Reduction of Particulate Matter Emissions for Fleets with Diesel Engines

A White Paper

HNO Green Fuels, Inc.

June 10, 2013

Background

Diesel engines provide power to a wide variety of vehicles, heavy equipment, and other machinery used in a large number of industries including mining, transportation, construction, agriculture, maritime, and many types of manufacturing operations. The exhaust from diesel engines contains a mixture of gases and very small particles that can create a health hazard when not properly controlled.

Diesel particulate matter is part of a complex mixture that makes up diesel exhaust. Diesel exhaust is commonly found throughout the environment and is estimated by EPA's National Scale Assessment to contribute to the human health risk in the United States and elsewhere throughout the globe. Diesel exhaust is composed of two phases, either gas or particle and both phases contribute to the risk. The gas phase is composed of many of the urban hazardous air pollutants, such as acetaldehyde, acrolein, benzene, 1,3-butadiene, formaldehyde and polycyclic aromatic hydrocarbons.

The particle phase also has many different types of particles that can be classified by size or composition. The size of diesel particulates that are of greatest health concern are those that are in the categories of fine, and ultra fine particles. The composition of these fine and ultra fine particles may be composed of elemental carbon with adsorbed compounds such as organic compounds, sulfate, nitrate, metals and other trace elements. Diesel exhaust is emitted from a broad range of diesel engines; the on road diesel engines of trucks, buses and cars and the off road diesel engines that include locomotives, marine vessels and heavy duty equipment.

Abstract

Hydrogen has a high specific energy, high flame propagation speed and a wide range of flammability and as such offers rich potential to promote combustion efficiency and reduce pollutant emissions in diesel fuel and other types of hydrocarbon-based fuels.

The fundamental combustion parameter that compactly characterizes and quantifies the effects of hydrogen addition is the laminar flame speed, which embodies information about the exothermicity, reactivity and diffusivity of the resulting mixture.

To-date, experiments have been conducted for the hydrocarbon fuels methylcyclohexane, toluene, decalin, propane and kerosene. For each fuel, flame speed data were measured under various conditions. Results show a surprising increase in laminar flame speed with added hydrogen. The exact nature of the hydrogen-enhanced burning is seen to depend on the fuel volatility. Under some conditions, hydrogen addition was observed to increase the hydrocarbon burning rate by more than a factor of two. The flame speed increase for many fuels extends to normal and elevated pressures.

Extensive testing in EPA approved engine testing laboratories has shown that particulate matter emissions can be reduced significantly when hydrogen is used to increase the combustion efficiently of the fuel in the combustion chamber. Utilizing this methodology, particulate matter reduction or elimination can be accomplished with both old and new diesel engines.

Further, a 24% savings of gasoline was achieved with certain classes of gasoline engines when conducting the standard Highway Fuel Economy Driving Schedule (HWFET) for light duty vehicles. This test represents highway driving conditions under 60 mph.

Problem Statement

The health effects of Particulate Matter emissions are well known throughout the world. Current methods for reducing particulate matter include the following:

- Performing routine preventive maintenance of diesel engines to minimize emissions,
- Installing aftermarket or retrofit engine exhaust filters,
- Installing cleaner burning engines,
- Installing aftermarket or retrofit diesel oxidation catalysts,
- Using special fuels or fuel additives (e.g., biodiesel),

Even after employing all of these strategies, particulate matter removal has not been effective enough.

Proposed Solution

LeefH2 (Leveraging Energy Efficient Fuel with Hydrogen) technology uses PEM Electrolysis (Proton Exchange Membrane) to generate Hydrogen gas (H2) on-demand. The hydrogen gas is used to increase the laminar flame speed of the diesel fuel and thereby increasing the combustion efficiency of the fuel. A huge environmental benefit of the process is that breathable oxygen is produced as a by-product.

PEM electrolysis is a process that is the reverse of a PEM fuel cell process; however the materials are typically different from PEM-FC. At the heart of a PEM or solid polymer electrolyser (SPE) is a proton exchange membrane. The SPEs were developed by the General Electric Company as fuel cells for the NASA space program (project Gemini). Subsequently, small-scale SPE water electrolysers were used for military and space applications in the early 1970s.

With the LeefH2 system, Hydrogen gas is injected into the air used for combustion to enhance the combustion efficiency of the fuel and the breathable O2 is release to the atmosphere for positive environmental benefits.

To-date, HNO Green Fuels, Inc. has been issued seven patents using PEM electrolysis to produce hydrogen gas for internal combustion engines and has filed an application for patent directed to using PEM electrolysis to produce hydrogen for jet engines.

Testing Data

The following tables show the test results achieved when certain amounts of hydrogen was added to the air for combustion of gasoline and diesel fuel. In the case for diesel engines, the particulate matter emissions were reduced by over 43%. This reduction occurred in the combustion chamber. In the case of the gasoline engine tested, there was an improvement of nearly 24% in fuel economy for highway driving under 60 mph.

The testing has been conducted at an independent EPA approved Engine Testing lab in Fullerton California. The test results shown here are the standard Highway Fuel Economy Driving Schedule (HWFET) for light duty vehicles which represents highway driving conditions under 60 mph, a steady state highway test at 65 MPH for a 1998 Ford 7.2 L diesel engine and a Supplementary Emissions Test (SET) used for emission certification of heavy-duty diesel engines in the USA. The actual reports can be seen in the appendix.

2010 Chevrolet Suburban, Gasoline V-8, 5.2 L
(HWFET)

Test Factor	**Standard Performance**	**Performance with LeefH2**	**Percentage Improvement**
THC (Total Hydrocarbons)	0.014 (grams/mi)	0.010 (grams/mi)	28%
Carbon Dioxide	341.40 (grams/mi)	274.51 (grams/mi)	19.59%
Fuel Economy	25.87 (mpg)	32.15 (mpg)	24.2%

1998 Ford F-350 Powerstroke Diesel 7.2 L
(Steady State @ 65 mph)

Test Factor	Standard Performance	Performance with LeefH2	Percentage Improvement
THC (Total Hydrocarbons)	0.375 (grams/mi)	0.279 (grams/mi)	25.6%
Carbon Dioxide	507.59 (grams/mi)	501.47 (grams/mi)	1.2%
Fuel Economy	20.28 (mpg)	20.52 (mpg)	1.18%
PARTIC WT.	0.29 (mg)	0.15 (mg)	48.2%

Cummins ISM 400-1800 Diesel
Supplemental Emissions Test (SET) 13 modes

Test Factor	Standard Performance	Performance with LeefH2	Percentage Improvement
CO	53.86 (grams/hr)	52.54 (grams/hr)	2.4%
Carbon Dioxide	89729 (grams/hr)	91745 (grams/hr)	(2.2%)
Fuel (overall)	27593 (grams/hr)	27571 (grams/hr)	0.079%
Fuel (idle)	1215 (grams/hr)	1065 (grams/hr)	12.3%
PARTIC WT.	0.41 (mg)	0.23 (mg)	43.9%

There is no doubt as to the positive effects of Hydrogen in the combustion process. Test results and scientific research have proven it. The only remaining issues would be user operability of the LeefH2 technology and its usefulness in a fleet and other internal combustion engine applications.

User Operability

The LeefH2 system can be installed in a vehicle in less than an hour. After installation of the LeefH2 system, the operation of the device is totally invisible to the vehicle operator. The LeefH2 is "controlled" with an on board diagnostic (OBD) interface that "reads" the vehicle's self-diagnostic and reporting capability. The OBD system normally gives the vehicle owner or a repair technician access to state of health information for various vehicle sub-systems. In this case, it also feeds our OBD interface vehicle data that determines when, how and at what levels the Hydrogen aspect of the LeefH2 unit should operate. The LeefH2 OBD interface also transmits various aspects of this vehicle data directly to a secure online database and website where it is instantly transformed into useful real-time information regarding a specific vehicle or the collective characteristic of a fleet of vehicles.

Fleet Benefits

There are tremendous benefits to be gained by having real-time graphical data relating to a vehicle's activity. One benefit, for example, is the ability to track a vehicle's idle time right down to the second. As most fleet operators know, idle time is a very big issue. These trends as well as many others can be readily seen and monitored by vehicle owners and fleet managers.

Conclusion

The LeefH2 system is more than just a fuel saving device. It is a multi-dimensional "Smart" system that addresses most of the concerns of a fleet operator, including the desire for the "greening" of the fleet. Particulate matter emissions, fuel savings at idle, and idle time for the entire fleet are just three aspects of a fleet operation that are met head-on by the LeefH2 technology. Reducing particulate matter by 40 plus percent in the combustion chamber is simply unprecedented.

With the right combination of the LeefH2 technology and minimal particulate filtration, particulate matter emissions for diesel engines can be a thing of the past.

Appendices

1. Baseline-2010 suburban
2. LeefH2-2010Suburban
3. Baseline-1998ford_diesel 350
4. LeefH2-1998Ford Diesel 350
5. Baseline-Cummins ISM-400
6. LeefH2-Cummins ISM-400

Ecologic Engine Testing Laboratories
1370 S. Acacia Ave. Fullerton California

TEST NUMBER	V5010426	DATE	01-12-2011	RANGE	AUTO
VEHICLE REF	DON OWENS	A.C.	YES	FUEL TYPE	INDOLENE
V.I.N.	1GNUCHE08AR239462	PROD. DATE	N/A	DENSITY	16.33
ENGINE FAM.	AGMXT05.3381	ENGINEER	D.OGDEN	SPECIF. CO2	13.4
EVAP FAMILY	N/A	OPER/DRVR	A.HERRERA	Gr.Cjgal.	2817
MAKE	CHEV.	TEST TYPE	HWFET .HWC	FUEL Fract.	.8641
MODEL	SUBURBAN	SHIFT FILE	AUTO .H_C	SP. GRAVITY	.741
YEAR	2010	INERTIA WGT	4750	N.H.V.	18504
TANK CAP	N/A	ACTUAL HP	13	WT FACTOR	1
ODOMETER	23073	INDIC. HP	10.6	WT FACTOR	0
TRANS.	AUTO	HP Spd/Sec	ARB 2/1	WT FACTOR	0
REMARKS	BASELINE				
REMARKS					
REMARKS					
START TIME	12:41:40	END TIME	12:54:25	FINAL ODO.	23083.2

#	EVENT	MILES	Km	TIME	TIME trace		HOLD	TIME trace		ERROR	GrCtrl
1	ph 1	10.232	16.445	765.0	0.0	for	0.0	0.0	for	0.0	787
2	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	5
3	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
4	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
5	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
6	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
7	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
8	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
9	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
10	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
11	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
12	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
13		0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
14		0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
15		0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0

TEST COMPLETED 765 .1 SECONDS DVT = 0.5 A = 0.0714 B = 0.9970 HP@50 = 10.6

PHASE 1	THC	CO	NOx	CO2	NMHC				
SAMPLE	5.2	37.5	0.0	1.716	12.6	Tdry =	72.6	Tdp =	0.0
AMBIENT	3.5	1.9	0.0	0.044	12.6	BARO. =	30.10	SEC =	765.0
GRAMS	0.141	4.746	0.000	3493.19	.034	NoxKf =	0.813	VOLc =	4015.0
GMS/MI	0.014	0.464	0.000	341.40	.003	M.P.G.	25.87	DF =	7.789
G/Mwgt	0.014	0.464	0.000	341.40	.003	MPGnhv	25.89	MI =	10.232
						R–H =	22.20	KM =	16.446

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WEIGHTED	THC	CO	NOx	CO2	NMHC	FUEL ECONOMY			
GRAMS/MI	0.014	0.464	0.000	341.40	.003	M.P.G.	25.87	NHVmpg	25.894
GRAMS/KM	0.009	0.289	0.000	212.40	.002	L/100k	9.09	NHVkpl	10.010

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MAXIMUM CFV RATIO = 0.875 RATIO LIMIT = 0.857

Ecologic Engine Testing Laboratories
1370 S. Acacia Ave. Fullerton California

TEST NUMBER	V5010429	DATE	01-12-2011	RANGE	AUTO
VEHICLE REF	DON OWENS	A.C.	YES	FUEL TYPE	INDOLENE
V.I.N.	1GNUCHE08AR239462	PROD. DATE	N/A	DENSITY	16.33
ENGINE FAM.	AGMXT05.3381	ENGINEER	D.OGDEN	SPECIF. CO2	13.4
EVAP FAMILY	N/A	OPER/DRVR	A.HERRERA	Gr.Cjgal.	2817
MAKE	CHEV.	TEST TYPE	HWFET .HWC	FUEL Fract.	.8641
MODEL	SUBURBAN	SHIFT FILE	AUTO .H_C	SP. GRAVITY	.741
YEAR	2010	INERTIA WGT	4750	N.H.V.	18504
TANK CAP	N/A	ACTUAL HP	13	WT FACTOR	1
ODOMETER	23106	INDIC. HP	10.6	WT FACTOR	0
TRANS.	AUTO	HP Spd/Sec	ARB 2/1	WT FACTOR	0
REMARKS	WITH ONE DEVICE ON				
REMARKS					
REMARKS					
START TIME	14:22:55	END TIME	14:35:40	FINAL ODO.	23116.2

#	EVENT	MILES	Km	TIME	TIME trace		HOLD	TIME trace		ERROR	GrCtrl
1	ph 1	10.240	16.458	765.0	0.0	for	0.0	0.0	for	0.0	787
2	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	5
3	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
4	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
5	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
6	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
7	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
8	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
9	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
10	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
11	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
12	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
13		0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
14		0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
15		0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0

TEST COMPLETED 765 .1 SECONDS DVT = 0.0 A = –0.1220 B = 1.0017 HP@50 = 10.4

PHASE 1	THC	CO	NOx	CO2	NMHC				
SAMPLE	5.4	40.8	0.0	1.385	12.1	Tdry =	73.5	Tdp =	0.6
AMBIENT	4.3	1.8	0.0	0.045	12.1	BARO. =	30.10	SEC =	765.0
GRAMS	0.102	5.209	0.000	2811.01	.019	NoxKf =	0.817	VOLc =	4031.8
GMS/MI	0.010	0.509	0.000	274.51	.001	M.P.G.	32.15	DF =	9.643
G/Mwgt	0.010	0.509	0.000	274.51	.001	MPGnhv	32.18	MI =	10.240
						R–H =	22.50	KM =	16.459

* *

WEIGHTED	THC	CO	NOx	CO2	NMHC	FUEL ECONOMY			
GRAMS/MI	0.010	0.509	0.000	274.51	.001	M.P.G.	32.15	NHVmpg	32.179
GRAMS/KM	0.006	0.316	0.000	170.79	.001	L/100k	7.31	NHVkpl	13.682

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MAXIMUM CFV RATIO = 0.876 RATIO LIMIT = 0.857

Ecologic Engine Testing Laboratories
1370 S. Acacia Ave. Fullerton California

TEST NUMBER	V5010613	DATE	01-24-2011	RANGE	AUTO
VEHICLE REF	DON OWENS1254	A.C.	YES	FUEL TYPE	Diesel
V.I.N.	1FTJW35F8VEC71254	PROD. DATE	10/97	DENSITY	20.2
ENGINE FAM.	VFM7.3W8D1AK	ENGINEER	D.OGDEN	SPECIF. CO2	13.4
EVAP FAMILY	N/A	OPER/DRVR	A.HERRERA	Gr.Cjgal.	2824
MAKE	FORD	TEST TYPE	HFET_D .HWC	FUEL Fract.	.872
MODEL	F-350 POWERSTROKE	SHIFT FILE	AUTO .H_C	SP. GRAVITY	.9328
YEAR	1998	INERTIA WGT	6875	N.H.V.	16600
TANK CAP	N/A	ACTUAL HP	12	WT FACTOR	1
ODOMETER	65390	INDIC. HP	9	WT FACTOR	0
TRANS.	AUTO	HP Spd/Sec	ARB 2/1	WT FACTOR	0
REMARKS	BASELINE				
REMARKS	STEADY STATE AT 65 MPH				
REMARKS					
START TIME	08:24:22	END TIME	08:37:07	FINAL ODO.	65404.0

#	EVENT	MILES	Km	TIME	TIME trace		HOLD	TIME trace		ERROR	GrCtrl
1	ph 1	13.993	22.491	765.0	0.0	for	0.0	0.1	for	765.0	787
2	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	535
3	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
4	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
5	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
6	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
7	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
8	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
9	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
10	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
11	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
12	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
13	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
14	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
15	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0

TEST COMPLETED 765 .1 SECONDS DVT = 765.0 A = 65.097 B = 0.0157 HP@50 = 0.0

PHASE 1	THC	CO	NOx	CO2				
SAMPLE	35.0	37.3	71.0	1.584	Tdry =	78.1	Tdp =	–1.2
AMBIENT	6.6	2.3	0.2	0.051	BARO. =	29.90	SEC =	765.0
GRAMS	5.247	10.351	27.518	7102.76	NoxKf =	0.806	VOLc =	8900.7
GMS/MI	0.375	0.740	1.967	507.59	M.P.G.	20.28	DF =	8.421
G/Mwgt	0.375	0.740	1.967	507.59	MPGnhv	20.53	MI =	13.993
					R–H =	16.80	KM =	22.491

* *

WEIGHTED	THC	CO	NOx	CO2	FUEL ECONOMY			
GRAMS/MI	0.375	0.740	1.967	507.59	M.P.G.	20.28	NHVmpg	20.527
GRAMS/KM	0.233	0.460	1.224	315.80	L/100k	11.59	NHVkpl	8.728

* *

Q.C. TIMES 0.0 0.0 9.2 AVG. 3.1

PARTIC. VOLp 1 = 9.563 C.F. PARTIC. WT, MG = 0.29

MAXIMUM CFV RATIO = 0.851 RATIO LIMIT = 0.880

Ecologic Engine Testing Laboratories
1370 S. Acacia Ave. Fullerton California

TEST NUMBER	V5010655	DATE	01-26-2011	RANGE	AUTO
VEHICLE REF	DON OWENS1254	A.C.	YES	FUEL TYPE	Diesel
V.I.N.	1FTJW35F8VEC71254	PROD. DATE	10/97	DENSITY	20.2
ENGINE FAM.	VFM7.3W8D1AK	ENGINEER	D.OGDEN	SPECIF. CO2	13.4
EVAP FAMILY	N/A	OPER/DRVR	A.HERREA	Gr.Cjgal.	2824
MAKE	FORD	TEST TYPE	HFET_D .HWC	FUEL Fract.	.872
MODEL	F-350 POWERS	SHIFT FILE	AUTO .H_C	SP. GRAVITY	.9328
YEAR	1998	INERTIA WGT	6875	N.H.V.	16600
TANK CAP	N/A	ACTUAL HP	12	WT FACTOR	1
ODOMETER	65595	INDIC. HP	9	WT FACTOR	0
TRANS.	AUTO	HP Spd/Sec	ARB 2/1	WT FACTOR	0
REMARKS	WITH 2 DEVICES AND 02 ON				
REMARKS	STEADY STATE @ 65 MPH				
REMARKS					
START TIME	08:50:56	END TIME	09:03:41	FINAL ODO.	65608.9

#	EVENT	MILES	Km	TIME	TIME trace		HOLD	TIME trace		ERROR	GrCtrl
1	ph 1	13.927	22.385	765.0	0.0	for	0.0	0.1	for	765.0	787
2	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	535
3	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
4	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
5	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
6	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
7	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
8	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
9	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
10	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
11	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
12	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
13	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
14	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0
15	end	0.000	0.000	0.0	0.0	for	0.0	0.0	for	0.0	0

TEST COMPLETED 765 .1 SECONDS DVT = 765.0 A = 65.5306 B = 0.0020 HP@50 = 0.0

PHASE 1	THC	CO	NOx	CO2				
SAMPLE	25.3	36.1	72.0	1.547	Tdry =	76.0	Tdp =	2.2
AMBIENT	4.3	1.8	0.1	0.046	BARO. =	30.10	SEC =	765.0
GRAMS	3.880	10.174	28.837	6984.00	NoxKf =	0.828	VOLc =	8942.0
GMS/MI	0.279	0.731	2.071	501.47	M.P.G.	20.54	DF =	8.628
G/Mwgt	0.279	0.731	2.071	501.47	MPGnhv	20.78	MI =	13.927
					R–H =	23.30	KM =	22.385

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WEIGHTED	THC	CO	NOx	CO2	FUEL ECONOMY			
GRAMS/MI	0.279	0.731	2.071	501.47	M.P.G.	20.54	NHVmpg	20.777
GRAMS/KM	0.173	0.454	1.288	312.00	L/100k	11.45	NHVkpl	8.834

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Q.C. TIMES 0.0 9.4 9.5 AVG. 6.3

PARTIC. VOLp 1 = 9.563 C.F. PARTIC. WT, MG = 0.15

MAXIMUM CFV RATIO = 0.854 RATIO LIMIT = 0.880

HNO Green Fuels

Cummins ISM 400-1800 Serial Nr.: 60412072

Olson-Ecologic Engine Testing Laboratories

Supplemental Emission Test (SET) Test Nr.: HNOHYDSET032213_04

Baseline

Mode	EngSpd RPM	DynTrq lb-ft	EngPwr Hp	Dilute WCO2 %	Dilute WCO ppm	Dilute WNOx ppm	Dilute WNO ppm	Dilute WHC ppmC	FUEL RT GM/MIN	AirMas scfm	EngExh deg/F	ABSHUM grain/lb	Air In degF	Baro P InHga	Exh. P In.H2O	Dilute KNOx ppm	FuelIn degF	Dilute KNO ppm	Fuel psig	Dilute WMethane ppm	Dilute WNMHC ppm	ABSHUM g/kg	Sat Vapor Press mmHg	Oil P psig	Humidy %
1	705.0	-1.1	-0.1	0.04	4.3	6.7	6.7	3.4	20.3	99.8	199.0	52.32	76.8	29.62	-2.0	6.2	87.9	6.2		0.0	3.4	7.474	23.57	21.4	38.0
2	1280.0	1200.2	295.8	1.74	16.4	154.4	153.4	9.4	725.5	465.9	728.2	51.86	76.6	29.63	11.9	145.6	88.5	144.6		0.0	9.4	7.409	23.45	28.5	37.8
3	1508.6	628.6	182.0	1.24	12.5	105.5	103.7	7.7	454.8	380.6	756.4	51.42	76.9	29.62	9.0	99.3	89.7	97.6		0.0	7.7	7.346	23.67	27.6	37.2
4	1518.4	948.6	274.2	1.61	10.0	229.8	226.2	9.2	638.5	474.9	765.7	50.72	77.4	29.62	13.9	216.0	91.2	212.7		0.0	9.2	7.246	24.04	27.0	36.1
5	1299.0	636.9	157.6	1.01	8.7	135.7	133.1	8.2	382.0	293.0	785.4	49.90	77.8	29.62	4.1	127.3	93.9	124.9		0.0	8.2	7.129	24.36	24.5	35.1
6	1296.1	957.4	236.2	1.37	10.3	185.9	183.3	8.9	556.3	370.5	831.3	49.50	78.1	29.63	8.5	174.2	95.8	171.8		0.0	8.9	7.072	24.64	24.6	34.4
7	1294.3	317.1	78.7	0.58	8.3	76.0	73.8	7.4	204.0	227.0	687.8	49.07	78.4	29.63	0.9	71.1	97.1	69.0		0.0	7.4	7.010	24.91	24.2	33.7
8	1512.1	1148.4	331.6	1.91	11.8	237.1	232.3	11.2	779.5	557.0	770.1	49.12	78.6	29.64	18.1	222.1	98.5	217.5		0.0	11.2	7.017	25.07	25.9	33.5
9	1517.1	318.2	92.0	0.72	10.1	87.6	84.2	9.2	247.8	275.0	681.9	48.85	78.9	29.64	3.5	81.9	100.3	78.7		0.0	9.2	6.979	25.30	24.6	33.1
10	1736.7	1099.5	364.1	2.12	13.3	255.9	249.5	13.2	869.8	665.6	747.0	48.79	79.0	29.65	26.8	239.5	101.7	233.5		0.0	13.2	6.970	25.42	25.3	32.9
11	1739.3	266.5	88.5	0.76	12.1	86.0	81.7	11.2	255.5	322.9	644.5	48.38	79.3	29.65	4.4	80.4	103.5	76.3		0.0	11.2	6.911	25.62	25.8	32.3
12	1742.3	821.0	271.9	1.53	11.0	204.9	199.5	11.8	649.3	536.5	705.6	48.21	79.3	29.66	16.1	191.5	105.6	186.4		0.0	11.8	6.887	25.63	24.8	32.2
13	1739.5	544.1	180.6	1.14	10.1	146.3	141.5	11.3	452.3	426.9	694.7	48.04	79.5	29.66	9.7	136.3	107.6	132.1		0.0	11.3	6.863	25.80		31.9

WT. FAC	Mode No	HC (GRAMS/HOUR)	CO (GRAMS/HOUR)	KNOX (GRAMS/HOUR)	KNO (GRAMS/HOUR)	FUEL (GRAMS/HOUR)	EXHAUST (GRAMS/HOUR)	CO2 (GRAMS/HOUR)	NMHC (GRAMS/HOUR)	Raw Exhaust Flow (scmm)	Raw Exhaust Flow (g/h)		Mode	Sample Time (Sec.)	GP (g/s)	(slpm)	(sl)	V_{sf} Ft.^{3}	VMIX Ft.^{3}
0.15	1	16.48	42.02	99.80	99.69	1215	279450	5593	16.48	3.87	300321	PARTIC. WT, MG = 0.41 0.00041	1	90	0.088	4.3780	6.5670	0.2319114	3712.8
0.08	2	22.55	80.15	1168.02	1159.89	43530	1417437	133600	22.56	19.60	1523303		2	48	0.454	22.5865	18.0692	0.6381078	1974.8
0.10	3	18.55	61.27	797.21	783.70	27285	1122078	95114	18.56	15.52	1205885		3	60	0.361	17.9598	17.9598	0.6342426	2469.6
0.10	4	22.15	48.98	1732.88	1705.99	38310	1390004	123634	22.16	19.23	1493821		4	60	0.453	22.5368	22.5368	0.7958776	2467.9
0.05	5	19.69	42.37	1022.26	1002.93	22920	794076	77576	19.70	10.98	853384		5	30	0.278	13.8305	6.9153	0.2442097	1235.6
0.05	6	21.44	50.42	1398.52	1379.15	33375	1078194	105433	21.44	14.91	1158723		6	30	0.359	17.8603	8.9301	0.3153644	1234.9
0.05	7	17.88	40.70	571.36	554.89	12240	540835	44646	17.89	7.48	581230		7	30	0.211	10.4973	5.2486	0.1853534	1236.5
0.09	8	27.04	57.45	1780.52	1744.18	46770	1609382	146584	27.05	22.26	1729585		8	54	0.536	26.6660	23.9994	0.8475308	2220.2
0.10	9	22.23	49.64	659.22	633.24	14865	648310	55775	22.23	8.97	696732		9	60	0.256	12.7360	12.7360	0.4497676	2476.1
0.08	10	31.85	64.74	1920.68	1872.89	52185	1897416	162771	31.86	26.24	2039132		10	48	0.619	30.7953	24.6362	0.8700192	1974.0
0.05	11	27.07	59.51	647.42	614.85	15330	750735	58417	27.08	10.38	806807		11	30	0.296	14.7260	7.3630	0.2600219	1239.1
0.05	12	28.53	53.65	1537.87	1497.56	38955	1469344	117201	28.54	20.32	1579088		12	30	0.506	25.1735	12.5868	0.4444969	1235.7
0.05	13	27.26	49.49	1098.22	1062.17	27135	1096555	87432	27.27	15.17	1178455		13	30	0.389	19.3528	9.6764	0.341718	1236.7

600 Sec.
0.17 Hr.

P_{mass} g

6.258622 24713.94 1.6194114

WTD AVG BHP = 188.13 **KW = 140.29**

	HC	CO	KNOX	KNO	FUEL	EXHAUST	CO2	NMHC	Raw Exhaust
WTD AVG GM/H =	**22.65**	**53.86**	**1055.02**	**1032**	**27593**	**1054476**	**89729**	**22.65**	1133234
WTD GM/BHPH =	**0.12**	**0.29**	**5.61**	**5.49**	**146.67**		**476.95**	**0.12**	
WTD GM/KWH =	**0.16**	**0.38**	**7.52**	**7.36**	**196.68**		**639.59**	**0.16**	

P_{wm}= 0.0516 g/bhp-hr

P_{wm}= 0.0693 g/kw-hr

HNO Green Fuels

Cummins ISM 400-1800 Serial Nr.: 60412072

Olson-Ecologic Engine Testing Laboratories

Supplemental Emission Test (SET) Test Nr.: HNOSETHYD040513_01

Mode	EngSpd RPM	DynTrq lb-ft	EngPwr Hp	Dilute WCO2 %	Dilute WCO ppm	Dilute WNOx ppm	Dilute WNO ppm	Dilute WHC ppmC	FUEL RT GM/MIN	AirMas scfm	EngExh deg/F	ABSHUM grain/lb	Air In degF	Baro P InHga	Exh. P In.H2O	Dilute KNOx ppm	FuelIn degF	Dilute KNO ppm	Dilute WMethane ppm	Dilute WNMHC ppm	ABSHUM g/kg	Sat Vapor Press mmHg	Oil P psig	Humidy %	CoolOt degF
1	706.4	-0.7	-0.1	0.05	3.3	6.0	5.3	3.8	17.8	97.1	216.3	60.87	80.4	29.81	-2.5	5.7	99.4	5.0	0.1	3.7	8.696	26.57	16.5	39.3	176.8
2	1280.6	1201.0	296.1	1.76	16.7	153.8	150.8	9.8	724.8	462.9	744.3	60.00	80.0	29.84	11.4	148.0	101.9	145.0	0.0	9.8	8.571	26.27	26.1	39.3	179.8
3	1509.4	629.0	182.2	1.25	12.7	104.8	101.0	7.8	454.0	381.5	767.3	59.16	80.0	29.83	8.4	100.6	103.7	96.9	0.0	7.8	8.452	26.24	26.0	38.8	178.7
4	1518.9	948.0	273.8	1.63	8.8	225.7	220.0	9.3	643.0	479.4	776.2	58.68	80.3	29.83	13.4	216.5	105.7	210.9	0.0	9.3	8.383	26.51	25.6	38.1	179.3
5	1299.3	636.9	157.6	1.03	10.3	133.4	129.4	8.0	383.0	295.9	796.9	58.06	80.7	29.83	3.6	127.7	107.7	123.8	0.0	8.0	8.294	26.87	23.5	37.2	179.3
6	1295.6	956.6	235.9	1.40	10.6	181.6	177.9	8.7	557.3	370.4	842.2	57.64	81.0	29.84	8.0	173.7	108.7	170.1	0.0	8.7	8.234	27.11	22.5	36.6	180.2
7	1294.6	317.5	78.7	0.61	8.1	74.8	71.3	7.1	204.0	228.1	695.2	57.08	81.3	29.84	0.5	71.4	109.4	68.0	0.1	7.0	8.154	27.37	22.7	35.9	177.6
8	1512.1	1148.4	331.6	1.96	12.0	228.9	222.5	11.0	781.5	563.9	778.0	57.32	81.5	29.85	17.8	218.8	110.6	212.6	0.0	11.0	8.189	27.56	24.2	35.8	179.7
9	1517.2	318.2	92.0	0.75	9.9	85.7	80.9	8.8	245.5	275.8	688.6	56.82	81.8	29.85	3.0	81.8	111.9	77.1	0.1	8.7	8.117	27.81	23.4	35.2	177.6
10	1736.6	1090.5	361.2	2.15	13.3	247.4	239.3	12.9	864.5	661.5	754.9	57.14	82.0	29.85	26.2	236.3	113.4	228.6	0.0	12.9	8.164	27.99	23.7	35.1	179.6
11	1739.4	266.4	88.6	0.78	11.5	83.3	77.6	10.8	255.0	324.1	650.9	56.41	82.2	29.85	4.0	79.4	115.8	73.9	0.1	10.7	8.058	28.18	24.0	34.5	177.4
12	1742.3	821.3	272.0	1.56	11.0	201.5	194.6	11.5	649.8	534.8	714.5	56.18	82.1	29.86	15.8	192.1	118.4	185.4	0.0	11.5	8.026	28.13	23.2	34.4	179.2
13	1739.7	543.9	180.6	1.16	10.1	141.0	134.7	10.9	453.5	428.1	698.4	56.03	82.3	29.86	9.4	134.3	120.7	128.2	0.1	10.8	8.004	28.23	23.2	34.2	178.8

WT. FAC	Mode No	HC (GRAMS/HOUR)	CO (GRAMS/HOUR)	KNOX (GRAMS/HOUR)	KNO (GRAMS/HOUR)	FUEL (GRAMS/HOUR)	EXHAUST (GRAMS/HOUR)	CO2 (GRAMS/HOUR)	NMHC (GRAMS/HOUR)	Raw Exhaust Flow (scmm)	Raw Exhaust Flow (g/h)		Mode	Sample Time (Sec.)	GP (g/s)	(slpm)	(sl)	V_{sf} $Ft.^3$	VMIX $Ft.^3$
0.15	1	18.16	31.93	92.02	80.17	1065	275450	7466	17.87	3.81	296023	PARTIC. WT, MG = 0.23 0.00023	1	90	0.088	4.3780	6.5670	0.23191	3707.1
0.08	2	23.64	81.67	1188.37	1164.82	43485	1429622	135570	23.64	19.77	1536399		2	48	0.453	22.5368	18.0294	0.6367	1977.0
0.10	3	18.78	62.10	807.30	777.93	27240	1120635	95924	18.78	15.50	1204334		3	60	0.361	17.9598	17.9598	0.63424	2469.9
0.10	4	22.39	50.19	1736.67	1691.70	38580	1390697	124860	22.40	19.24	1494567		4	60	0.453	22.5368	22.5368	0.79588	2468.0
0.05	5	19.19	42.95	1025.27	994.36	22980	800774	79091	19.20	11.08	860583		5	30	0.278	13.8305	6.9153	0.24421	1235.3
0.05	6	20.87	51.64	1394.20	1365.45	33435	1082898	107841	20.88	14.98	1163778		6	30	0.359	17.8603	8.9301	0.31536	1234.9
0.05	7	17.13	39.57	573.66	546.65	12240	550712	46802	16.86	7.62	591843		7	30	0.211	10.4973	5.2486	0.18535	1236.3
0.09	8	26.40	58.75	1754.56	1704.79	46890	1633057	150720	26.40	22.59	1755028		8	54	0.536	26.6660	23.9994	0.84753	2220.9
0.10	9	21.35	48.34	658.60	620.50	14730	659440	58033	21.06	9.12	708693		9	60	0.256	12.7360	12.7360	0.44977	2476.3
0.08	10	30.98	64.84	1896.13	1833.76	51870	1903047	165005	30.99	26.32	2045183		10	48	0.619	30.7953	24.6362	0.87002	1974.7
0.05	11	26.11	56.48	639.47	595.38	15300	761041	60151	25.79	10.53	817882		11	30	0.296	14.7260	7.3630	0.26002	1239.0
0.05	12	27.74	53.51	1541.92	1488.63	38985	1484791	119698	27.74	20.54	1595689		12	30	0.506	25.1735	12.5868	0.4445	1235.0
0.05	13	26.27	49.45	1080.87	1031.81	27210	1115344	89073	26.15	15.43	1198648		13	30	0.389	19.3528	9.6764	0.34172	1237.7

WTD AVG BHP = 187.89 **KW = 140.11**

600 Sec.
0.17 Hr.

		P_{mass} g
6.257216	24712.22	0.90859

	HC	CO	KNOX	KNO	FUEL	EXHAUST	CO2	NMHC	Raw Exhaust
WTD AVG GM/H =	22.59	52.54	1051.50	1015	27571	1061761	91745	22.48	1141063
WTD GM/BHPH =	0.12	0.28	5.60	5.40	146.74		488.28	0.12	
WTD GM/KWH =	0.16	0.37	7.50	7.25	196.78		654.80	0.16	

P_{wm} = 0.0290 g/bhp-hr

P_{wm} = 0.0389 g/kw-hr