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OVERVIEW OF ENVIROFUELS DFC (DIESEL FUEL CATALYZER) PERFORMANCE TESTS

PUBLIC VERSION

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PATENTED TECHNOLOGY » PROVEN RESULTS » PAYBACK

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EXECUTIVE SUMMARY

EnviroFuels, LLC (EnviroFuels) maintains an active testing program, conducted in both laboratory and field environments to confirm the validity of its technology, namely EnviroFuels DFC (Diesel Fuel Catalyzer). Through the laboratory tests, EnviroFuels seeks to understand how its diesel fuel technology impacts combustion. Through the field tests, EnviroFuels seeks to demonstrate the efficacy of its technology in diverse applications such as railroad locomotives, oil and gas drilling rigs, various marine vessels, and large mining equipment. This document summarizes completed laboratory and field tests.

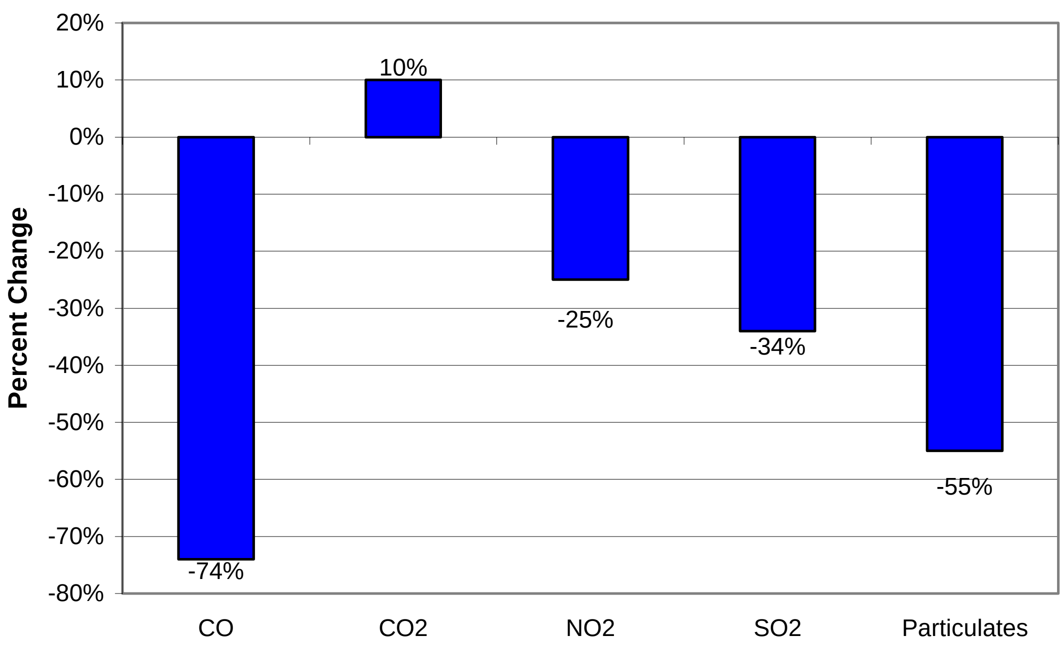
LABORATORY TESTS

Diesel Combustion Emissions Test

Location: University of Denver, Denver, Colorado, U.S.A.
Method: Open flame

This test was performed by Dr. Dwight Smith, Professor and Chancellor Emeritus, in the Department of Chemistry and Biochemistry at the University of Denver. This test used an open flame that was burning diesel fuel and measured emission rates for carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and particulate matter. Untreated diesel fuel was fed to the burner, and the resulting emissions were measured. Then, diesel fuel treated with EnviroFuels DFC was fed to the burner. The following chart displays the percent difference in emissions.

Figure 1: Open-Flame, Diesel Combustion Emissions



As the previous chart displays, DFC significantly affected the combustion emissions. In addition to significant decreases in particulate matter and SO_2, DFC produces a more complete combustion reaction. The slight increase in CO_2 and large decrease in CO displayed above confirm that a more complete combustion reaction was realized during this test. The reductions in CO_2 achieved in field tests through the use of DFC directly result from burning less fuel due to the increased engine efficiency. It is important to note that the laboratory test discussed here utilized a constant fuel source. Therefore, in this laboratory environment, CO_2 emissions would not decrease, because the fuel flow rate is constant.

Fuel Analysis, Comparison of Untreated Diesel Fuel to Treated Diesel Fuel

Location: Chemical Technology and Laboratory Services, Inc., Kingwood, Texas, U.S.A.

This test proves that DFC does not fundamentally alter the properties of diesel fuel. Engine owners and operators can use DFC with confidence that the fuel remains within the OEM specifications and will not harm the engine. The following table presents the comparison of the properties between the untreated diesel fuel and the diesel fuel treated with EnviroFuels DFC.

Table 1: Properties of Diesel Fuel, Untreated vs. Treated

Property	Baseline	Treated	Units
API Gravity	33.4	33.4	°
Flash point, PMCC, procedure A	63.0	63.5	°C
Cloud point	-9	-9	°C
Pour point	-30	-30	°C
Viscosity, 100 °F	2.448	2.446	mm^2/s
Condradson carbon residue	0.18	0.18	wt-%
Sulfur	0.2839	0.2799	mass-%
Copper corrosion, 3 hr, 50 °C	1a	1a	
Ash	<0.001	<0.001	mass-%
Water and sediment	0	0	volume-%
Neutralization number	< 0.01	< 0.01	mg KOH/g
Particulate contamination, 3.8L filtered	< 0.01	< 0.01	mg/L
Cetane index, calculated	42.0	42.0	
Distillation, % recovered			
50%	255.0	255.0	°C
90%	323.5	325.0	°C
End	355.0	353.5	°C
Thermal stability, 300 °F, 90 min, pad rating	2	2	
Heat of combustion, net	18,287	18,242	BTU/lb
Nitrate cetane improvers	negative	negative	

Biodiesel Combustion Emissions Test

Location: University of Denver, Denver, Colorado, U.S.A.
Method: Open flame

This test used an open flame that was burning two types of diesel fuel, ECD-LS (8 ppm sulfur) and CERT 2007 (380 ppm sulfur). Each type of diesel fuel was blended with biodiesel to a concentration of 20 percent biodiesel (B20). The test measured emission rates for carbon monoxide (CO) and nitrogen oxides (NO_x). Each untreated biodiesel blend was fed to the burner, and the resulting emissions were measured. Then, each biodiesel blend treated with EnviroFuels DFC was fed to the burner. The following table displays the percent reductions in emissions.

Table 2: Biodiesel Open-flame Emissions Results

Fuel Blend	Percent Change	
	CO	NO_x
ECD-LS 20 + DFC	-10%	-18%
CERT 20 + DFC	-10%	N/A

Natural Gas Combustion Emissions Test

Location: University of Denver, Denver, Colorado, U.S.A.

This test investigated the effect of EnviroFuels DFC on emissions from combustion of natural gas. The test method called for bubbling the metered fuel through the liquid DFC, which created an aerosol. CO and NO_x measurements were made by isolating the filtered plume in a gas spectroscopic cell and measuring concentrations using FTIR spectroscopy. NO was used as the index for NO_x. The test produced the following results:

Table 3: Emissions Results for Natural Gas

Pollutant	Percent Change
NO (index for NO_x)	-18%
CO	-87%

While particulate reductions were not measured in this test, particulates emissions closely correlate to CO. Based on this correlation, estimated particulate emissions would have been reduced by approximately 65 percent.

Coal Combustion Emissions Test

Location: University of Denver, Denver, Colorado, U.S.A.

This test utilized controlled combustion of uniform granulated coal wafers prepared with a laboratory press and stainless steel die set. It measured the impact of EnviroFuels technology on carbon monoxide (CO) and particulate emissions generated by combustion of coal. Measurements for sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) emissions are currently in progress. The controlled combustion events occurred in a quartz chamber that was designed in the laboratory specifically for this application. An absorption train and spectroscopic cell were used to capture gaseous emissions samples, while quartz filter assemblies were used to capture particulate emissions samples. The gaseous samples were analyzed with FTIR spectroscopy, while the particulate samples were measured gravimetrically.

The test used the following types of coal:

- High sulfur coal: Ohio composite with 3.4 percent sulfur, 2.75 percent of which is pyretic sulfur.
- Low sulfur coal: Western coal with 0.34 percent sulfur, most of which is organic sulfur 0.33 percent.

The EnviroFuels technology was administered to the coal by allowing the coal to absorb the diluted aqueous parent solution. The test produced the following results:

Table 4: Emissions Results for Coal

Coal Type	Percent Change	
	PM	CO
Low-Sulfur Coal	-7%	-25%
High-Sulfur Coal	-10%	Not measured

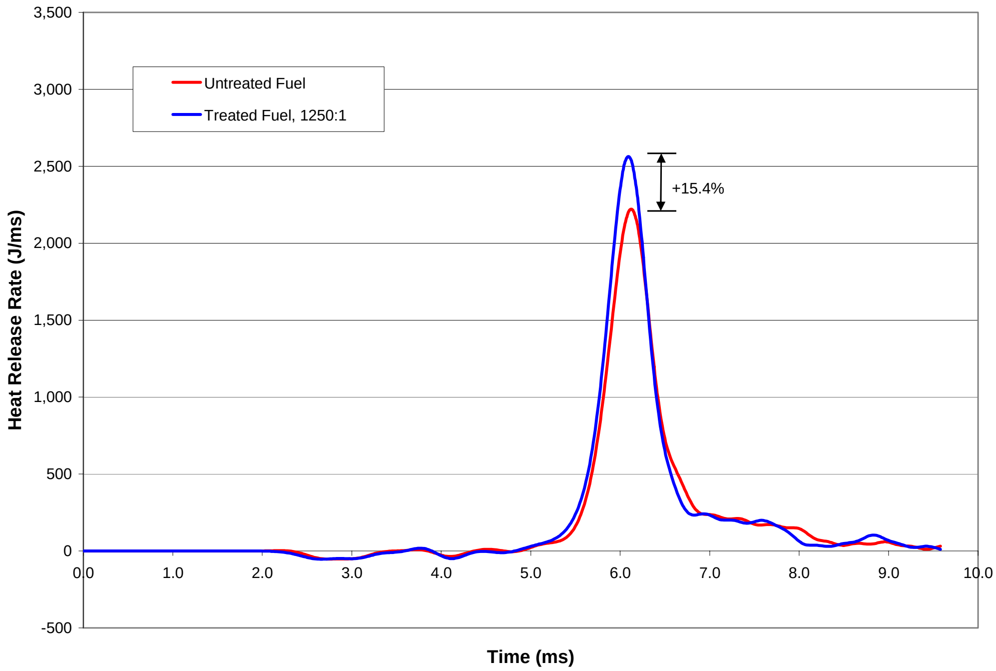
Ignition Quality Test

Location: Southwest Research Institute (SwRI), San Antonio, Texas, U.S.A.
Method: Ignition Quality Test (IQT)

Background of IQT Methodology
The IQT methodology was originally developed by SwRI for determining the cetane number of fuels. EnviroFuels worked with SwRI, modifying the IQT methodology to measure the total energy as heat released and the rate of energy as heat released for a combustion event. The apparatus is a "bomb-type" combustion chamber, also known as a constant volume combustion apparatus (CVCA). The chamber is pressurized with hot air at temperature and pressure settings that approximate the conditions of an engine cylinder just prior to combustion. The fuel is injected into the hot air mass in the cylinder, causing combustion to occur. High-speed computer analysis monitors the pressure curve as the combustion process is completed. This methodology is extremely accurate and precise. Over 500 data points are collected for each combustion event, and the average of 32 combustion events is used for the final reported result.

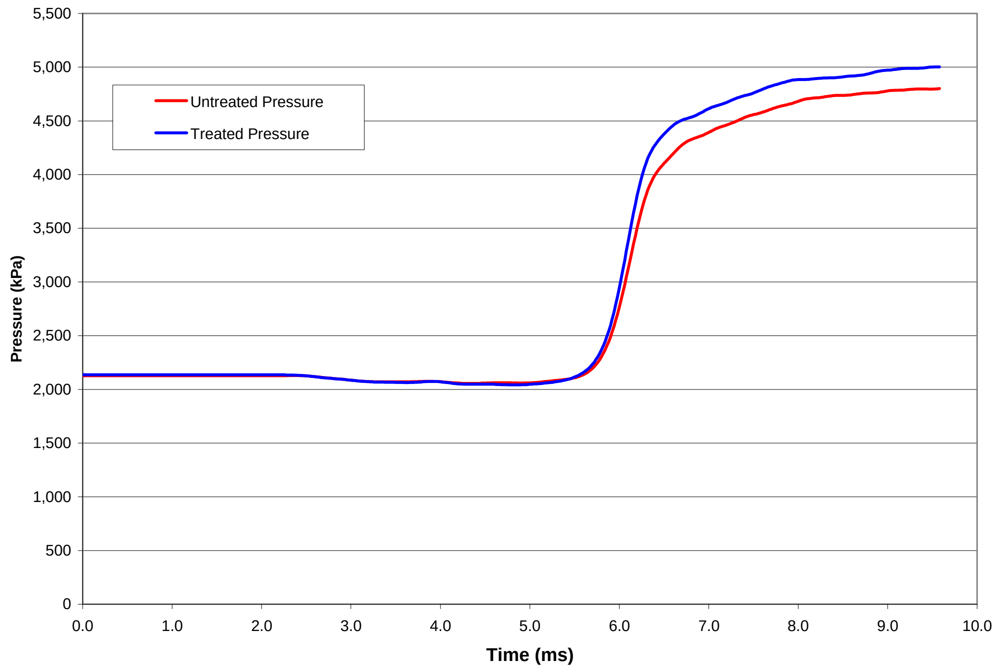
This test measured the rate of heat release in a combustion event. The following chart displays the increased rate of heat release produced by high-sulfur diesel fuel treated with EnviroFuels DFC.

Figure 2: Heat Release Rate from IQT



As indicated by the graph above, the shape of the curve is directly related to combustion efficiency. The taller curve for the treated fuel batch indicates that more energy is released by the combustion event within the same amount of time. EnviroFuels DFC does not affect the cetane number, as exhibited by the similar ignition delays between treated and untreated fuel batches.

Figure 3: Pressure Change from IQT



FIELD TESTS

The following field tests were performed in applications and operating environments spanning rail, dredging, mining, and oil & gas drilling. These tests were designed to evaluate the effect of DFC on fuel consumption, fuel combustion emissions, or both fuel consumption and emissions.

St. Lawrence & Atlantic Railroad

Location: Auburn, Maine, U.S.A.
Engine: EMD 16-645E3
Locomotive: GP-40-3

This test was performed through a program of the United States Environmental Protection Agency (EPA), known as the Environmental Technology Verification (ETV) program. The test protocol required all data collection and analysis to be completed by independent third-party contractors, ensuring objectivity throughout the test. Environment Canada was the testing contractor, and the Southern Research Institute (SRI) analyzed, verified, and reported the data.

Background
EnviroFuels provided the product, and the St. Lawrence & Atlantic Railroad, a Genessee & Wyoming subsidiary, provided the aforementioned locomotive in addition to a resistive load bank, fuel, plant facilities, and extensive support. The ETV test was designed to observe the impact of EnviroFuels DFC on fuel efficiency and emission rates for CO_2, CO, NO_x, total unburned hydrocarbons (THC), smoke opacity, and total particulate matter (TPM).

The test first analyzed untreated diesel fuel to establish a baseline. Once the baseline was established and satisfied the test protocol's requirements, the engine was treated with EnviroFuels DFC. The treatment period lasted for two (2) months, during which the locomotive consumed approximately 35,000 gallons of fuel treated with the appropriate amount of EnviroFuels DFC. Then, the performance test runs were completed.

Results
The ETV Report clearly states the positive performance of EnviroFuels DFC:

> *Brake-specific fuel consumption (BSFC) and brake-specific gaseous emissions showed statistically significant improvements at the majority of the operating notches.*

The following is a summary of the data generated during the ETV test.

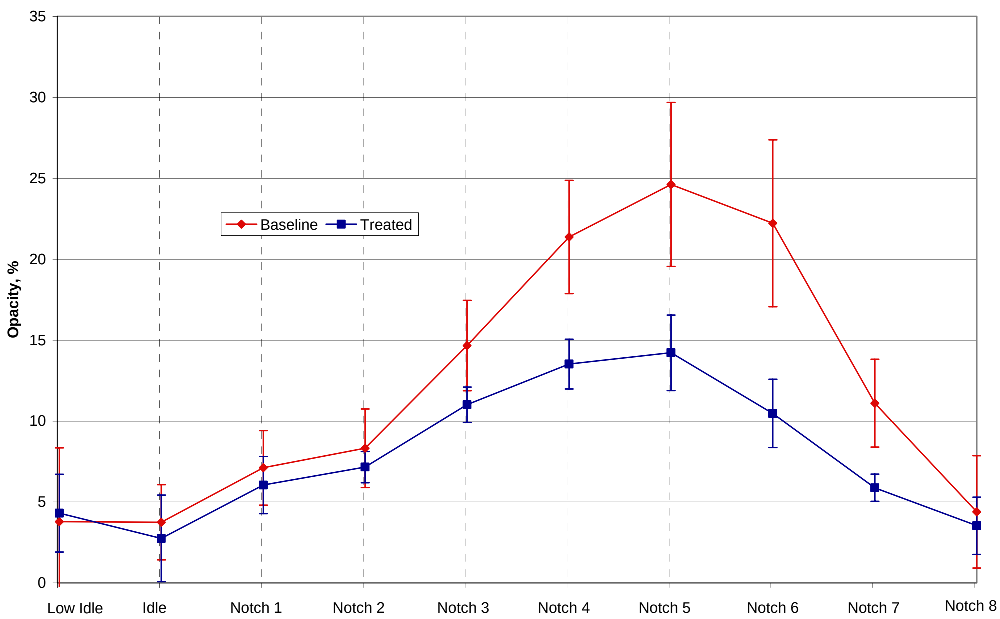
Table 5: ETV Test Results

Measurement	Line-Haul Duty Cycle	Switching Duty Cycle
Change in Brake-Specific Fuel Consumption	-5%	-10%
Change in CO_2 Emissions	-5%	-10%
Change in CO Emissions	-44%	-39%
Change in THC Emissions	-22%	-27%
Change in NO_x Emissions	***	-9%

Note: ***Not statistically reportable

The following chart displays the steady-state opacity reductions observed during the ETV test.

Figure 4: Steady State Opacity



Oil and Gas Drilling Company

Location: Denton, Texas, U.S.A.
Engine: Caterpillar D399

This test was performed to assess EnviroFuels DFC's impact on power, fuel economy, and emissions on a drilling rig for an oil and gas drilling company. EnviroFuels conducted fuel economy and power tests. A contracted emissions tester performed emissions tests.

Background
The tested engine was a Caterpillar D399, manufactured in 1966. The engine is rated at maximum 1,100-horsepower (hp) and 800-kilowatts (kW). Older diesel engines, even after

rebuilds, lose power. The drilling company wanted to evaluate EnviroFuels DFC's ability to restore power.

The test engine, along with two identical engines, provided power to the drilling rig. The above tests were performed on an untreated engine. After establishing the baseline test and performance operating levels, the engine was treated with EnviroFuels DFC. Once the engine was conditioned with EnviroFuels DFC, it was tested on the same parameters. The baseline and final test results were compared to determine performance changes in the engine.

Results

The field test showed that the treated engine consumed less fuel than the baseline engine on a power-corrected basis. The test also showed reductions in CO, NO_x, and unburned hydrocarbons. The same engine produced more output, measured by kilowatts. The test results are summarized below for emissions, power, and fuel consumption.

Table 6: Emissions Results, Drilling Rig

Average Emissions from Emissions Monitoring Device:

Test	CO (ppm)	NOx (ppm)	UBHC (ppm)	Opacity (%)	Tgas (deg. F)	Tamb (deg. F)
Baseline	417.9	1,066.6	0.718	6.1	912.3	79.8
Final	182.4	948.7	0.131	3.5	674.2	73.3
Percent Change	-56.4%	-11.1%	-81.7%	-42.8%	-26.1%	-8.2%

Calculated Mass Emission Rates (grams per hour):

Test	CO	NOx	UBHC	Opacity	Tgas	Tamb
Baseline, g/hr	1,796	7,532	8.72			
Final, g/hr	751	6,414	1.53			
Percent Change	-58.2%	-14.8%	-82.5%			

Calculated Mass Emission Rates (grams per kilowatt-hour):

Test	CO	NOx	UBHC	Opacity	Tgas	Tamb
Baseline, g/kW-hr	2.31	9.71	0.0112			
Final, g/kW-hr	0.99	8.44	0.0020			
Percent Change	-57.3%	-13.1%	-82.1%			

Table 7: Power and Fuel Consumption Results, Drilling Rig

	Baseline Test	Treated Test	Percent Change
Test Information:			
Date	5/17/2005	10/11/2005	
Test duration	0:50:05	1:30:12	
Power Output:			
Percent power output	97%	95%	-2.1%
Power, kW	776	760	-2.1%
Fuel Consumption Data:			
Mean, gal/hr	62.8	57.7	-8.2%
Minimum, gal/hr	62.0	57.3	
Maximum, gal/hr	63.4	57.9	
Standard deviation	0.59	0.17	
Stdev/Mean	0.9%	0.3%	
Power Corrected Fuel Consumption:			
kW/gal/hr	12.35	13.18	6.7%

The treated engine was tested for maximum power output. The engine produced 954 kW of power. This maximum power output represents a 2.5 percent increase over its maximum emergency power of 930 kW. The continuous use rated power for the unit is 800 kW.

Mexican Rail Road

Location: Mexico
Locomotive: GE C30-7

This locomotive fuel-efficiency test was conducted on two GE locomotives and utilized both on-rail and load-cell testing methods for measuring fuel efficiency. Throughout the test, the locomotives primarily operated on a single freight line between Tierra Blanca and Coatzacoalcos, Mexico.

On-Rail Testing
The on-road fuel-efficiency metric was throttle notch eight (TN8) fuel consumption. The locomotives were equipped with fuel meters and onboard PLC systems. The PLC and locomotive event recorder data were regularly downloaded and analyzed to quantify TN8 fuel consumption. These data sets exhibited exceptional statistical quality and reliability, as indicated by the low standard deviation values displayed below.

Table 8: On-rail TN8 Fuel-Consumption Results

Locomotive 9607

AVERAGE FUEL CONSUMPTION, TN8			
Baseline (liters/h)	Performance (liters/h)	Absolute Change	Percent Change
517.0	497.1	-19.9	-3.8%

OTHER STATISTICAL METRICS		
Metric	Baseline	Performance
Minimum value	436.4	418.2
Maximum value	541.9	523.1
Standard Deviation	19.2	21.8
Std. Dev. (% of mean)	3.7%	4.4%
Sample Size	145	141
$t_{0.025, DF}$	2.253	
t_{test}	8.198	
Statistically Significant?	Yes	

Locomotive 9624

AVERAGE FUEL CONSUMPTION, TN8			
Baseline (liters/h)	Performance (liters/h)	Absolute Change	Percent Change
500.4	455.7	-44.7	-8.9%

OTHER STATISTICAL METRICS		
Metric	Baseline	Performance
Minimum value	418.6	417.2
Maximum value	536.4	483.1
Standard Deviation	25.7	17.5
Std. Dev. (% of mean)	5.1%	3.8%
Sample Size	98	97
$t_{0.025, DF}$	2.259	
t_{test}	14.183	
Statistically Significant?	Yes	

Both test locomotives demonstrated statistically significant (95 percent confidence level) improvements in TN8 fuel consumption, ranging from 3.8 percent to 8.9 percent.

Load-Cell Testing

The most accurate method available for determining locomotive fuel efficiency utilizes a resistive load cell and gravimetric fuel-consumption measurement to determine brake-specific fuel consumption (BSFC), which is the mass of fuel consumed per unit of energy produced by the locomotive. The baseline load-cell test was conducted at the beginning of the test prior to dosing. After three months of operation with treated fuel, the locomotives were administered the exact same load-cell test procedure as that conducted during the baseline test.

Table 9: Locomotive 9607 Load-Cell Test Results

ABSOLUTE CHANGE			
Notch	Fuel consumption (lbs/hr)	Power (hp)	BSFC (lbs/hp-hr)
1	(16.20)	(44.08)	0.0775
2	(34.80)	(80.07)	0.0185
3	(26.40)	(62.57)	0.0070
4	(16.20)	(33.70)	-0.0009
5	1.80	8.49	-0.0013
6	9.30	28.22	-0.0013
7	24.60	109.57	-0.0082
8	(6.00)	17.36	-0.0050

PERCENT CHANGE			
Notch	Fuel consumption	Power	BSFC
1	-20%	-30%	14.0%
2	-20%	-23%	3.7%
3	-9%	-10%	1.5%
4	-4%	-4%	-0.2%
5	0%	1%	-0.3%
6	1%	2%	-0.3%
7	3%	5%	-2.1%
8	-1%	1%	-1.3%

The above results indicate slight improvements in BSFC for throttle notches four through eight. EnviroFuels believes that the following factors negatively impacted the test results on locomotive 9607.

The 9624 locomotive exhibited very positive results, as displayed in the following tables.

Table 10: Locomotive 9624 Load-Cell Test Results

ABSOLUTE CHANGE			
Notch	Fuel consumption (lbs/hr)	Power (hp)	BSFC (lbs/hp-hr)
1	0.00	9.71	-0.0723
2	64.80	199.15	-0.0835
3	81.00	271.58	-0.0580
4	67.80	255.30	-0.0389
5	27.60	103.37	-0.0107
6	15.30	115.70	-0.0168
7	47.40	422.25	-0.0445
8	67.20	495.23	-0.0402

PERCENT CHANGE			
Notch	Fuel consumption	Power	BSFC
1	0%	12%	-10.4%
2	52%	82%	-16.4%
3	32%	50%	-12.3%
4	17%	29%	-8.8%
5	5%	8%	-2.6%
6	2%	7%	-4.1%
7	5%	19%	-11.4%
8	7%	19%	-10.5%

The improvement in TN8 BSFC was 10.5 percent. EnviroFuels believes the fuel-efficiency improvements reported on the 9624 locomotive to be more representative of what railroads can expect from using DFC.

EnviroFuels provided the results on Locomotive 9607 to document the complete results of the field test. There were several factors that contributed to the results on Locomotive 9607. Such factors may have had a material impact on this test and should be evaluated alongside the data. The factors that may have had an impact on the results from Locomotive 9607 include the following:

- The locomotive never achieved rated power. Due to insufficient power production, the unit required mechanical and electrical adjustments prior to both baseline and performance tests. Such adjustments introduced an element of variability into the test on this locomotive. Locomotive 9624, however, did not encounter such issues.
- Locomotive 9607 was at the end of its life cycle. There were no rebuild events since its original manufacture in 1980.
- Governor hunting on Locomotive 9607 contributed to erratic engine operation that did not allow the engine to reach a true stead-state level of operation.

Latin American Railway

Location: Latin America
Engine: EMD 16-645F3

This over-the-rail test examined changes in fuel economy resulting from the addition of EnviroFuels DFC to the treated engines. It was conducted on a 47-mile single track, which allowed the locomotives to always operate on the same stretch of track under consistent conditions.

Four locomotives were used in the test. The locomotives were paired together in two consists, each including a treated and an untreated locomotive. This arrangement ensured that untreated and treated locomotive performance was comparable, as it normalized for external factors that impact fuel consumption such as gross-ton miles, throttle notch, or operational habits of different engineers. The locomotives were always fueled at the same location, ensuring accurate record keeping and consistent locomotive dosing with DFC.

An 11-percent improvement in locomotive fuel economy was observed in the treated locomotives after they were sufficiently treated with EnviroFuels DFC. Furthermore, the turbochargers on the treated locomotives released from their respective geartrains (also known as "free-wheeling") in throttle notch seven, while the turbochargers of the untreated locomotives remained on their respective geartrains when at the same throttle setting. This observation indicates that the treated locomotives were producing more power than the untreated locomotives at the same throttle setting.

Global Dredging Company

Location: Cutter dredge working in Port of Miami and Freeport, Texas
Engines: Two EMD 20-645E3 gen-sets

This test was conducted on a cutter dredge that is owned and operated by a global dredging company. The evaluation examined changes in fuel economy, operational performance, and internal surface conditions of the engines due to the application of EnviroFuels DFC and EnviroFuels LTP.

Background
The dredge is powered by four EMD 20-645E3 turbocharged diesel engines. Two of the engines are primarily responsible for supplying power to the cutter head. These twin gen-sets are capable of generating over four megawatts of power through a common bus. In this single-bus configuration, each engine generates 50 percent of load demand under identical operating conditions. With the engines equally sharing the load and operating at a constant speed of 900 rpms, the generator engines presented a suitable real-time performance monitoring environment. Both engines were in sound mechanical condition with over 31,000 operational hours on each engine since their last overhaul. The two additional engines power the main pumps, in clutch-driven parallel, that transport material through a pipeline.

The test protocol was designed to measure the fuel economy and detergency effects of EnviroFuels DFC and EnviroFuels LTP. A side-by-side comparison of the generators was mutually determined by the dredging company and EnviroFuels to be the operational environment with the most comparable attributes and fewest external variables. The starboard engines were treated with EnviroFuels DFC and then with EnviroFuels LTP, while the port engines was left untreated to measure the side-by-side effects of EnviroFuels technology.

Results
During the baseline period, prior to initiating EnviroFuels DFC treatment, the starboard engine consumed 2.4 percent more fuel than the port engine over a period when each engine consumed nearly 10,000 gallons of fuel. Despite the fact that the starboard and port engines equally share the load of the dredging activities, the fuel monitoring system confirmed that there was an initial difference in efficiency between the engines. The dredge's engineers suggested that the performance difference between the two engines could be contributed to the fact that there was significant blockage on the starboard engine's turbocharger screen due to carbon deposits.

With EnviroFuels DFC treatment alone, the starboard engine ultimately consumed 6.8 percent (Period 12) less fuel than the untreated Port engine per 10,000-gallons of fuel consumption by the starboard engine. Compared to the baseline, the starboard engine, or treated engine, consumed 9.2 percent less fuel over the final 10,000-gallon fuel consumption interval of the evaluation.

During the baseline period, the starboard engine consumed more fuel than the port engine. Through treatment with EnviroFuels DFC, the treated starboard engine, reversed a historical trend of greater fuel consumption and then consumed significantly less fuel than the untreated port engine.

Starting in Period 12, after fuel economy benefits were observed using EnviroFuels DFC only, the starboard engines were treated with EnviroFuels LTP in addition to DFC. Initial crankcase treatment of EnviroFuels LTP was at a one-time volume ratio of 1:32 (EnviroFuels LTP to lube oil). Subsequent daily make-up oil was treated with EnviroFuels LTP at the maintenance volume ratio of 1:125.

After the initial treatment with EnviroFuels LTP, oil filter change frequency doubled; but the oil filter change interval stabilized thereafter. After one week of treatment with EnviroFuels LTP, just after Period 13, an additional four percent fuel economy improvement was measured.

The volumetric fuel consumption differential between the starboard and port engine is displayed in the figure and table below:

Figure 5: Percent Difference in Fuel Consumption between Starboard and Port Engines

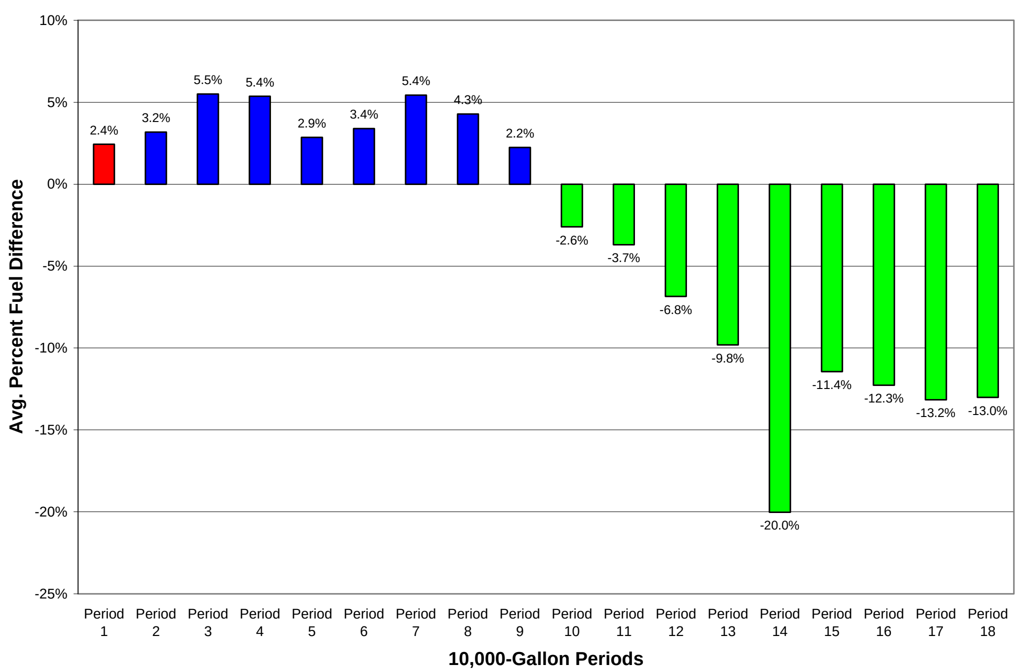


Table 11: Fuel Consumption Data, Cutter Dredge

Period	Port Engine Untreated (gallons)	Starboard Engine Treated (gallons)	Percent Difference
1	9,451	9,570	2.4%
2	9,832	10,001	3.2%
3	9,630	10,003	5.5%
4	9,601	9,987	5.4%
5	9,819	9,999	2.9%
6	9,807	10,003	3.4%
7	9,646	9,999	5.4%

Period	Port Engine Untreated (gallons)	Starboard Engine Treated (gallons)	Percent Difference
10	10,247	10,001	-2.6%
11	10,187	10,007	-3.7%
12	9,996	9,341	-6.8%
13	11,139	10,001	-9.8%
14	12,621	10,002	-20.0%
15	10,000	8,882	-11.4%
16	10,003	8,762	-12.3%

After two months, or 1,500 hours, of treatment with EnviroFuels DFC, the treated starboard engine showed evidence of significant reduction in the amount of carbon build-up that had been generated over the course of 31,000 operational hours. In comparison to the untreated port engine, the observed detergency effects of EnviroFuels DFC suggests additional preventative maintenance benefits may be realized by removing oxidized hydrocarbons that result from the combustion process inside the engine.