necessary to ensure achievement of data quality goals. He will perform on-site activities required for data quality audits under the direction of the GHG Center QA Manager and perform other QA/QC procedures as described in Section 3.0. He will also communicate with the SwRI Program and Quality Managers to coordinate the internal audit activities of the SwRI Quality Manager with those of the GHG Center. Mr. Chatterton will communicate test results to the deputy director at the completion of each test run. The field team leader and deputy director will then determine if sufficient test runs have been conducted to report statistically valid fuel economy improvements.

2.7.2.4 GHG Center Quality Manager

Southern's QA Manager, Mr. Richard Adamson, is responsible for ensuring that all verification tests are performed in compliance with the QA requirements of the GHG Center QMP, GVPs, and TQAP. He has review this TQAP. He has reviewed the applicable elements of the SwRI Quality System and approved the quality requirements for implementation by SwRI technical and quality staff on this test. He will also review the verification test results and ensure that applicable internal assessments are conducted as described in Section 9.5. He will reconcile the DQOs and MQOs at the conclusion of testing and will conduct or supervise the ADQ. In addition, the QA manager will review the results of the PEA that is administered by the field team leader. Mr. Adamson will report all internal reviews, DQO reconciliation, the ADQ, the PEA, and any corrective action results directly to the GHG Center Deputy Director who will provide copies to the project manager for corrective action as applicable and citation in the final verification report. He will review and approve the final verification report and statement. He is administratively independent from the GHG Center Deputy Director.

2.7.3 SwRI

2.7.3.1 SwRI Program Manager

Mr. Bob Fanick is the SwRI Program Manager for this test program. He will be the primary contact for SwRI and will be responsible for set-up and testing of the engine. He will also review the TQAP and verification report.

2.7.3.2 SwRI Quality Manager

Mr. Mike Van Hecke plays a central role in the introduction, implementation, and consistent application of continuous quality improvement at the DEER. He fulfills the role as quality management representative for SwRI and conducts audits of all pertinent quality standards to ensure compliance. He is administratively independent of the unit generating the data and conducts QA activities as specified in SwRI's internal SOPs. He will conduct these internal QA activities on this test as described in Section 9 and report results to the GHG Center QA Manager. However, these activities do not replace or eliminate the need for the GHG Center internal QA reviews and activities outlined in Section 2.7.2.4 above.

2.7.3.3 Support Personnel

All persons supporting the project will be qualified as prescribed by SwRI QPP 10 (Training and Motivation).

2.7.4 White Sands

Mr. Bret Christiansen will serve as White Sands' primary contact person. Mr. Christiansen will provide technical support for the CleanBoost technology including instructions for product dosing, application, and break-in. Mr. Christiansen will review the TQAP and verification report and provide written comments. Mr. Christiansen or a designated White Sands representative will be present during the verification testing to insure proper application of the CleanBoost additive. White Sands is also responsible for providing the CleanBoost additive to the test facility in sufficient quantities to complete the entire verification test.

2.8 SCHEDULE AND MILESTONES

The tentative schedule of activities for testing the CleanBoost technology is as follows:

Verification Test Plan Development	**Dates**
GHG Center Internal Draft Development	October 15, – November 10, 2004
White Sands Review/Revision	November 10 – 17, 2004
EPA TQAP Review and Approval	November 17 – December 17, 2004
Final Document Posted	December, 2004

Verification Testing and Analysis	**Dates**
Preliminary Teleconference and Project Review	Mid-December, 2004
Testing	January, 2005 (exact dates to be determined)
Data Validation and Analysis	January, 2005

Verification Report Development	**Dates**
GHG Center Internal Draft Development	January 3 – 28, 2005
White Sands Review and Report Revision	February 1 – 15, 2005
EPA and Industry Peer-Review	February 18 – 28, 2005
Final Report Revision and EPA Approval	March 2005
Final Report Posted	March 31, 2005

2.9 DOCUMENTATION AND RECORDS

Test-specific documentation and records generated by SwRI will be processed as specified in:

- SwRI QPP 03 (Document Preparation and Control);
- SwRI QPP 07 (Testing and Sample Analysis); and
- SwRI QPP 14 (Quality Records).

Copies of results and supporting data will be transferred to the GHG Center and managed according to the GHG Center QMP. See Section 8 for details of test data acquisition and management. SwRI, in accordance with Part A, Sections 5.1 and 5.3 of EPA's QMP, will retain all test-specific documentation and records for seven years after the final payment of the agreement between SwRI and the GHG ETV Center. Southern will retain all verification reports and statements for seven years after final payment of the agreement between Southern and EPA.

3.0 DATA QUALITY OBJECTIVES

3.1 DATA QUALITY OBJECTIVES

DQOs are statements about the planned overall accuracy of the verification parameters. Three documents provide the basis for this subsection: (1) the [*GVP*], (2) the *Test and Quality Assurance Plan—ConocoPhillips Fuel-Efficient High-Performance SAE 75W90 Rear Axle Gear Lubricant* (SRI/USEPA-GHG-TQAP-28), and (3) the *Test and Quality Assurance Plan—Universal Cams, LLC Dynamic Cam Diesel Engine Retrofit System* (SRI/USEPA-GHG-TQAP-31). An abbreviated discussion of DQO development is presented here.

The primary verification parameter for this technology is reduction in BSFC. Improvement in BSFC will be expressed as the mean change, or delta (Δ), between results from the baseline and CleanBoost treated fuel tests. Based on tests previously conducted by White Sands, an approximate 3 percent decrease in BSFC is expected. Therefore, the DQO for this parameter is to demonstrate a statistically significant BSFC delta of 3 percent or greater. This section provides a brief description of the data analysis and statistical procedures used here to demonstrate if this DQO is met. More detailed presentations of the statistical analyses that will be used are presented in the reference materials cited above and Appendix B of this TQAP.

This verification also includes determination of NO_X, CO, THC, PM, PM2.5, and Fe emissions as secondary verification parameters. These emissions tend to be much lower than any applicable standards, and their higher measurement variability (because of low absolute values) lead to large Δ determination errors. Therefore, this verification will not adopt explicit engine emissions DQOs analogous to the BSFC DQO. The implicit DQOs will be that all emissions tests will conform to the specified reference methods. Each of the reference methods include numerous QA/QC checks and data quality indicators (DQIs) that, if met, ensure that the tests were properly performed. Section 6.0 summarizes these checks. Although explicit DQOs are not specified for these emission parameters, the analysis described in Section 3.1.1 for determination of statistical significance in changes in BSFC will also be used to evaluate if changes in emissions are significant.

3.1.1 Determination of Statistical Significance

The mean BSFC delta cannot be deemed statistically significant if it is equal to or smaller than the 95 percent confidence interval. The confidence interval (*e*) is a function of the sample standard deviation (s_{n-1}) and the number of test runs conducted during the test campaign. The coefficient of variation (COV), or the sample standard deviation normalized against the sample mean (for each test condition), combined with the number of test runs will therefore serve as the DQI that links the width of the confidence interval with the DQO. The mean delta for BSFC must be greater than *e*. If it is not, the 95 percent confidence interval is wider than the change itself, and it cannot be deemed statistically significant.

Data collected during several similar ETV verifications show that, when the BSFC test methods are properly applied, a COV of 0.7 percent is achievable for BSFC. The data evaluated to develop this COV includes nine test series for similar diesel engine retrofit technology engine dynamometer tests. Each test series consisted of three test runs (n=3). By conducting at least three baseline and modified fuel test runs and achieving the 0.7 percent COV, this verification will be able to demonstrate a statistically significant BSFC delta of 3 percent or greater. If fuel consumption changes are statistically significant, the GHG Center will calculate the difference's confidence interval. After the 3rd test run, and after each following run (up to the 6th), analysts will calculate a test statistic, t_{test}, and compare it with the Student's T distribution value with ($n_1 + n_2 - 2$) degrees of freedom as follows:

$$t_{test} = \frac{(\overline{X}_1 - \overline{X}_2) - (\mu_1 - \mu_2)}{\sqrt{s_p^{\,2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \qquad \text{Equation 2}$$

$$s_p^2 = \frac{(n_1 - 1)s_1^{\,2} + (n_2 - 1)s_2^{\,2}}{n_1 + n_2 - 2} \qquad \text{Equation 3}$$

Where:

X_1 = mean fuel economy with baseline fuel
X_2 = mean fuel economy with treated fuel
$\mu_1 - \mu_2$ = zero (H_o hypothesizes that there is no difference between the population means)
n_1 = number of repeated test runs with baseline fuel
n_2 = number of repeated test runs with treated fuel
s_1^2 = sample standard deviation with baseline fuel, squared
s_2^2 = sample standard deviation with treated fuel, squared
s_p^2 = pooled standard deviation, squared

Selected T-distribution values at a 95-percent confidence coefficient ($t_{0.025,\ DF}$) appear in the following table.

Table 3-1. Selected T-distribution Values

n_1	n_2	Degrees of Freedom, DF (n_1+n_2-2)	$t_{0.025,\ DF}$
3	3	4	2.776
4	4	6	2.447
5	5	8	2.306
6	6	10	2.228

If $t_{test} > t_{0.025,DF}$, then it is concluded that the data shows a statistically significant difference between the baseline and treated fuel BSFC. Otherwise, it will be concluded that a significant BSFC difference did not occur. If significant, the difference and its confidence interval will be reported.

Use of equations 2 and 3 requires the assumption that the baseline and treated fuel test run results have similar variance. The ratio of the sample variances (sample standard deviation squared) between the two fuel test series is a measure of this similarity. Analysts will calculate an F_{test} statistic according to Equation 4 and compare the results to the values in Table 3-1 to determine the degree of similarity between the sample variances.

$$F_{test} = \frac{s^2{}_{\max}}{s^2{}_{\min}} \qquad \text{Equation 4}$$

Where:

F_{test} = F-test statistic
s^2_{max} = larger of the sample standard deviations, squared
s^2_{min} = smaller of the sample standard deviations, squared

Table 3-2 presents selected $F_{0.05}$ distribution values for the expected number of test runs and the acceptable uncertainty (α; 0.05).

Table 3-2. Selected $F_{0.05}$ Distribution Values

	s^2_{max} number of runs	3	4	5	6
s^2_{min} number of runs	Degrees of Freedom	2	3	4	5
3	2	19.00	19.16	19.25	19.30
4	3	9.55	9.28	9.12	9.01
5	4	6.94	6.59	6.39	6.26
6	5	5.79	5.41	5.19	5.05

If the F-test statistic is less than the corresponding value in Table 3-2, then analysts will conclude that the sample variances are substantially the same and the statistical significance evaluation and confidence interval calculations are valid approaches. If a statistically significant difference in BSFC is observed, the 95-percent confidence interval will be calculated. The half width (e) of the 95 percent confidence interval is:

$$e = t_{.025,DF}\sqrt{s_p{}^2\left(\frac{1}{n_1}+\frac{1}{n_2}\right)} \qquad \text{Equation 5}$$

Reported results for improvement in BSFC will include the 95 percent confidence interval, if the results are statistically significant.

3.1.2 Baseline Emissions and BSFC Normalization Procedure

The CleanBoost fuel treatment is generally regarded as an immediate effect fuel modification and this verification was designed to evaluate the immediate effect only. Although baseline engine performance drift is not likely during this verification, baseline testing with reference fuel will be repeated after the conclusion of testing with the CleanBoost treated fuel to confirm this (as specified in Section 2.2.1). A statistical analysis of the two baseline test series will be conducted using the procedures detailed in Appendix B. The GVP and Appendix B contain procedures for baseline normalization should a statistically significant change in baseline BSFC occur. If the results from the two sets of baseline tests are not statistically different, then the pooled variance for all of the baseline runs will be used to evaluate changes to BSFC as outlined above.

4.0 SAMPLING AND ANALYTICAL PROCEDURES

4.1 EXHAUST GAS SAMPLING SYSTEM

The exhaust gas constant volume sampling measurement system conforms to 40 CFR 86.1310, 89.308, and 89.309. The system that will be used at SwRI is depicted in Figure 4-1 below.

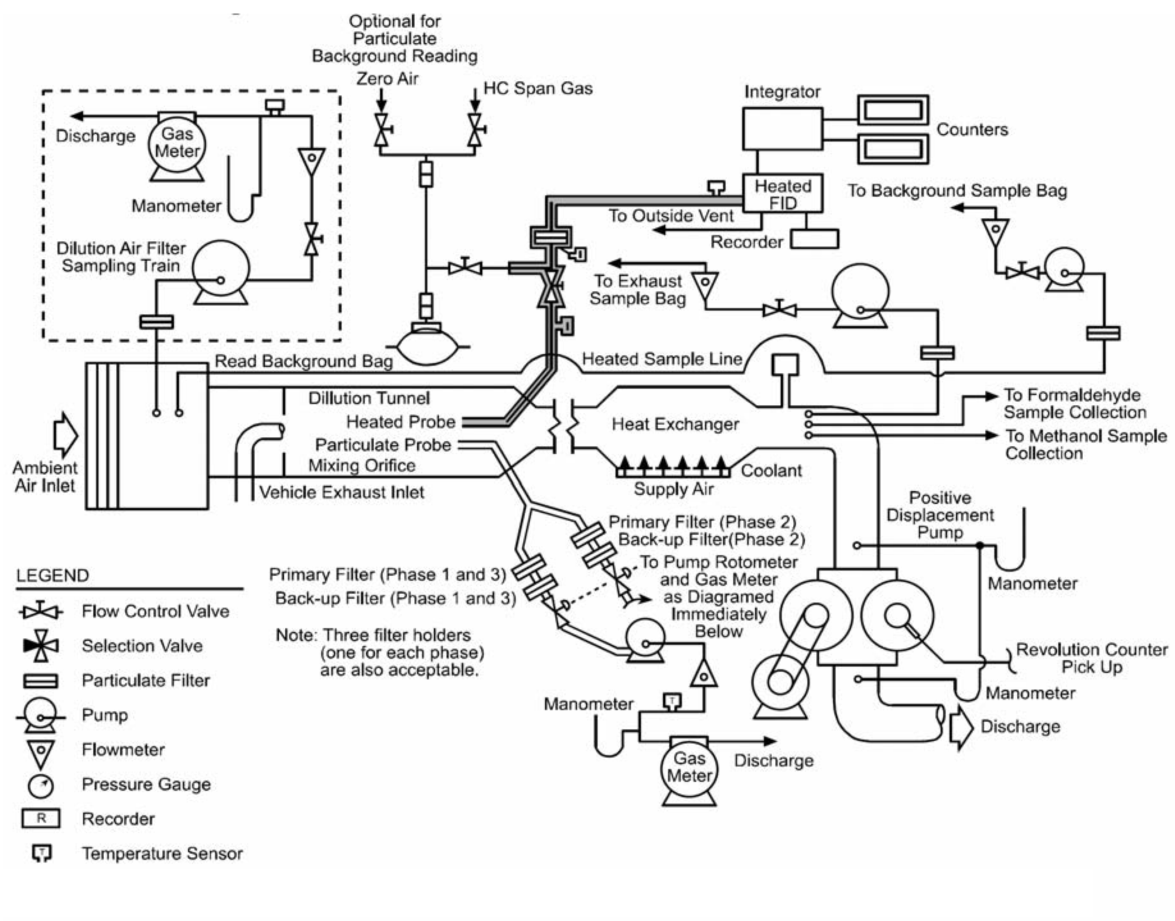

Figure 4-1. SwRI Gaseous and Particulate Emissions Sampling System (PDP-CVS)

Table 4-1 lists the major equipment to be used during the test campaign, expected values, and instrument spans. Typical manufacturers and model numbers are listed for reference only and may vary by test cell.

Table 4-1. Exhaust Gas Measurement System Specifications

Parameter or Subsystem	Expected Operating Range	Manufacturer, Model / Operating Principle	Span	Measurement Frequency
Dynamometer speed	0 - 2100 RPM	Varies with test cell	Varies with test cell up to 6000 RPM	10 Hz (10/s)
Dynamometer load	0 - 368 hp, 0 - 1350 lb.ft	Varies with test cell	Varies; up to 600 hp, 2600 lb.ft	10 Hz (10/s)
CVS pressure	950 - 1050 millibar	SwRI-built constant volume sampler	0 - 1500 millibar	10 Hz (10/s)
CVS temperature	0 to 191 °C		0 - 200 °C	
CVS volumetric flow rate	2000 ft^3 / min (nominal)		1800-2200 ft^3 / min; Varies with test cell	
CO	0 - 300 ppmv	Horiba OPE-135 / NDIR	0 - 1000 ppmv	1 analysis per bag, 2 bags (1 dilute exhaust, 1 ambient air) per each cold-start. Similar set of 2 bags for each hot-start
CO_2	0 - 10000 ppmv	Horiba OPE-135 / NDIR	0 - 10000 ppmv	
CH_4	0 - 10 ppmv 0-100 ppm	GC/FID	10 ppmv 100 ppmv	
NO_X	0 - 300 ppmv	Rosemount 955 / Chemiluminescence	0 - 300 ppmv	10 Hz (10/s) (Note: online gas analysis through sampling probe)
THC	0 - 100 ppmv	Rosemount 402 / HFID	0 - 100 ppmv	
PM	0 - 5 mg	Gravimetric	0 - 100 mg	1 per each cold- and hot-start
PM2.5	0 - 5 mg	Gravimetric	0 - 100 mg	1 per each cold- and hot-start
Fe	0 - 5 mg	ICP spectroscopy	0 - 100 mg	1 per each cold- and hot-start

4.2 FILTER WEIGHING

Particulate filters are stored, conditioned, and weighed in a dedicated facility which conforms to 40 CFR 86.1312. The chamber in which the particulate filters are conditioned and weighed conforms to 40 CFR 86.112 without deviation.

4.3 GASEOUS ANALYZERS

Gaseous analyzers conform to §86.309, §86.1311, and §89, Subpart D, App B, Figure 1. Their operation is specified in SwRI SOP# 07-009, which conforms to required elements B4 (Analytical Methods), B5 (Quality Control), and B6 (Instrument/Equipment Testing, Inspection, and Maintenance) of EPA QA/R-5.

4.4 PM2.5 AND FE DETERMINATIONS

PM2.5 and Fe measurements will be conducted as secondary verification parameters. These parameters are not included in the FTP or GVP. A MOUDI Model 110 cascade impactor will be used to determine emissions of PM2.5. Engine exhaust gases are sampled isokinetically and collected particulate matter is separated into equivalent aerodynamic diameter cut sizes of greater than 10, 5.6, 2.5, 1.8, 1.0, 0.56, 0.32, 0.18, 0.10, and 0.06 micrometers (µm). The mass of particulate matter collected on each stage is determined gravimetrically using the same procedures as the FTP PM determination. PM2.5 emissions are reported as the total mass collected on the stages up to 2.5 µm.

Particulate phase Fe emissions will be determined using the PM catches for each test conducted. At the conclusion of the PM gravimetric analyses, the filters will be digested in solutions of nitric / perchloric acid and aqua regia. The resulting solution is analyzed for Fe content using ion chromatography/mass spectroscopy (IC/MS) procedures. Analytical instrumentation will be standardized using NIST traceable standard reference materials. A blank sample is run to verify zero, and a independent check standard is run to verify calibration. SwRI internal control limits are 90 -110 percent recovery on the check standard.

5.0 SAMPLE HANDLING AND CUSTODY

Only particulate matter (PM) filter measurements and bag samples involve manual handling, since gaseous emission measurements are made and recorded by the computer-controlled data system associated with the continuous sampling system.

The PM filters are prepared and processed according to SwRI SOP# 07-020 which specifies a method of conditioning and weighing filters used to collect particulate samples during exhaust emission testing. This SwRI SOP conforms to required element B3 (Sample Handling and Custody) of EPA QA/R-5.

Samples are handled according to SwRI SOP 07-023. This SOP conforms to required element B3 (Sample Handling and Custody) of EPA QA/R-5.

6.0 DATA QUALITY INDICATOR GOALS AND QA/QC CHECKS

Test measurements that contribute to a verification parameter's determination have specific data quality indicator goals (DQIGs) that, if met, imply achievement of the parameter's DQOs. For this test, completion of the QA/QC checks and achievement of the DQI goals ensures that the specified test methods have been completed in accordance with the TQAP and CFR test method requirements. Based on historical data, when testing is properly completed, the specified DQOs should be achievable.

Tables 6-1 through 6-5 list the individual analyzer and system DQIGs in terms of accuracy. A variety of calibrations, QA/QC checks, and other procedures ensure the achievement of each DQIG. The table summarizes those QA/QC checks for each of the major test systems.

Table 6-1. CVS System Data Quality Indicators and QA/QC Checks

Parameter	Data Quality Indicators Goals			QA/QC Checks		
	Accuracy	How Verified	Frequency	Description	Frequency	Allowable Result
Pressure	± 2.0 % of reading	Calibration of sensors with NIST-traceable standard	At initial installation or after major repairs	Inspect calibration certificates	Prior to test	Current calibration meeting DQI goal
Temperature	± 2.0 % of reading	Calibration of sensors with NIST-traceable standard	At initial installation or after major repairs	Inspect calibration certificates	Prior to test	Current calibration meeting DQI goal
Volumetric flow rate	± 0.5 % of reading	CVS and propane critical orifice calibration	At initial installation or after major repairs	Inspect calibration data	Prior to test	Current calibration meeting DQI goal
				Propane composition verification via analysis with FID	Prior to placing new propane tank in service	< 0.35 % difference from previously used and verified tank
				Propane injection check	Weekly	Difference between injected and recovered propane ≤ ± 2.0 %
				Sample bag leak check	Before each test run	Maintain 10” Hg for 10 seconds
				Flow rate verification	Before each test run	≤ ± 5 cfm of nominal test point
				Dilution air temperature	During each test run	Between 20 and 30 ^{o}C

Table 6-2. Instrumental Analyzers Data Quality Indicators and QA/QC Checks

Parameter	Data Quality Indicators Goals			QA/QC Checks		
	Accuracy	How Verified	Frequency	Description	Frequency	Allowable Result
CO CO_2 NO_x THC	± 1.0 % FS or ± 2.0 % for each calibration gas	11-point calibration (including zero) with gas divider; protocol calibration gases	Monthly	Review and verify analyzer calibration	Once during test and upon completion of new calibration	Current calibration meeting DQI goal
				Gas divider linearity verification	monthly	All points within ± 2.0 % of linear fit; FS within ± 0.5 % of known value
				Calibration gas certification or naming	Prior to service	Average concentration of three readings must be within ± 1 % for calibration gas and NIST-traceable reference material
				Zero gas verification	Prior to service	THC < 1 ppmv CO < 1 ppmv CO_2 < 400 ppmv NO_X < 0.1 ppmv O_2 between 18 and 21 %
				Analyzer zero and span	Before and after each test run	All values within ± 2.0 % of point of ± 1.0 % of FS; zero point within ± 0.2 % of FS
				Analyzer drift	For each bag analysis	Post-test zero or span drift shall not exceed ± 2.0 % FS
CO_2 only				Wet CO_2 interference check	Monthly	CO (0 to 300 ppmv) interference ≤ 3 ppmv; CO (> 300 ppmv) interference ≤ 1 % FS
NO_X only				CO_2 Quench Check	Annually	NO_x quench ≤ 3.0 %
				Converter Efficiency Check	Monthly	Converter Efficiency >90%

Table 6-3. PM, PM2.5, and Fe Analysis Data Quality Indicators and QA/QC Checks

Data Quality Indicators Goals				QA/QC Checks		
Parmater	Accuracy	How Verified	Frequency	Description	Frequency	Allowable Result
PM and PM2.5	± 1.0 µg	NIST-traceable scale calibration, weighing room controls, filter weight control	Daily	NIST-traceable calibration weight cross-check	Daily	Weight change <10 µg
				Weight room temperature	Daily	Between 19 and 25 °C
				Weight room relative humidity	Daily	Between 35 and 53% RH
				Reference filter weight change	Daily	Weight change <20 µg
Fe	±10 % reading	NIST-traceable instrument calibration	Daily	Analysis of blank and check standards	Every 10 analyses	±10 percent of reading

Table 6-4. Supplementary Instruments and Additional QA/QC Checks

Description	Frequency	Allowable Result
Test cell Wet/dry bulb thermometer calibration	Monthly	Within ± 1.0 °F NIST-traceable standard
Test cell Barometer calibration	Weekly	Within ± 0.1" Hg of NIST-traceable standard
Test cell temperature	Each test run	Between 68 and 86 °F
Test fuel analysis	Prior to testing	Conforms to 40 CFR §86.1313 specifications (See Appendix A-2)

Table 6-5. Dynamometer Data Quality Indicators and QA/QC Checks

	Data Quality Indicators Goals			QA/QC Checks		
Parameter	Accuracy	How Verified	Frequency	Description	Frequency	Allowable Result
Speed	± 2.0 %	60-tooth wheel combined with frequency counter	At initial installation or after major repairs	Inspect calibration certificate	Prior to test	Current calibration meeting DQI goal
Load (Torque Sensor)	±0.5%	NIST-traceable weights and torque arm	Weekly	Inspect calibration certificate	Prior to test and after new calibration	Current calibration meeting DQI goal
				Torque trace acceptance test	Each test run	± 2.5 lb.ft for values ≤ 550 lb.ft, ± 5.0 lb.ft for values ≤ 1050 lb.ft, ± 10 lb.ft for values ≤ 1550 lb.ft

7.0 INSTRUMENT CALIBRATION AND FREQUENCY

The calibration schedule for major instruments is included with other QC activities in Table 6-1 above. 40 CFR 86.1316-86.1326 completely specifies the methods, frequency, and requirements of these calibrations. Specific instruments and the applicable SOPs for implementation are described below. The general reference is *SwRI QPP 05 - Measurement and Test Equipment*. Records of all calibration activities are retained at SwRI and will be inspected by the GHG Field Team Leader and/or QA Manager to ensure the TQAP and CFR requirements are met.

8.0 DATA ACQUISITION AND MANAGEMENT

This section describes the generation and processing of test data at SwRI and the flow and disposition of these data from origin to the GHG Center for reporting and archiving. Data acquisition and data management at SwRI are performed according to SwRI *QPP 08 - Data Processing and Reduction*, which conforms to required element B10 (Data Management) of EPA QA/R-5. The SwRI project manager is operationally responsible for all aspects of a test, and the SwRI QA Manager is operationally responsible for all data quality aspects of a test.

SwRI will submit copies of initial raw and intermediate data at the end of each test sequence and at test completion. These data include:

- documents describing the engine inspection and setup activities;
- tracking forms for daily test activities and QC check results;
- external documents such as test fuel lot analyses and NIST-traceable calibration gas certificates;
- test cell data system printouts showing run summary instrument results for test cell system (dyno, CVS, direct and bag cart analysis instruments, etc.); and
- QC check summary printouts (zero, span drift, etc.).

SwRI will prepare and submit a letter report in printed and electronic format to the GHG Center after completion of the field activities. The report will describe the test conditions, document all QA/QC procedures, and summarize intermediate data. The SwRI QAO will also submit a QA report documenting the internal data assessment activities of the test as described in Section 9.0.

The GHG Center Project Manager will incorporate the SwRI material into the final verification report and statement and submit for review according to the GHG Center QMP and ETV Program guidance documents. The GHG Center QA Manager will incorporate the SwRI QA material into the GHG Center's internal assessment documentation for the test, along with assessment activities of the Center. These will include the supplemental TSA, performance audit, and ADQ described in Section 14.

9.0 INTERNAL AND EXTERNAL AUDITS

Several assessments are specified for this verification in accordance with the GHG Center QMP and the ETV Program QMP.

9.1 TECHNICAL SYSTEMS AUDIT

The GHG Center staff has previously conducted a quality and technical systems audits (TSA) of the SwRI DEER on an earlier ETV test. That TSA addressed major test components including documentation and adherence to standard procedures for testing, instrument calibration and QC checks, data processing, audits, and reporting. It also included review of some of the documentation of elements of the SwRI/DEER quality system. In view of the positive findings of that TSA and the similarity between the previous verification and the upcoming test, a second TSA on this technology class is not proposed for the upcoming test.

A tracking checklist of calibrations and QC activities, adapted to the experimental details of this test, will be used to verify that equipment, SOPs, and calibrations are as described in this TQAP. The field team leader will complete the items on this checklist during his observation of the test and return the form to the GHG Center QA manager as part of the QC documentation of the test. He will incorporate this material into the ADQ described below.

9.2 PERFORMANCE EVALUATION AUDITS

The GHG Center specifies internal Performance Evaluation Audits (PEAs), as applicable, on critical measurements of every verification test. The Center will use the SwRI quality infrastructure for an internal PEA for this test. SwRI maintains a set of NIST-certified gas standard mixtures in the concentration ranges applicable to these measurements. The monthly calibration procedure requires that the DEER challenge the analytical instruments with these standards as a performance check independent of the calibration gas standards. The GHG Center will use this internal check in lieu of a blind PEA. The standard mixture challenge from that time will be used as a PEA if a monthly analyzer calibration under SOP 6-012 has been performed within a week of testing on the test cell used for this study. A separate challenge, according to the applicable portion of the SOP, will otherwise be conducted during the period of the test.

9.3 AUDIT OF DATA QUALITY

The GHG Center QA Manager will oversee an audit of data quality (ADQ) of at least 10% of all of the verification data in accordance with Table 9-1 of the ETV QMP. The ADQ will be conducted in accordance with EPA's [*Guidance on Technical Audits and Related Assessments for Environmental Data Operations*]. The ADQ will include (1) verification of input data and outputs reported by test cell instrumentation, (2) checks of intermediate calculations, and (3) a review of study statistics. The ADQ will also draw conclusions about the quality of the data from the project and their fitness for their intended use. Effort on this audit will be assigned as follows. The SwRI QAO, in this case, will conduct an internal ADQ of results generated by SwRI covering the areas described above and submit the audit report to the GHG Center QA Manager. The GHG Center QA Manager will review and incorporate this into an overall ADQ report, including documentation of subcontractor oversight and review of the final processing and reporting of the results.

9.4 EXTERNAL ASSESSMENTS

SwRI and GHG Center staff will cooperate with any external assessments by EPA. EPA personnel may conduct optional external assessments (TSA, PEA, or ADQ) during this or any subsequent test. The external assessments will be conducted as described in EPA QA/G-7.

9.5 INTERNAL ASSESSMENTS

Internal assessment reports will be reviewed by the SwRI QAO and GHG Center QA Manager. The written report of the ADQ will be reviewed by the GHG Center QA Manager and submitted as a separate addendum to the verification report.

10.0 CORRECTIVE ACTION

A corrective action must occur when the result of an audit or quality control measurement is shown to be unsatisfactory as defined by the DQOs or by the measurement objectives for each task. The corrective action process involves the GHG Center project and QA staff as well as subcontractor personnel. A written corrective action report is required on major corrective actions that deviate from the TQAP. Corrective action is performed at SwRI according to *QPP 11 - Nonconformance and Corrective Action,* which conforms to required elements B5 (Quality Control) and C1 (Assessments and Response Actions) of EPA QA/R-5. Situations requiring corrective action will be communicated to the GHG Center field team leader who will, under direction of the GHG Center project manager, assess the incident and take and document appropriate action on behalf of the center. The project manager is responsible for and is authorized to halt work if it is determined that a serious problem exists.

11.0 DATA REDUCTION, REVIEW, VALIDATION, AND REPORTING

The field team leader's primary on-site function will be to monitor SwRI's activities. He will be able to review, verify, and validate certain data (test cell file data, QA/QC check results) during testing. The GHG Center project manager will incorporate the SwRI material into the final verification report and statement and submit this information for review according to the GHG Center QMP and ETV program guidance documents. The GHG Center QA Manager will incorporate the SwRI QA material into the GHG Center's internal assessment documentation for the test along with assessment activities of the Center. These will include the performance audit and ADQ described in Section 9.0.

12.0 REPORTING OF DATA QUALITY INDICATORS

The GHG Center staff will collect and tabulate the DQIG values specified in Table 6-1 as part of the data processing steps described above. These will be reviewed both internally and by the GHG Center QA Manager in the preparation of their verification report and assessment reports and to determine achievement of the DQOs. These reports, as specified in the GHG Center QMP, are submitted to both the EPA project officer and QA Manager.

13.0 DEVIATIONS FROM GVP

The technical aspects of this TQAP were constructed to be consistent with the technical requirements and philosophy of the GVP. The only planned deviations from the GVP are the omission of the additional GVP test runs at maximum power and torque. No other deviations from the GVP or this document are anticipated. If any such deviations are identified in the course of implementing this test, SwRI staff will consult with GHG Center staff as soon as possible to resolve the issues. Section 2.7 of EPA/QA R-5 states that the EPA will be notified of any significant deviations and the QAO will revise this document and submit it to EPA for review and approval.

14.0 REFERENCED QUALITY DOCUMENTS

14.1 EPA-ETV

EPA QA/R-5	EPA Requirements for Quality Assurance Project Plans, EPA QA/R-5, Office of Environmental Information, U.S. Environmental Protection Agency, EPA/240/B-01/003, March 2001.
EPA ETV QMP	Environmental Technology Verification Program Quality and Management Plan for the Pilot Period (1995-2000), National Risk Management Research Laboratory, National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, EPA/600/R-98/064, May 1998 (or current version).
EPA QA/G-5	Guidance on Quality Assurance Project Plans, EPA QA/G-5, Office of Environmental Information, U.S. Environmental Protection Agency, EPA/600/R-98/018, February 1998.
EPA QA/G-7	Guidance on Technical Audits and Related Assessments, EPA QA/G-7, Office of Environmental Information, U.S. Environmental Protection Agency, EPA/600/R-99/080, January 2000.
GVP	Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines (Draft), EPA Cooperative Agreement No. CR826152-01-3, January 2002.
	Environmental Technology Verification Protocol – Determination of Emissions Reductions Obtained by Use of Alternative or Reformulated Liquid Fuels, Fuel Additives, Fuel Emulsions, and Lubricants for Highway and Nonroad Use Diesel Engines and Light Duty Gasoline Engines and Vehicles. EPA Cooperative Agreement No. CR826152-01-3, September 2003.

14.2 GHGTC

GHGTC QMP	Greenhouse Gas Technology Center Quality Management Plan, Version 1.4, March, 2003.
SRI/USEPA-GHG-QAP-28	Test and Quality Assurance Plan—ConocoPhillips Fuel-Efficient High-Performance SAE 75W90 Rear Axle Gear Lubricant, SRI/USEPA-GHG-QAP-29, March 2003.
SRI/USEPA-GHG-	Environmental Technology Verification Report—ConocoPhillips Fuel-Efficient

VR-28	High-Performance SAE 75W90 Rear Axle Gear Lubricant, SRI/USEPA-GHG-VR-28, August 2003.
SRI/USEPA-GHG-QAP-31	Test and Quality Assurance Plan—Universal Cams, LLC Dynamic Cam Diesel Engine Retrofit System, SRI/USEPA-GHG-QAP-31, April 2004.

14.3 SOUTHWEST RESEARCH INSTITUTE

SwRI QAPP	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 (Version 1.0 April 8, 2002).

Quality Policy and Procedures (QPPs)

QSM	Quality System Manual – 2000, April 2001
QPP-03	Document Preparation and Control
QPP-05	Measurement and Test Equipment
QPP-07	Testing and Sample Analysis
QPP-07-003	Transient Test for Heavy-Duty Diesel Engines
QPP-08	Data Processing and Reduction
QPP-09	Analysis and Reporting
QPP-10	Training and Motivation
QPP-11	Nonconformance and Corrective Actions
QPP-12	Internal Audits
QPP-14	Quality Records

Standard Operating Procedures (SOPs)

SOP-06-003	Linearity Verification of Gas Dividers
SOP-06-002	NO_x Converter Efficiency Determination
SOP-06-012	Monthly Calibration of Analyzers for Continuous Dilute Gaseous Exhaust
SOP-06-016	Wet CO_2 Interference Check for CO Analyzers
SOP-06-021	FID Response for Methane
SOP-06-025	NO_x Analyzer and System Response Checks
SOP-06-041	NOx Analyzer CO_2 Quench Check
SOP-06-044	Hydrocarbon Analyzer Optimization
SOP-07-001	Power Validation for Heavy-Duty Diesel Engines
SOP-07-002	Power Mapping for Heavy-Duty Diesel Engines
SOP-07-009	Emissions Testing During Heavy-Duty Diesel Engine Transient Cycle
SOP-07-020	Particulate Filter Conditioning and Weighing
SOP-07-023	Operation of Bag Cart
SOP-12-001	Quality Audits

Appendix A
Test Log Forms and Checklists

Appendix A-1. Test Results Summary and DQO Checks

- Complete after each hot start test run is complete.
- After the third hot start test (and any additional tests), calculate the mean, sample standard deviation, and coefficient of variation (COV) for each parameter. COV is the sample standard deviation divided by the mean, as a percentage.
- Verify that the Data Quality Objectives (DQOs) are met for each parameter.
- Signature:____

Table A-1a: Baseline Test Results & DQO Check

Parameter	Hot Start Run Number	Reported Value, g/Bhp-hr*	Mean, g/BHP-hr	s_{n-1}, g/Bhp-hr	Calculated COV, %	DQO COV, %,
BSFC	1					
	2					
	3					0.7
CO_2	1					
	2					
	3					0.8
PM	1					
	2					
	3					2.2
NO_X	1					
	2					
	3					1.2

*The value is the weighted value of the single cold start FTP test with the hot start FTP test for each run. See the TQAP for detailed calculations.

Table A-1b: Candidate Test Results & DQO Check

Parameter	Hot Start Run Number	Reported Value, g/Bhp-hr*	Mean g/BHP-hr	s_{n-1}, g/Bhp-hr	Calculated COV, %	DQO COV, %,
BSFC	1					
	2					
	3					0.7
CO_2	1					
	2					
	3					0.8
PM	1					
	2					
	3					2.2
NO_X	1					
	2					
	3					1.2

Appendix A-2. Test Fuel Verification

- Obtain a copy of the test fuel lot analysis.
- Review all analysis results and test method documentation.
- Properties and test methods must conform to the specifications given in the following table.

Audit Date: _____________ Signature: ____

Fuel Lot ID: __________________ Date Received: ___________

Table A-2. Test Fuel Specifications

Description	ASTM Test Method No.	Specified Value	Analysis Value	Mfg. Certified Value	Meets Spec.?
Cetane Number	D613	40 - 50			
Cetane Index	D976	40 - 50			
Distillation Range: IBP 10 % point 50 % point 90 % point Endpoint	D 86	 340 - 400 ^{o}F 400 - 460 ^{o}F 470 - 540 ^{o}F 560 - 630 ^{o}F 610 - 690 ^{o}F			
Sulfur	D 2622	0.03 - 0.05 %			
Viscosity	D 445	2.0 - 3.2			
Flashpoint	D 93	130 ^{o}F min.			
Hydrocarbons: Olefins Aromatics	 D 1319 D 5186	 Balance 27 %			
Specific Gravity	D 287	32-37 ^{o}API			

Notes: ____

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Appendix A-3
QA/QC Checks

Signature: ____

Table A3-1: QA/QC Checks						
QA/QC Check Description	**Frequency**	**Allowable Result**	**Date Check Completed (SwRI)**	**Date Audit Completed (GHG Center)**	**OK?**	**Audit Data Source**
Dynamometer						
Dynamometer Calibration Certificates Review	Prior to test	Sensor accuracies (speed and load) meet Table 6-1 specifications				
Torque trace acceptance test	Each test run	± 2.5 lb.ft for values ≤ 550 lb.ft, ± 5.0 lb.ft for values ≤ 1050 lb.ft, ± 10 lb.ft for values ≤ 1550 lb.ft				
CVS System						
CVS System Calibration Certificates Review	Prior to test	Sensor accuracies (P, T, Q) meet Table 6-1 specifications				
Propane tank composition verification	Prior to placing new propane tank in service	< 0.35 % difference from previously used and verified tank				
Propane injection check	Weekly	Difference between injected and recovered propane ≤ ± 2.0 %				
Sample bag leak check	Before each test run	Maintain 10" Hg for 10 seconds				
Flow rate verification	Before each test run	≤ ± 5 cfm of nominal test point				
Dilution air temperature verification	During each test run	Between 20 and 30 ^{o}C				
Emission Analyzers						
Analyzer calibrations review	Once during test and upon completion of new calibration	All values within ± 2.0 % of point of ± 1.0 % of FS;				

Table A3-1: QA/QC Checks						
QA/QC Check Description	**Frequency**	**Allowable Result**	**Date Check Completed (SwRI)**	**Date Audit Completed (GHG Center)**	**OK?**	**Audit Data Source**
Gas divider linearity verification	monthly	All points within ± 2.0 % of linear fit; FS within ± 0.5 % of known value				
Calibration gas certification or naming	Prior to service	Average concentration of three readings must be within ± 1 % for calibration gas and NIST-traceable reference material				
Zero gas verification	Prior to service	THC < 1 ppmv CO < 1 ppmv CO_2 < 400 ppmv NO_X < 0.1 ppmv O_2 between 18 and 21 %				
Analyzer zero and span	Before and after each test run	All values within ± 2.0 % of point of ± 1.0 % of FS; zero point within ± 0.2 % of FS				
Analyzer drift	For each bag analysis	Post-test zero or span drift shall not exceed ± 2.0 % FS				
Wet CO_2 interference check	Monthly	CO (0 to 300 ppmv) interference ≤ 3 ppmv; CO (> 300 ppmv) interference ≤ 1 % FS				
CO_2 Quench Check	Annually	NO_x quench ≤ 3.0 %				
Converter Efficiency Check	Monthly	Converter Efficiency >90 %				
Particulate Measurement						
NIST-traceable calibration weight cross-check	Daily	Weight change < 10 µg				
Weight room temperature	Daily	Between 19 and 25 °C				
Weight room relative humidity	Daily	Between 35 and 53 % RH				
Reference filter weight change	Daily	Weight change < 20 µg				

Table A3-1: QA/QC Checks						
QA/QC Check Description	**Frequency**	**Allowable Result**	**Date Check Completed (SwRI)**	**Date Audit Completed (GHG Center)**	**OK?**	**Audit Data Source**
Ambient Monitoring						
Test cell Wet/dry bulb thermometer calibration	Monthly	± 1.0 °F NIST-traceable standard				
Test cell Barometer calibration	Weekly	Within ± 0.1" Hg of NIST-traceable standard				
Test cell temperature	Each test run	Between 68 and 86 °F				

Appendix A-4. Corrective Action Report

Verification Title:____

Verification Description:____

Description of Problem:____

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Originator:______________________________ Date:_______________

Investigation and Results:____

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Investigator:____________________________ Date:_______________

Corrective Action Taken:____

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Originator:______________________________ Date:_______________
Approver:_______________________________ Date:_______________

Carbon copy: GHG Center Project Manager, GHG Center Director, SRI QA Manager, APPCD Project Officer

Appendix B
Baseline Emissions and Fuel Economy Normalization Procedure

Changes to engine emissions or fuel economy resulting from the use of CleanBoost will be calculated by comparing the test results while using the CleanBoost treated fuel with test results while using the baseline reference fuel. Oftentimes, there can be an observed change in engine performance, both in emissions and in fuel economy over time. This is referred to as baseline performance drift. Therefore, analysts must evaluate engine performance with the baseline fuel before and after testing with the treated fuel to determine the overall reference fuel mean engine performance for comparison to the treated fuel engine performance.

There are three ways that the emissions or fuel economy changes caused by the treated fuel (and not the baseline drift, if any) can be analyzed:

(1) Determine that there is no statistical difference in engine performance with reference fuel from the initial to final data sets. In this case, all baseline data collected with reference fuel is pooled together and compared to the treated fuel data;
(2) Compare each individual set of reference fuel data to the treated fuel data to obtain a range of fuel economy changes based on the two data sets;
(3) Determine that the two reference fuel data sets are statistically different and cannot be directly pooled. Assume that the change in reference fuel performance from the initial and final baseline tests is the result of a systematic drift in vehicle performance. In this case, all data can be normalized to account for such systematic changes. The normalized reference fuel data is then pooled and compared to the normalized treated fuel data.

The following discussion is an excerpt from a similar verification previously conducted by the GHG Center. It is presented here to provide a detailed example of this analysis. This test evaluated changes in vehicle fuel economy as a result of using a candidate axle lubricant (indicated as FEHP). The statistical analysis and procedural approach shown here will be used on the current verification to evaluate changes in engine emissions and fuel economy that are a direct result of use of the CleanBoost technology. The data presented here are used as an example only and are not intended to represent anticipated changes in fuel economy as a result of CleanBoost.

Reference Lubricant Fuel Economy

Analysts evaluated the two sets of reference lubricant fuel economy data to determine the statistical significance of the difference in mean fuel economy between the data sets. An F-test was completed on the two reference lubricant data sets to compare the data variance of the two groups. Table B-1 presents the results of the F-test.

Table B-1: F-test Evaluation of Reference Lubricant Fuel Economy Data Set Variances	
Parameter	**Value**
Standard Deviation, initial reference lubricant tests (mpg)	0.0408
Standard Deviation, final reference lubricant tests (mpg)	0.0448
F_{test}	1.207
$F_{0.05}$	5.192
$F_{test} < F_{0.05}$ (variances statistically equivalent)?	Yes

Results of the F-test indicate that the two sets of reference lubricant data have equivalent variances at a 95 percent confidence level. Therefore, analysts applied the t-test to evaluate the statistical significance of the change in fuel economy between the two reference lubricant data sets. Table B-2 presents the results of the t-test analysis for the two reference lubricant data sets.

The t-test results indicate that there is a statistically significant difference between the two reference lubricant fuel economy data sets at a 95 percent confidence level. Based on this analysis and SwRI's previous experience, it is likely that the change in fuel economy is the result of a systematic drift in vehicle performance due to mileage effects or other phenomena. Therefore, analysts calculated the fuel economy improvement using the method discussed in bullet item (3) above.

Table B-2: Statistical Analysis of Reference Lubricant Tests Fuel Economy Difference	
Parameter	**Value**
Initial Ref. Lubricant Standard Deviation (mpg)	0.0408
Final Ref. Lubricant Standard Deviation (mpg)	0.0448
Mean Fuel Economy – Initial Reference Lubricant (mpg)	18.021
Mean Fuel Economy – Final Reference Lubricant(mpg)	18.139
Change in Fuel Economy (mpg)	0.118
Change in Fuel Economy (%)	0.655
COV-Initial Reference Lubricant (%)	0.226
COV-Final Reference Lubricant (%)	0.247
Initial Ref. Lubricant Test count	5
Final Ref. Lubricant Test count	6
Total count	11
Degrees of Freedom	9
$(\text{Pooled std dev})^2$	0.0019
(Pooled std dev)	0.043
Critical t distribution value ($t_{0.025, DF}$)	2.262
Calculated t-test value, t_{test}	4.525
$t_{test} > t_{0.025,DF}$ (Is the change statistically significant)?	YES

Fuel Economy Change

The two reference lubricant data sets are statistically independent based on the statistical analysis of the reference lubricant fuel economy data presented in Table B-2. Analysts must compare the complete reference lubricant data set and FEHP lubricant test results to determine a representative fuel economy change resulting from the use of FEHP lubricant. No viable explanation for the shift in reference lubricant fuel economy was determined after review of test and QA/QC data. SwRI concluded that there was a "drift" in vehicle performance associated with the mileage accumulation on the test vehicle. The GHG Center evaluated the test data by making the assumption that, during this test period, vehicle drift occurred and that the drift follows a linear behavior with fuel economy improving with mileage accumulation. The fuel economy data for all runs were therefore normalized to remove the effects of the observed linear vehicle performance drift. Any fuel economy change calculated for the normalized data set was then attributable solely to the FEHP lubricant and not mileage or other effects.

A linear regression was performed on the reference lubricant data (initial and final) to complete the normalization This provides the linear drift relationship. Table B-3 presents the results of the linear regression. Figure B-1 presents the fuel economy results vs. vehicle mileage with the linear regression results.

Table B-3: Reference Lubricant Data Regression Statistics

Parameter	Value
Intercept	17.397
Slope	3.86E-05
Standard error – intercept	0.163
Standard error – slope	9.10E-06
R-Square	0.6664
Regression sum of squares	0.0364
Residual sum of squares	0.0182
Observations	11

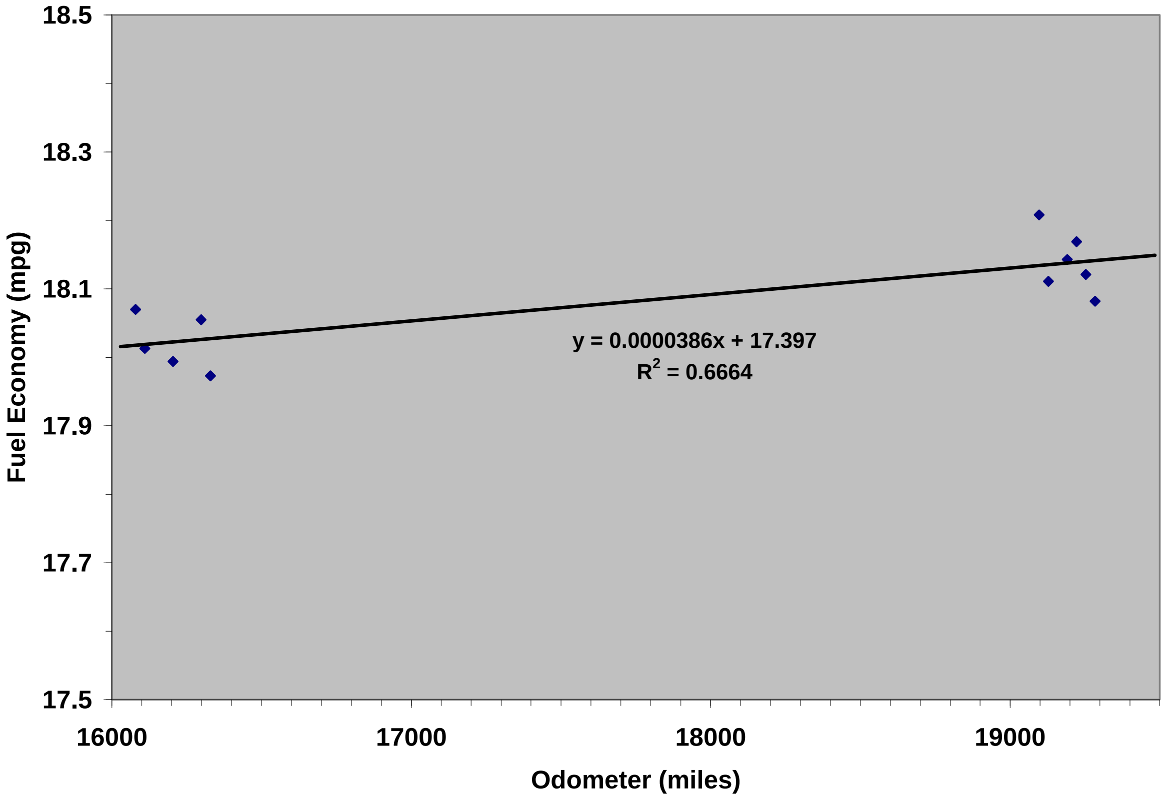

Figure B-1: Reference Lubricant Fuel Economy Results vs. Mileage With Drift Regression Line

All test data (reference lubricant and FEHP) was normalized to a common point for comparison based on the reference lubricant regression. Therefore, the GHG Center normalized the test data to the y-intercept. Data was normalized using the following equation:

$$FE_{N,i} = FE_i \frac{b}{mx_i + b}$$

where:

$FE_{N,i}$	=	normalized fuel economy for test run i
FE_i	=	fuel economy for test run i
m	=	slope of “drift” line
b	=	intercept of “drift” line
x_i	=	vehicle odometer reading at beginning of test run i

Table B-4 presents the results of the normalization procedure. Figure B-2 presents the normalized test results as a function of mileage.

Table B-4: Normalized Fuel Economy Test Results		
Test Run ID	**Composite Fuel Economy (mpg)**	**Normalized Fuel Economy (mpg)**
Reference Lubricant		
Base-1	18.070	17.448
Base-2	18.013	17.392
Base-4	17.994	17.370
Base-6	18.055	17.425
Base-7	17.973	17.345
Mean	**18.021**	**17.396**
Standard Deviation	**0.0408**	**0.0414**
FEHP Lubricant		
FEHP-1	18.272	17.588
FEHP-2-R2	18.272	17.584
FEHP-3	18.284	17.594
FEHP-4	18.233	17.543
FEHP-5	18.263	17.571
FEHP-6	18.206	17.515
Mean	**18.255**	**17.566**
Standard Deviation	**0.0296**	**0.0307**
Reference Lubricant		
Post Base-1R2	18.208	17.468
Post Base-2	18.111	17.374
Post Base-3	18.143	17.402
Post Base-4	18.169	17.426
Post Base-5	18.121	17.379
Post Base-6	18.082	17.340
Mean	**18.139**	17.398
Standard Deviation	**0.0448**	**0.0447**

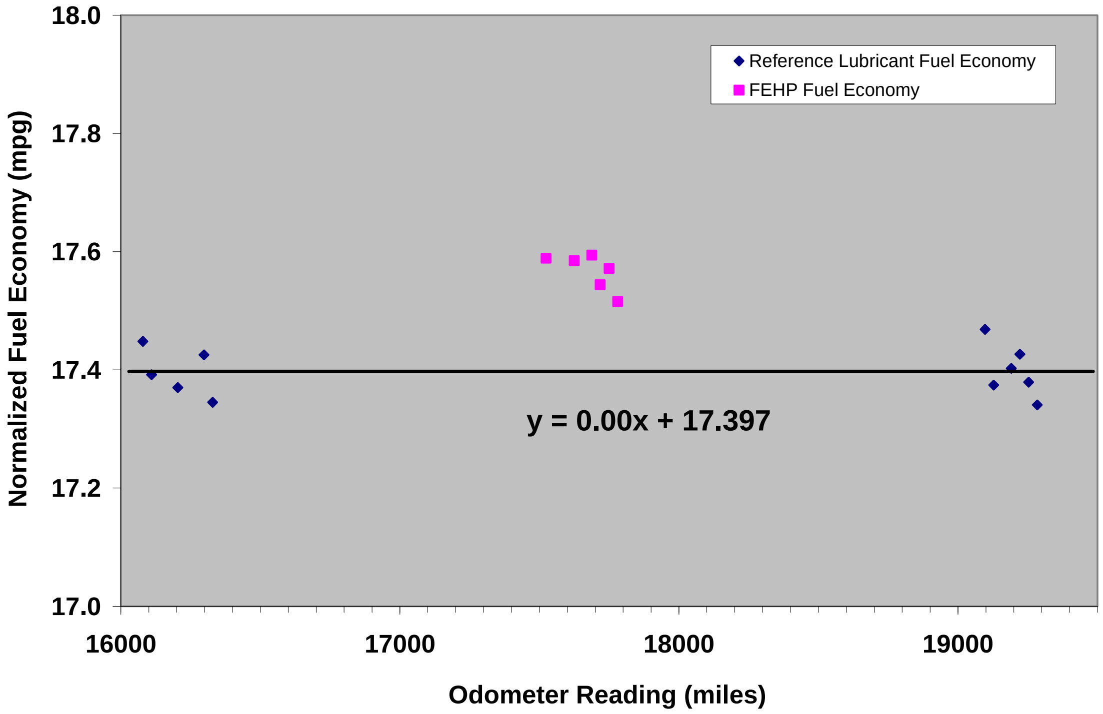

Figure B-2: Normalized Reference Lubricant and FEHP Fuel Economy Results vs. Mileage

Analysts evaluated the normalized reference lubricant data to determine if the two data sets are from the same population and can, therefore, be pooled to determine a mean reference fuel economy for comparison to the normalized FEHP fuel economy. An F-test was initially completed on the two normalized reference lubricant data sets to compare the data variance of the two groups. Table B-5 presents the results of the F-test.

Table B-5: F-test Evaluation of Reference Lubricant Fuel Economy Data Set Variances

Parameter	Value
Standard Deviation, initial reference lubricant tests (mpg)	0.0414
Standard Deviation, final reference lubricant tests (mpg)	0.0447
F_{test}	1.166
$F_{0.05}$	5.192
$F_{test} < F_{0.05}$ (variances equal)?	Yes

Results of the F-test indicate that the two sets of normalized reference lubricant data have equivalent variances at a 95 percent confidence level. Therefore, analysts applied the t-test to evaluate the statistical significance of the change in fuel economy between the two normalized reference lubricant data sets. Table B-6 presents the results of the t-test analysis for the two normalized reference lubricant data sets.

Table B-6: Statistical Analysis of Normalized Reference Lubricant Fuel Economy Difference	
Parameter	**Value**
Initial Ref. Lubricant Standard Deviation (mpg)	0.0414
Final Reference Lubricant Standard Deviation (mpg)	0.0447
Mean Fuel Economy – Initial Reference Lubricant (mpg)	17.396
Mean Fuel Economy – Final Reference Lubricant (mpg)	17.398
Change in Fuel Economy (mpg)	0.002
Change in Fuel Economy (%)	0.011
COV-Reference Lubricant (%)	0.238
COV-FEHP Lubricant (%)	0.257
Reference Lubricant Test count	5
FEHP Test count	6
Total count	11
Degrees of Freedom	9
$(\text{Pooled std dev})^2$	0.0019
(Pooled std dev)	0.043
Critical t distribution value ($t_{0.025, DF}$)	2.262
Calculated t-test value, t_{test}	0.076
$t_{test} > t_{0.025,DF}$ (Is the change statistically significant)?	NO

The t-test results indicate that there is not a statistically significant difference between the two normalized reference lubricant fuel economy data sets at a 95 percent confidence level. The two data sets have statistically equivalent means and are from the same population. Therefore, the reference lubricant data was pooled. Table B-7 presents the results of the pooled reference lubricant data analysis.

Table B-7: Summary of Pooled Normalized Reference Lubricant Data	
Parameter	**Value**
Ref. Lubricant Mean Normalized Fuel Economy (mpg)	17.397
Standard Deviation (mpg) – Pooled Normalize Reference Lubricant	0.0411
COV-Pooled Normalized Reference Lubricant (%)	0.236

The mean pooled, normalized reference lubricant fuel economy is compared to the mean normalized FEHP fuel economy to determine the change in fuel economy resulting from the use of the FEHP lubricant. The calculated fuel economy improvement attributable to the use of the FEHP lubricant in the test vehicle is

$$\Delta = 17.566 \text{ mpg} - 17.397 \text{ mpg} = 0.169 \text{ mpg}$$

This represents a **0.97 percent** improvement in fuel economy when using the FEHP lubricant when compared to the reference lubricant fuel economy.