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**Fuel Consumption and Emissions Report  
for  
CARBON CHAIN TECHNOLOGIES LIMITED**

**Testing 2ct Treated Gasoline Fuel**

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**TEXAS TRANSPORTATION INSTITUTE  
THE TEXAS A&M UNIVERSITY SYSTEM  
COLLEGE STATION, TEXAS**

August, 2008



# **Fuel Consumption and Emissions Report for CARBON CHAIN TECHNOLOGIES LIMITED**

## **Testing 2ct Treated Gasoline Fuel**

Prepared by the  
Texas Transportation Institute

August, 2008

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## **INTRODUCTION**

Recent increases in the cost of petroleum-based fuels have resulted in an unprecedented interest in products that have the potential to improve fuel economy. At the request of Carbon Chain Technologies Limited (CCT), the Texas Transportation Institute (TTI) in conjunction with Sensors Inc. (the research team) recently conducted a series of fuel economy and in-use emissions tests of light-duty gasoline vehicles (LDGVs). The purpose of this testing program was to evaluate the performance of CCT combustion enhancer<sup>1</sup>, known as 2ct on a LDGV.

A test procedure based on the TMC<sup>2</sup>/SAE<sup>3</sup> Type II test procedure (SAE J-1321) was developed and used to evaluate the product's effectiveness in improving the fuel economy of LDGVs. A similar procedure was developed and utilized to evaluate the impact of 2ct on the exhaust emissions. SAE J-1321 is primarily designed for heavy-duty diesel vehicles (HDD trucks and buses) and cannot be directly applied to LDGVs. The research team therefore developed a protocol closely assimilating SAE J-1321 to be used for LDGVs.

To facilitate the tests, fuel consumption in a test vehicle was compared to fuel consumption in an identical control vehicle before and after 2ct combustion enhancer treatment at the recommended dose rate of 1:500 vol/vol. The manufacturer claims that the product will improve fuel economy and reduce exhaust emissions after two tanks full of treated fuel. For this test, the research team ran the test vehicle for a notional 1,000 miles to ensure that there was no question of conditioning not having been achieved. This report deals with the two pertinent test segments according to SAE J-1321: - untreated baseline testing, and – post treatment. Each segment of testing consisted of a gravimetric fuel consumption testing followed by emissions testing using SEMTECH-DS manufactured by Sensors Inc. and Montana-2100 manufactured by Clean Air Technology International Inc. (CATI) portable emissions measurement units.

## **TEST PROTOCOL**

### **Fuel Consumption Testing**

SAE J-1321 is the standard testing procedure for fuel consumption in the U.S. Fuel consumption can be measured by using a portable weigh tank method (gravimetric method) or utilizing a fuel flow meter (flow meter method). The gravimetric method is by far the most widely used fuel consumption measurement method because of its relative simplicity and consistency. The research team used a modified version of the SAE J-1321 gravimetric method for this study.

SAE J-1321 is primarily designed for heavy-duty diesel vehicles (HDD trucks and buses). Due to this characteristic, it cannot be directly applied to other types of vehicles such as LDGVs. The research team proposed a series of test protocols for this vehicle type to address this issue. These protocols closely assimilate SAE J-1321 with some modifications to make them suitable for LDGVs.

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<sup>1</sup> The client defines its 2ct combustion enhancer as a petroleum fuels technology comprising hydrocarbon components that is mixed with fuel to improve the combustion burn, of all grades of petroleum fuel.

<sup>2</sup> Technology and Maintenance Council (TMC) of American Trucking Association (ATA).

<sup>3</sup> Society of Automotive Engineers (SAE).

### SAE J-1321<sup>4</sup>

The Joint TMC/SAE fuel consumption test procedure – Type II – SAE J-1321 is the proposed test protocol for this vehicle class. The procedure includes the following elements.

- Two vehicles are used for the test — a control vehicle (“Vehicle C”) and a test vehicle (“Vehicle T”). Vehicle C is the control vehicle and is not modified in any way during the entire test and is dedicated to the test until the entire test process is complete. This includes load, trailer, and driver.
- The gravimetric method uses a portable auxiliary tank of at least 16 gallons to measure the fuel consumption. The tank is topped off and weighed before the test run and weighed again after the completion of the test run during which the vehicles perform the same driving pattern.
- The fuel consumption calculations are based on T/C ([vehicle T]/[Vehicle C]) ratios. A T/C ratio is the ratio of the quantity of fuel consumed by the test vehicle (vehicle T) to the quantity of fuel consumed by the control vehicle (vehicle C) during one test run.
- The testing consists of two sets of tests — baseline and treatment. Each set is composed of a minimum of three valid T/C ratios according to SAE J-1321.
  - Baseline: to establish baseline fuel consumption of the test vehicle running on untreated fuel (vehicle T); and
  - Treatment: to establish the fuel consumption of the test vehicle after modification.
- For each test run weather data is recorded. This includes wind velocity, wind direction, temperature, and humidity.
- Both vehicles must follow the warm-up process according to J-1321.
- Vehicle “C” begins the test first and vehicle “T” follows after five minutes.
- Observers are assigned to each vehicle to monitor and record the progress of the test vehicles at assigned points along the track to ensure that the vehicles complete the runs within the set tolerances. Time duration for all test runs must be repeated within  $\pm 0.5$  percent. During the test run, which requires one hour to complete, repeatability must be within 18 seconds.

Modified Test Protocol for Light Duty Gasoline Vehicles. The test protocol for this vehicle class is similar to SAE J-1321 as described above with a few minor deviations from the standard procedure to accommodate the technical issues of applying SAE J-1321 to small gasoline vehicles.

SAE J-1321 requires using a portable tank of at least 16 gallons, however, this could not be achieved for LDGVs due to the following characteristics of gasoline vehicles: fuel pump is located inside the fuel tank; there is a sensor on the fuel pump assembly that sends information to vehicle’s computer; and a gasoline vapor recovery system is mounted on the fuel tank. To account for these issues the original tank of the truck was placed inside the cargo bed of the truck and was used as an auxiliary tank (Figure 1). Although the effective size of the original tank is 21 gallons, only six gallons of fuel was used during the test to be as consistent as possible with J-1321 in terms of criteria for finishing the test (fuel consumption for a test run must be a minimum of 30 percent of tank capacity or six gallons; in the case of LDGV this criterion was modified to 30 percent of fuel in tank or two gallons).

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<sup>4</sup> SAE International, Joint TMC/SAE Fuel Consumption Test Procedure – Type II, SAE Surface Vehicle Recommended Practice J1321, 1986.



**Figure 1. Toyota Tacoma Original Fuel Tank Used in the Gravimetric Fuel Consumption Measurement.**

After the baseline tests were completed, the test vehicle was subjected to a period of approximately 1,000 miles running on the treated fuel. CCT representatives monitored the conditioning at 250-mile increments and confirmed the completion of conditioning.

#### *Test Procedure for Emissions Testing*

Emissions of total hydrocarbons (THC), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), oxides of nitrogen (NO<sub>x</sub>), and particulate matter (PM) were measured using two Portable Emissions Measurement System (PEMS) units. The SEMTECH-DS was used to measure THC, CO, CO<sub>2</sub>, and NO<sub>x</sub> emissions, and PM emissions were measured using the OEM-2100 Montana system.

The SEMTECH-DS unit includes a set of gas analyzers, an engine diagnostic scanner, a Global Position System (GPS), an exhaust flow meter (EFM), and embedded software. The gas analyzers measure the concentrations of NO<sub>x</sub> (nitric oxide [NO] and nitrogen dioxide [NO<sub>2</sub>]), THC, CO, CO<sub>2</sub>, and oxygen (O<sub>2</sub>) in the vehicle exhaust. By using the electronic vehicle EFMs for measuring exhaust mass flow, the SEMTECH post-processor application software uses the measured exhaust mass flow information to calculate exhaust mass emissions for all measured exhaust gases.

The OEM-2100 Montana system has a laser light scattering detector and a sample conditioning system to measure PM concentration in the exhaust. The PM concentrations were converted to PM mass emissions using concentration rates produced by the CATI unit and the exhaust flow rates produced by the SEMTECH-DS unit.

Currently, there is no standard test procedure for on-road emissions measurement. Therefore, a test procedure was developed by the research team to capture a wide array of operational conditions. This procedure follows the preparation and calculation methods of J-1321. The following describes this testing method.

The emissions testing was performed directly after completing the fuel efficiency testing. Both the control vehicle (Vehicle C) and the test vehicle (Vehicle T) were used for testing similar to



fuel consumption testing. Both vehicles followed the warm-up process according to J-1321. Vehicle “C” began the test first and vehicle “T” followed after five minutes.

Both vehicles were driven at least four times according to the following driving pattern — drivers were asked to drive from 50 mph-to-90 mph in 10-mph increments and maintain their speed at each speed for at least 60 seconds, and then stop.

For both vehicles, the emissions rates (g/s) at each steady-state speed were cleaned and used to build a virtual drive cycle consisting 20-second samples of steady state speed. The total grams of emissions for this synthetic drive cycle were used according to the calculation procedure of SAE J-1321 (i.e., T/C ratios were the base of the calculations). The results are presented as the percent difference of emissions rates.

Two sets of tests were performed — baseline and treatment. Each set was composed of a minimum of three valid T/C ratios according to SAE J-1321: Baseline – to establish baseline emissions rates of the test vehicle running on untreated fuel (vehicle T); and Treatment – to establish the emissions rate of the test vehicle after treatment.

## **TESTING INFORMATION**

### **Test Facility**

The test was conducted at the Pecos Research and Testing Center (RTC) outside Pecos, Texas. The city of Pecos is located on the Pecos River at the northern border of the Chihuahuah Desert. It is 208 miles east of El Paso, 392 miles west of Fort Worth on I-20, and about 80 miles from the Midland-Odessa International airport. The dry, seasonable climate of Pecos enables year-round research and testing. The Pecos RTC operates as an academic-industry collaboration among the TTI, Applied Research Associates (ARA), and the Pecos Economic Development Corporation (PEDC).<sup>5</sup>

The total size of the facility is 5,800-acres and is comprised of a nine-mile, three-lane circular high speed track for speeds up to 200 mph, an El Camino road course, serpentine track, skid pad, flint stone road, cobblestone road, and gravel road. For this high-speed study, the nine-mile circular track was used. Figure 2 shows the location of the Pecos facility as well as an aerial view of the test tracks.

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<sup>5</sup> Pecos Economic Development Corporation. <http://www.pecos.net/news/pedc/whoware.htm>, accessed June 2008.



**Figure 2. Location and Layout of the Test Track.**

### **Test Fuels**

Regular gasoline was purchased and stored in the Pecos facility prior to the testing. This fuel was used as “base fuel.” A specific portion of this fuel was mixed with 2ct combustion enhancer at the recommended ratio of 1:500 (volume-to-volume) and was used as “treated fuel.” The mixing was performed by representatives of TTI under supervision of CCT. Treated fuel was used for conditioning and treatment testing.

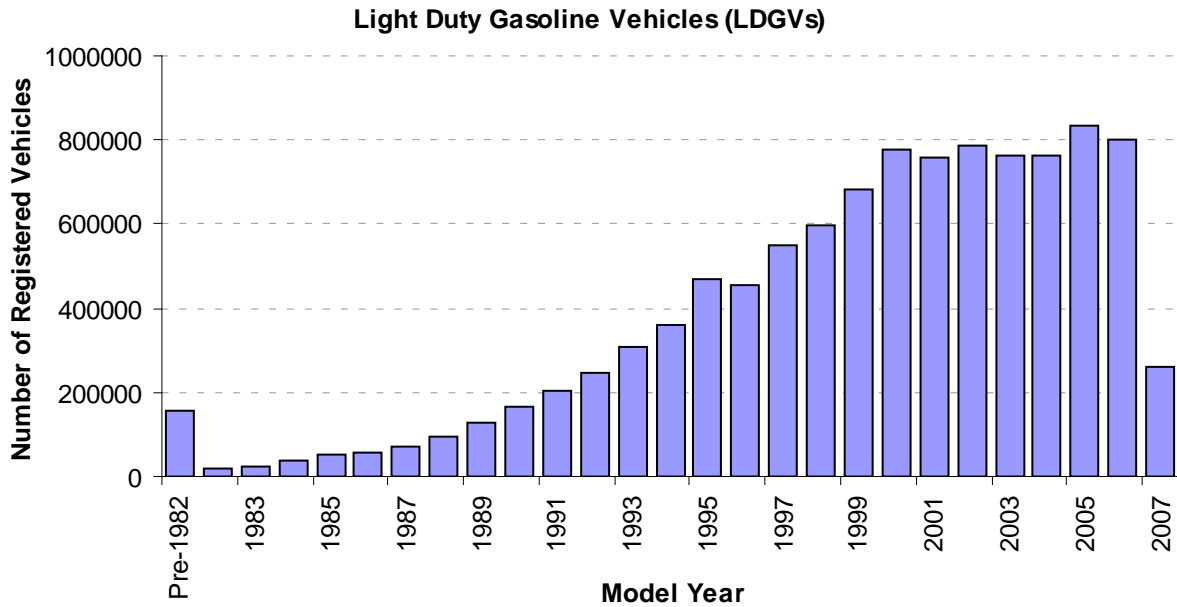
### **Test Vehicles**

Two 2005 model year Toyota Tacoma trucks were selected for testing. Table 1 shows the information for these vehicles.

The vehicle registration data from Texas were used to assist in determining which vehicle model year to select for testing. Figure 3 shows the vehicle fleet distributions for Texas. This figure shows that 2005 is the year with the most registered vehicles in the LDGV class and therefore this model year was selected.

**Table 1. Test and Control Vehicle Information.**

	<b>Control Vehicle (C)</b>	<b>Test Vehicle (T)</b>
<b>Make/Model</b>	Toyota/Tacoma 2WD	Toyota/Tacoma 2WD
<b>Model Year</b>	2005	2005
<b>Type</b>	Small Pickup Truck	Small Pickup Truck
<b>Cabin</b>	Regular	Regular
<b>G.V.W.R. (lbs)</b>	4,550	4,550
<b>Measured G.V.W. (lbs)</b>	3,820	3,820
<b>Mileage</b>	25,000	24,000
<b>Engine Size</b>	2.7 Liter, 4 cylinder	2.7 Liter, 4 cylinder
<b>Power / Torque</b>	164 hp / 183 lb-ft	164 hp / 183 lb-ft



**Figure 3. 2007 LDGV Registration Information for Texas.**

### **Modifications to Test Vehicle**

At the request of CCT, the following modifications were made to test vehicle’s exhaust line (Vehicle T) and emissions sampling procedure for this vehicle in order to demonstrate that 2ct is a combustion enhancer:

- The oxygen sensor on the test vehicle was disabled. This was performed to make the engine work under “real conditions” by preventing the engine’s computer from modifying the combustion condition through changing the fuel flow based on the inputs of oxygen sensor. The oxygen sensor was disabled for the entire duration of fuel consumption and emissions testing.
- For the test vehicle, the “engine-out” emissions sample was used instead of the regular “tailpipe-out” sample. Figure 4 shows this setting on the test vehicle. This was performed to eliminate the effect of the catalytic converter on the emissions of test vehicle. The gaseous emissions sample line was connected to the exhaust line before the catalytic converter. The PM emissions sample was taken from the tailpipe.

Note that the above modifications were applied only to test vehicle (Vehicle T). The control vehicle (Vehicle C) was used in its original state (unmodified state) for the entire duration of the study and the emissions samples were all tailpipe-out samples.



**Figure 4. Emissions Measurement Unit Installed on the Test Vehicle.**

### **Test Cargo**

According to SAE J-1321, the vehicles under test should have a cargo with weights representative of the fleet operations and within the capability of the vehicles. To comply with this criterion, both control and test vehicles were loaded with QUIKRETE® cement bags to reach the gross vehicle weight of 3,820 lbs. (including the driver's weight). Weight Certificates for both vehicles were obtained at the Flying J Weighbridge in Pecos, Texas.

### **Drive Cycles**

Both control and test vehicles were tested according to the explained test procedures. In order to maintain the consistency between test runs, the vehicles were driven according to following drive cycles. Prior to testing, a warm-up driving period of 45 miles was executed for both vehicles.

#### Test Drive Cycles

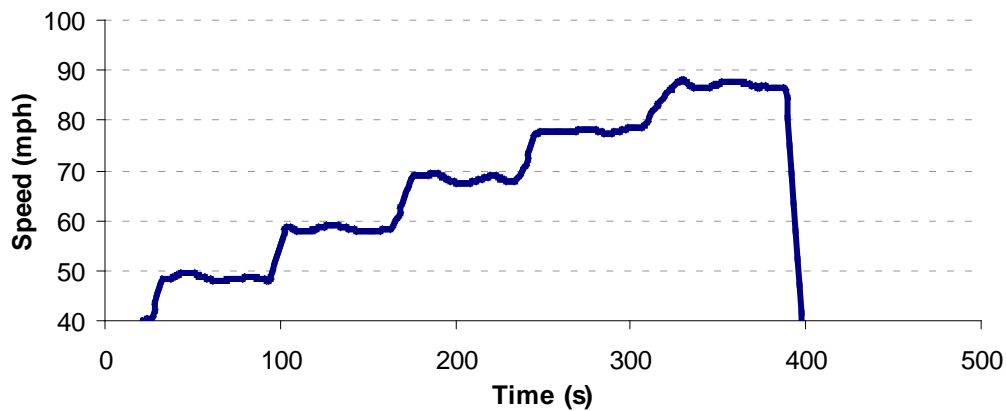
The proposed drive cycle for the SAE J-1321 fuel consumption portion of the study consisted of the following four basic elements for both vehicles:

- normal acceleration from stop-to-70 mph;
- maintaining the 70 mph speed and driving around the track for seven laps (63 miles);
- at the end of the seventh lap, stop at the same spot that the test had began; and
- keep the engine running at idle for one minute, and then shutting down the engine.

A separate drive cycle was developed for emissions measurement components. The drive cycle consisted of intervals of different steady-state speeds from 50 mph to 90 mph. The drive cycle consisted of the following elements:

- accelerate from stop-to-50 mph;
- maintain 50 mph for at least 60 seconds;
- increase the speed by 10 mph and maintain the new speed for 60 seconds. Repeat this process until reaching 90 mph; and
- decelerate and stop.

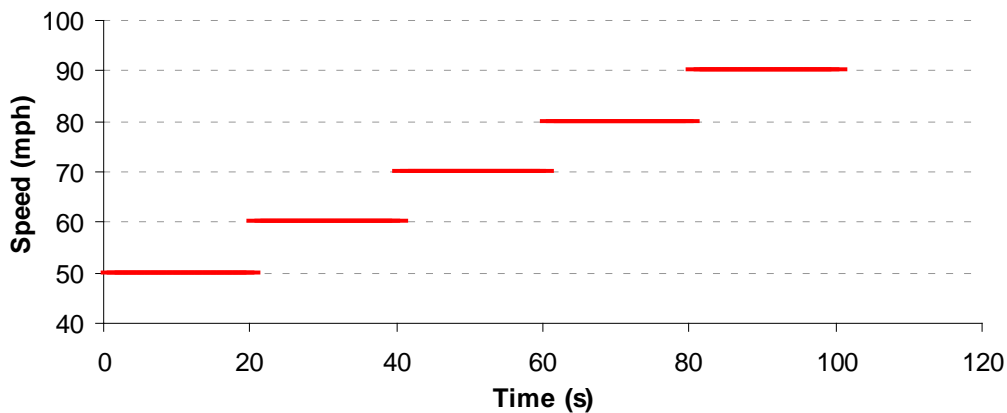
Figure 5 shows this drive cycle for the emissions testing.



**Figure 5. Test Drive Cycle.**

### Analysis Drive Cycle

A synthetic drive cycle was used for data analysis. The drive cycle consists of normalized (to speed) emissions data for 20-second samples of speeds from 50 mph-to-90 mph. Figure 6 shows this cycle.



**Figure 6. Synthetic Analysis Drive Cycle.**

The main purpose of this cycle is to provide maximum consistency between different runs and vehicles. From the available 60-second of data for each cruise speed, the continuous 20-second window with emissions data that had the minimum coefficient of variation (standard deviation divided by mean) was considered the best representative of that speed and was selected for analysis purposes. Note that the above process was performed separately for each pollutant and therefore the selected windows of data could be different.

The selected 20-second emissions rates data for each target speed were further normalized based on that target speed according to the following equation:

$$nE_{ij} = oE_{ij} \times \frac{u_j^T}{u_j^O} \quad [1]$$

Where:

- $nE_{ij}$  = normalized emissions rates for pollutant i at speed  $u_j$ ;
- $oE_{ij}$  = observed emissions rates for pollutant i at speed  $u_j$ ;
- $u_j^T$  = target speed (50, 60, 70, 80, and 90 mph); and
- $u_j^O$  = observed speed (50, 60, 70, 80, and 90 mph).

## RESULTS

### Fuel Consumption

A work plan was developed based upon the SAE J-1321 Recommended Practice (*In-Service Fuel Consumption Test Procedure – Type II*). In this procedure, fuel consumption measurements in a test vehicle (Vehicle T) are compared to measurements from a control vehicle (Vehicle C) before and after treatment. The difference between the T/C ratios of before and after treatment cases are used to calculate a fuel savings percentage presumably resulting from the treatment.

For this study, a test run was defined as seven laps (63 miles) of continuous driving on the high speed test track at constant speed of 70 mph. Vehicle operation was synchronized to ensure precisely identical duty cycles. Both vehicles were outfitted with removable fuel tanks (shown in Figure 1) that were weighed between each test run to determine the amount of fuel consumed. The temperature of fuel was also measured during weight measurements. The T/C ratios for all test runs were calculated, and the first three ratios that fell within SAE J-1321 prescribed 2 percent filtering band were used to compute an average value representing each segment of testing.

Table 2 shows the data for the three T/C ratios that were used in the calculations. Baseline testing was performed on April 15, 2008. Treatment testing was conducted on April 23, 2008.

**Table 2. Gravimetric Fuel Consumption Results.**

Base Condition (4/15/2008)						
	RUN 1		RUN 2		RUN 3	
	Control Veh.	Test Veh.	Control Veh.	Test Veh.	Control Veh.	Test Veh.
Fuel Used (lb)	15.99	20.6	15.84	20.23	15.89	20.32
Distance (mi)	63	63	63	63	63	63
T/C Ratio	1.288		1.277		1.279	
Min Acceptable T/C Ratio	1.262					
Average T/C Ratio	1.281					
After Treatment (4/23/2008)						
	RUN 1		RUN 2		RUN 3	
	Control Veh.	Test Veh.	Control Veh.	Test Veh.	Control Veh.	Test Veh.
Fuel Used (lb)	17.29	20.56	16.67	19.9	16.79	20.11
Distance (mi)	63	63	63	63	63	63
T/C Ratio	1.189		1.194		1.198	
Min Acceptable T/C Ratio	1.174					
Average T/C Ratio	1.194					
Fuel Saved (%)	6.8%					
Improvement (%)	7.3%					

Results in Table 2 show that the addition of 2ct combustion enhancer gasoline fuel produced an improvement of 7.3 percent under the modified J1321 test procedure and test vehicle modification (i.e. disabled oxygen sensor). The *fuel saved* and *improvement* values in Table 2 are calculated according to J1321 as following:

$$\% \text{ Fuel Saved} = (\text{Ave. Baseline T/C} - \text{Ave. Treatment T/C}) \div \text{Ave. Baseline T/C} \quad [2]$$

$$\% \text{ Improvement} = (\text{Ave. Baseline T/C} - \text{Ave. Treatment T/C}) \div \text{Ave. Treatment T/C} \quad [3]$$

### Emissions

The emissions testing work plan was developed in a similar manner to the fuel consumption testing. This work plan is explained in detail in the *Analysis Drive Cycle* section. This section also explains the construction of synthetic drive cycles and the data cleaning step. The total emissions of each pollutant were calculated for the synthetic cycle. When applicable, these values for a test vehicle (Vehicle T) are compared to measurements from a control vehicle (Vehicle C) before and after treatment. The difference between T/C ratios of before and after treatment cases are used to calculate an improvement percentage presumably resulting from the treatment.

The T/C approach does not provide satisfactory results when T/C ratios are big (i.e., over 5) because any small change in T and C values will be translated into unrealistic changes in T/C ratios. The removal of the oxygen sensor caused the test vehicle (Vehicle T) to emit increased amounts of NOx and THC emissions which resulted in T/C ratios higher than 20. In the circumstances, it was decided to use the actual measurements of these emissions from the test vehicle (Vehicle T) to evaluate the changes in the emissions. The T/C approach was used for the remainder of the pollutants (CO<sub>2</sub>, CO, and PM) as the T/C ratios were less than 5.

For this study, a test run was defined as one complete cycle at cruise speeds 50 mph to 90 mph (Figure 5) on the high-speed test track. Similar to fuel consumption testing, vehicle operation was synchronized to ensure identical duty cycles. PEMS units (SEMTECH-DS and OEM-2100) were installed on both vehicles as shown in Figure 4. In the case of CO<sub>2</sub>, CO, and PM emissions, the T/C ratios for all test runs were calculated, and the first three ratios that resulted in the lowest coefficient of variation were used to compute an average values representing each segment of testing.

Note that the SAE J-1321 prescribed 2 percent filtering band is usually unreachable for emissions analysis because of the inherent higher variability in the emissions data. In the case of NO<sub>x</sub> and THC emissions, all the observations were used in the calculation of the average emissions rates for baseline and after-treatment cases.

Table 3 and Table 4 show the summary of the emissions results for all pollutants. Results in Table 3 are based on T/C ratios while results of Table 4 are based on total measured emissions for the analysis drive cycle. The trade-off between different pollutants and fuel consumption is explained in more detail under Data Quality on page 12. Baseline emissions testing was performed on April 18, 2008, after which time the treatment fuel was applied and the process of conditioning was initiated.

**Table 3. CO<sub>2</sub>, CO, and PM Emissions Results for the Toyota Tacoma**

Pollutant	Baseline T/C		Treatment T/C		Improvement	<i>t</i> -test p-value <sup>6</sup>
	Average	Coeff. Var.	Average	Coeff. Var.		
CO <sub>2</sub>	1.027	2.0%	0.961	1.5%	6.9%	0.0107
CO	3.42	4.9%	2.69	3.8%	27.1%	0.0031
PM	1.65	6.1%	1.9	7.7%	-13.2%	0.0708

**Table 4. NO<sub>x</sub> and THC Emissions Results for the Toyota Tacoma**

Pollutant	Baseline (g)		Treatment (g)		Improvement	<i>t</i> -test p-value <sup>7</sup>
	Average	Coeff. Var.	Average	Coeff. Var.		
NO <sub>x</sub>	17.886	1.5%	20.64	2.8%	-13.3%	3×10 <sup>-5</sup>
THC	1.79	2.9%	1.771	0.9%	1.1%	0.4903

The improvement percentages in Table 3 and Table 4 are calculated according to the J-1321 calculation method (Equation 3). Positive improvement values mean a decrease in the total emissions for the cycle while a negative value indicates an increase of the pollutant. To test whether the average differences are statistically significant, an unpaired *t*-test was employed. The results of this test are listed in the right-most column of Table 3 and Table 4 and discussed in the Data Quality section.

CO<sub>2</sub> is the result of fuel combustion and directly correlates with fuel consumption. It was observed that CO<sub>2</sub> comprised 97 percent of all the carbon-based emissions of the test vehicle (Vehicle T). For the control vehicle (Vehicle C), which was tested in its original condition, this number was 99 percent.

Results in Table 3 show an improvement of 6.9 percent for CO<sub>2</sub> emissions. This can be closely interpreted as the improvement in fuel consumption. A comparison with gravimetric fuel consumption results shows that CO<sub>2</sub> results of Table 3 are consistent with the fuel consumption

<sup>6</sup> The results of this column are discussed in the Data Quality section.



results of Table 2. The results also indicate a 27.1 percent improvement for CO emissions. CO<sub>2</sub> and CO differences are found to be statistically significant at the 95 percent degree of confidence level while PM emissions differences are not statistically significant. The results in Table 4 show a 13 percent increase in NO<sub>x</sub> emissions. These differences are statistically significant at the 95 percent degree of confidence level. The THC emissions differences between baseline and after-treatment are not statistically significant at the 95 percent degree of confidence level.

### **Data Quality**

An unpaired *t*-test was employed to determine whether the average differences are statistically significant. A *t*-test is a statistical hypothesis test to test whether the means of two normally distributed populations are equal. Given two data sets, each characterized by its mean, standard deviation and number of data points, one can use some *t*-test to determine whether the means are distinct.

In statistics, a result is called *statistically significant* if it is unlikely to have occurred by chance. A *statistically significant difference* simply means there is statistical evidence that there is a difference. It does not mean the difference is necessarily large, important, or significant in the common meaning of the word. A *p*-value less than 0.05 in this column indicates a statistically significant difference between baseline and after treatment at the 95 percent degree of confidence level. In contrast, a *p*-value larger than 0.05 indicates that the difference between the two sets of data is not statistically significant at the 95% degree of confidence level.

In interpreting the results of Tables 3 and 4, one should consider the trade-offs between different pollutants and fuel consumption<sup>7</sup>. In the combustion of hydrocarbon fuels, oxides of nitrogen (NO<sub>x</sub>) are formed from the dissociation of ambient nitrogen above 2000 deg K (above 1725 °C/3140 °F) at a rate that increases with pressure, temperature, and residence time. Increasing these parameters also result in lower CO and HC emissions (higher combustion efficiency) and therefore lower fuel consumption. This trade-off between NO<sub>x</sub> and carbon emissions is well known and has been a long standing challenge for all industries with emissions regulations. Because of the basic physics behind the formation of NO<sub>x</sub>, it is generally accepted that any method of increasing engine power, combustion efficiency, or fuel economy will result in a NO<sub>x</sub> penalty.

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<sup>7</sup> Payri, Benajes, Arrègle, and Riesco (2006). Combustion and Exhaust Emissions in a Heavy-Duty Diesel Engine with Increased Premixed Combustion Phase by Means of Injection Retarding, *Oil & Gas Science and Technology*, Vol. 61(2), 247-258.

## SUMMARY

The results in this report are based on collaborative testing performed by team members from the Texas Transportation Institute, Clean Air Technologies Inc. and Sensors, Inc. The tests were performed in April, 2008 at the Pecos Research and Testing Center (RTC) outside Pecos, Texas. The research team used well-known test procedures that are fully documented in this report. The findings are based on the specific test procedures and conditions also fully documented in this report.

In summary, the results presented in this report demonstrate that gasoline fuel that was treated with 2ct combustion enhancer improved the fuel consumption of the tested vehicle by 7.3%. The results also show statistically significant changes of carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), and oxides of nitrogen (NO<sub>x</sub>). CO<sub>2</sub> was reduced by 6.9%, CO was reduced by 27.1%, and NO<sub>x</sub> was increased by 13.3%<sup>8</sup>.

Joe Zietsman  
Director, Center for Air Quality Studies  
Texas Transportation Institute

A handwritten signature in black ink on a light blue rectangular background. The signature is stylized and cursive, starting with a large 'J' and ending with a wavy line. Below the signature is a horizontal dashed line.

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<sup>8</sup> A detailed discussion on the trade-off between NO<sub>x</sub> emissions and fuel consumption is provided on page 12.