Independent Third Party Review and Audit of

GO2

Diesel Fuel Optimizer Performance Testing

Utilizing PEMS

On behalf of

CERION ENERGY

December 20, 2011

Prepared by:

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Objective

The objective of this exercise was to conduct an independent third party review and audit of the portable emissions measurement systems (PEMS), test design protocols, methodologies, in-use test data, post-test data analysis techniques, and test results submitted to Emisstar by Cerion Energy to determine the veracity of their findings reported concerning the performance of the corporation's GO_2 diesel fuel optimizer on diesel engine fuel economy and emissions for the luxury motor yacht "Big Fish". Results from this review may have broader implications for the use of nano-particle based fuel optimization technologies in the global recreational diesel luxury yachting market.

This document provides a complete reporting of our independent review and audit. The information provided herein is divided into four (4) sections. First, a review of PEMS instrumentation utilized to conduct the test and information about the host vessel is provided. Second, we review the test design protocols and methodologies followed by Cerion Energy. Third, we perform thorough and independent Quality Assurance (QA) /Quality Control (QC), data post-processing, analysis and reporting. Finally, we independently generate summary results from the raw test data in graphical and tabular form and we provide overall observations of the results of the sea trial.

Section 1: PEMS Test Instrumentation and Vessel Information

1.1 PEMS Test Instrumentation

Cerion Energy utilized one (1) OEM-2100AX or "Axion" PEMS unit for this test, manufactured by Clean Air Technologies International[1] of Buffalo, New York (CATI). The Axion sensor package measures criteria and greenhouse gas pollutants on a second-by-second basis, including oxygen (O_2). carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbons (THC, Oxides of Nitrogen (NO_x) and particulate matter (PM_{10}) to ten microns. To the best of our knowledge, the Axion represents the second generation PEMS system manufactured by CATI, replacing its predecessor the "Montana". Features and specifications[2] for the Axion PEMS technology are summarized below in Table 1.

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[1] www.cleanairt.com

[2] http://www.cleanairt.com/faq.html#descriptionofaxion

Table 1 – Axion OEM-2100AX PEMS Unit Features and Specifications

Feature	Specification
Axion Exterior + Case Dimensions	550mm x 430mm x 215mm
Combined Weight (Unit + Case)	68 lbs.
Power	12-14V DC
Gas Sampling Rate	1 Hertz
Sample Flow Rates: a) Gas analyzers (GA1, GA2) b) PM Detector	 5.0 liters per minute 4.0 liters per minute
Analyzers a) NDIR b) O_2 Sensor c) NO_x Sensor d) PM Laser-Light Scattering Detector	Pollutant Measured CO, CO_2 and THC O_2 NO_x PM_{10}
Engine Sensor Array a) MAP Transducer b) Optical Tachometer c) Air Intake Temperature	Parameters Measured Manifold Absolute Pressure (MAP) Engine RPM Thermocouple

1.2 Vessel Information

Cerion Energy conducted both the baseline diesel and GO_2 product tests on the luxury motor yacht Big Fish[3], a diesel powered recreational luxury yacht designed by Gregory Marshall Design and built in 2010 by McMullen & Wing New Zealand. The Big Fish operates out of Bikini and Marshall Islands and is available for reserved private charter throughout the South Pacific, Tahiti, Antarctica, Northern Europe and elsewhere. Specifications for the Big Fish are provided in Figure 1 and Table 2 below:

[3] http://www.charterworld.com/index.html?sub=yacht-charter&charter=mymy-big-fish-5764

Figure 1 – Luxury Motor Yacht Big Fish

Table 2 – Luxury Motor Yacht Big Fish Specifications

Category	Description
Vessel	Big Fish
Domicile / Ports of Call	Bikini, Marshal Islands
Builder / Designer	McMullen & Wing Ltd/Gregory Marshall
Year	2010
Specifications	
L.O.A.	45 Meters
Beam	9.3 Meters
Charter Guests	12 Daytime, 10 Overnight
Cabins	5
Cruise Speed	11 knots
Crew	10
Draft	2.95 meters
Engines	
No.	2
Make	Caterpillar
Model	3508B DI-TA
Year	2010
HP	2100 HP
Displacement	34.5 L

Section 2: Test Design, Protocols and Methodologies

Cerion employed a "sea trial" test design, whereby a single vessel carried out standard operations at sea during both the baseline and product test configurations. In-use emissions were measured on one of the vessel's two propulsion engines (Port) at 1200 RPM, after a fifteen to twenty minute engine stabilization period before recording actual engine parameters and emission values. A total of six (6) test repeats were performed at the selected RPM interval. Baseline testing was performed in the United States on May 23, 2011, during sea trials off of Ft. Lauderdale, Florida, on the Atlantic Ocean. During the baseline measurement period, Cerion test engineers observed sea condition 1 on the Sea State[4]. Also recorded was a 28°C air temperature and 29°C water temperature. Product testing was performed in the Sir Francis Drake Passage on November 18, 2011, off Tortola in the British Virgin Islands after the Big Fish completed a product break-in period which coincided with a regularly chartered service. During the product measurement period, Cerion test engineers observed a sea condition 1 on the Sea State. Also recorded was a 29°C air temperature and 29°C water temperature

Section 3: Data Quality Assurance and Quality Control (QA/QC) and Reporting

Data screening and quality assurance are procedures for reviewing data collected on board, determining whether any errors or problems exist in the data, correcting these errors or problems where possible, and removing invalid data if errors or problems cannot be corrected. The goal of data screening and quality assurance is to produce a database that contains valid data. For this review and audit, Emisstar screened and selected ten minute increments of time aligned data from each test configuration where variability in engine parameter and emissions data was smallest. Figure 2 exhibits a time trace of the complete data set by engine parameter value and emission concentration.

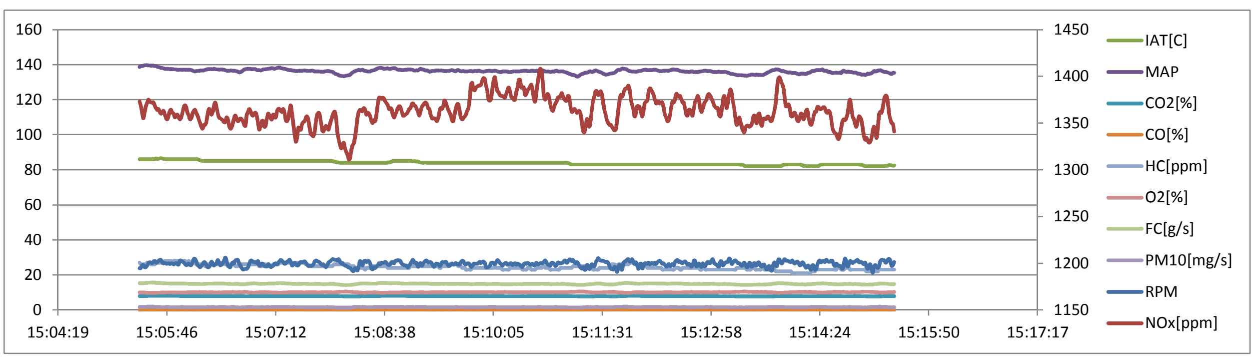


Figure 2 – Time Trace of Big Fish Data Set by Recorded Engine Parameter Value and Emission Concentration

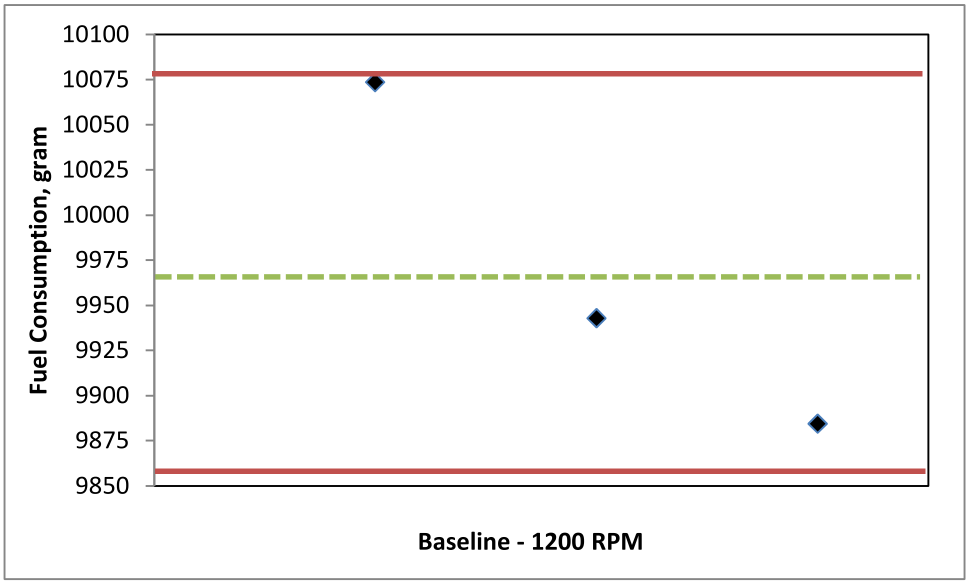
[4] http://www.boats.dt.navy.mil/pdfs/seastate.pdf

Following one method of internal quality assurance and control, Emisstar performed an exploratory statistical analysis to determine the correlation between emissions and engine parameters as compared to published information from peer-reviewed technical journals and acceptable industry standards. In addition, we examined the repeatability of all test runs by plotting repeatability boundaries. Screened time aligned data increments were subsequently used to perform data reduction and analysis, including determination of fuel economy and mass emission rates, and to document the results in this final report.

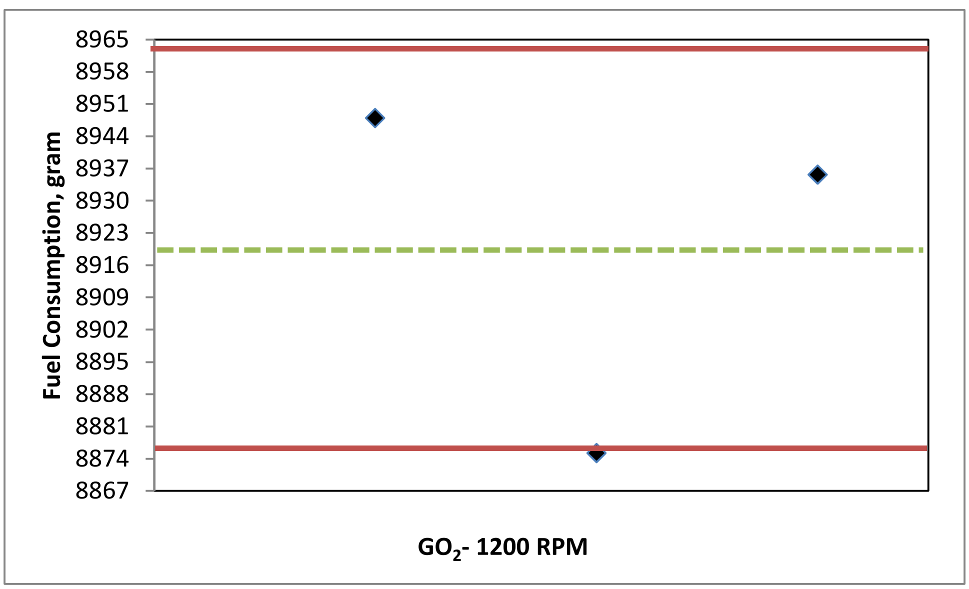
3.1 Repeatability

Figures 3 and 4 below display examples of the repeatability evaluation performed for fuel economy results obtained from the test vessel during this test as scatter diagrams. Average mass fuel economy values for three test runs, mean value of emissions, and repeatability boundaries (denoted by the red horizontal lines) are presented. For both the baseline and Cerion GO_2 product evaluation and for all pollutants, average mass emission rates were contained within the acceptable repeatability boundaries determined by the following equation:

$$\text{Confficient of Repeatability} = \pm 1.96\sigma = \pm 1.96\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$



<u>Figure 3</u> – Example of Repeatability Analysis Performed for Fuel Economy Port Engine, Baseline at 1200RPM



<u>Figure 4</u> – Example of Repeatability Analysis Performed for Fuel Economy Port Engine, GO_2 at 1200RPM

3.2 Confidence Interval

Confidence intervals at the 95% confidence level were computed using the following standard equation for overall fuel consumption and average mass emissions from the test vessel:

$$\text{Confidence Interval} = \pm 1.96\frac{\sigma}{\sqrt{N}} = \pm 1.96\sqrt{\frac{1}{N(N-1)}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

Where,

- σ is standard deviation
- N is number of samples
- $\bar{x}$ mean value
- x_i mass emissions or fuel consumption in each test run

3.3 Calculating Percent Difference – GO_2 versus Baseline

Percent difference of fuel consumption and mass emission rates were calculated using the following equitation:

$$Percent\ Difference = \frac{GO_2 - Baseline}{Baseline} \times 100$$

3.4 Exploratory Analysis and Statistical Evaluation

Emisstar performed a statistical evaluation of carbon dioxide emissions, manifold air pressure, exhaust flow, and intake flow versus fuel consumption. These outputs were computed to ensure data integrity and correlation between each other. All data analyzed passed statistical rigor and were accepted into the audit exercise. Figures 5-8 provide a graphical comparison of the results as obtained from the test vessel during this test.

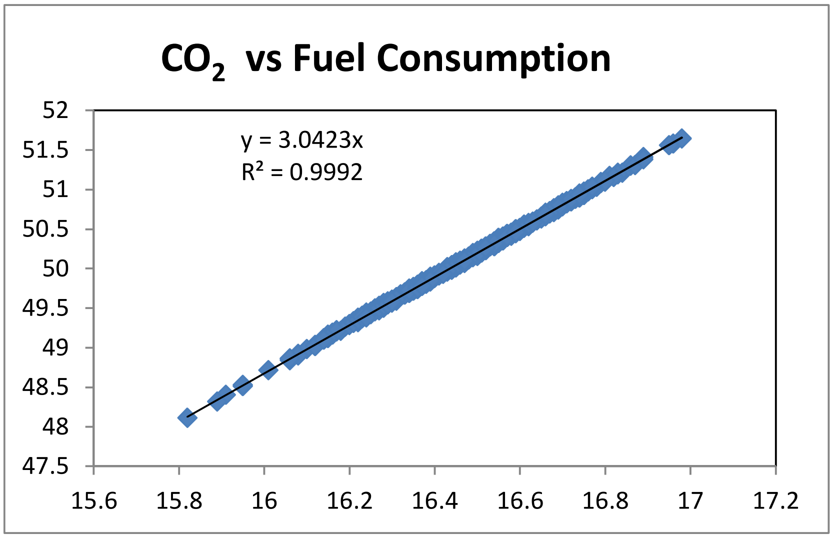


Figure 5 – Correlation of Carbon Dioxide vs. Fuel Consumption at 1200RPM

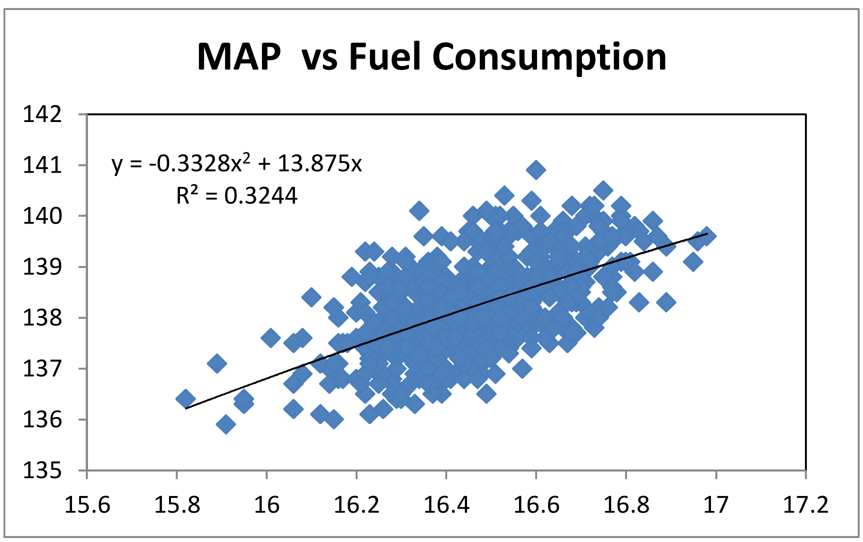


Figure 6 – Correlation of Manifold Air Pressure vs. Fuel Consumption at 1200RPM

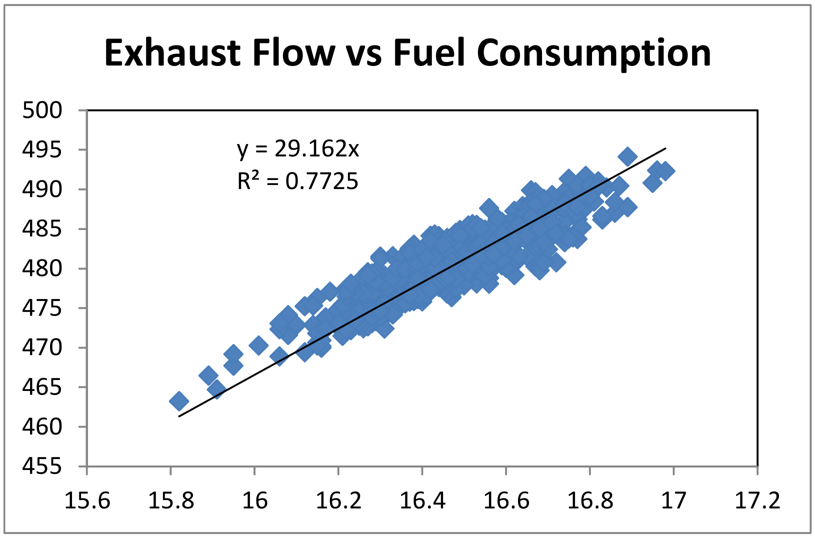


Figure 7 - Correlation of Exhaust Flow vs. Fuel Consumption at 1200RPM

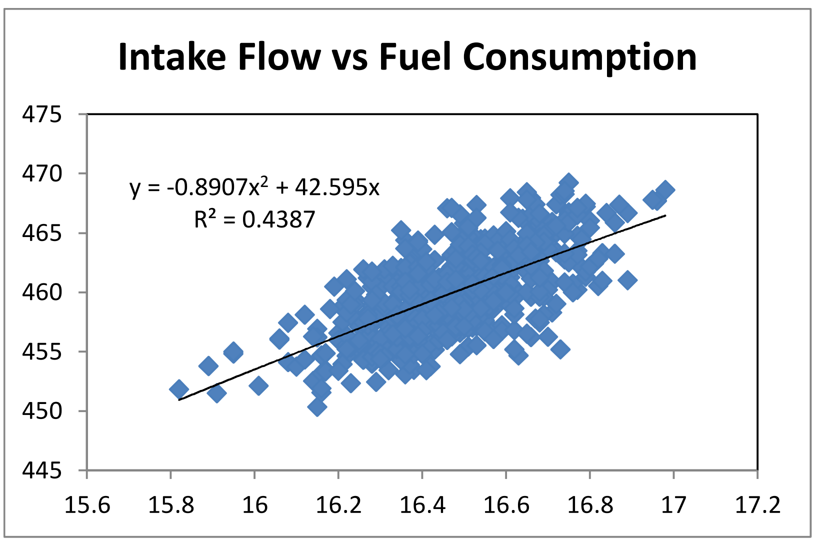


Figure 8 – Correlation of Intake Flow vs. Fuel Consumption at 1200RPM

3.5 Calculating Fuel Economy Using the Carbon Mass Balance Method

The carbon mass balance method offers a practical and highly accurate method of evaluating real-world fuel economy of heavy-duty diesel engines based on the analysis of carbon-containing elements from the exhaust gas emissions using PEMS. Instead of directly measuring the volume or weight of the intake fuel into the engine using volumetric or gravimetric methods, the carbon balance method measures the amount of carbon in the exhaust, which virtually eliminates all variables associated with the day-to-day operation of industrial and commercial fleets. Therefore, this method is widely accepted and used by the Environmental Protection Agency (EPA) as a viable fuel consumption measurement technique.

Fuel used in combustion engines is primarily composed of mixtures of carbon and hydrogen. When the fuel is burned, those elements combine with oxygen (O_2) from the air to produce carbon dioxide (CO_2) and water (H_2O). However, if the combustion process is not complete, the exhaust gases may also contain unburned hydrocarbon (HC) and carbon monoxide (CO). Because the PEMS system includes multiple analyzers which are capable of measuring all components of the exhaust gas containing carbon species, one can accurately analyze the flow rate of carbon-containing materials in the exhaust, and therefore, the mass of carbon after the combustion can be determined.

PEMS technology capabilities have advanced rapidly over the past several years. For reference, the EPA has already established a design and performance standard to meet the audit criteria under CFR 40 Part 1065 Subpart D [Federal Register / Vol. 70, No. 133; page 40423].[5] EPA's regulations on using carbon balance method in testing fuel consumption are also found in Code of Federal Regulations, CFR Part 600.

Test results using PEMS exhaust measurement yield a consistent 3 to 4% low bias range compared to gravimetric results with a similar vehicle.[6] The average coefficient of variation (COV), based on several repeated laps performed on every test segment, was 2.98% for the gravimetric measurement and 3.26% for the PEMS, which yields a 95% confidence interval. As such, the carbon balance technique through PEMS measurement is a streamlined and accurate method for evaluation of fuel consumption on a real-time basis.

The CATI Axion PEMS system calculates mass fuel flow rates using the carbon balance method while taking into account combustion chemistry and assuming applicability of the ideal gas law. The equivalent molar formula of the fuel is considered as CH_xO_z. CATI employs the following general engine combustion reaction in order to calculate mass emissions and fuel consumption:

$$CH_xO_z + u\,(0.21O_2 + 0.79N_2) \rightarrow bCO_2 + cCO + dC_6H_{14} + eNO + fH_2O_{(w)} + gO_2 + hN_2$$

[5] U.S. Environmental Protection Agency, Assessments and Standards Division, In-Use Testing Program for Heavy-Duty Diesel Engines and Vehicles—Technical Support Document, EPA 420-R-05-006, 2005.
[6] Evaluating Real-World Fuel Economy on Heavy Duty Vehicles using a Portable Emissions Measurement System, *Carl Ensfield, L.J. Bachman, A. Erb, C Bynum*, SAE Paper No. 2006-01-3543

Where *b, c, d, e, f, g, h,* and *u* are corresponding stoichiometric coefficients for the reaction.

Fuel consumption rates are calculated using dry basis mole fractions of measured species and exhaust flow rate.

$$M_f = M_e\,(y_{CO} + y_{CO2} + 6y_{HC})\,MW_{fuel}$$

Where:

M_f = the mass per time of fuel consumption
$MWfuel$ = the molecular weight of fuel consumption
M_e = molar exhaust flow rate

M_e, the dry basis molar exhaust flow rate is calculated using factions of measured species using the following equation:

$$M_e = \frac{2M_{air}y_{O2,in}}{(2y_{O2,out} + y_{CO} + y_{CO2} + y_{NO} - 7y_{HC}) - (y_{CO} + y_{CO2} + y_{NO} + 6y_{HC})(z - 0.5x)}$$

Where:

yO_2,in = the mole fraction of O_2 in the intake air
yN_2,in = the mole fraction of N_2 in the intake air
x and z = equivalent molecular formula of the fuel considered as CH_xO_z

Section 4: Summary Results and Observations

From a total of six (6) test repeats provided by Cerion, Emisstar screened and selected three (3) repeats to minimize variability between repeats. The results presented below include tables and figures for the operation of the vessel at 1200 RPM, which best represents the vessel's engine operating RPM.

4.1 Summary Results

Table 3 and Figure 8 summarize exhaust mass emissions data and fuel consumed in grams for 1200 RPM during Baseline and Cerion GO_2 product test configurations. Table 4 and Figure 9 exhibit a comparison of fuel consumption and mass emissions for Baseline and Cerion GO_2 product tests and summarize percentage differences.

Table 3 – Fuel Consumption and Mass Emission Values for 1200RPM – Baseline and Cerion GO_2

	Average Fuel Consumption and Mass Emissions							Confidence Interval					
	RPM	FC [g]	CO_2 [g]	CO [mg/10]	HC [mg/10]	NO_x [mg/100]	PM_{10} [mg]	FC[g]	CO_2[g]	CO [mg/10]	HC [mg/10]	NO_x [mg/100]	PM_{10} [mg]
Baseline	1200	9967	30369	6050	3651	5708	1283	110	208	1563	1850	51	1.4
GO_2	1200	8920	28147	3801	2150	4933	1028	44	128	446	682	222	60

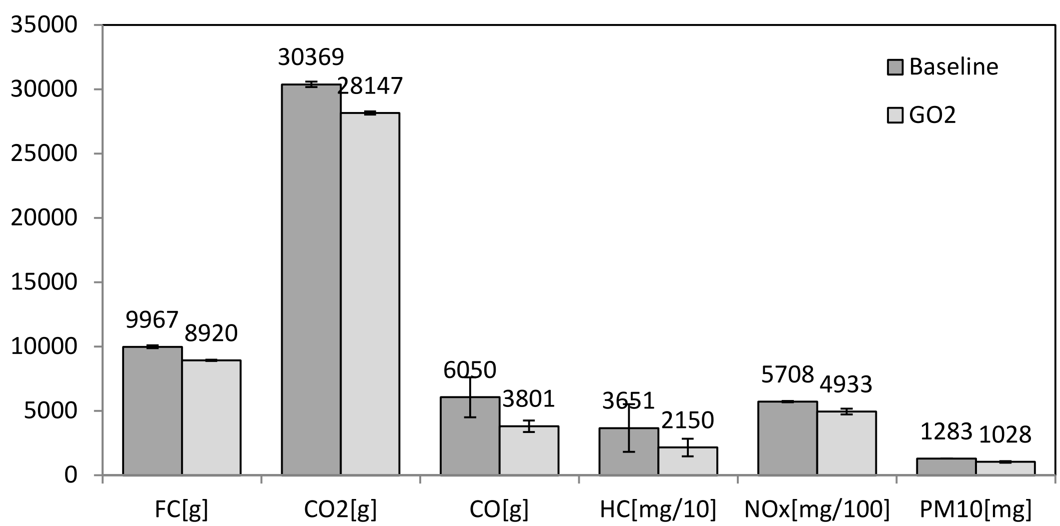


Figure 9 – Fuel Consumption and Mass Emission Values for 1200RPM – Baseline and Cerion GO_2

Table 4 – Percent Differences in Fuel Consumption and Mass Emissions between Baseline and Cerion GO_2 at 1200RPM

Baseline vs. GO_2	Percentage Difference					
RPM	FC	CO_2	CO	HC	NO_x	PM_{10}
1200	-11%	-7%	-37%	-41%	-14%	-20%

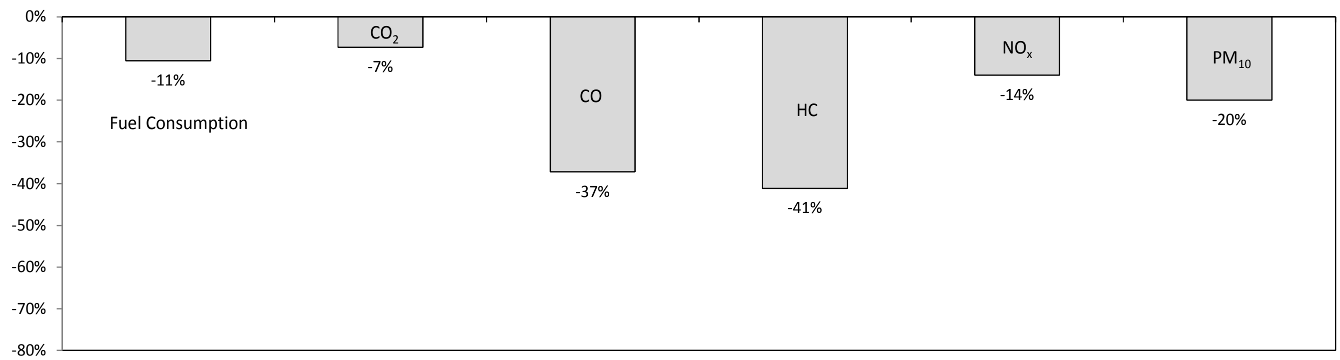


Figure 10 – Percent Differences in Fuel Consumption and Mass Emissions between Baseline and Cerion GO_2 at 1200RPM

4.2 Emisstar Observations

Based upon the completed review and audit, Emisstar makes the following general observations:

- An audit of Cerion test logs, data sets and phone interviews with the test engineer leads Emisstar to conclude that this test was authentic and took place as described.
- An eleven percent (11%) improvement in vessel fuel economy over baseline was observed while operating with the GO2 diesel optimizer, which is consistent with other test results audited by Emisstar for this combustion catalyst technology.
- The following emission reductions were observed:
  - CO2: Seven percent (7%)
  - CO: Thirty-seven percent (37%)
  - HC: Forty-one percent (41%)
  - NO_x: Fourteen percent (14%)
  - Particulate Matter (PM_{10}): Twenty (20%)
- Calculation of fuel economy using the carbon balance method is standard practice in the transportation industry and recognized by both EPA and SAE.

Other observations:

- Environmental conditions influencing the data set were controlled using post-test correction factors for ambient temperature, ocean current, water salinity, viscosity, vessel weight and hull-surface cohesion. Further analysis of same will likely yield a correction of +/- one-half of one percent (0.5 %) when reporting final adjusted net fuel economy improvement figures for this project data set.

About Emisstar

Emisstar is a clean energy technology and emissions consulting services firm and a recognized national leader in fuel economy and emissions measurement. We guide our clients through the transition to more sustainable, lower carbon and energy-efficient economic activity by accelerating the integration of clean technologies with the built and mobile environments. Our offices in key strategic markets throughout the U.S. provide clients nationwide access to an extensive scope of services in the energy and emissions arena. Our services include developing strategic plans and sustainability initiatives that utilize renewable energy and efficient goods movement; providing state-of-the-art technical services to effectively meet the requirements of complex energy and emissions regulations; assisting Fortune 500 companies access millions of dollars in grant funding; assessing, optimizing and verifying technologies with portable emissions measurement systems testing and Emisstar's proprietary Test Channel™ network; and strategically guiding leading technology developers in a dynamic marketplace. Visit us at www.emisstar.com for further information.

Legal Name:	Emisstar LLC
Year of Incorporation:	2005
Number of Years in Business:	6
Type of Operation:	Limited Liability Company
Office Locations:	CA, NY and TX
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