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Final Version

Environmental Technology Verification Report

Taconic Energy, Inc.
TEA Fuel Additive

Prepared by:

Greenhouse Gas Technology Center

Operated by
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.

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Vehicle Fuel Additive
APPLICATION:	Gasoline Passenger Vehicles
TECHNOLOGY NAME:	TEA Fuel Additive
COMPANY:	Taconic Energy, Inc.
LOCATION:	Saratoga Springs, NY
WEB ADDRESS:	http://www.taconicenergy.com

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 goal of ETV is to further environmental protection by accelerating the acceptance and use of improved and innovative environmental technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the purchase, design, distribution, financing, permitting, and use of environmental technologies.

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

The Greenhouse Gas Technology Center (GHG Center), operated by Southern Research Institute (Southern), is one of six verification organizations operating under the ETV program. One sector of significant interest to GHG Center stakeholders is transportation - particularly technologies that result in fuel economy improvements. Taconic Energy (Taconic) has developed the TEA fuel additive for gasoline passenger vehicles and requested that the GHG Center independently verify its performance. The GHG Center verified the fuel economy performance attributable to the TEA additive at the Transportation Research Center (TRC) in East Liberty Ohio in October 2010.

TECHNOLOGY DESCRIPTION

Taconic Energy has registered with the EPA three products within the TEA additive technology family in accordance with the regulations found in 40 Code of Federal Regulations (CFR) Part 79 of the Federal Register. Gasoline containing any of these registered materials retains their EPA baseline fuel designation. The additive family TEA-037, 037E, and 037M differ in the types and amounts of solvent systems. The active ingredient of this technology serves primarily as a friction modifier ameliorating the in-cylinder friction losses in a gasoline engine.

The following technology information is provided by Taconic and does not represent verified information. Taconic Energy has completed development and rigorous testing of this active ingredient in a variety of vehicles. According to Taconic, the additive typically improves fuel economy in passenger vehicles by 1-5% and provides associated emission reductions. Taconic claims that the additive has been shown to have an almost immediate effect on fuel economy with no required break-in period, a slight increase in improvement over time, and impacts of the additive are not immediately eliminated when the additive is removed. There is a carryover effect that requires accumulation of significant mileage to return to the original equipment condition. The physical properties of the three products within the TEA additive technology family are governed by the amount and type of solvent used in formulation.

VERIFICATION DESCRIPTION

Details on the verification test design, measurement test procedures, and quality assurance/quality control (QA/QC) procedures are contained in two related documents. Technology and site specific information can be found in the document titled *Test and Quality Assurance Plan (TQAP) – Taconic Energy, Inc. TEA Fuel Additive.* The TQAP describes the system under test, project participants, site specific instrumentation and measurements, and verification specific QA/QC goals. The TQAP was reviewed and revised based on comments received from peer and stakeholder reviews, and the EPA Quality Assurance Team. The TQAP meets the requirements of the GHG Center's Quality Management Plan (QMP) and satisfies ETV QMP requirements.

The primary performance parameter for this technology was the fuel economy change (Δ or "delta") due to TEA additive use. The GHG Center performed a series of controlled dynamometer tests on a representative vehicle (2008 Chrysler Town and Country passenger van). Once the fuel economy change was established, a percentage fuel savings was determined relative to the reference fuel. The test plan was designed to evaluate the immediate effect of the additive by comparing a set of baseline and candidate test runs occurring over a very short test period. Each fuel economy test run conformed to the widely accepted Highway Fuel Economy Test (HwFET) and the New York City Cycle Test (NYCC).

All tests were conducted on a chassis dynamometer at the laboratories of TRC. GHG Center personnel ensured that the test facility equipment specification and calibrations conformed to the method criteria during all tests. Emissions and fuel consumption were measured over the duty cycle gravimetrically and also by monitoring the tailpipe exhaust emissions. The vehicle tests also quantified pollutant and greenhouse gas emissions (CO, CO_2, NO_X, and THC) as secondary verification parameters. Testing was conducted during the period of October 26 through 28, 2010 with six replicate test runs conducted at each test condition.

Quality assurance (QA) oversight of the verification testing was provided following specifications in the ETV QMP. The GHG Center's QA manager conducted an internal technical systems audit (an audit of the testing and measurement systems used by TRC) and an audit of data quality on the data generated during this verification and a review of this report. Data review and validation was conducted at three levels including the field team leader, the project manager, and the QA manager.

VERIFICATION OF PERFORMANCE

Results of the verification testing for fuel economy using baseline and additized fuels and the HwFET vehicle duty cycle are summarized in Table S-1. The table summarizes test results obtained using both the carbon balance and gravimetric analyses for each fuel, and summarizes the statistical delta analysis comparing results from the baseline and additized fuels tests. Due to unfavorable results of the first set of additized fuel tests on the HwFET cycle, the verification testing was modified to deviate from the planned sequence. Specifically, the vendor requested that the analysts run the same sequence of HwFET tests on a second lot of additized fuel before moving on with further NYCC duty cycle testing. When results of the second lot of additized fuel confirmed results of the first, further testing of additized fuel (on the NYCC duty cycle) was cancelled. The rationale for this decision was that demonstrating a statistically significant delta would be even more difficult on the NYCC duty cycle where baseline fuel economy was 8.5 mpg less than it was on the HwFET cycle. Therefore the testing was aborted to minimize unnecessary vendor testing costs and no further testing was conducted.

Table S-1. Statistical Analysis of Test Results (Delta)

Statistical Parameter	Additized Fuel - Lot 1		Additized Fuel - Lot 2	
	Carbon Balance	**Gravimetric**	**Carbon Balance**	**Gravimetric**
Average Fuel Economy (mpg)	32.03	31.06	31.88	31.14
Difference from Baseline (mpg)	0.20	0.09	0.05	-0.03
Difference from Baseline (%)	0.62	0.29	0.26	-0.09
F_{test}	4.00	4.61	1.66	1.25
F, 0.05, DF	5.05	5.05	5.05	5.05
Equal Variance?	**Yes**	**Yes**	**Yes**	**Yes**
Pooled Standard Deviation - S_p	0.16	0.15	0.18	0.18
t_{test}	2.12	1.04	0.47	-0.27
DF	10.0	10.0	10.0	10.0
T, 0.05, DF	2.23	2.23	2.23	2.23
Statistical Significance?	**No**	**No**	**No**	**No**
$\pm$ Confidence Interval	0.21	0.20	0.24	0.24
Confidence Interval of Mean Fuel Economy Change (%)	105.0	214.7	475.6	-815.3

Results of the analysis show that there was no statistically significant change in vehicle fuel economy between the baseline and additized fuels on the HwFET duty cycle. As a secondary verification parameter, engine emissions of pollutant and greenhouse gases (CO, CO_2, NO_X, and THC) were also determined during each test. Table S-2 summarizes the average emission rates for each pollutant under each HwFET test series. Emissions of NOx, THC, and NMHC were very low for all test periods. Although statistical analyses were not performed on the CO and CO_2 emissions, the additive did not appear to have a measureable impact on engine emissions.

Table S-2. Summary of Engine Emissions

Pollutant	Average Measured Emission Rate (grams/mile)		
	Baseline Fuel	**Additized Fuel - Lot 1**	**Additized Fuel - Lot 2**
NOx	0.018	0.021	0.023
THC	0.004	0.007	0.008
NMHC	0.001	0.005	0.005
CO	0.207	0.188	0.227
CO_2	276	275	276

Signed by Cynthia Sonich-Mullin (6/10/2013)

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Greenhouse Gas Technology Center

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

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ACRONYMS AND ABBREVIATIONS

2WD	Two-wheel drive
4WD	Four-wheel drive
°C	degrees Centigrade
CFR	Code of Federal Regulations
CO	carbon monoxide
CO_2	carbon dioxide
COA	certificate of analysis
COV	coefficient of variation
CVS	constant volume sampling
DF	degrees of freedom
DQI	data quality indicator
DQO	data quality objective
EPA	Environmental Protection Agency
EPA-ORD	Environmental Protection Agency Office of Research and Development
ETV	Environmental Technology Verification
°F	degrees Fahrenheit
F	F Statistic
FS	full scale
FTP	Federal Test Procedure
GHG	greenhouse gas
Hg	elemental Mercury
HwFET	Highway Fuel Economy Test
Hz	Hertz
ISO	International Organization for Standardization
Lbf	pounds force
Lbs	pounds
mpg	miles per gallon
mph	miles per hour
NMHC	non-methane hydrocarbons
NIST	National Institute of Standards and Technology
NO_x	Blend of NO, NO_2, and other oxides of nitrogen
NYCC	New York City Cycle
O2	Oxygen
Pbar	picobar
ppm	parts per million
ppmC	parts per million (carbon)
QA	quality assurance
QA/QC	quality assurance / quality control
QMP	Quality Management Plan
RH	Relative Humidity
SCFM	standard cubic feet per minute
SRI	Southern Research Institute
SRM	standard reference material
THC	total hydrocarbons (as carbon)

TQAP	test and quality assurance plan
TRC	Transportation Research Center
TSA	technical systems audit
U.S. EPA	United States Environmental Protection Agency

1.0 INTRODUCTION

1.1. BACKGROUND

The U.S. EPA-ORD operates the ETV program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The goal of ETV is to further environmental protection by accelerating the acceptance and use of improved and innovative environmental technologies. With performance data developed under this program, technology buyers, financiers, and permitters in the United States and abroad will be better equipped to make informed decisions regarding environmental technology purchase and use.

The GHG Center is one of six verification organizations operating under the ETV program. The GHG Center is managed by EPA's partner verification organization, Southern, which conducts verification testing of promising greenhouse gas mitigation and monitoring technologies. The GHG Center's verification process consists of developing verification protocols, conducting field tests, collecting and interpreting field and other data, obtaining independent stakeholder input, and reporting findings. Performance evaluations are conducted according to externally reviewed verification TQAPs and established protocols for quality assurance.

The GHG Center is guided by volunteer groups of stakeholders. The GHG Center's Executive Stakeholder Group consists of national and international experts in the areas of climate science and environmental policy, technology, and regulation. It also includes industry trade organizations, environmental technology finance groups, governmental organizations, and other interested groups. The GHG Center's activities are also guided by industry specific stakeholders who provide guidance on the verification testing strategy related to their area of expertise and peer-review key documents prepared by the GHG Center.

One sector of significant interest to GHG Center stakeholders is transportation - particularly technologies that result in fuel economy improvements. Considering the magnitude of annual fuel consumption, even an incremental improvement in fuel efficiency would have a significant benefit on fleet and business economics, foreign oil imports, and nationwide air quality. Small fuel efficiency or emission rate improvements are expected to have a significant beneficial impact on nationwide greenhouse gas emissions.

Taconic developed the TEA fuel additive for gasoline passenger vehicles and requested that the GHG Center independently verify its performance. Throughout development of the additive Taconic has been supported by internal funding and funding from the New York State Energy Research & Development Authority. The development process involved a series of controlled in-use tests operating vehicles over a 32 mile cycle on the Taconic Parkway in upstate New York. During these tests, using a variety of vehicles (model years 2008 to 2010), a fuel economy increase of 1-5% was observed.

Taconic's TEA additive was determined to be a suitable verification candidate considering its potentially significant beneficial environmental quality impacts and ETV stakeholder interest in verified transportation sector emission reduction technologies. The GHG Center determined the fuel economy performance attributable to the TEA additive at TRC in East Liberty Ohio in October 2010.

Details of the verification test design, measurement test procedures, and quality assurance/quality control (QA/QC) procedures are contained in two related documents. Technology and site specific information can be found in the document titled *Test and Quality Assurance Plan (TQAP) – Taconic Energy, Inc. TEA Fuel Additive* [1]. It can be downloaded from the GHG Center's web-site (www.sri-rtp.com) or the ETV Program web-site (www.epa.gov/etv). This TQAP describes the system under test, project participants, site specific instrumentation and measurements, and verification specific QA/QC goals. The TQAP was reviewed and revised based on comments received from peer and stakeholder reviews, and the EPA Quality Assurance Team. The TQAP meets the requirements of the GHG Center's Quality Management Plan QMP and satisfies ETV QMP requirements.

The remainder of Section 1.0 describes the technology and outlines the performance verification procedures that were followed. Section 2.0 presents test results, and Section 3.0 assesses the quality of the data obtained.

1.2. TACONIC ENERGY TEA FUEL ADDITIVE TECHNOLOGY DESCRIPTION

Taconic Energy has registered with the EPA three products within the TEA additive technology family in accordance with the regulations found in 40 Code of Federal Regulations (CFR) Part 79 of the Federal Register. Gasoline containing any of these registered materials retains their EPA baseline fuel designation. The additive family TEA-037, 037E, and 037M differ in the types and amounts of solvent systems. The active ingredient of this technology serves primarily as a friction modifier ameliorating the in-cylinder friction losses in a gasoline engine.

The following technology information is provided by Taconic and does not represent verified information. Taconic Energy has completed development and rigorous testing of this active ingredient in a variety of vehicles. According to Taconic, the additive typically improves fuel economy in passenger vehicles by 1-5% and provides associated emission reductions. Taconic claims that the additive has been shown to have an almost immediate effect on fuel economy with no required break-in period, a slight increase in improvement over time, and impacts of the additive are not immediately eliminated when the additive is removed. There is a carryover effect that requires accumulation of significant mileage to return to the original equipment condition.

The physical properties of the three products within the TEA additive technology family are governed by the amount and type of solvent. Below is a summary of the properties of the active material as well as those of the material diluted with the most volatile solvent.

<u>Physical Properties of the active material in TEA-037 family of additives</u>

- **Appearance (@ 20 °C):** Solid
- **Color:** White to slightly yellow
- **Odor:** Pungent
- **Density (@ 20 °C):** 0.98
- **Flash Point:** >200 °F (87.2 °C)
- **Explosive properties:** Material does not have explosive properties
- **Boiling Point:** 423 °F (217 °C)

Physical Properties of TEA-037M (contains lowest flash point solvent)

- **Appearance (@ 20 °C):** Clear liquid
- **Color:** White to slightly yellow
- **Odor:** Pungent
- **Density (@ 20 °C):** > 0.79
- **Flash Point:** 54 °F (12 °C)
- **Explosive properties:** Material has explosive properties above 54 °F (12 °C)
- **Boiling Point:** 148 °F (65 °C)

1.3. PERFORMANCE VERIFICATION OVERVIEW

In collaboration with TRC, the GHG Center performed a series of controlled dynamometer tests on a representative vehicle. The test vehicle used for this verification was a 2008 Chrysler Town and Country passenger van rented by TRC from a local rental agency. This vehicle was equipped with a 3.8 liter gasoline engine and automatic transmission and had an accumulated prior use of approximately 25,000 miles. The vehicle has an EPA fuel economy rating of 16, 18, and 23 miles per gallon (mpg) for city, combined, and highway driving conditions, respectively. The emission control information tag for the test vehicle selected is shown in Figure 1-1. This test vehicle was approved by Taconic prior to esting and was checked for on board diagnostic issues. The vehicle also underwent a complete inspection for any other mechanical problems, the front end alignment was checked, and tires were properly inflated and checked before each day's testing began. Marks were placed in the floor so that the vehicle could be placed on chassis dynamometer in the exact place from test to test. The vehicle was cross tied onto the dynamometer and the ties equally torqued to prevent unnecessary down force on the vehicle.

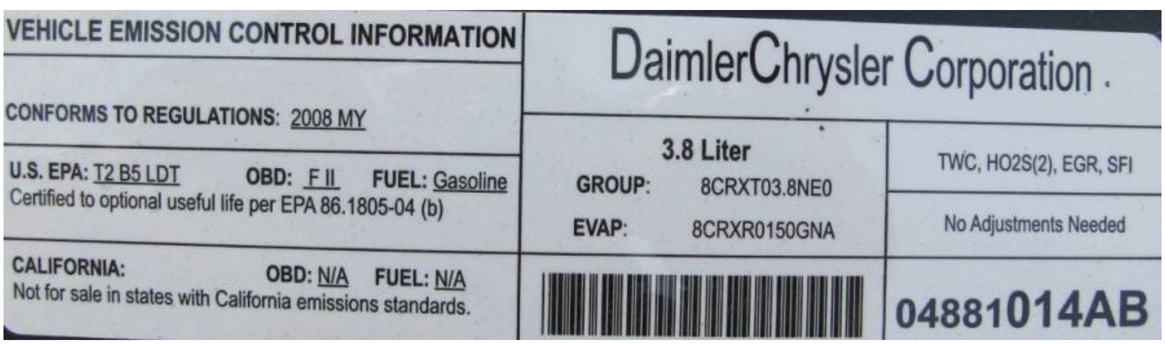

Figure 1-1. Test Vehicle Emission Control Information

For fuel control, a dedicated lot of fuel was stored in an isolated fuel storage and conditioning room at approximately 50 °F for baseline and additive testing. Mixing took place immediately before the TEA-037 additive tests began and about 3 ounces was added to a 50 gallon drum, which is less than 0.047 % additive in the fuel. The GHG Center verified the fuel economy change (Δ or "delta") due to TEA additive use. Delta was the primary performance parameter as quantified by the following equation:

$$\Delta = \textit{Mean Fuel Economy}_{Add} - \textit{Mean Fuel Economy}_{Ref\ Fuel} \qquad \text{(Eqn. 1)}$$

Where:
Δ = fuel economy change, mpg
Mean Fuel Economy $_{Add}$ = average fuel economy with additized fuel, mpg

Mean Fuel Economy $_{Ref.Fuel}$ = average fuel economy with reference fuel, mpg

Once the fuel economy change was established, a percentage fuel savings was determined relative to the reference fuel.

$$Percentage\ Fuel\ Savings = \frac{\Delta}{Mean\ Fuel\ Economy_{Ref\ Fuel}} \qquad \text{(Eqn. 2)}$$

The test plan was designed to evaluate the immediate effect of the additive by comparing a set of baseline and candidate test runs occurring over a very short test period. Each fuel economy test run conformed to the widely accepted HwFET and the NYCC [2]. The verification consisted of a series of fuel economy tests where the general test sequence was:

- Preparation of vehicle for testing;
- Reference fuel economy baseline test 1 (NYCC);
- Reference fuel economy baseline test 2 (HwFET);
- Removal of reference fuel; preparation for additized fuel economy test (HwFET);
- Additized fuel economy test 1 (HwFET);
- Removal of first batch additized fuel; preparation for second batch additized fuel economy test (HwFET);
- Additized fuel economy test 2 (HwFET (2))

Due to preliminary results of the first set of additized fuel tests on the HwFET cycle, this test sequence was modified to deviate from the plan. Specifically in that the additized fuel was not tested under the NYCC test cycle. Instead, a second batch of the same formulation of additized fuel was prepared and the vehicle was retested under the HwFET cycle. Testing of the second batch of additized fuel under the HwFET cycle confirmed results from the first round of tests, and the NYCC duty cycle testing was aborted. More detail regarding the test results and rationale for aborting the NYCC cycle testing is provided in Section 3.0 of this report.

All tests were conducted on a chassis dynamometer at the laboratories of TRC. GHG Center personnel ensured that the test facility equipment specification and calibrations conformed to the method criteria during all tests. Emissions and fuel consumption were measured over the duty cycle gravimetrically and also by monitoring the tailpipe exhaust emissions. The vehicle tests also quantified pollutant and greenhouse gas emissions (CO, CO_2, NO_X, and THC) as secondary verification parameters. Testing was conducted during the period of October 26 through 28, 2010 with six replicate test runs conducted at each test condition. The test periods and conditions are summarized in Table 1-1. The detailed rationale, approaches, and methodologies for the verification testing are provided in the TQAP and not repeated here.

Table 1-1. Summary of Test Runs and Conditions

Test Condition	Valid Replicates	Date (time)	Average Dynamometer Ambient Conditions		
			Temp (^{o}F)	RH (%)	Pbar (in. Hg)
Baseline NYCC	6	10-26-10 (1201-1428)	71.8	51.2	28.25
Baseline HwFET	6	10-27-10 (1032-1240)	72.1	49.8	28.64
Additive HwFET-1	6	10-27-10 (1608-1813)	72.0	47.8	28.59
Additive HwFET-2	6	10-28-10 (1159-1405)	72.0	45.0	28.91

As specified in the test plan, the fuel economy determination stems from the carbon in the emissions measured during the two driving cycles correlated with the known amount of carbon in the fuel, based on the Certificate of Analysis (COA) and the distance driven on the dynamometer. This determination method, as specified in 40 CFR § 600.113, is known as the "carbon balance" method. Carbon mass in the fuel per unit volume divided by carbon mass in the emissions yields the fuel economy in mpg.

To further validate test results, TRC and the GHG Center cross checked the carbon balance method fuel economy results with separate gravimetric fuel economy determinations. After each set of test runs at each testing condition, analysts calculated and compared the carbon balance and gravimetric means and Coefficient of Variations (COVs).

2.0 VERIFICATION RESULTS

Results of the verification testing for fuel economy using baseline and additized fuels and the HwFET vehicle duty cycle are summarized in Tables 2-1 through 2-4. Tables 2-1 through 2-3 summarize test results using both the carbon balance and gravimetric analyses for each run, and Table 2-4 summarizes the statistical delta analysis comparing results from the baseline and additized fuels tests. Supporting data and statistical analyses for each set of tests are presented in Appendix A.

Table 2-1. Summary of Baseline HwFET Fuel Economy Tests

	Fuel Economy (mpg)		
	Carbon Balance Method	Gravimetric	Difference
Run 1	31.80	31.17	0.63
Run 2	32.00	31.47	0.53
Run 3	32.10	31.31	0.79
Run 4	31.60	30.92	0.68
Run 5	31.60	31.08	0.52
Run 6	31.90	31.06	0.84
Average	31.83	31.17	0.66
Standard Deviation	0.21	0.20	0.13
COV	0.65	0.63	0.02

Table 2-2. Summary of Additized Fuel HwFET Fuel Economy Tests (Lot 1)

	Fuel Economy (mpg)		
	Carbon Balance Method	Gravimetric	Difference
Run 1	32.00	31.32	0.68
Run 2	32.10	31.30	0.80
Run 3	32.20	31.32	0.88
Run 4	31.90	31.31	0.59
Run 5	32.00	31.08	0.92
Run 6	32.00	31.25	0.72
Average	32.03	31.26	0.77
Standard Deviation	0.10	0.09	0.12
COV	0.32	0.29	0.03

Table 2-3. Summary of Additized Fuel HwFET Fuel Economy Tests (Lot 2)

	Fuel Economy (mpg)		
	Carbon Balance Method	**Gravimetric**	**Difference**
Run 1	31.70	30.99	0.71
Run 2	31.70	31.16	0.54
Run 3	31.90	30.92	0.98
Run 4	31.90	31.16	0.74
Run 5	32.00	31.38	0.62
Run 6	32.10	31.25	0.85
Average	31.88	31.14	0.74
Standard Deviation	0.16	0.17	0.16
COV	0.50	0.54	0.04

Table 2-4. Statistical Analysis of Test Results (Delta)

	Additized Fuel - Lot 1		Additized Fuel - Lot 2	
Statistical Parameter	**Carbon Balance**	**Gravimetric**	**Carbon Balance**	**Gravimetric**
Average Fuel Economy(mpg)	32.03	31.06	31.88	31.14
Difference from Baseline (mpg)	0.20	0.09	0.05	-0.03
Difference from Baseline (%)	0.62	0.29	0.26	-0.09
F_{test}	4.00	4.61	1.66	1.25
F, 0.05, DF	5.05	5.05	5.05	5.05
Equal Variance?	**Yes**	**Yes**	**Yes**	**Yes**
Pooled Standard Deviation - S_p	0.16	0.15	0.18	0.18
t_{test}	2.12	1.04	0.47	-0.27
DF	10.0	10.0	10.0	10.0
T, 0.05, DF	2.23	2.23	2.23	2.23
Statistical Significance?	**No**	**No**	**No**	**No**
± Confidence Interval	0.21	0.20	0.24	0.24
Confidence Interval of Mean Fuel Economy Change (%)	105.0	214.7	475.6	-815.3

Results of the analysis show that there was no statistically significant change in vehicle fuel economy between the baseline and additized fuels on the HwFET duty cycle. As shown in Table 1-1, baseline fuel testing was completed on the NYCC and HwFET duty cycles first. After treating a first lot of fuel with additive, the HwFET testing was repeated. After careful review, validation, and analysis of these data, it was determined that a statistically significant delta was not measured. The vendor requested at that point that analysts run the same sequence of HwFET tests on a second lot of additized fuel before moving on with further NYCC duty cycle testing. When results of the second lot of additized fuel confirmed results of the first, further testing of additized fuel (on the NYCC duty cycle) was cancelled. The rationale for this decision was that demonstrating a statistically significant delta would be even more difficult on the NYCC duty cycle where baseline fuel economy was 8.5 mpg less than it was on the HwFET cycle. Therefore the testing was aborted to minimize unnecessary vendor testing costs and no further testing was conducted.

As a secondary verification parameter, engine emissions of pollutant and greenhouse gases (CO, CO_2, NO_X, and THC) were also determined during each test. Table 2-5 summarizes the average emission rates for each pollutant under each HwFET test series. Emissions of NOx, THC, and NMHC were very low for all test periods. Although statistical analyses were not performed on the CO and CO_2 emissions, the additive did not appear to have a measureable impact on engine emissions.

Table 2-5. Summary of Engine Emissions

Pollutant	Average Measured Emission Rate (grams/mile)		
	Baseline Fuel	**Additized Fuel - Lot 1**	**Additized Fuel - Lot 2**
NOx	0.018	0.021	0.023
THC	0.004	0.007	0.008
NMHC	0.001	0.005	0.005
CO	0.207	0.188	0.227
CO_2	276	275	276

3.0 DATA QUALITY ASSESSMENT

3.1. DATA QUALITY OBJECTIVES

Under the ETV program, the GHG Center specifies Data Quality Objectives (DQOs) for each verification parameter before testing commences as a statement of data quality. This verification's DQO was the fuel economy change's desired confidence level, as stated in the test plan:

> *The data quality objective is to determine a statistically significant fuel economy improvement of 2 percent or better (1 percent is desirable). For the desired target vehicle with a minimum fuel economy of 16 mpg, this corresponds to detecting a mean fuel economy improvement of 0.32 mpg with a 95 percent confidence interval of less than ± 0.32 mpg.*
>
> *Based on previous experience, statistically significant mean fuel economy improvements as low as 0.12 mpg should be detectable using the procedures and methods in this plan. That is, fuel economy improvements of less than 1 percent should be detectable for a target vehicle with mean fuel economy of 16 mpg.*

Results of the testing show consistently repeatable results over each set of test condition replicates. Standard deviations on the average 31.5 mpg test results ranged from approximately 0.1 to 0.2 mpg. The resulting 95 percent confidence interval was approximately 0.22 and the absolute delta mpg changes were all 0.20 mpg or less. Therefore, even though the confidence interval DQO was met, changes in fuel economy were demonstrated as statistically insignificant.

3.2. DATA QUALITY INDICATORS

TRC Inc. is registered to the International Standards Organization (ISO) 9001 Quality and ISO 14001 Environmental Quality Standards. Within the emissions laboratory, the quality control measures employed on a daily, weekly, and yearly basis closely follow the equipment, calibration, and precision specifications to the governing inherent to the U.S. EPA and associated ISO and Society of Automotive Engineers Procedural Specifications. Measurement Data Quality Indicators (DQIs) and QA/QC checks specified in the Test Plan for the dynamometer, Constant Volume Sampling (CVS) system, and emissions analyzers were documented throughout the testing and are summarized below. Supporting documentation of all of the QA/QC checks conducted during this verification is maintained at the GHG Center.

TRC and the manufacturer verified the speed and torque sensor accuracies during initial installation and startup. The QA/QC checks outlined in Table 3-2 are daily operational checks which confirmed that the dynamometer was functioning properly during the verification.

Table 3-1. Chassis Dynamometer Specifications and DQI Goals

Measurement Variable	Operating Range Expected in Field	Instrument Manufacturer / Type	Instrument Range	Measurement Frequency	Data Quality Indicator Goals	
					Accuracy	How Verified / Determined
Speed	0 to 60 mph	AVL 48" Roll Dual Axle 2WD/4WD Dynamometer	0 to 125 mph	10 Hz with reporting at 1 Hz	± 0.02% FS	Sensors calibrated and verified during original installation.
Load	0 to 500 Lbf		± 8,000N		± 0.1% FS	

Table 3-2. Chassis Dynamometer QA/QC Checks

QA/QC Check	When Performed	Expected or Allowable Result	Response to Check
Road load horsepower calibration	Before initiating test program	Triplicate coast down checks within ± 2.0% of target curve	All QA/QC checks were within the expected or allowable criteria
Dyno calibration certificate inspection	Once during the test program	Sensor accuracies conform to Table 3-1 specifications	
Parasitic friction verification	Before initiating test program	± 2.2 Lbf from existing settings	
Dyno warmup verification	Before initiating test program	Daily vehicle-off coast down at 6,000 lbs within ± 2 lbf	
Road load and inertia simulation check	55-45 mile per hour coast down at end of each FTP test run	± 0.3 second average over the entire FTP driving sequence	
Valid driver's trace	End of each test run	No deviation from tolerances given in 40 CFR § 86.115	

Table 3-3 summarizes the Horiba Analytical CVS system specifications.

Table 3-3. CVS Specifications and DQI Goals

Measurement Variable	Operating Range Expected in Field	Instrument Description	Range	Measurement Frequency	Data Quality Indicator Goals		
					Accuracy	How Verified / Determined	Completeness
Pressure	950 to 1050 millibar	Horiba Analytical Constant Volume Sampler	0-150 psia	1 Hz	± 0.2 % FS	Pressure yearly, temperature every 6 months	100 %
Temperature	20 to 45 °C		0-600 °C		± 0.05% resistance versus temperature		
Volumetric Flow Rate	350 to 500 scfm		200, 350, or 550 scfm		Calculated		

Similar to the chassis dynamometer, TRC and Horiba verified the CVS sensor accuracies during initial installation and startup. The QA/QC checks outlined in Table 3-4 are daily operational checks which confirm proper CVS function and were documented during the verification.

Table 3-4. CVS System QA/QC Checks

QA/QC Check	When Performed / Frequency	Expected or Allowable Result	Response to Check Failure or Out of Control Condition
CVS critical flow orifice calibration certificate inspection	Lifetime calibration	NA	NA
Propane injection check	Daily	difference between injected and recovered propane ≤ ± 2.0 %.	All QA/QC checks were within the expected or allowable criteria
Flow rate verification	Daily	± 5 scfm of appropriate nominal set point	
Sample bag leak check	Before each test run	Maintain 10 in. Hg vacuum for 10 seconds	

The Horiba Analytical CVS system specifications are summarized in Table 3-5.

Table 3-5 - Emissions Analyzer Specifications and DQI Goals

Measurement Variable	Expected Operating Range	Instrument Manufacturer / Type	Instrument Range	Measurement Frequency	Data Quality Indicator Goals		
					Accuracy	How Verified / Determined	Completeness
Low CO	0-200 ppm	Horiba 9000 Series	0-25, 50, 250 ppm	Monthly	± 1.0 % FS or ± 2.0 % of the calibration point	Gas divider with protocol calibration gases at 11 points evenly spaced throughout span (including zero)	100 %
CO	0-1000 ppm		0-500, 1000, 3000 ppm				
CO_2	0-2.0 % (vol)		0-2 & 6 %				
NO_X	0-100 ppm		0-25, 50, 100 ppm				
THC	0-250 ppmC (carbon)		0-10, 30, 300, 1000 ppmC				

TRC verified each analyzer's performance through a series of zero and calibration gas challenges. Each zero and calibration gas was verified National Institute of Standards and Technology (NIST)-traceable. Table 3-6. summarizes the QA/QC checks conducted during the verification.

Table 3-6. Emissions Analyzer QA/QC Checks

QA/QC Check	When Performed/Frequency	Expected or Allowable Result	Response to Check Failure or Out of Control Condition
NIST-traceable calibration gas verifications	Prior to being put into service	Average of three readings must be within ± 1% of verified NIST SRM concentration	All QA/QC checks were within the expected or allowable criteria
Zero-gas verification	Prior to being put into service	HC < 1 ppmC CO < 1 ppm CO_2 < 400 ppm NO_x < 0.1 ppm O_2 between 18 and 21%	
Gas divider linearity verification	Every 2 Years	All points within ± 2% of linear fit FS within ± 0.5% of known value	
Analyzer calibrations	Monthly	All values within ± 2% of point or ± 1% of FS; Zero point within ± 0.2% of FS	
Wet CO_2 interference check	Quarterly	CO 0-300 ppm, interference ≤ 3 ppm CO > 300 ppm, interference ≤ 1% FS	
NO_X analyzer interference check	Monthly	CO_2 interference ≤ 3 %	
NO_X analyzer converter efficiency check	Monthly	NO_x converter efficiency > 95%	
Calibration gas certificate inspection	Once during testing	Certificates must be current; concentrations consistent with cylinder tags	
Bag cart operation	Prior to analyzing each bag	Post-test zero or span drift shall not exceed ±2% full-scale	

The Field Team Leader obtained certificates for all calibration and zero gases used during the test program, which are maintained in the GHG Center verification archives. All certificates were current and the cylinder tag concentrations matched those on the applicable certificate.

The verification utilized certification-grade test fuel to complete all testing, with an associated COA for fuel properties to ensure that the fuel conformed to 40 CFR § 86.113 specifications. Table 3-7 summarizes results of the fuel analysis and demonstrates conformance with test specifications.

Table 3-7. Test Fuel Specifications

Parameter	Expected or Allowable Result	Analysis Value
Octane, Research	87 minimum	96.1
Sensitivity (Research Octane minus Motor Octane)	7.5 minimum	7.9
Lead	0.050 g/U.S. gallons maximum	<0.001
Distillation Range		
Initial Boiling Point	75 to 95 °F	93 °F
10 pct. Point	120 to 135 °F	122 °F
50 pct. Point	200 to 230 °F	225 °F
90 pct. Point	300 to 325 °F	302 °F
End Point	415 °F maximum	365 °F
Sulfur	0.10 wt. percent maximum	0.00003
Phosphorus	0.005 g/US gallon maximum	<0.001
Reid Vapor Pressure	8.0 to 9.2 psi	8.9
Hydrocarbon composition		
Olefins, max. pct	10 % maximum	1.8%
Aromatics, max. pct	35 % maximum	32.7%
Saturates	remainder	65.5%

3.3. FUEL ECONOMY GRAVIMETRIC CROSS CHECKS

TRC and the GHG Center cross checked the carbon balance method fuel economy results with separate gravimetric fuel economy determinations. Results of these cross checks are summarized with the test results in Tables 2-1 through 2-3 of this report. The gravimetric method did show a consistent bias in reporting results approximately 2.3 percent lower than the results of the carbon balance method. The bias was extremely consistent though with an average COV in the two methods' measured mpgs of 0.03 mpg. The statistical analyses of results presented in Table 2-4 verify the utility of using the two different methods and serve to confirm test findings.

3.4. AUDITS

A Technical Systems Audit (TSA) was conducted during the verification testing by the GHG Center field testing leader which included an audit of the following test system components:

- Chassis dynamometer equipment, calibrations, and setup
- CVS equipment, calibrations
- Instrumental analyzer system, calibrations
- Fuel delivery system (including volumetric and gravimetric measuring equipment) and calibrations.

During the TSA, the Field Team Leader verified that the equipment and calibrations were as specified in the Test Plan. A Calibration and QA/QC Audit Checklist form was used to document TSA calibration findings and is maintained in GHG Center archives.

The auditor's main findings were several minor issues relating to the operation of the chassis dynamometer that varied somewhat from the test plan specifications. Each issue was considered minor and appropriate corrective action was taken and documented. Copies of each of the corrective action reports are provided in Appendix B.

Southern's QA manager also conducted an Audit of Data Quality. This consisted of verifying computations and traceability from the raw data collected through final results reported and verifying that all required QA/QC checks were conducted and documented. The audit found the results to be of acceptable quality.

4.0 REFERENCES

[1] Southern Research Institute, "*Test and Quality Assurance Plan – Taconic Energy, Inc. TEA Fuel Additive",* SRI/USEPA-GHG-QAP-49, www.sri-rtp.com, Greenhouse Gas Technology Center, Southern Research Institute, Durham, NC, August 2010.

[2]. Code of Federal Regulations (CFR) Title 40 Part 86, *"Control of Emissions from New and In-Use Highway Vehicles and Engines"*, § 86.115, and Part 600, "Fuel Economy of Motor Vehicles" (3), § 600.109

Appendices

Appendix A – Test Data and Statistical Analyses

Carbon Balance and Gravimetric Cross Checks - Baseline HwFET										
							Southern Research Project Number		13134	
Run	Test	Date	Start Time	End Time	Fuel Container Weight (lbs)			MPG (Carbon Balance)	MPG (Gravimetric)	MPG Difference
					Start	End	Net			
1	Baseline HwFET - 1	10/27/2010	10:32	10:45	23.725	21.695	2.03	31.80	31.17	0.63
2	Baseline HwFET - 2	10/27/2010	10:46	10:59	22.27	20.26	2.01	32.00	31.47	0.53
3	Baseline HwFET - 3	10/27/2010	11:00	11:13	21.615	19.595	2.02	32.10	31.31	0.79
4	Baseline HwFET - 4	10/27/2010	11:59	12:12	21.695	19.65	2.045	31.60	30.92	0.68
5	Baseline HwFET - 5	10/27/2010	12:13	12:26	20.26	18.225	2.035	31.60	31.08	0.52
6	Baseline HwFET - 6	10/27/2010	12:27	12:40	19.595	17.56	2.035	31.90	31.06	0.84
							Average	31.83	31.17	
Total Mileage of Test 1		10.262					Standard Deviation	0.21	0.20	
Total Mileage of Test 2		10.26					% COV	0.65	0.63	
Total Mileage of Test 3		10.258					Specific Gravity of Fuel (lbs/gal):		6.166	
Total Mileage of Test 4		10.256					Average Difference in MPG		0.66	
Total Mileage of Test 5		10.259					Difference in % COV's		0.02	
Total Mileage of Test 6		10.252						2.08%		

Carbon Balance and Gravimetric Cross Checks - Additive HwFET (Batch 1)										
							Southern Research Project Number		13134	
Run	Test	Date	Start Time	End Time	Fuel Container Weight (lbs)			MPG (Carbon Balance)	MPG (Gravimetric)	MPG Difference
					Start	End	Net			
1	Additive HwFET - 1	10/27/2010	16:08	16:21	32.715	30.695	2.02	32.00	31.32	0.68
2	Additive HwFET - 2	10/27/2010	16:22	16:34	33.13	31.11	2.02	32.10	31.30	0.80
3	Additive HwFET - 3	10/27/2010	16:35	16:48	33.615	31.595	2.02	32.20	31.32	0.88
4	Additive HwFET - 4	10/27/2010	17:33	17:46	30.695	28.675	2.02	31.90	31.31	0.59
5	Additive HwFET - 5	10/27/2010	17:47	18:00	31.11	29.075	2.035	32.00	31.08	0.92
6	Additive HwFET - 6	10/27/2010	18:01	18:13	31.595	29.57	2.025	32.00	31.25	0.75
							Average	32.03	31.26	
Total Mileage of Test 1		10.259					Standard Deviation	0.10	0.09	
Total Mileage of Test 2		10.255					% COV	0.32	0.29	
Total Mileage of Test 3		10.26					Specific Gravity of Fuel (lbs/gal):		6.166	
Total Mileage of Test 4		10.257					Average Difference in MPG		0.77036894	
Total Mileage of Test 5		10.259					Difference in % COV's		0.030424043	
Total Mileage of Test 6		10.262						2.40%		

Statistical Analysis -Carbon Balance (Batch 1)		
Calculation	**Baseline Fuel**	**Additized Fuel**
Average MPG - X_2, X_1	31.83	32.03
Standard Deviation - s_2, s_1	0.21	0.10
% Difference vs. Reference	0.62%	
F_{test}	4.00	
F, 0.05, DF	5.05	
Equal Variance	**Yes**	
Pooled Standard Deviation - s_p	0.16	
n_1 - (Additized Fuel)	6	
n_2 - (Baseline Fuel)	6	
t_{test}	2.12	
DF	10.00	
t, 0.05, DF	2.23	
Statistically Significant Difference	**No**	
± Confidence Interval	0.21	
Confidence Interval as percent of mean fuel economy change	105.0%	

Statistical Analysis - Gravimetric (Batch 1)		
Calculation	**Baseline Fuel**	**Additized Fuel**
Average MPG - X_2, X_1	31.17	31.26
Standard Deviation - s_2, s_1	0.20	0.09
% Difference vs. Reference	0.29%	
F_{test}	4.61	
F, 0.05, DF	5.05	
Equal Variance	**Yes**	
Pooled Standard Deviation - s_p	0.15	
n_1 - (Additized Fuel)	6	
n_2 - (Baseline Fuel)	6	
t_{test}	1.04	
DF	10.00	
t, 0.05, DF	2.23	
Statistically Significant Difference	**No**	
± Confidence Interval	0.20	
Confidence Interval as percent of mean fuel economy change	214.7%	

Carbon Balance and Gravimetric Cross Checks - Additive 2 HwFET (Batch 2)										
							Southern Research Project Number		13134	
Run	Test	Date	Start Time	End Time	Fuel Container Weight (lbs)			MPG (Carbon Balance)	MPG (Gravimetric)	MPG Difference
					Start	End	Net			
1	Additive HwFET 2 - 1	10/28/2010	11:59	12:12	29.135	27.095	2.04	31.70	30.99	0.71
2	Additive HwFET 2 - 2	10/28/2010	12:13	12:26	28.745	26.715	2.03	31.70	31.16	0.54
3	Additive HwFET 2 - 3	10/28/2010	12:27	12:39	26.25	24.205	2.045	31.90	30.92	0.98
4	Additive HwFET 2 - 4	10/28/2010	13:25	13:38	26.985	24.955	2.03	31.90	31.16	0.74
5	Additive HwFET 2 - 5	10/28/2010	13:39	13:52	26.715	24.7	2.015	32.00	31.38	0.62
6	Additive HwFET 2 - 6	10/28/2010	13:53	14:05	24.205	22.18	2.025	32.10	31.25	0.85
					Average			31.88	31.14	
Total Mileage of Test 1		10.253			Standard Deviation			0.16	0.17	
Total Mileage of Test 2		10.257			% COV			0.50	0.54	
Total Mileage of Test 3		10.255			Specific Gravity of Fuel (lbs/gal):				6.166	
Total Mileage of Test 4		10.257			Average Difference in MPG				0.74	
Total Mileage of Test 5		10.256			Difference in % COV's				0.04	
Total Mileage of Test 6		10.263								

Statistical Analysis - Carbon Balance (Batch 2)		
Calculation	Baseline Fuel	Additized Fuel
Average MPG - X_2, X_1	31.83	31.88
Standard Deviation - s_2, s_1	0.21	0.16
% Difference vs. Reference	0.16%	
F_{test}	1.66	
F, 0.05, DF	5.05	
Equal Variance	Yes	
Pooled Standard Deviation - s_p	0.18	
n_1 - (Additized Fuel)	6	
n_2 - (Baseline Fuel)	6	
t_{test}	0.47	
DF	10.00	
t, 0.05, DF	2.23	
Statistically Significant Difference	No	
± Confidence Interval	0.24	
Confidence Interval as percent of mean fuel economy change	475.6%	

Statistical Analysis - Gravimetric (Batch 2)		
Calculation	**Baseline Fuel**	**Additized Fuel**
Average MPG - X_2, X_1	31.17	31.14
Standard Deviation - s_2, s_1	0.20	0.17
% Difference vs. Reference	-0.09%	
F_{test}	1.35	
F, 0.05, DF	5.05	
Equal Variance	**Yes**	
Pooled Standard Deviation - s_p	0.18	
n_1 - (Additized Fuel)	6	
n_2 - (Baseline Fuel)	6	
t_{test}	-0.27	
DF	10.00	
t, 0.05, DF	2.23	
Statistically Significant Difference	**No**	
± Confidence Interval	0.24	
Confidence Interval as percent of mean fuel economy change	-815.3%	

Appendix B – Corrective Action Reports

CORRECTIVE ACTION REPORT

Verification Title: SRI/USEPA-GHG-QAP-49

Verification Description: Taconic Energy Fuel Additive Testing

Description of Problem: No recommended fuel pump pressure setting for external fuel cart.

Originator: Austin Vaillancourt Date: 10/25/2010

Investigation and Results: Need to match the external fuel pump with the test vehicle's internal fuel pump which operates at ~60psig.

Investigator: Austin Vaillancourt Date: 10/25/2010

Corrective Action Taken: Will now operate external fuel pump pressure at ~60psig.

Originator: Austin Vaillancourt Date: 10/25/2010
Approver:__________ Date:__________

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

CORRECTIVE ACTION REPORT

Verification Title: SRI/USEPA-GHG-QAP-49

Verification Description: Taconic Energy Fuel Additive Testing

Description of Problem: Did not consider what do to about engine evaps and fuel can vents.

Originator: Austin Vaillancourt Date: 10/25/2010

Investigation and Results: Need to be vented to atmosphere or out of dyno cell to avoid background contamination during testing.

Investigator: Austin Vaillancourt Date: 10/25/2010

Corrective Action Taken: Tied into a suction vent to the roof.

Originator: Austin Vaillancourt Date: 10/25/2010
Approver:__________ Date:__________

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

CORRECTIVE ACTION REPORT

Verification Title: SRI/USEPA-GHG-QAP-49

Verification Description: Taconic Energy Fuel Additive Testing

Description of Problem: Referring to Table 20. The following QA/QC checks have been altered to better describe the internal calibration methods used at TRC. "Road Load Horsepower Calibration" & "Dyno Warm-up Verification".

Originator: Austin Vaillancourt | Date: 10/25/2010

Investigation and Results: TRC's dynamometer operates differently where this QA/QC check specifically is not necessary. The alternative method needs to be verified that it does not affect data quality.

Investigator: Austin Vaillancourt | Date: 10/25/2010

Corrective Action Taken: Both of the QA/QC checks are now verified via a coastdown done every morning prior to testing. A force is calculated where three coefficients (A, B & C) are fit to a curve ($y=A+Bx+Cx^2$) where x is set to 40mph. If the value does not vary more than ±2.2lbf from test to test, it will not affect the data quality (See Daily Coast Downs).

Originator: Austin Vaillancourt | Date: 10/25/2010
Approver: ____________ | Date: ____________

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

CORRECTIVE ACTION REPORT

Verification Title: SRI/USEPA-GHG-QAP-49

Verification Description: Taconic Energy Fuel Additive Testing

Description of Problem: CVS system cannot handle more than 3 consecutive samples. Current test plan has vehicle repeatability testing occurring with 4 consecutive samples.

Originator: Austin Vaillancourt | Date: 10/21/2010

Investigation and Results: Need to change sequence to accommodate the system & not affect data quality.

Investigator: Austin Vaillancourt | Date: 10/21/2010

Corrective Action Taken: Changed test plan. Will now run 2 preconditioning HwFET's, 2 sample HwFET, 2 warm-up HwFET's, and 2 sample HwFET's.

Originator: Austin Vaillancourt | Date: 10/21/2010
Approver: ____________ | Date: ____________

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

CORRECTIVE ACTION REPORT

Verification Title: SRI/USEPA-GHG-QAP-49

Verification Description: Taconic Energy Fuel Additive Testing

Description of Problem: Referring to Table 21. The following QA/QC checks have been altered to better describe the internal calibration methods used at TRC. "Propane critical orifice cal. cert. review"

Originator: Austin Vaillancourt   Date: 10/25/2010

Investigation and Results: TRC CVS system operates differently where this QA/QC check specifically is not necessary. The alternative method needs to be verified that it does not affect data quality.

Investigator: Austin Vaillancourt   Date: 10/25/2010

Corrective Action Taken: TRC uses a bomb method, where propane injected is verified by weight as well. This measurement is cross checked with the computers propane injection value & cannot deviate more that ±2%.

Originator: Austin Vaillancourt   Date: 10/25/2010
Approver: ______________________   Date: ____________

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